A Framework to Evaluate the Impact of ICT Usage on Collaborative Product Development Performance in Manufacturing Firms

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C. W. Chathurani Silva

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Dedication

To my beloved

Mother

&

Father

ABSTRACT

Manufacturers are increasingly adopting collaborative product development (CPD) to achieve competitive advantage through joint synergies. Information and communication technology (ICT) is the major enabler of communication, collaboration, product designing, development, knowledge and information management, project management, and market research activities involved in CPD. Most ICT implementations incur a significant cost for firms, thus a deeper understanding of the impact of ICT usage on CPD performance would be immensely useful for managing ICT resources effectively in innovation programmes. However, existing evidence for the direct relationships between ICT usage and performance dimensions are counterintuitive (negative or insignificant). Not considering the different aspects of ICT usage was identified as a key reason for the lack of strong empirical evidence. Furthermore, the impact of ICT usage on collaboration-based product development performance and indirect impact through this collaboration performance on new product performance, as well as moderating effects of project characteristics on the direct and indirect ICT impact have largely been ignored in the literature. Therefore, drawing on relational resource-based view and organizational information processing theory, this study develops and utilizes a model including multidimensional ICT usage and CPD performance measurements, and possible moderating project characteristics, for better evaluating the impact of ICT usage on CPD performance.

Initially, product development professionals from manufacturing firms and knowledgeable managers from ICT vendor firms were interviewed for a preliminary qualitative evaluation of the suggested model with industry perspectives. In addition, a quantitative investigation of secondary data obtained from the PDMA's (Product Development and Management Association) 2012 comparative performance assessment study was conducted prior to the main survey in order to assess the significance of the proposed model with a different source of data. In the final main quantitative study, data collected from 244 CPD projects via an online global survey were used to test the research hypotheses.

The study contributes to the current body of knowledge by revealing a positive direct impact of ICT usage on new product performance in terms of quality, commercial success, and time performance, and collaboration performance, which also in turn increases new product performance. In addition, moderating effects of project characteristics (complexity and uncertainty) on these associations have been explored. The study implies that manufacturers need to value not only the direct project benefits of ICT use, but also the collaboration-related outcomes that significantly increase the likelihood of achieving higher performance in their present and future CPD projects. Adequate attention must be paid to individual ICT usage dimensions as well. Particularly, other than frequency of ICT use, manufacturing firms need to improve the utilization of available features and functionalities of the tools (intensity) and the ICT proficiency of R&D staff, to gain the desired results in CPD projects.

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Chathurani Silva

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LIST OF ABBREVIATIONS

CAD	Computer aided design
CAE	Computer aided engineering
CE	Concurrent engineering
CPAS	Comparative performance assessment study
CPD	Collaborative product development
ICT	Information and communication technology
IS	Information systems
NPD	New product development
OIPT	Organizational information processing theory
PD	Product development
PDM	Product data management
PDMA	Product development and management association
PLM	Product lifecycle management
PLS	Partial least square
PPM	Project and portfolio management
RRBV	Relational resource-based view
SEM	Structural equation modeling

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1. Silva, C., Mathrani, S., Jayamaha, N., (2016). The Impact of ICT Usage on Collaborative Product Innovation Performance. *International Journal of Innovation Management*, *20*(5).

2. Silva, C., Mathrani, S., & Jayamaha, N. (2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. *International Journal of Innovation, Management and Technology, 5*(1), 43-49.

3. Silva, C., Mathrani, S., Jayamaha, N. (March, 2016). The Impact of ICT Usage on Collaborative Product Development Performance: A Conceptual Model and Industry Perspective. *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management,* Kuala Lumpur, Malaysia.

4. Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2015). The Impact of ICT Usage on Collaborative Product Innovation Performance. *Proceedings of the ISPIM (International Society for Professional Innovation Management) Innovation Summit*, Brisbane, Australia.

5. Silva, C., Mathrani, S., Jayamaha, N., (Nov., 2015). Testing Moderating Effects with Higher-order Constructs in PLS. Presented at *Joint Conference of the NZ Statistical Association and Operations Research Society of NZ*. Christchurch, New Zealand.

6. Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2014). The Impact of IT Usage on Collaborative New Product Development Performance. *Proceedings of the 25th Australasian Conference on Information Systems*. Auckland, New Zealand.

7. Silva, C., Mathrani, S., Jayamaha, N., (Nov., 2014). FIMIX-PLS Approach for Organization Classification in Innovation Management Research. Presented at *Joint Conference of the NZ Statistical Association and Operations Research Society of NZ*. Wellington, New Zealand.

8. Silva, C., Mathrani, S., & Jayamaha, N. (Mar., 2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. Presented at *Journal Conference on Innovation Management and Technology*. Penang, Malaysia.

9. Silva, C., Mathrani, S., & Jayamaha, N. (Jul., 2013). A framework to evaluate the impact of ICT usage on collaborative product development performance. *Proceedings of the 4th Annual New Zealand Information Systems Doctoral Consortium*. Auckland, New Zealand.

1. Introduction

1.1 Introduction

Innovation has become a necessity for existence in today's industrial business environment. The success of manufacturing companies mainly depends upon their ability to introduce new or improved products to the market speedily and at a relatively low cost. Organizations are keen to identify appropriate structural mechanisms and strategies to facilitate the generation of successful new products. Promising ideas and the expertise required to develop new products may be present with a company's stakeholders such as suppliers, customers, competitors, or staff. Developing new or improved products by joining complementary resources and experience of one or more external (e.g. suppliers and customers) and/or internal partners (cross-functional teams) with mutual goals is known as collaborative product development (CPD) (Büyüközkan & Arsenyan, 2012).

Information and communication technologies (ICTs), including tools for face-to-face communication, provide the key media for processing required information and facilitating communication between CPD partners (Curşeu, Schalk, & Wessel, 2008; Montoya, Massey, Hung, & Crisp, 2009). Real time communication, concurrent operations, and increased information access facilitated by intensive use of ICT help firms to overcome social, technical and organizational barriers against CPD (Boutellier, Gassmann, Macho, & Roux, 1998; Swink, 2006). However, the increased use of ICT tools incurs significant costs to companies. The effectiveness of using ICT tools in CPD projects may vary depending on the requirement for processing information, determined by the characteristics of the projects. However, access to product-related information sometimes leads to issues such as leakage of proprietary knowledge and loss of control over the product development process (Hoecht & Trott, 2006; Littler, Leverick, & Bruce, 1995). Therefore, adjusting the extent of communication and exchanging information via ICTs based on the requirements of CPD are vital for project success while these are quite challenging (Boutellier et al., 1998; Hoegl, 2005).

ICT impact on project performance can be direct as well as indirect through collaboration or collaboration outcomes such as knowledge-sharing (Banker, Bardhan, & Asdemir, 2006; Thomas, 2013). However, several limitations have been identified in previous studies in relation to: evaluating the impact of ICT usage or degree of using ICT tools on a new product's quality, time performance, and commercial success, and understanding the factors mediating and moderating these effects. Uncovering a detailed picture of the impact of ICT usage on collaborative product development performance could fill in existing gaps in the literature. Therefore, this study adopts more informative ICT usage evaluation criteria, broad CPD performance outcomes, and project characteristics that could moderate the association between ICT usage and CPD performance. The study uses qualitative (interviews) and quantitative (secondary and primary) data to explore the current context of using ICT in CPD projects and to examine the direct, indirect, and moderated impact of ICT usage on CPD performance.

1.2 BACKGROUND TO THE STUDY

Collaboration may occur at any of the product development stages, namely, conceptualization, development, and commercialization. Conceptualization is the stage where a series of strategic planning and analysing activities are carried out in order to finalize the conceptual design. These concepts are transformed into physical products in the development stage (Song, Thieme, & Xie, 1998). After testing the physical usability of the new product via prototypes, it is tested for manufacturing feasibility. Products passing all design and development stages successfully are then launched or introduced to the market in the commercialization stage. CPD enables firms to bring valuable technological and market knowledge to the new product from various sources including product or collaborative experts (Littler et al., 1995; Parker 2000). Therefore, CPD becomes a process in which firms gain benefits such as high quality, shorter times to market, and low cost to manufacturers (Mathrani & Liu, 2015; Swink, 2006).

Firms integrate or collaborate with external partners (e.g. suppliers, customers) and internal cross-functional teams at varying levels depending on organizational, environmental, or project-related factors. However, firms possessing differing levels of ability to collaborate with external and internal parties realize different levels of project and market performance (Mishra & Shah, 2009). At any level of collaboration, communication between partners and exchange of quality and timely information are vital for determining the degree of collaborative competence (Paulraj, Lado, & Chen, 2008; Sivadas & Dwyer, 2000). Face-to-face communication has been recognized as the best medium of communication in CPD specifically for transferring tacit knowledge

(Badrinarayanan & Arnett, 2008). However, as the number of virtually involved partners increases, CPD teams find less opportunity to meet face-to-face and tend to rely largely on information and communication technologies (Dube & Pare, 2004; Lockwood, Montoya, & Massey, 2013). ICT allows integrating more partners in CPD projects through efficient processing and communication of large volumes of information. Therefore, particularly in dispersed CPD projects, ICT becomes the main platform for communication, knowledge transfer, and work synchronization.

Rapid developments in ICT make the collaborative product development processes more complex to manage. As a result, technical (e.g. Lee, 2012; Luh, Pan, & Chu, 2011; Sun, Fan, Shen, & Xiao, 2012) and methodological (Arsenyan & Büyüközkan, 2012; Camarinha-Matos, Afsarmanesh, Galeano, & Molina, 2009) advancements to existing ICT in support of CPD are increasingly evident. However, heavy dependence on ICT itself may also cause some issues such as difficulty to change patterns of use (Montoya et al., 2009) and unnecessary leakage of commercially sensitive information (Hoecht & Trott, 2006). Past research has evaluated the usage of different ICT tools in collaborative product development projects (e.g. de Grosbois, Kumar, & Kumar, 2012; Markham & Lee, 2013). Some of these studies explored ICT usage based on the characteristics of CPD projects (e.g. Corso & Paolucci, 2001; de Grosbois et al., 2012). Very little research has focused on evaluating the frequency (Montoya et al., 2009) and proficiency (Chen, Tsou, & Huang, 2009) of ICT use and utilization of the functionalities of the tools (Kern & Kersten, 2007) in CPD programmes. However, the criteria of manufacturers for selecting ICT tools for CPD programmes, the importance of different ICT usage aspects (e.g. frequency, proficiency, and intensity), the positive outcomes of using ICT in CPD, and the barriers to achieving these outcomes have not been sufficiently explored in the literature.

The impact of ICT usage on CPD project performance has been discussed previously in product innovation research. Most of the studies focused on the impact of one (Banker, Bardhan, & Asdemir, 2006) or several individual ICT tools (Durmusoglu & Barczak, 2011; Peng, Heim, & Mallick, 2014) while very few discussed overall ICT usage (Barczak, Sultan, & Hultink, 2007). Research on the ICT-CPD performance relationship has mainly evaluated the direct effect of ICT usage on final project success associated with quality, financial, or time performance (e.g. Barczak et al., 2007; Durmusoglu & Barczak, 2011). These studies found little or no significant impact of ICT on some performance aspects (e.g. speed-to-market). Operationalizing ICT usage as the number of tools used in a project (or a project phase) is a major inadequacy found in most empirical investigations (e.g. Barczak et al., 2007; Durmusoglu & Barczak, 2011). The fundamental reason seems to be the difficulty of estimating the actual usage of different ICT tools in a selected CPD project or phase. Fichman (2001) emphasized that multidimensional measurement of ICT usage leads to a clearer exploration of the role of these tools in innovation. Some researchers have suggested the use of additional dimensions of ICT usage such as communication frequency and proficiency of use in order to reveal a more detailed picture of the effect of ICT on project performance (Durmusoglu & Barczak, 2011; Thomas, 2013). Recently, Kawakami, Barczak, and Durmusoglu (2015) uncovered a positive effect of frequency of ICT use on NPD task proficiency which in turn improves NPD performance.

Research suggesting both a direct and an indirect impact of ICT usage on new product performance is rare to find in the literature. For example, Banker et al. (2006) found that PLM systems have an indirect impact on project performance through collaboration. In a study, Peng et al. (2014) found that communication and collaboration tools such as e-mail and groupware and product data and knowledge management tools do not significantly support collaboration between partners, while project management tools support this in low complex projects. However, these researchers did not examine the ICT usage-CPD performance association or the mediating effect of collaboration. Thomas (2013) found that e-mail supports knowledge exchange in CPD, which in turn increases project performance, to a greater extent than rich communication media such as video conferencing and Web meetings. Although knowledge exchange is a basic element of collaboration, no study focusing on the direct ICT impact on the collaboration process performance comprising all of its key elements (e.g. knowledge/information sharing, benefits sharing, risks sharing, and trust creation) (Büyüközkan & Arsenyan, 2012; Camarinha-Matos et al., 2009) or indirect impact through all these elements on new product performance was found in the literature. Essentially, CPD performance representing the degree of success in achieving both collaboration performance and new product performance has not been adequately addressed in previous research focusing on the impact of ICT usage.

Since ICT tools incur substantial costs to companies and intensive use of these tools leads to unnecessary information outflows, careful management of ICT usage to simply meet the information processing requirements of CPD projects would be worthwhile. Recent research has highlighted the need to investigate factors moderating the effectiveness of ICT usage, which may help in the proper management of ICT in CPD programmes (Durmusoglu & Barczak, 2011; Thomas, 2013). Project characteristics such as complexity, uncertainty, and urgency represent the degree of the information processing requirement in CPD projects (Heim, Mallick, & Peng, 2012; Peng et al., 2014; Veldhuizen, Hultink, & Griffin, 2006). However, very few studies addressing the relationship between ICT usage and CPD performance have examined the moderating effect of such project characteristics on this association. For example, Peng et al. (2014) studied the moderating effect of project complexity on the association between several ICT tools and NPD collaboration. Their study revealed that the associations are relatively strong when products are large, and weak when the project is novel and the interdependence of tasks is high. However, no empirical evidence for the moderating effects on the direct association between ICT usage and new product performance dimensions (e.g. quality, time, and financial success) or indirect association through collaboration-based performance was found.

In conclusion, four major gaps were identified in the existing literature. Prior studies addressing the impact of ICT usage on CPD performance have (1) not sufficiently explored the importance of multidimensional aspects of overall ICT usage in improving CPD programmes in manufacturing firms; (2) not incorporated CPD performance reflecting both final project performance and collaboration performance; (3) observed several inconclusive evidence for the association between ICT usage and CPD performance aspects; (4) paid little attention to the moderating effect of project characteristics on the direct and indirect associations between ICT usage and new product outcomes resulting from collaboration outcomes.

1.2.1 Research questions

In order to fill the gaps identified in the review of background literature, the following research questions were formulated to be answered in this study:

(1) How do manufacturing firms manage ICT usage in terms of frequency, proficiency, and intensity, for improving their collaborative product development activities?

(2) Does ICT usage have a significant impact on CPD performance?

(3) Do the project characteristics representing the information processing requirement in CPD projects significantly moderate the relationship between ICT usage and CPD performance?

These research questions have been addressed in different phases of the research as explained in section 1.3.1.

1.3 Aim and Purpose of the Study

The primary objective of this study is to explore a comprehensive view of the impact of ICT usage on collaborative product development performance. Little empirical evidence available in respect of the direct effect of ICT usage on project outcomes (Barczak et al., 2007; Kawakami et al., 2015) and collaboration (Peng et al., 2014), and the indirect effect through collaboration (Banker et al., 2006) on project outcomes are the main reasons for this investigation. Several scholars have suggested the importance of adopting a multi-dimensional ICT usage measurement for better revealing ICT impact (Chen et al., 2009; Durmusoglu & Barczak, 2011; Fichman, 2001). Therefore, this study incorporates three dimensions of ICT usage (frequency, proficiency, and intensity of use) and collaborative product development performance as a means to attain the above objective. In addition to the performance criteria used in previous studies (quality, time, and/or commercial success) (e.g. Barczak et al., 2007; Durmusoglu & Barczak, 2011; Kawakami et al., 2015), this study incorporates collaboration performance that reflects the degree of achieving inter-firm relational-based outcomes of CPD (Büyüközkan & Arsenyan, 2012; Cousins & Lawson, 2007) rather than NPD collaboration (Banker et al., 2006; Peng et al., 2014). Hence, the CPD performance defined in this study represents the degree to which a product development project achieved its new product performance in terms of quality, commercial success, and time as well as collaboration performance.

Furthermore, the study aims to uncover the moderating effect of project characteristics on the relationship between ICT usage and collaborative product development performance. Previously, researchers have highlighted the need for understanding how the impact of ICT usage on the performance of product development projects varies based on factors that affect the information processing requirement of the projects (e.g. Thomas, 2013). Understanding these effects in relation to different dimensions of CPD performance will enable manufacturing firms to better utilize their ICT resources for the success of collaborative product development projects. However, existing knowledge on such moderating effects is extremely poor (e.g. Peng et al., 2014).

The theoretical support for achieving the research objectives and the methodology adopted in each research phase are briefly explained in the following section.

1.3.1 Theoretical basis and methodology

CPD is a business activity that involves several networked firms aiming for the success of a collective product innovation effort. The relational resource-based view (RRBV) argues that collaborative firms can achieve competitive advantage through relation-specific assets, effective governance, knowledge-sharing routines, and complementary resources and capabilities. It stimulates understanding that the intangible resources such as knowledge and trust shared by collaborative firms support achieving a sustainable competitive advantage (Dyer & Singh, 1998; Lavie, 2006). Drawing on this theory, the current study suggests that the effective use of ICT positively impacts on both product development and the collaboration processes of CPD and helps manufacturing firms to improve both tangible (e.g. profits) and intangible (e.g. knowledge-sharing) CPD outcomes. The RRBV supports theorizing both the direct and indirect effects of ICT usage on new product performance, through collaboration performance.

According to the organizational information processing theory (OIPT), the information processing capability of a firm needs the right balance with the information processing requirement of the tasks performed by the firm, in order to achieve higher organizational performance (Daft & Lengel, 1986; Galbraith, 1984). Since ICT is the key means for communication, collaboration, and product development in CPD, its usage in terms of frequency, proficiency, and intensity reflects the information processing capability of firms undertaking CPD projects. A CPD project's information requirement may depend on the degree of complexity, uncertainty, and urgency of the project. Therefore, drawing on OIPT, this study argues that ICT usage has varied effects on CPD performance for different levels of project characteristics that represent the information processing requirement of the projects.

First, the study developed and utilized a model for evaluating the impact of ICT usage on CPD performance based on RRBV, OIPT, and reviews of the literature. Second, it collected qualitative data from manufacturing and ICT vendors through interviews and analysed the data using directed qualitative content analysis. The findings offered industrial evidence for the effectiveness of managing ICT usage in improving CPD programmes, and identified barriers to the effective use of ICT in CPD. This answered the first research question and helped the examining and fine-tuning of the initial conceptual model which contained several new constructs (e.g. collaboration performance and intensity of ICT use) with practitioners' perspectives.

Next, secondary data obtained from the 2012 NPD best practices survey (i.e. Comparative Performance Assessment Study or CPAS) conducted by the Product Development and Management Association (PDMA) were analysed using the hierarchical multiple regression approach. This preliminary study answered the second research question and evaluated the impact of ICT usage, with a different source of data. This analysis was important for studying the capability of previously used ICT measurement criteria in revealing the impact of ICT usage and to justify the importance of a multi-dimensional measurement (frequency, proficiency, and intensity of ICT use) proposed in the present study. In the final stage, an online survey on globally operated CPD projects was conducted to investigate the conceptualized direct, indirect, and moderated effects of ICT usage on CPD performance. The empirical data were analysed using partial least square structural equation modeling (PLS-SEM), and the results were discussed providing deeper insights into the impact of ICT usage on CPD performance. This answered the second and third research questions concerning all direct, indirect and moderated effects of ICT usage on collaborative product development performance.

In summary, the main stages of the study and the key methods adopted in each stage are as follows.

1. Preliminary qualitative study for exploring the industrial perspective on the initial conceptual research model and finalizing it for evaluation in the final quantitative research phase. Methods – interviews (data collection) and directed qualitative content analysis (data analysis).
2. Preliminary quantitative study for an initial evaluation of the impact of ICT usage on CPD performance and for identifying industry sector(s) to be focused upon in the main questionnaire survey. Methods – secondary data from PDMA's 2012 CPAS (data collection) and hierarchical regression (data analysis).

3. Main survey for evaluating the impact of ICT usage on CPD performance and moderating effects of project characteristics on this impact. Methods – online survey (data collection) and PLS-based structural equation modeling (data analysis).

1.4 Significance of the Research

This research significantly contributes to the extension of theory and the understanding of CPD practitioners towards using ICT tools for improving the performance of collaborative product development projects. Adopting the RRBV and OIPT for evaluating the impact of ICT usage on collaborative product development performance extends these theories while reflecting their usefulness in studying technology-related themes in contemporary business environments. Since the study followed a mixed methods approach including preliminary qualitative data evaluation prior to the main quantitative study improves the practical validity of the theoretical model investigated and the findings. The use of secondary data obtained from a proper source (PDMA Research Foundation) effectively demonstrates the usefulness of the informative ICT usage measurement and CPD performance (adopted in the primary survey) for uncovering the impact of ICT usage with increased accuracy. Use of appropriate theoretical perspectives, different methodologies and sources of data, and suitable reliability and validity procedures, establishes the rigour of the research and increases the generalizability of the findings.

Empirical evidence for the impact of ICT usage in terms of frequency, proficiency, and intensity extend the literature on the impact of ICT usage on CPD performance (e.g. Barczak et al., 2007; Durmusoglu & Barczak, 2011; Kawakami et al., 2015). This adds new knowledge on the value of different aspects of ICT usage in manufacturing sector's CPD projects. Revealing the direct and indirect effects of overall ICT usage on new product performance (quality, time, and commercial success) through collaboration performance extends prior studies (Peng et al., 2014) addressing the impact of several ICT tools on PD collaboration. The investigated moderating effects of project characteristics on the relationship between overall ICT usage and CPD performance significantly extend existing literature on the direct and indirect effects of individual ICT tools on PD performance (Banker et al., 2006; Thomas, 2013), and contribute to the little evidence available for related moderating effects (Peng et al., 2014).

Improved understanding of the ICT impact on new product quality, commercial success, and time performance inform CPD practitioners about the ability of ICT tools to offer required facilities for achieving a project's performance objectives. Effects related to the impact on collaboration performance leads to exploration of the value of ICT in realizing intangible CPD outcomes such as knowledge-sharing and trust creation, which are also important in order to reach higher project performance. In addition, positive outcomes of ICT usage and barriers for the effective use of ICT in manufacturing collaborative product development projects provide insights to practitioners, which will be useful in ICT investments and implementations.

1.5 Research Framework

Figure 1.1 illustrates the research framework or outline of the study including all the key steps followed by the research.

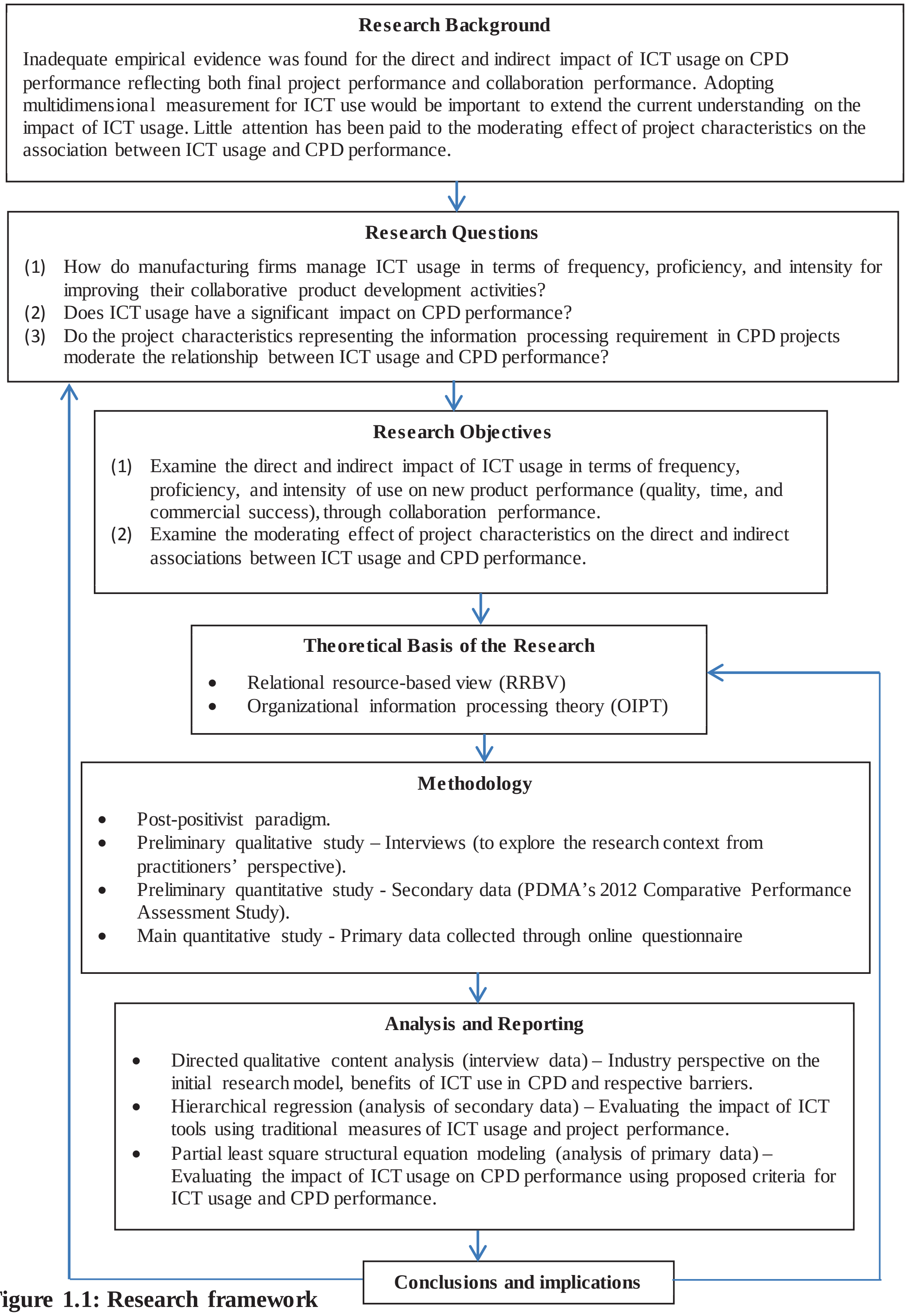

Figure 1.1: Research framework

1.6 ORGANIZATION OF THE CHAPTERS

The rest of the chapters in the thesis are organised as follows.

Chapter 2 (Product Development and Collaboration) presents a broad review of background literature related to collaborative product development and related concepts. Stages of product the development process, PD strategies including collaborative product development, and drivers of CPD performance are discussed.

Chapter 3 (Literature Review of Related works) reviews background literature related to the specific area of study. Based on the existing literature for the impact of ICT usage on collaborative product development performance, it identifies the key gaps to be addressed in the study.

Chapter 4 (Conceptual Model and Methodology) describes the research model and the complete methodology applied throughout the study. First, it develops an initial conceptual model for understanding the impact of ICT usage on collaborative product development performance. Next, the research paradigm, research design, the specific methodologies followed in qualitative and quantitative phases of the research, and justifications for selecting the methods, are explained. This includes relevant technical details on the procedures, strategies, and techniques used in selection of the samples, data collections, and data analyses.

Chapter 5 (Preliminary Qualitative Study) presents the qualitative study conducted prior to the main quantitative study (survey). First, it explains the importance of answering the first research question through a qualitative investigation. Second, the chapter briefly explains the methodology followed in the qualitative study including introductions to the firms selected. Next, the findings of the study are presented, discussed, and compared with relevant literature. Finally, a simplified version of the conceptual research model (to be tested in the final quantitative research phase) is presented along with conclusions and limitations of the study.

Chapter 6 (Preliminary Quantitative Study) presents the quantitative study conducted based on the secondary data obtained from the PDMA's 2012 comparative performance assessment study. First, it presents the research model (which has the same theoretical basis as the main study) and hypotheses of the preliminary study. Second, the methodology of the study including relevant details about the CPAS 2012 data is explained. Next, results of the data analysis are presented followed by a detailed discussion. This analysis partially addresses the second research question of the study based on availability of data in the secondary source. In the last section, theoretical implications and limitations of the preliminary quantitative study and suggestions for the final research phase are explained.

Chapter 7 (Development of Hypotheses and Survey Instrument) includes details about operationalization of the constructs of the conceptual model (the finalized model in the qualitative preliminary study), development of the hypotheses, structure of the sample obtained, and validation of the survey instrument.

Chapter 8 (Results and Discussion of Primary Data Analysis) presents results of the statistical analysis on primary data collected by the online survey. First, it presents descriptive statistics on the survey variables and their respective interpretations. Then, results of the PLS analysis performed for testing the hypotheses developed in Chapter 7 are presented followed by a discussion including possible explanations for the relationships revealed. This main quantitative research phase addresses the second and third research questions of the study.

Chapter 9 (Conclusions) presents the overall conclusions of the study mainly based on the findings of the preliminary qualitative and final quantitative (survey) research phases that address the research questions with the central research model developed in the study. In addition, the theoretical contribution and managerial implications of the findings are presented. Finally, the chapter discusses the limitations of the study and suggests some directions for future research.

2. Product Development and Collaboration

2.1 Introduction

This review provides the broad background literature related to the area of study. First, this chapter introduces the product development process and the activities involved in the major phases of the process. Second, it describes prominent strategies including CPD deployed by manufacturing firms in their new product development projects. This review highlights how CPD enables the practising of the principles of other strategies in product development, such as concurrent engineering and agile product development. Next, the chapter elaborates on the collaborative product development concept, the main focus of the study. Finally, this chapter identifies the drivers of CPD performance, namely, market orientation, supportive innovative climate, senior management commitment, strategy, trust, collaborative competence, and information sharing, and highlights the importance of ICT in information sharing.

2.2 Product Development Stages

The product development (PD) process comprises various planning, assessment, and development activities associated with introducing a new or improved product to the market. The following sections broadly describe the activities involved in the key stages of the process – idea generation or conceptualization, product development, and commercialization.

2.2.1 Conceptualization phase

The period before the actual development of a product occurs is the conceptualization or pre-development phase. All PD activities, from opportunity identification to concept definition, are covered in this stage. It includes front-end activities, namely: initial screening, preliminary market assessment, preliminary technical assessment, the detailed market study, market research, the voice of customer research, and the business and financial analysis (Cooper, 2013). Due to potential market, technological, environmental uncertainties and decision making complexities, this phase has been identified as the fuzzy front end (Achiche, Appio, McAloone, & Di Minin, 2012; Barczak, Hultink, & Sultan, 2008; Reid & De Brentani, 2004). Sound predevelopment work enables product developers to understand the design changes earlier in the product development process and ensures a high likelihood of success with the new product (Cooper, 2013).

2.2.2 Product development phase

The actual development of the physical product or implementation of the development plan prepared in the predevelopment phase is carried out in this stage (Cooper, 2001). In addition to the technical work, parallel marketing and operational activities are also undertaken. After developing the lab-tested physical prototype of the product, external validation of the product and project is carried out in order to ensure the consistency of the developed product with the original definition specified in the previous stage. A strong tendency to integrate with internal cross-functional teams and external partners such as suppliers and customers is observed during this stage due to the requirement of finalizing product, process, and information systems decisions (Bonaccorsi & Lipparini, 1994; Durmuşoğlu & Barczak, 2011; Petersen, Handfield, & Ragatz, 2005).

2.2.3 Commercialization phase

Launch or commercialization is the stage where the new product is made available to the market and is the penultimate stage in the NPD process, followed only by the post-launch evaluation (Hart & Tzokas, 2010). A well-integrated, properly targeted launch is extremely important to earn profits on the new product (Cooper, 2013). The quality in product availability, pricing, promotions, advertising, and product distribution determine the quality of product launch phase that is critical for the final performance of the new product (Song, Song, & Benedetto, 2011). Product launch strategy and the timing of the launch have been largely discussed in the literature (Calantone & Benedetto, 2012; Talke & Hultink, 2010). According to Hultink, Griffin, Hart, and Robben (1997), the proper combination of strategic and tactical product launch decisions is important for increasing new product performance. Collaborative decision-making starting from the early product development phases is a highly significant strategic activity for successful commercialization (Di Benedetto, 1999; Snow, Fjeldstad, Lettl, & Miles, 2011).

2.3 Product Development Strategies

All models structuring the product development process directly or indirectly underlie the concept that proper management of the product development process is a key to increasing an organization's innovation profits. Since the innovative capability of manufacturers is substantially responsible for their business success, organizations nowadays search, experiment, and practise various strategies for new product development. Concurrent engineering (CE), lean product development (LPD), agile product development, and collaborative product development are such strategies.

2.3.1 Concurrent engineering

Typically, the main concern of product designers is to increase products' performance and functionality without giving much consideration to process design and/or manufacturing constraints. Conventional sequential performance of product development activities does not allow manufacturing organizations to avoid this problem (Jo, Parsaei, & Sullivan, 1993; Parsaei & Sullivan, 2012). Concurrent engineering (CE) integrates engineering activities involved in designing products and related processes. These activities are performed in parallel rather than in sequence and, therefore, CE is also called simultaneous engineering. A number of scholars have stressed the importance of adopting the CE concept in NPD (e.g. Hambali, Sapuan, Ismail, Nukman, & Karim, 2009; Lawson & Karandikar, 1994; Suk-Ki & Schniederjans, 2000). CE supports reducing new products' uncertainty caused by technology and market changes (Koufteros, Vonderembse, & Doll, 2001; Meybodi, 2013). It is a significant strategy which enables new products to reach the market in less time through reduced development lead time (Smith & Eppinger, 1998; Wu, Kefan, Gang, & Ping, 2010). As a result of the parallel completion of tasks, CE raises productivity and minimizes waste in the design and production processes. Valle and Vázquez-Bustelo (2009) found that the effectiveness of the CE practices depends on the context of the NPD project. According to their study, CE provides better NPD results in terms of development time and quality when it is applied in incremental innovations rather than radical innovations. Effective communication and systematic involvement of customers, suppliers, distributors, and powerful information infrastructure, as well as the effective use of modern technology, are the key success factors for global CE where product development and manufacturing is carried out in different sites that are often geographically dispersed across countries (Abdalla, 1999).

Set-based concurrent engineering (SBCE) is the strategy used by Toyota which has become the most successful in creating shortest development and manufacturing cycle times in the vehicle industry (Khan et al., 2011; Sobek, Ward, & Liker, 1999). In traditional point-based CE, a solution point in the solution space is modified until it meets the design objectives. The success of this method largely depends on the goodness of the initially selected solution. In contrast, SBCE begins with broadly considering sets of possible solutions and gradually narrows these possibilities to converge on a final solution. Relative to point-based CE, SBCE takes more time in the early stages to define solutions but less time for converging on a final solution. According to Al-Ashaab et al. (2013), SBCE provides the following advantages over the traditional approach: less rework in later design stages, opportunity to select the best out of all alternative solutions falling within the intersection of all functions involved, and reduced risk of failure.

The engineering philosophy has recently been shifted from CE to collaborative engineering where no single company has all the necessary knowledge for completely designing and manufacturing competitive new products in-house. Achieving different objectives of participant designers is possible with novel methodologies used in collaborative engineering (Inoue, Nahm, Tanaka, & Ishikawa, 2013). A computer-based approach is relatively more powerful and efficient than a team-based approach for implementing CE practices, especially when collaborative team members are physically dispersed (Parsaei & Sullivan, 2012). Advanced ICT tools have been developed to ensure effective sharing of information and coordination in collaborative engineering. While ICT plays a vital role in creating competitive advantage in product development by exchanging information across design experts, CE mainly relies on human interactions within and across design teams.

2.3.2 Lean product development

Developing more innovative new products while consuming fewer resources leads to more profitability from new products in companies through reduced product development costs. The application of lean concepts such as waste minimization and process streamlining is vital to reduce product development and manufacturing costs. In addition, lean product development (LPD) principles and methods could provide the means for improving knowledge transfer in product development (Lindlöf, Söderberg, & Persson, 2012). This means making knowledge gained from the failures and successes of previous projects readily available and accessible. Toyota, a world famous lean practitioner, is highly successful in the transfer of product development knowledge (Kennedy & Ward, 2003). However, practising LPD requires a proper pre-analysis of types and causes of wastes. The most well-known reasons for product development waste are – (1) weak planning and leadership of PD programmes, (2) lack of frequent and compressive coordination and poor communication among internal and external partners, (3) no utilization of the legacy of knowledge and not learning from past mistakes, (4) excessive conservatism, bureaucracy, and compartmentalization, (5) non-optimal use of human resources, (6) traditional focus on point designs, (7) use of obsolete 2D drawings instead of selectively accessible 3D data, and (8) push-based rather than pull-based specifications and requirements (Oppenheim, 2004).

According to Karlsson and Åhlström (1996), CPD characteristics such as supplier involvement and cross-functional integration are frequently observed in lean product development. LPD also has a strong customer focus, which makes it possible to have high customer perceived value when a new product is being developed (Gautam & Singh, 2008). Some scholars have introduced several new models and frameworks to support the implementation of lean principles in product development. These recent developments promote LPD in the manufacturing industry where there were relatively fewer well-established LPD methodologies available. For example, Rossi, Taisch, and Terzi (2012) developed a five-steps methodology which allows for continuous NPD process improvement. These steps are: (1) waste identification and evaluation, (2) waste prioritization, (3) sub-process current analysis (4) sub-process criticalities analysis, and (5) corrective active implementation. Soares, Bastos, Gavazzo, Pereira, and Baptista (2013) presented a reference model for lean implementation in product and process development. Supportive organizational management, respect for people, continuous improvement, clear, accurate and timely information flow, and value created by reduced cost and lead time are the main components of this model. The multilevel LPD system design framework developed by Letens, Farris, and Aken (2011) captures key LPD system principles at the functional, project and portfolio levels.

2.3.3 Agile product development

Agility in product development ensures flexibility of the processes to modify products as a response to changing customer needs or to improved technical solutions being introduced (Smith, 2007). Applications of agile methods to product development evolved mainly to quickly adopt changing customer requirements in the software industry (e.g. Agile Manifesto, 2001). However, compared to NPD in general manufacturing, software product development has less rework cost due to less involvement of physical parts assembly and prototypes. According to Kettunen (2009), this difference changes the applicability of agile principles even in embedded software product development (e.g. where the software is a component of the final physical product). Additionally, product design principles such as modularity and customization in agile manufacturing are directly applicable in new software product development agility improvement frameworks. Agile development is different from the traditional sequential waterfall approach of software product development[1] because of adapting incremental, iterative work cadences (Agile Methodology, 2008). Application of these methods allows introducing more customized new products within a shorter development time. Since the requirements are analysed throughout the project lifecycle, it reduces the development cost as well. Although, agile product development concepts are more popular in the software industry where customer-required changes are easily adaptable during development, manufacturing sector applications to improve quality are increasingly being introduced. For example, in a study on the pump manufacturing industry, Vinodh et al. (2009) emphasized that, in implementing agile product development, technology-related strategies such as CAD (computer-aided design) and rapid prototyping are more powerful than management-related strategies such as total quality management and 5S (a popular Japanese workplace organization method).

Thomke and Reinertsen (1998) proposed three important strategies to introduce development flexibility required to adopt agile product development. These comprise – (1) adopting flexible technologies (for fast and low cost design iterations), (2) modifying management processes, and (3) leveraging design architecture (e.g. modular designs, reduced interdependent modules). Gunasekaran (1999) presented a framework to develop agile manufacturing systems along four major dimensions – strategies,

[1] A model which assumes a sequential progress of product development process stages: concept validation, design, testing, production or implementation, and maintenance (Boehm, 1988).

technology, people, and systems. Use of product development software, such as CAD, CAE (computer aided engineering), and CAPP (computer aided process planning) was identified under systems and technology dimensions in this framework. Some important concepts such as supply chain integration, CE, and virtual enterprise, prioritized in CPD were emphasized under the strategies dimension while IT-proficient staff was included within the people dimension of the framework. Therefore, agility in product development facilitated by ICT can be identified as an integral part of the framework that has strong synergies with CPD principles.

2.3.4 CPD compared to other product development strategies

The principles of the concepts discussed above have close relationships with the principles of CPD which is the main focus of the present study. As the above review suggests, the involvement of suppliers, customers, and cross-functional teams is emphasized in all three strategies – concurrent engineering, lean product development, and agile product development. However, this involvement is not the key focus of these strategies, whereas developing new products with the joining of different partners with mutual goals and experience as complementary resources is the basis of collaborative product development (Büyüközkan & Arsenyan, 2012). The involvement of external and internal partners at any point of the development process (conceptualization, development, or commercialization) is possible with CPD while CE and agile product development emphasizes this participation, particularly when designing a new product. In agile product development customers' involvement is the major focus whereas many external (e.g. suppliers, customers, consultants, competitors) and internal cross-functional teams (e.g. R&D, marketing, and manufacturing) contribute in CPD. CPD outperforms earlier concurrent and cooperative efforts, by producing key benefits such as improved product development cycle times and reduced new product introduction times, non-value added work, scrap, and number of engineering change orders, as well as increased design reuse (Swink, 2006). Therefore, CPD helps in practising lean principles as it reduces potential wastages in the development process. Recent research towards merging CPD and lean philosophies highlight basically the links of these product development strategies (e.g. Tuli & Shankar, 2015). Overall, CPD can be identified as a strategy that allows organizations to adhere to the principles of many useful product development concepts such as concurrent engineering, lean product development, and agile product development.

2.4 Collaborative Product Development

The timely introduction of new products with customer-accepted quality and prices is a real challenge for today's manufacturing firms. Many organizations do not individually possess all the capabilities and resources necessary to develop new products with customer-specified features, and thus venture into CPD (McGrath, 2004). Organizations collaborate with one or more external partners (e.g. suppliers and customers) and/or internal partners (e.g. cross-functional teams) in order to develop new or improved products by joining their complementary resource and experience at various stages of the product development process (Büyüközkan & Arsenyan, 2012). Swink (1999) found that integrations with suppliers and the manufacturing function increase new product manufacturability which in turn improves the quality of the design. A company's competence for collaboration is collectively determined by the degree of involvement of suppliers, customers, and cross-functional teams. This collaborative competence significantly contributes to improve project and market performance in NPD (Mishra & Shah, 2009).

Networking, coordination, and cooperation are closely related concepts with collaboration (Camarinha-Matos et al., 2009). Networking means a basic exchange of information, and communication between partners for mutual benefits. Coordinated networks adjust activities to increase the efficiency of the results. Moreover, cooperation involves the sharing of resources for achieving compatible goals. Relative to all these concepts, collaboration is the most complex process that shares information, resources, and responsibilities, and manages activities to achieve a common goal creating value jointly. In brief, collaboration is a concept that incorporates all the networking, coordination, and cooperation characteristics of the teams.

The key benefits of CPD are reducing development cost and time, acquiring useful new knowledge (skills and technology), and expanding existing markets. Factors such as frequent communication among involved parties, presence of a product or collaboration champion, partners contributing as expected, perception of equal benefits among partners, trust between partners, flexible corporate systems and management style, and choice of a partner, improve the likelihood of CPD success (Büyüközkan & Arsenyan, 2012; Littler et al., 1995; Parker, 2000). Therefore, managements must pay thorough attention to these factors in order to ensure success in CPD. But CPD not only offers benefits to manufacturing firms. It also results in some costs and risks that are inevitable. Difficulty in protection of proprietary company information and reduced control over strategic management and planning are the major risks associated (Hoyer, Chandy, Dorotic, Krafft, & Singh, 2010; Littler et al., 1995; Parker, 2000). Kayis et al. (2007) categorized the potential risks in multi-located CPD projects into eight areas namely: schedule, technical, external, organizational, communication, location, resource, and financial. However, nowadays it is nearly impossible for manufacturing firms to respond to changing customer requirements and technologies, and increasing competition, without engaging in collaborations. New business models and tools are increasingly being developed to facilitate CPD (Eppler, Hoffmann, & Bresciani, 2011) as well as to handle risks that are likely to occur (Kayis et al., 2007). Therefore, organizations need to carefully decide on their partners, the PD stages, and the type of collaboration based on the requirements of their NPD projects.

Research focusing on customer (Bonner, 2010), supplier (Bonaccorsi & Lipparini, 1994; Handfield & Lawson, 2007) and cross-functional team collaborations in NPD are largely available while there are a few addressing collaborations with other parties such as universities and competitors (Brettel & Cleven, 2011; Flores et al., 2009). The following sections review key literature on external and internal NPD collaborations, and their influence on collaborative product development performance.

2.4.1 External collaborations

External parties that collaborate in manufacturing product development projects are – suppliers, customers, competitors, universities, and independent experts. Organizations may acquire the required expertise from these external partners to develop their new products. Collaborations with external parties involve various costs for ensuring success. However, these costs must not exceed the benefits received through the collaborations (Lau, Tang, & Yam, 2010; Nordlund, Lempiala, & Holopainen, 2011). Orientation towards innovation is an important contributor for external NPD collaboration (Brettel & Cleven, 2011). Nieto and Santamaría (2007) found a positive impact of collaborations with suppliers, customers, and other third parties, while finding a negative impact in competitor collaborations on a new product's novelty. The researchers suggest that lack of trust and the risk of opportunistic behaviour by competitors are likely to restrict seeing competitor collaboration as a good option in novel NPD projects. In their study on supply chain integration for NPD in Chinese manufacturing companies, Feng (2013) emphasized the importance of customer integration in reducing NPD cost and increasing speed, which in turn improve market performance. The study also found a direct and indirect positive influence of supplier integration on a new product's market performance. These findings related to external collaborations are elaborated upon in the following sections presenting specific details on supplier, customer, and other parties' collaborations in NPD.

2.4.1.1 Supplier collaboration

Supplier collaboration is the most common type of external collaboration. It has been identified widely as a strategy for obtaining the competitive advantage in CPD (Cousins & Lawson, 2007; Croom, 2001; Handfield, Ragatz, Peterson, & Monczka, 1999). High-tech industries such as automotive (Langner & Seidel, 2009) and telecommunication (Humphreys, Huang, Cadden, & McIvor, 2007) collaborate relatively much more with suppliers when compared to other industries. High uncertainties due to technological newness and project complexities in these industries drive manufacturers to collaborations. Suppliers may collaborate at any stage of the PD process; however, their involvement in the conceptualization and product design stages is mostly evident (Humphreys et al., 2007; Langner & Seidel, 2009). The selection of suppliers, managing supplier relationships, and the effect of supplier integration on CPD performance are the main areas addressed in supplier- collaboration-related studies.

Increasing attention to introducing frameworks facilitating early selection of suppliers (Humphreys et al., 2007) and supplier relationship management (Park, Shin, Chang, & Park, 2010) justifies the inevitable necessity of supplier collaboration in NPD. Due to the various issues associated with supplier integrations, most manufacturing firms carefully select the suppliers that are to be involved in their NPD projects. Some manufacturing organizations allow selected suppliers to attend design meetings and participate in the design process. The level of knowledge about the supplier's capabilities and the degree to which these capabilities complimented the manufacturer's capabilities are critical for the success in product development through supplier collaboration (Handfield et al., 1999; Petersen et al., 2005). Early assessment of supplier capabilities and setting joint technology goals are effective means for achieving this (Handfield & Lawson, 2007). Supporting this notion, Song and Di Benedetto (2008) emphasizes the significance of supplier qualifications in terms of abilities, skills, and willingness to make a sufficient financial investment, before entering into ventures in radical NPD projects. However, in a study that developed a supplier selection tool, Humphreys et al. (2007) emphasized the need for assessing the balance between customer requirements and supplier capabilities rather than the R&D capabilities of suppliers. The tool consisting of multidimensional criteria, included – satisfaction (level of satisfaction by supplier capability), flexibility (the level to which supplier capability exceeds the manufacturer's requirement), risk (the level to which supplier capability fails to meet customer requirement) and confidence (the suppliers ability to maintain trustworthiness for a long period). The use of these measures in supplier evaluations implies the importance of reducing the potential risk when selecting a supplier for CPD.

A number of researchers have suggested that partnerships with critical component suppliers should be changed from traditional arm's-length purchasing agreements to integrated partnerships, in order to avoid potential schedule problems and lower quality in NPD (e.g. Bonaccorsi & Lipparini, 1994; Yan & Dooley, 2014). The problems become even more severe if the same supplier is relying on others for the purchase of the same part. Organizations that maintain long-term relationships with key suppliers tend to realize long-term collaboration benefits (Van Echtelt, Wynstra, Van Weele, & Duysters, 2008). The timing of integration and the degree of design responsibility awarded to suppliers become critical decisions in the supplier integration process (Handfield et al., 1999; Petersen et al., 2005). The intention of suppliers for an early involvement in a customer's NPD process is dependent on factors such as: customer promise, interdependence, customer technological innovativeness, and supplier technical capability (LaBahn & Krapfel, 2000). Therefore, early supplier involvement is particularly important when the product technology is new to the manufacturer (Parker, Zsidisin, & Ragatz, 2008).

Resistance to sharing information, the not-invented-here syndrome, lack of trust, and lack of absorptive capacity are the major barriers to effective supplier integration (Cousins, Lawson, Petersen, & Handfield, 2011; Ragatz et al., 1997). Avoiding these barriers is possible through relationship structuring, formal trust development processes, formalized risk and reward-sharing agreements, joint agreement on performance measurements, top management commitment from both companies, confidence in the supplier's capabilities, and asset sharing (Ragatz et al., 1997; Walter, 2003).

Socialization mechanisms such as supplier conferences and on-site visits also increase the level of supplier integration in NPD (Cousins & Lawson, 2007). Purchasing managers should work closely with design experts to communicate the potential design contributions of leading-edge suppliers (Handfield et al., 1999). Contributing to NPD, while managing overall costs, becomes a challenge to the purchasing function when supporting supplier integration. The tools such as regular innovation meetings with suppliers and technology roadmaps linking the firm's business strategy, innovation strategy, and sourcing strategy may ease the facing of this challenge (Schiele, 2010).

Through NPD collaborations with manufacturers, suppliers receive direct financial benefits on sales volume and indirect advantages such as technological knowledge and a reputation of doing business with leading-edge firms (Smals & Smits, 2012). Hong and Hartley (2011) found that interactive teams of manufacturers and suppliers provide more quality-related benefits when the component technology is new to the suppliers. Knowledge exchange with suppliers improves both product development performance and the financial performance of the new product (Cousins et al., 2011). Lau et al. (2010) found that information sharing and co-development with suppliers improves project performance and innovativeness of the product. Overall, supplier collaborations are important to acquire needed expertise in NPD and result in quality and financial benefits to the manufacturing firms. Handfield and Lawson (2007) have highlighted the need for investigating the effect of ICT on supplier integration in CPD projects, and their informal interaction that is required for the transfer of tacit knowledge. In conclusion, the selection and management of suppliers and maintaining strong relationships with them through frequent communication and intensive sharing of information are vital for product development project success.

2.4.1.2 Customer collaboration

Manufacturing firms collaborate with customers mainly to bring the customer's voice into the new product and thereby develop a product which will meet, as far as is possible, the customer's requirements. Translating those customer requirements into design specifications is a major challenge to customer requirement management in NPD (Jiao, 2006). Quality function deployment (QFD) is a widely used tool in this translation that helps product designers to decide design specifications based on customer needs and competitive analysis (Chan & Wu, 2002; Franceschini, 2016). Both individual and business customers may collaborate in the NPD process. In more innovative product development projects, customer collaborations help organizations to attain high performance by increasing the quality of information received (Bonner, 2010). However, integration with customers is not always effective. For instance, information sharing and co-development with customers can lead to a reduction in the new product's innovativeness that contributes to the new product performance (Lau et al., 2010). Demand for customization, technology-related factors, individual consumer or customer level factors (e.g. expertise, motivation for collaboration), learning and knowledge transfer, strategic, structural and organizational factors (e.g. cultural views of collaboration and trust) are the driving and restraining forces of collaborative innovation with customers (Greer & Lei, 2012). Strategic trends such as open innovation, mass customization, and personalization have been identified as effective means for co-creation of value between organizations and customers (Romero & Molina, 2011). Crowdsourcing is a recent open innovation business strategy that facilitates customer collaboration. This enables the outsourcing of NPD activities to an undefined large network of people, which in turn results in certain benefits associated with new product customization as well as issues such as the feeling of being exploited and cheated (Djelassi & Decoopman, 2013).

The impact of customer collaboration at different stages of the NPD process has been discussed in the literature (e.g. Hoyer et al., 2010). Customer involvement at the fuzzy-front-end of the NPD process is a significant means to obtain original, new, and feasible ideas which are valuable for developing new products that meet customer needs (Filieri, 2013). Based on the type of information flow between manufacturer and customer, Athaide and Klink (2009) identified three approaches that firms use for managing customer involvement in NPD. Both buyer-guided and seller-guided approaches rely on a unilateral flow of information while the bilateral approach ensures a mutual exchange of information. Perceived customer knowledge, prior relationship history, product customization, and technological uncertainty should be taken into consideration when selecting a suitable approach. ICT tools are being increasingly developed to facilitate collaborative product designing through handling multiple customer requirements (e.g. Gologlu & Mizrak, 2011). However, collaborative ICT tools that make product information accessible to multiple customers need to be carefully managed for acquiring benefits while reducing risks and costs.

2.4.1.3 Collaborations with other external parties

Manufacturing firms sometimes collaborate with external parties, other than suppliers and customers, in their NPD projects. These partners include universities, competitors, and independent experts. Lai, Chen, Chiu, and Pai (2011) emphasized that the involvement of professional entities such as universities and research organizations affect both market performance and design performance of new products. Their ability to provide manufacturers with advanced technical theory and market knowledge are the possible reasons for this influence. However, collaborating with universities depends on both organizations' openness to learning and using universities' knowledge and infrastructures that facilitate joint developments with companies (Flores et al., 2009). Competitor collaborations help organizations to acquire new technologies or skills. But, in these collaborations, partner firms need to limit the degree of transparency and carefully decide technologies or skills to be transferred. In particular, strengths of the partner firms need to be complementary for being successful in terms of reduced costs and time through fast improvement of capability (Brettel & Cleven, 2011; Hamel, 1989). However, a negative effect of competitor collaborations on CPD performance is mostly evident mainly due to high risks of unexpected transfer of sensitive knowledge and the reduced ease of knowledge access (Brettel & Cleven, 2011; Un, Cuervo-Cazurra, & Asakawa, 2010).

Conceptualization and the implementation of some innovative product ideas may be possible through collaborations with experts such as engineering offices and independent research institutes. However, such collaborations have not shown any significant influence on NPD performance. The specific requirements of collaborations with independent experts (e.g. engineering consultants) may cause this insignificance (Brettel & Cleven, 2011). Yet, according to Lai et al. (2011), trust plays a relatively less significant role in third party collaborations, such as with universities and research institutions, when compared to supplier and customer collaborations. In addition, unnecessary dependence on outside knowledge can be a disadvantage in product development (Brettel & Cleven, 2011).

2.4.2 Internal collaborations

Teams integrating people from different functional departments, also called cross-functional teams, contribute a lot in increasing NPD performance (De Clercq, Thongpapanl, & Dimov, 2011; McDonough, 2000). R&D-marketing and R&D-manufacturing collaborations are quite common and have been largely studied previously. Song et al. (1998) suggested that function-specific and stage-specific patterns of cross-functional integrations are more effective than integrating all functions during all NPD stages. According to Troy, Hirunyawipada, and Paswan (2008), integrating fewer functions may provide better results. In particular, R&D-marketing integration is typical in NPD but does not indicate any significant impact on success.

Internal cross-functional integration not only provides a structural mechanism that increases the level of integration in NPD (Jassawalla & Sashittal, 1998) but also forms a basis for external NPD integration (Feng, 2013). In addition, it helps to transform tacit knowledge into collective (usable) knowledge and team socialization may increase the effectiveness of this transformation (Hirunyawipada, Beyerlein, & Blankson, 2010). The overall success of cross-functional collaboration in NPD is contingent on a range of organizational and relational factors (Holland, Gaston, & Gomes, 2000; Jassawalla & Sashittal, 1998; McDonough, 2000). The key factors are strategic alignment between functions, developing appropriate goals, decentralization of new product decisions, nature of the leadership, flexibility, openness, social interaction and trust. Furthering this knowledge, De Clercq et al. (2011) found that an organization's relational context (social interaction, trust, and goal congruence) is more important than its structural context (decision autonomy and shared responsibility) for achieving higher product innovativeness through cross-functional collaboration. According to some other research, internal drivers such as a firm's evaluation criteria, reward structures, and innovation-oriented leadership, are relatively more important than the external forces such as competitiveness and technological change, in improving cross-functional cooperation for innovativeness (Song, Montoya-Weiss, & Schmidt, 1997; Stock, Totzauer, & Zacharias, 2014)

Prior studies have focused on factors moderating the effect of cross-functional integration on CPD success. Song and Montoya-Weiss (2001) studied the moderating role of perceived technological uncertainty in cross-functional integration effectiveness. The moderating effect is negative for development process proficiency dimensions such as marketing proficiency, competitive and market intelligence (early assessment of market and competitive activities), and is positive for technical proficiency. Also, perceived high technological uncertainty strengthens the positive effect of cross-functional integration on project performance. However, this study has not evaluated the moderating effect of other project characteristics such as project complexity, on the effectiveness of cross-functional integration. Troy et al. (2008) found that the sharing of information better strengthens the relationship between cross-functional integration and new product success, than does a cooperative climate. They highlighted the significance of sharing information in more formal settings rather than in a socially cooperative climate for the success of projects.

Table 2.1 summarizes the benefits and risks of different types of product development collaborations, identified in the above literature review.

Table 2.1: Benefits and risks of different types of collaborations in product development

Type of collaboration	*Benefits*	*Risks or limitations*
Supplier collaboration	• Opportunity to utilize supplier's capabilities to set joint technology goals. • Long-term collaboration benefits through long-term relationships with key suppliers. • Better quality designs. • Higher financial performance of the new products. • Effective transfer of tacit knowledge through informal interaction with suppliers.	• Selecting suppliers based on their qualifications and capabilities. • Maintaining the balance between customer requirements and supplier capabilities. • The timing of integration and the degree of design responsibility awarded to suppliers. • Resistance to sharing information, • Problems associated with the credit for invention • Lack of trust • Lack of absorptive capacity
Customer collaboration	• Customized new products through co-innovation with customers. • Ability to obtain original, new, and feasible ideas through customer collaboration in conceptualization stage. • Co-creation of value • Increased overall quality of products. • High demand for the developed products.	• Translating vast customer requirements into design specifications. • Selecting suitable customers and managing their involvement. • Reduced innovativeness of the new products.
Collaborations with other external parties (e.g. universities and independent experts)	• Accelerated capability enhancement • Ability to acquire advanced technical theory, skills, and market knowledge. • High performing designs. • Greater assurance of market success.	• Excessive dependency on outside knowledge • High risk of failure • High risk of unexpected transfer of sensitive knowledge • No easy access to knowledge.
Internal cross-functional collaborations	• Providing structural mechanisms for increasing overall integration (both internal external) in product development. • Increased product innovativeness • Help to transform tacit knowledge into usable knowledge. • High effectiveness when technological uncertainty is high.	• High dependence on organizational and relational factors (e.g. strategic alignment between functions, human resources practices, leadership, and flexibility). • Greater need of formal information sharing facilities.

2.4.3 Drivers of collaborative product development performance

Success of a CPD project depends upon various organizational, internal and external environmental factors. These factors may depend on whether the project is collaborative or not. Since collaborations in NPD provide many advantages as well as disadvantages to organizations, manufacturing firms usually attempt to very carefully select suitable projects to collaborate. However, projects not involving any type of collaboration (at least internal cross-functional team collaborations) are rare to find. A competitive environment for the new product and the consistency in organization and management of the product development system including organizational structure, technical structure, technical skills, problem-solving processes, culture, and strategy are the major drivers of product development performance (Clark, 1991). However, Cooper (1979) states that intensity of competition is a barrier to new product success because customers are more likely to be well-satisfied with existing products in such a competitive market. Based on results of the NPD performance and best practices survey (American Productivity and Quality Centre), Cooper, Edgett, and Kleinschmidt (2004) emphasized that the supportive innovative climate and culture, senior management commitment, and having a product innovation strategy are major organizational drivers of NPD performance. Although the existence of a systematic, formal process for NPD is important, it does not drive NPD performance, and the nature of the NPD process and the method of implementation seem to be rather significant (Cooper, Edgett, and Kleinschmidt, 2004).

However, in a collaborative setting where a number of internal and external partners act as a team to develop new products for generating joint value, some extra factors would also be important. In addition to the competitiveness, Lin, Hsing, and Wang (2008) emphasized that market demand, information sharing, and communication between collaborative partners are major driving forces of the collaborative design performance. According to Littler et al. (1995), factors such as trust between partners, consideration of marketing issues, flexibility of systems and style, and the fit of the CPD project with existing business, discriminate between successful and unsuccessful CPD projects. Although many manufacturers collaborate in their NPD projects, the level of success that they achieve depends upon the degree of collaborative competence possessed by them (Mishra & Shah, 2009). Therefore, based on literature reviewed above, the drivers of product development performance can be identified and categorized into two groups, as follows.

Drivers common to the performance of all NPD projects

- Market orientation
- Supportive innovative climate/culture
- Senior management support
- Strategy

Additional drivers of the performance of CPD projects

- Trust between partners
- Collaborative competence
- Frequent communication and information sharing

The following sub-sections elaborate on each of these drivers of product development performance.

2.4.3.1 Market orientation

The degree to which organizations address customer needs in their NPD projects or market orientation is a key to increased NPD performance (Cooper et al., 2004). The best market-oriented firms practise followings to get the voice-of-customer or market input into their new products.

1. Planning the market launch based on the inputs from market and buyer behaviour studies.
2. Using market research as a tool to help define the product.
3. Considering the customer or user as an integral part of the development process.
4. Identification of customer needs and problems as a key input to product design.
5. Working with highly innovative users or customers.

All these practices essentially help firms to understand exact requirements in the marketplace and to achieve greater performance by developing new products that fulfil those requirements. Supporting these notions with empirical evidence, some research have found a positive influence of market orientation on the new product’s market performance (e.g. Atuahene-Gima, 1995; Murray, Gao, & Kotabe, 2011). This positive effect is stronger for incremental innovations relative to the radical innovations. The greater uncertainty involved in radical projects is a possible reason for this moderating effect of the type of innovation. Responding to key customer needs for which a single organization does not have the necessary capabilities to fulfil, is one of the main reasons for collaborations in NPD (Büyüközkan & Arsenyan, 2012; Littler et al., 1995). Collaborations in such situations increase a firm's ability to make use of valuable market opportunities. In one study, Narver, Slater, and MacLachlan (2004) extended the idea of market orientation as a two-dimensional concept comprising responsive and proactive market orientation. Attempts to understand and satisfy expressed and latent needs of the customers are known as responsive and proactive market orientations respectively. The results of this study imply an insufficiency of the responsive market orientation, and emphasize the strong positive role of proactive market orientation for sustainable new product success.

2.4.3.2 Supportive innovative climate

Organizations having an innovative climate have an increased likelihood of being successful in NPD (Cooper et al., 2004). An innovative climate consists of two aspects, namely, general climate and specific actions and programmes for motivating a positive climate. The key elements of a general positive innovative climate are – (1) a supportive climate for entrepreneurship and product innovation, (2) rewards for new product champions or product innovators, (3) rewards for project teams, (4) understanding the NPD process of the business, (5) open communication among employees across functions or locations, (6) risk averseness, and (7) no punishment for failure. These characteristics of a firm set up an organizational environment that gives every employee an opportunity to express their innovative ideas with no fear. Open communication across all boundaries is vital for ensuring the success of innovations that are compatible with the right requirements and the resource availability of the firm or potential collaborators. The second climate factor represents more action-oriented items and specific programmes. The key elements of this climate are – (1) making resources available for creative work, (2) encouraging skunk works and unofficial projects, (3) time off or scouting time, (4) rewarding new product ideas, and (5) having a new product idea suggestion scheme in place. These characteristics may not be available in all firms that have an innovative climate. A firm needs to have considerable financial strength to be able to provide the necessary resources and equipment for implementing such innovative programmes.

2.4.3.3 Senior management commitment

Leadership, empowerment, and resource commitment provided by senior management is an important driver of new product development success (Cooper et al., 2004). The following are the key practices of senior management in high performing companies:

(1) Providing strong support, empowerment, and authority to the people working on NPD projects.
(2) New product metrics (e.g. percentage sales) are an explicit part of senior management's personal and annual objectives.
(3) Understanding of the business's NPD process.
(4) Engaging in the design of the NPD process.
(5) Measuring new product results each year.
(6) Strong commitment to new products and product development.
(7) Not micro-managing NPD projects (give the authority to the leaders of the NPD teams).
(8) Involvement in Go/No-Go and spending decisions for new products (having a dominant role in the project review process).

Although the overall level of the senior management commitment of many firms is fairly satisfactory, most of them neither include new product metrics in their annual objectives nor engage in the NPD process design. Not only is the empowerment in decision-making important, the senior manager's active involvement in the implementation of programmes in NPD is also important (Clark, 1991; Felekoglu & Moultrie, 2014). Therefore, the increased attention of senior management on practices (2) and (4) above would further improve innovation project performance.

2.4.3.4 Strategy

Having a product innovation and technology strategy consisting of the following six elements is highly correlated with the NPD performance of a firm (Cooper et al., 2004).

(1) The role of NPD in achieving the overall business goals.
(2) Strategic arenas or strategic focus areas on which NPD efforts should concentrate.
(3) Clearly defined NPD goals.
(4) Long term commitment.

(5) Strategic buckets (resources directed to different project types or different strategic focus areas).
(6) Product roadmap in place (the plan to achieve the objectives set).

Although many firms have most of these elements of strategy in place, strategic buckets and the product roadmap are the two elements that are very poorly practised. Since these two practices represent the means of implementing a strategy, organizations need to pay increased attention to these areas in their NPD strategic management process. Having allocated funds and other resources for specific projects and ensuring the possibility of achieving the goals at the projected times would reduce the likelihood of project failures.

2.4.3.5 Trust

Past CPD research identifies trust as a major driver of new product success (e.g. Dayan & Di Benedetto, 2010; Littler et al., 1995). According to Bstieler (2006), communication behaviour and fairness have a positive impact on trust between partner firms, whereas conflicts during product development and perceived egoism cause damage to the trust. In his study, timely, reliable, and adequate sharing of information has been considered as the required communication behaviour. This kind of information sharing helps partners in understanding the needs of each other, thus improving harmony and the teams' relationships. Honesty, keeping promises, not making unwarranted claims, and a supportive attitude are the key characteristics of trustworthy partner firms. Trust improves many aspects of CPD performance, namely, partnership satisfaction, intentions for continuing partnerships, financial performance, and time efficiency. Interpersonal trust also increases team learning and has more impact on new product success when task complexity is high (Dayan & Di Benedetto, 2010). The intensive loads of information to be shared in complex projects may cause this strong significant effect.

2.4.3.6 Collaborative competence

Mishra and Shah (2009) explained collaborative competence as the ability to simultaneously collaborate with suppliers, customers, and cross-functional teams. This study revealed that collaborative competence results in increased project performance which in turn improves market performance. The concept of network competence, the ability to handle, use, and exploit inter-organizational relationships (Ritter & Gemünden, 2003) is almost similar to collaborative competence. Network competence positively affects the extent of inter-organizational technological collaborations and the product and process innovation performance of the firm. Access to resources, network orientation of human resource management, integration of intra-organizational communication, and openness of corporate culture are the organizational antecedents that influence the network competence. These factors increase the transparency of product- and process-related technological knowledge to various partners in the network and hence help to develop their complementary capabilities.

2.4.3.7 Frequent communication and information sharing

Firms with increased communication and ability to share technological and market-related information with collaborative partners are likely to be more successful in their CPD efforts (Lam & Chin, 2005; Littler et al., 1995). Information required in CPD may come from several sources such as component parts suppliers, customers, and different departments (engineering, marketing, purchasing and manufacturing) of the firm itself. Frequent communication with suppliers is an important factor affecting product development budgets and costs (Hoegl, 2005). Sharing of information and knowledge with customers and suppliers helps to improve the performance of NPD projects (Fang, Palmatier, & Evans, 2008; Thomas, 2013). However, it is also known that information sharing in CPD projects can result in issues such as leakage of commercially sensitive information, lack of control over project activities, and long development times (Büyüközkan & Arsenyan, 2012; Littler et al., 1995). Therefore, proper management of the technologies facilitating communication and information sharing is essential for successful CPD.

In order to communicate and share information with CPD partners, firms use several traditional (e.g. telephone, fax, e-mail, face-to-face) as well as modern (e.g. electronic data exchange, ERP) means of information and communication technologies. Although traditional methods are found to be more effective in terms of information sharing (Carr & Kaynak, 2007), as the number of remotely collaborating partners (e.g. suppliers) increases, firms need to rely on advanced ICT tools (Dube & Pare, 2004). Additionally, when products are more complex and product or process technology is uncertain, product developers need more frequent consultation and information sharing with partners in order to deal with increased information deficits and integration requirements in such projects (Kim & Wilemon, 2007; Ragatz, Handfield, & Petersen, 2002). Therefore, when selecting ICT tools for CPD, a firm needs to consider the available features and functionalities in ICT tools and how these satisfy the specific communication and information requirements of the firm's CPD projects.

2.5 SUMMARY

The product development process is a series of activities associated with introducing a new or improved product to the market. The major stages of this process are conceptualization, product development, and commercialization or product launch. Firms deploy various strategies to achieve competitive advantage in product development. Collaborating with one or more external partners (e.g. suppliers and customers) and/or internal partners (e.g. cross-functional teams) in order to develop new or improved products by joining firms' complementary resource and experience at various stages of the product development process is known as collaborative product development (CPD). CPD is a widely adopted product development strategy which allows the application of key principles of other important strategies such as concurrent engineering, lean product development, and agile product development. The performance of CPD projects is driven by market orientation, supportive innovative culture, senior management support, strategy, trust, collaborative competence, and frequent communication and information sharing. Firms use ICT tools to facilitate information sharing in their CPD projects and it is important to consider the capacity of ICT tools as well as the specific communication and information needs of the projects when selecting and using these tools. The next chapter reviews literature related to the use of ICT tools in product development and ICT impact on different dimensions of CPD performance. It identifies key gaps in the literature in relation to evaluating the impact of ICT usage on CPD performance.

3. Literature Review of Related Works

3.1 Introduction

This literature review specifically addresses the role of information and communication technology in CPD. First it introduces several ICT tools used in CPD for facilitating CPD tasks such as communication/collaboration, product design/development, knowledge/information management, project management, and market research/analysis. Next, the chapter reviews available literature related to the impact of ICT usage on collaborative product development performance, the primary theme of the study. Based on previous research focusing on the impact of ICT usage on product development performance, this chapter identifies some significant gaps in the literature.

3.2 Use of ICT Tools in Collaborative Product Development

Information and communication technology (ICT) provides the key means for communication, concurrency, knowledge codification, and identification of experts that are essential in CPD. ICT assists organizations in becoming more market-oriented or in introducing new products matched to market demands by increasing the degree of integration, cooperation, and collaboration with relevant bodies (Vilaseca-Requena, Torrent-Sellens, & Jiménez-Zarco, 2007). Furthermore, ICT tools facilitate access to a variety of sources of new product ideas inside and outside of the firm, enable several attempts at low costs (easy simulation, prototyping etc.), and simplify the rewarding for innovations. Therefore, the use of ICT tools in product development supports creating an innovative climate within the organization. Also, easy and systematic transfer of information, real-time involvement in an NPD project, and high quality communication enabled by ICT could help in getting more support from senior management. High quality communication, shared problem solving, and the sharing of benefits and burdens helps in creating trust in CPD (Bstieler, 2006) and these are essentially supported by the use of ICT. Peng et al. (2014) found that product design and project management ICT tools improve collaboration in NPD. Therefore, improved communication and information sharing facilitated by ICT, which themselves drive CPD success, can stimulate most other drivers of CPD performance such as trust, collaborative competence, market orientation, innovative climate, and senior management support.

ICT tools assist in the storing, retrieving, analysing, and sharing of product- and market-related data. Most of today's CPD teams are dispersed over organizational boundaries and become virtual teams. Conventional NPD teams use ICT only as a punctual tool to support face-to-face work while most work of virtual collaborative teams is performed through ICT (Dube & Pare, 2004). Therefore, ICT tools that enable design, development, prototyping, and commercialization tasks are increasingly developed to facilitate collaboration in these project phases (Awazu et al., 2009). Organizations consider team virtuality, cultural diversity, project phase, tasks, and product complexity when selecting ICT tools for CPD activities (Dube & Pare, 2004; Lockwood et al., 2013). One reason for this is, capacity for synchronizing work, coordinating different user inputs, usage of virtual memory, and the level of security provided are different from one ICT tool to another. Many modern ICT tools have a number of advanced features compared to their traditional versions due to the increased collaborative trend in NPD during the recent past (Tony & William, 2001). Based on the tasks performed in CPD projects, Barczak et al. (2007) and Kawakami, Durmusoglu, and Barczak (2011) classified ICT tools used in CPD into five categories, namely, communication and collaboration, product development, project management, information and knowledge management, and market research and analysis tools. The following sections present some key ICT tools in each category and their functionalities that are useful in CPD.

3.2.1 Communication and collaboration ICT

3.2.1.1 E-mail

Electronic mail (e-mail) is an ICT that exchanges digital messages from one person to one or more recipients. E-mail is the most widely-used ICT in business communication, and it solves the problems of logistics (lower cost than postal mail and no risk of loss or damage) and synchronization (the sender and the recipient(s) are not required to be online concurrently). The users need to connect to a mail server to send or receive messages (Partridge, 2008). Since e-mails allow the transfer of files (of small size) as attachments, they are frequently used in CPD to send files (design specifications, sketches, or documents) (Boutellier et al., 1998; Peng et al., 2014). Therefore, the use of e-mails is rich rather than lean in modern CPD contexts (Eriksson & Dickson, 2000). Using e-mails is convenient for anyone involved in a CPD project since e-mail is easily accessible (both checking and replying to e-mails are possible with mobile devices such as smartphones and tablet computers). However, detailed replies need computers with a proper keyboard. Sometimes e-mails can waste time during projects because it is possible to receive unwanted or duplicated information due to the availability of the "copy all" option and convenient mailing lists (Androutsopoulos, Koutsias, Chandrinos, & Spyropoulos, 2000; McGee, 2013).

3.2.1.2 Instant messaging

Instant messaging transmits real-time text between two or more participants over the networks such as the internet (Baron, 2013). Social networks such as Facebook chat offer an instant messaging facility. This is an effective and efficient method of communication because it permits immediate receipt of reply or acknowledgement. Instant messaging often has added features such as users seeing each other by webcams, and file transfers (limited file sizes). Some instant messaging services also offer web conferencing facility, which can integrate instant messaging and video calling (e.g. Skype). Usually, the text conversations are saved and audio conversations can be recorded for later reference. There are two types of instant messaging – Enterprise Instant Messaging (EIM) and Consumer Instant Messaging (CIM). Small scaled companies are not able to use EIM that uses internal IM servers. CIM are not expensive to implement and a high investment on new hardware or server software is not needed. The most common instant messaging services are: SMS, Facebook Messenger, WhatsApp, Instagram, Qzone, WeChat, Tencent, Google+, Skype, Twitter, and LinkedIn (Baron, 2013; Church & de Oliveira, 2013).

3.2.1.3 Web meetings

Web meetings are a real-time communication method over the internet, which facilitates communication from one sender to many receivers. The different types of Web meetings are: Web seminars (webinars) and webcasts (media presentations distributed from one source to many simultaneous viewers or listeners). Web conferencing software is required to be installed on each participant's computer. Web meetings are used by geographically dispersed CPD partners for exchanging text, voice, or video messages related to new designs. Other features of Web meetings include: slideshow presentations, VoIP (real time audio communication through computers), polls and surveys (multiple choice questions to the audience from the presenter), Whiteboard (a feature that allows attendees or the presenter to highlight or mark items on a presentation), sharing of screens, desktop, or application, and meeting recording (Frost, 2006; Molay, 2007).

3.2.1.4 Video conferencing

Video conferencing is a popular method of communication and collaboration in CPD as it facilitates communication from multiple locations by simultaneous bi-directional audio and video transmission. A video conferencing system requires the following components to operate – video camera or webcam for video input, computer monitor, projector or television for video output, microphone or any other audio outlet for audio input, telephone or speakers linked with the display device for audio output, telephone network, local area network, or internet for data transfer, and a computer for data processing (Firestone, Ramalingam, & Fry, 2007). As it provides a method of face-to-face meetings for distributed teams, use of video conferencing is common in complex CPD projects where many R&D teams are involved (Boutellier et al., 1998; Thomas, 2013). This might be convenient in modern CPD contexts where high capacity broadband telecommunication services, powerful processors, and video compression technologies are widely available. However, failing to make all relevant people or resources available at the time of the conference may make video conferencing less effective (Thomas, 2013).

3.2.1.5 Groupware

Groupware is a collaborative software which has been designed to facilitate the cooperative work of a group of people involved in a common task to achieve their mutual goals (Andriessen, 2012; Carstensen & Schmidt, 1999). Groupware tools are divided into three categories based on the level of collaboration: communication (exchange of unstructured information – e.g. instant messaging, conferencing (interactive work towards a common goal – e.g. brainstorming), and coordination (complex interdependent work towards a common goal) (Ellis, Gibbs, & Rein, 1991). These groupware tools offer coordination support, improved efficiency and creativity in CPD (Boutellier et al., 1998; Evans, Gao, Martin, & Simmonds, 2015).

3.2.1.6 Weblogs

Weblogs are basically link-driven sites (Blood, 2000). Weblog editors provide links to useful news articles (according to their understanding) and little-known Websites, together with their commentary. These sites provide important filtering for readers, which is useful for product developers to gather valuable information on their products, technologies, and markets within a relatively short period of time. Weblogs are interactive as they allow readers to leave comments and exchange messages between each other. This enables digital 'word of mouth' and provides consumer-generated advertising of products (Mutum, 2010). Therefore, many of today's firms use Weblogs to engage online communities for increasing advertising of their products. In addition, branding of new products and building public relations are possible with Weblogs. In addition, Weblogs offer digital learning environments and virtual collaboration opportunities (Boulos, Maramba, & Wheeler, 2006).

3.2.2 Product design and development tools

3.2.2.1 Idea management software

Companies use Idea generation software to collect new product ideas or suggestions from their employees or external sources. Idea management tools manage and polish these ideas through comments from people and discussions. In addition, these ICTs cluster similar ideas and select the best ideas through reviews and voting scores. Use of these tools supports developing strong relationships with various stakeholders through making prompt updates available and regular communications (Capterra, 2016; Durmusoglu & Barczak, 2011).

3.2.2.2 Computer-aided design (CAD) and collaborative CAD

Computer-aided design (CAD) tools are the software assisting in creation, modification, analysis or optimization of designs (Sarcar, Rao, & Narayan, 2008). These tools include computer programmes to implement interactive computer graphics. In most software, images are constructed out of basic geometric elements such as points, lines, and circles. CAD helps designers to visualize the product and its parts. This eases the design process by reducing the time for synthesizing, analysing, and documentation of the design. As CAD tools allow systematic engineering analysis within a short time, it is possible for R&D people to review many design alternatives. Calculations and checks available in these systems are important to develop new products with fewer errors and increased accuracy. The documentation of the specification of product components and bills of materials produced by CAD systems, support computer-integrated manufacturing.

Synchronized model construction and modification are possible with modern collaborative CAD systems that facilitate real-time collaborative product design (Li, Gao, & Wang, 2007). The internet has significantly improved the power of these systems. Unlike earlier platform-dependent collaborative CAD systems developed on local area networks, modern Web-based systems enable multiple users to share their design models over the internet. There have been three types of such Web-based CAD systems. The first type of tools integrate Web-based solid model displays with online multimedia tools such as Web meetings and online chat that enable distributed designers to share their design ideas. Advancing this communication feature, the second type of software allows the designers to share designs by facilitating online development and editing solid models. The third category of the tools are the latest which allow collaborative designers to concurrently develop common models (Liu, Raorane, & Leu, 2007). Functionalities ranging from simple to advanced are available in these tools. Some of these are: freehand sketching, 2D profile designing, facilities for creating and editing in virtual 3D with basic geometric shapes and comprehensive symbols, tolerances, and dimensioning. The ability of advanced collaborative CAD to generate complex entities from raw or scanned makes reverse engineering feasible (NIC, 2014).

3.2.2.3 Rapid/virtual prototyping and simulation software

The quick and easy creation of actual or virtual prototypes/models and a preview of the functioning of the developed designs are possible with rapid prototyping and simulation software (Ferrise, Bordegoni, & Cugini, 2013; Thomke, 1998a). Designers determine the quality of the new product through simulation. Prototypes can be tested in real or simulated environments where the product is used. Speed and convenience in modification and low cost are the key objectives of product developers in using rapid prototyping software (Prabaharan, 2013; Thomke, 1998a) In addition, improved communication between multiple stakeholders and collaborative problem solving have been easy with modern collaborative prototyping tools (Bogers & Horst, 2014). Interfaces that can directly convert designs into simulation models are available in advanced CAD systems. Utilization of these features leads to reduced model building costs by decreasing the cost of conversion tools and required operating time. Simulation software solutions offer product developers an increased ability to conduct experiments under various conditions and an opportunity to investigate low-cost design iterations.

Therefore, these tools are of relatively high importance in industries where products are expensive and usable environments are easily unavailable (e.g. automotive) (Thomke, 1998b). However, inaccuracy in the simulation model used and considerable deviance from the real environments could create unexpected errors in designs (Seth, Vance, & Oliver, 2011; Thomke, 1998a).

In addition to cost and time advantages, the use of virtual simulation tools leads to the achievement of other performance aspects such as improved problem solving, collaboration, and product innovativeness. Both the use of knowledge from general rules (e.g. theories in physics) to solve specific problems and developing solutions from knowledge generated through examples and analysing patterns, are possible with these tools. This improves the ability of problem solving in product development. Since virtual experiments use hypotheses formulated based on less formalized knowledge and test these with no logically bounded constraints, creativity which leads to more innovative designs is improved (Becker, Salvatore, & Zirpoli, 2005; Bogers & Horst, 2014).

3.2.3 Knowledge and information management tools

3.2.3.1 Product data management (PDM) systems

Product data management (PDM) systems manage and control all the product-related information including: product specifications, engineering drawings, part files, project plans, assembly diagrams, and engineering change orders. Retrieval of product data, management of product structure/design variations, and re-use of designs are the key product development functions facilitated by PDM systems (Liu & Xu, 2001; Tang, Guo, Huang, Li, & Li, 2015). These functions are enabled by features in PDM such as data warehousing, module for product structure definition, module for information management, network-based infrastructure, and interfaces to handle user queries (Ahmed & Gerhard, 2007; Stark, 2016). PDM tools connect different areas of the enterprise while ensuring that the right information in the right form is available to the right person at the right time. Improved collaboration, reduced development cycle times, uncomplicated and early access to information are the major benefits of using PDM in product development. Overcoming several barriers in traditional systems, Web-based PDM software products offer improved user-friendliness, accessibility, and linking of stakeholders in different geographical locations easily over the internet. Previously, these systems had several issues in transferring complex data and security issues (Xu & Liu, 2003). However, modern improvements to the PDM systems with new virtual reality and PLM technologies overcome many of these issues (d'Avolio, Bandinelli, & Rinaldi, 2015; Ming, Yan, Lu, & Ma, 2005; Noël & Azli, 2013).

3.2.3.2 Knowledge management systems

Knowledge management systems support generation, codification, reuse, and the transfer of knowledge (Ruggles, 2009; Teigland, Fey, & Birkinshaw, 2000). Since product development is truly a knowledge intensive activity, great amounts of knowledge are generated through the experience of the various partners involved in CPD. Proper management of this knowledge using required ICTs is important for achieving high performance in CPD projects (Teigland et al., 2000). The technologies utilized in knowledge management are – intranets, Web portals, content management, document management systems, information retrieval engines, relational and object databases, electronic publishing systems, groupware and workflow systems, push technologies (technologies that send information to the clients automatically), intelligent software agents, help-desk applications, customer relationship management, data warehousing, data mining, business process re-engineering, and knowledge creation applications (Tyndale, 2002). Knowledge management tools enable learning from past experiences on solutions and mistakes made. An increased innovation rate, fast acquisition of competency, high productivity, and increased customer satisfaction are expected through the use of these tools (Rao, 2012).

3.2.4 Project management tools

3.2.4.1 Project scheduling and tracking software

Firms often undertake several CPD projects simultaneously with limited resources available. Most of the projects involve large numbers of internal and external partners around the world. Therefore, the planning and scheduling of CPD projects are complex tasks that are almost impossible to accomplish without proper software support. Project management (PM) software includes features for creating work breakdown structures, sequencing (creating links), cost estimation, assigning resources, setting milestones/deadlines, and tracking progress (Pons, 2008). MS Project is the most popular tool for planning, scheduling, and tracking projects (Microsoft, 2016). Zoho, Smartsheet, Teamwork, Basecamp, Centraldesktop, and Goplan are some other tools which have similar kinds of features. Many scheduling and project tracking tools create reports such as PERT diagrams, Gantt charts, and resource histograms. These tools also support collaboration by sharing files, tracking tasks, and providing varying levels of access to projects and data to different classes of users identified (Nevogt, 2015).

3.2.4.2 Project and portfolio management (PPM) tools

Portfolio management involves both revising and updating existing active product development projects and selecting the most feasible set of new projects. Therefore, the tasks of portfolio management include evaluating, prioritizing, and selecting multiple new projects, and accelerating or de-prioritizing (killing) existing projects, and the allocation of resources to active projects (Cooper, Edgett, & Kleinschmidt, 2001). Project and portfolio management (PPM) software facilitates this dynamic decision-making process. The functionalities supporting portfolio management, project management, resource management, time and financial management are included in these tools. In addition, PPM tools support business intelligence and real-time visibility into the status of projects and portfolios. These allow manufactures to improve the decision-making process, collaboration (through increased visibility and resource management), productivity and speed (through the better strategic alignment of projects, killing low-value projects, and eliminating unstructured data management) (Changepoint, 2015; Sopheon, 2016). However, developing context-specific performance measures for project portfolios while ensuring better flexibility is required rather than adopting measures for strategic alignment in general (Martinsuo, 2013). Therefore, the capacity of PPM software tools in these aspects would be important in achieving overall project success.

3.2.4.3 Product lifecycle management (PLM) systems

Traditional project management focuses on a single project in a single location and emphasizes scheduling, planning and tracking of the project. In contrast, modern collaborative PM software supports all levels of collaboration (varied from simple to rigorous communication) and helps to increase the efficiency and effectiveness of project managers and team members (Romano, Fang, & Nunamaker, 2002). Product lifecycle is a paradigm focusing on managing products throughout their lifecycles, which emerged in 2001 while previous paradigm was departmental where the marketing department decided the product needs in the market, the engineering department designed the products, and the manufacturing department produced the products (Stark, 2015). PLM systems provide a product lifecycle portal for various partners (investors, customers, developers, manufacturers, and suppliers) (Ming et al., 2005). Various powerful functionalities for supporting vault management, configuration management, release and change management, and project management are included in modern PLM systems (Milhim, Deng, Schiffauerova, & Zeng, 2012). Therefore, PLM is regarded as a full integration of all the ICTs for design and operational activities throughout the product lifecycle (d'Avolio et al., 2015). The technological solutions included in PLM systems are – PPM, PDM, CAD, CAE, product and process simulation, finite element analysis, modal testing analysis, and manufacturing operations management (SAP, 2014; Seimens, 2016). PLM software supports collaboration within CPD teams by facilitating the faster sharing of information, revising interdependencies between tasks, and the concurrent execution of tasks (Banker et al., 2006).

3.2.5 Market research and analysis tools

3.2.5.1 Online market research tools

Online surveys, online communities, and online focus group discussions are widely used Web-based market research techniques. These tools are primarily used in the front end of NPD (Creusen, Hultink, & Eling, 2013; Kleef, Trijp, & Luning, 2005). Questionnaires that ask the same set of questions from a large group of consumers are useful to know the preferences or problems of the majority, or of a particular group of people. In addition, internet-based idea competitions are conducted to generate idealised designs, identify customer-preferred product configurations, and find the best solutions to problems in products (Creusen et al., 2013). Online focus groups are internet-based platforms for discussions within distributed groups (8-10 participants). These are used to discuss a set of new product concepts or to identify drivers of consumer choice for a specific product (Kleef et al., 2005). A moderator invites a qualified, pre-screened group of people from various locations in the world and guides real-time discussions among the participants over the internet. These tools provide computer interfaces that display multiple chat messages. In addition, the participants can use input devices such as microphones and cameras in their computers (Davis, 2001). Some firms actively involve or monitor online communities such as Weblogs, Twitter, and Facebook where consumers share their knowledge about products, their problems and improvements, and sometimes new product ideas (Creusen et al., 2013; Marion, Barczak, & Hultink, 2014). Gathering information through these communities is a cost-effective and convenient way of increasing a company's social capital (total resources generated through relationships) which leads to co-innovation (Bugshan, 2015).

3.2.5.2 Secondary data

Data that have been previously collected by external individuals or organizations for some purpose are known as secondary data. Firms use these data obtained from different sources to conduct market research that offers valuable inputs to their NPD programmes. These sources include: government sources (census data), searchable databases, data published by trade, business, and professional associations, corporate filings (annual reports), and media (e.g. online news) (Kawakami et al., 2011; Study.com, 2003). Organizations may need to obtain authority from relevant bodies to access some of the data which are not publicly available. Advantages of using secondary data include: low-cost, less time than collecting primary data, ability to access large amounts of data, and providing important information for future primary data collections (e.g. defining population, estimating size and structure of sample required). However, when using secondary data for market research, firms need to be cautious about the time scale of the data, reliability, measurement errors, source biases, complexities, the absence of key variables (due to the specific interests of the data collecting entities), and the definitions used by the data collectors (Bryman & Bell, 2015; Crawford, 1997).

3.2.5.3 Statistical software

Statistical software tools (e.g. SPSS, SAS, and Minitab) facilitate analysing data collected in market research and generate outputs that provide important insights to new product developers. These outputs include descriptive statistics, graphs, and detailed results of statistical tests (Minitab, 2016; SPSS, 2016). CPD teams can ensure better awareness and transparency by sharing these outputs among partners. Statistical software tools are able to handle a range of datasets, whether they are large, complex, or small. Companies can improve the quality of their decision-making process by using these software tools that facilitate exploration of important patterns and relationships which cannot be revealed merely through industry expertise, experience, and the exposure of practitioners. Although, software providers make continuous efforts to increase the user-friendliness of their tools, users may need specific skills and competencies in using appropriate statistical techniques and interpreting outputs.

Table 3.1 presents all the above ICT categories and the main tools in each category, and summarizes key CPD tasks performed by those tools.

Table 3.1: Types of ICT tools used in collaborative product development

Type of ICT tools	*Examples of ICT Tools*	*Key tasks performed in CPD*
1. Communication and collaboration tools	E-mail, instant messaging, Web meetings, video conferencing, groupware, Weblogs	Facilitate fast transfer of text, graphics, and video messages and support communication, coordination, collaboration, solving problems among members in CPD teams (Boutellier et al., 1998; Peng et al., 2014; Thomas, 2013).
2. Product design and development tools	Idea management software (e.g. Innovation Central, Discovery Central)	Capture, evaluate, and refine new product ideas (Capterra, 2016; Durmusoglu & Barczak, 2011)
	Computer-aided design (CAD) and collaborative CAD systems, rapid/virtual prototyping tools, and simulation software	Facilitate concurrent creation and modification of product designs, digital models, and prototypes and preview, experiment, and evaluate models and their functioning (Bryden, 2014; Red et al., 2010; Sarcar et al., 2008; S. H. Thomke, 1998a, 1998b)
3. Knowledge and information management tools	PDM systems and knowledge management systems	Facilitate management, retrieval and sharing of product information and generate, codify, reuse, and transfer knowledge (Ruggles, 2009; Stark, 2016; Tony Liu & William Xu, 2001)
4. Project management tools	Project scheduling and tracking software, project and portfolio management (PPM) tools, product lifecycle management (PLM) systems	Create work breakdown structures, facilitate sequencing tasks, estimate costs, assign resources, set milestones/deadlines, track project progress, evaluate, prioritize, and select multiple and complex projects, facilitate collaboration, and integrate design and operational activities (Banker et al., 2006; d'Avolio et al., 2015; Pons, 2008)
5. Market research and analysis tools	Online market research tools and secondary data	Particularly support front end of new product development to understand problems in existing products, and decide new product configurations from consumers' perspectives (Creusen et al., 2013; Marion et al., 2014; Van Kleef et al., 2005)
	Minitab, SPSS	Analyse market research data, generate useful statistical outputs, and support high quality decision making (Minitab, 2016; SPSS, 2016)

3.3 The Impact of ICT usage on CPD Performance

The impact of ICT usage on different aspects of a CPD project's performance has been addressed in previous studies (Barczak et al., 2007; Boutellier et al., 1998; Kawakami et al., 2015; Peng et al., 2014). Several qualitative investigations and literature reviews suggest that the role of ICT in CPD is substantial while exploring the conditions for the effective use of these tools (e.g. Bhatt & Ved, 2013; Boutellier et al., 1998; Ozer, 2000; Swink, 2006). In a study focused on several ICT tools used in CPD programmes, Boutellier et al. (1998) highlighted the importance of organizational and human-related factors for the successful utilization of ICT. The study suggests that the ability of ICT tools to substitute face-to-face communication is the major challenge faced by dispersed CPD teams. Lack of such communication implies ignorance of sensory information, feelings context, and intuition. However, many modern easy-to-use communication tools (e.g. Web meetings, video conferencing) are available for facilitating non-verbal aspects such as body language and gestures. However, this may not be as effective as actual face-to-face meetings which are almost impossible in large distributed CPD projects. Some useful strategies for more effective use of ICT are: bringing teams together in a single place in complex projects or stages, using ICT tools according to the requirements of the project phases, and continuity of teams to ensure trust between partners. In addition, tools such as e-mails are valuable as they support in the clear transfer of information (in text format) between CPD team members who have cultural, language, and accent differences leading to ambiguous exchange of information in verbal communication.

Swink (2006) suggested that ICT tools help to overcome organizational, physical, relational, and knowledge barriers for collaboration in NPD. ICTs help in overcoming physical barriers as they facilitate real-time and advanced communication between CPD teams in dispersed locations. In addition, tools for co-design and distributed project management enable collaborations to be more structured through frequent design reviews and regular status reports. However, project team members who are not very familiar with co-development environments, often see such collaborations as threats to their independent creativity. ICT tools essentially support cross-functional team structuring and open or improved access to information. These allow an overcoming of the organization's hierarchical barriers through rearranged reporting relationships and reward structures. Use of ICT can help in overcoming relational barriers between people who have different personal and technical skills and have reluctance towards performing tasks collaboratively. Information and knowledge management ICTs help in overcoming knowledge barriers. However, the codification of knowledge and relevant experts to handle these systems are necessary for their effective use.

CPD performance criteria defined by Bstieler (2006) include relational outcomes such as partnership efficacy and development-based outcomes such as project performance. Many prior CPD studies focused only on the second criterion of performance for understanding ICT impact (Barczak et al., 2007; Durmusoglu & Barczak, 2011). New product performance indicators such as quality of design, market performance, time-to-market, and financial performance are the development-based outcomes addressed in these studies. But another stream of studies have focused on the impact of ICT usage or integration through these tools on intangible project outcomes such as knowledge-sharing, risks and benefits sharing, and collaboration (e.g. Cousins & Lawson, 2007; Peng et al., 2014; Thomas, 2013). Therefore, from a holistic point of view, this study incorporates both new product outcomes and collaboration outcomes of CPD to reveal significant empirical findings on the impact of ICT usage on CPD performance. The following sections review available literature on the impact of ICT usage on the different CPD performance aspects highlighted above.

3.3.1 The impact of ICT usage on collaboration outcomes of CPD projects

A set of studies have shed light on the impact of ICT usage on intangible outcomes such as NPD collaboration (Peng et al., 2014), knowledge transfer (Corso & Paolucci, 2001), and the creation of trust (Lockwood & Massey, 2012). Peng et al. (2014) observed a positive impact of product design and project management ICT tools on NPD collaboration with suppliers, customers, and cross-functional teams. However, this study found no significant impact of communication and collaborative tools (e-mail and groupware) and shared part databases on collaboration. The researchers have identified less sample variation in the use of e-mail and groupware as a possible reason for the observed insignificant effect of these tools while recommending further research for the impact of shared part databases. In addition, this study has not included all types of ICT tools used in CPD and adopted only a single measure for evaluating overall usage of each of the six tools considered. NPD collaboration is usually referred to as the frequency and openness of collaborative interactions and the amount of design information exchanged among partners (Banker et al., 2006; Peng et al., 2014). Many ICT tools facilitating collaboration and knowledge management include features assisting in overcoming barriers to collaboration such as – little understanding on collaboration benefits, language and cultural barriers, unawareness of procedures to follow in collaborative business environments, and lack of training on tools (Evans, Gao, Martin, & Simmonds, 2015). Therefore, organizations have a great potential to improve collaboration in their NPD programmes with the use of user friendly less formal features available in ICT tools (Hall, 2001; Muethel, Siebdrat, & Hoegl, 2012). A study that examined the effectiveness of different ICT tools on knowledge exchange between manufacturer and supplier found that e-mail is an effective means of knowledge exchange while video conferencing and Web-based tools (e.g. wikis and blogs) are not (Thomas, 2013). Difficulties in having complicated conversations without being in the same location and failures to establish the required coordination among participants were suggested as possible reasons for the insignificant impact of video conferencing. However, using a single measurement item for evaluating the usage of each ICT tool is a limitation of the above study and the researchers have suggested that composite construct for ICT usage would better assess the impact. As CPD projects are different in terms of utilized amount of available features and functionalities in ICT tools (Kern & Kersten, 2007), considering this aspect as a dimension of overall ICT usage can be useful in such comprehensive investigations.

As Corso and Paolucci (2001) suggest, the use of ICT affects the knowledge transfer in CPD through mechanisms such as reuse and the recommendation of knowledge. The transferred knowledge provides long term benefits in the product development process. Tools that facilitate collaborative access to standard components enable reusing and enlarging knowledge possessed by initial product designers. The integration of analysis, the roles, and collaborative work of teams facilitated by ICT, leads to a recommendation of knowledge for more feasible new design alternatives. However, Corso did not observe any impact of using ICT tools to simply automate design tasks on knowledge transfer. As this implies, the use of ICT is likely to provide knowledge-sharing benefits when firms use these tools for facilitating entire CPD projects rather than a few individual activities such as designing or communication. The requirement for sharing or reducing an individual firm's development risks and the sharing of benefits and rewards are the key reasons for collaboration in NPD projects (Bhaskaran & Krishnan, 2009; Figueiredo, Silveira, & Sbragia, 2008; Littler et al., 1995). ICT tools support streamlining analysis, reporting, and submission which can lead to reduced risk (Bhatt & Ved, 2013). In addition, an automated validation process and greater compliance with customer requirements decreases the risk of low market acceptance. Information sharing using ICTs supports transparency in task management and increases team effectiveness as well as building trust between partners (Weimann, Pollock, Scott, & Brown, 2013). However, no empirical study that examined the impact of the overall usage of ICT in a CPD project on the achievement of collaboration outcomes such as the sharing of benefits, risks, information and knowledge, and trust creation was found in the literature.

The mediating role of some of these outcomes on the association between ICT usage and new product performance dimensions has been addressed in some studies. For example, Banker et al. (2006) emphasized that NPD collaboration mediates the positive relationship between PLM software and NPD performance in terms of product design cycle time and new product quality. Choi, Lee, and Yoo (2010) found that the use of ICT tools increases both knowledge-sharing and the application of knowledge which in turn improve team performance. According to Lockwood and Massey (2012), rich media ICTs such as video conferencing and 3D virtual reality tools improve trust within dispersed teams. This trust between CPD team members has a strong positive impact on product development performance (Muethel et al., 2012). However, strong empirical evidence for the mediation effect of overall collaboration-based performance on the association between ICT usage (including all types of ICT tools) and new product performance was not available. Furthermore, Peng et al. (2014) found that the impact of ICT usage on NPD collaboration varies across projects with different characteristics such as uncertainty and complexity. Therefore, investigating the moderating effects of project characteristics will help uncovering a clearer picture of the impact of ICT usage on collaboration related performance.

3.3.2 The impact of ICT usage on new product quality

The use of ICT tools contributes to improving the quality of new products in various ways. Receiving real-time feedback from a wide customer base via a powerful communication ICT (Bhatt & Ved, 2013) and easy modifications to designs with interactive design software (Sarcar et al., 2008) make it possible to develop products with customer-desired quality. In addition, automation of the design and development process with appropriate design tools will increase the accuracy through precise calculations and better adherence to specifications (conformance quality) of the final product (Bhatt & Ved, 2013; Sarcar et al., 2008). ICT tools used in collaborative projects facilitate collective memory and thus support the efficient and high-quality codification of knowledge (Steinmueller, 2000; Vaccaro, Veloso, & Brusoni, 2009). Therefore, the use of collaboration software has direct and indirect positive impacts on new product quality through collaboration (Banker et al., 2006). Extending this literature, Durmusoglu and Barczak (2011) revealed the positive impact of e-mail, decision support systems for project evaluation, file transfer protocols, online needs surveys, virtual prototyping, and concept testing software on new product quality. However, they found no significant impact of product design software, idea generation software, shared drives, or secondary data on quality. Product design and development ICT tools (e.g. CAD systems, idea generation software) have an integral ability to avoid the errors in design, drafting, and documentation which are likely to occur in a manual process (Sarcar et al., 2008). ICT tools such as shared drives, market research analysis tools such as secondary data (e.g. searchable databases), and idea generation software, should increase manufacturers' ability to improve quality through the availability of customer demand information and the effective re-use of knowledge on previous designs. Therefore, the association between ICT usage and new product quality needs further investigation with more informative multidimensional ICT usage evaluation.

Frequency and proficiency of use are two possible dimensions of ICT usage to be considered in such extended investigations of ICT impact (Durmusoglu & Barczak, 2011). In addition, how the direct and indirect effects of ICT usage on new product quality vary across different levels of project complexities needs empirical confirmations as the codification of knowledge generated and exchanged in highly complex projects is relatively complicated (Kim & Wilemon, 2007; Steinmueller, 2000). As previous research suggests that intensity of communication in CPD projects better contributes to quality in highly uncertain projects (Yan & Dooley, 2013), ICT usage can have different effects on new product quality based on project uncertainty. However, prior studies investigating the moderating impact of project characteristics such as complexity and uncertainty on the relationship between ICT usage and CPD performance were not found.

3.3.3 The impact of ICT usage on commercial success of a new product

Research suggests that the intense use of ICT helps in reducing development costs (e.g. Banker et al., 2006), which can lead to higher profits from CPD projects. Using suitable ICT tools for product design, simulation, performance evaluation, and knowledge management enhances the opportunity to: design products with increased productivity, optimize resource consumption, and re-use existing resources for higher financial feasibility (Bhatt & Ved, 2013; Sarcar et al., 2008). In one study, Barczak et al. (2007) found a significant positive influence of overall ICT usage on the new product's market performance (market share and achieving projected profits). Although this study suggested that ICT usage in NPD projects leads to greater commercial success in these projects, the observed contribution of ICT usage on market performance was somewhat low (R^2 of the regression model is 6%). In their explanations, the authors have suggested that enhancing cooperation and cross-functional integration through intensive usage of ICT tools helps to introduce new designs that better satisfy needs in the marketplace. These suggestions motivate searching for an indirect impact of ICT usage via collaboration related performance of CPD projects on their financial or commercial success. This kind of evaluation may lead to revealing the right value of ICT usage (both directly and indirectly) in achieving financial success of CPD projects. Furthermore, since the above study has simply measured overall ICT usage by counting the number of tools used in a project, the impact could be better explored by using a multidimensional ICT usage evaluation criterion.

In a later study focusing on individual ICT tools, Durmusoglu and Barczak (2011) revealed the positive impact of tools such: as e-mail, product design software, decision support systems for project evaluation, file transfer protocols, secondary data, online needs surveys, virtual prototyping, and concept testing software on market performance. However, they found no significant impact of Web-meetings, idea generation software, or shared drives/project rooms on the financial success of the projects. The researchers have mentioned that the low usage of some tools (Web meetings) in firms by that time could be one reason for not observing a significant impact. In addition, Thomas (2013) found no significant impact of video conferencing and a negative impact of Web meetings on supplier knowledge-sharing which in turn improves project performance including financial performance. Although the positive impact of ICT usage on a CPD project's commercial success is not well-supported in the literature, ICT tools essentially improve manufacturers' ability to design new products better satisfying customer requirements, and improve their ability to collaborate by facilitating fast and frequent communication and high-quality information sharing. Therefore, further studying the direct impact of ICT usage on a CPD project's commercial success and exploring the indirect impact through collaboration-related performance, would significantly contribute to extend the existing literature. In addition, variations in information handling convenience based on project complexity and uncertainty (Kim & Wilemon, 2003; Lakemond, Magnusson, Johansson, & Säfsten, 2013) lead to hypothesising different moderating effects of project characteristics on the association between ICT usage and CPD performance where strong empirical evidence for these is lacking.

3.3.4 The impact of ICT usage on time performance of a new product

Higher quality in the execution of technical activities and team organization has positive impacts on the time efficiency of CPD projects (Bstieler, 2005). These technical activities include: assessing the technical viability of new product ideas, prototyping, assessing the technical functioning of prototypes, and the field trials of the new product. Most of these activities and project management that is a major part of team organization are facilitated by ICT tools. Therefore, ICT tools have been largely identified as a key organizational resource that increases the efficiency of the product development process. However, existing empirical evidence do not strongly suggest a positive impact of ICT usage on the time performance of CPD projects. For example, Barczak et al. (2007) who found a positive impact of ICT usage on a new product's market performance, revealed no significant impact in respect of time-to-market. According to the authors, using specific tools for the long-term is important for achieving efficiency in CPD projects rather than simply performing CPD activities using ICT tools because people take a substantial time to adopt the tools. Reductions in product developed cycle time can be expected through the use of familiar ICT tools, though it is difficult to observe a significant change in the time-to-market. Yet, in a study focusing only on collaborative PLM software, Banker et al. (2006) revealed a positive impact of these tools on development cycle time, after controlling for the design and process maturity and the size of the product. Furthermore, this study found a positive indirect impact of these tools on cycle time through NPD collaboration.

In a study on knowledge management ICT, Vaccaro, Parente, and Veloso (2010) revealed a positive direct impact of these tools on a new product's speed-to-market. As this study suggests, the impact can be varied based on the technological sector and the activities such as creation and re-use of knowledge. Available literature on the impact of communication ICT tools on time performance varies in its findings. Several studies found a negative or insignificant impact of rich media communication technologies on product development time or efficiency (Oke & Idiagbon-Oke, 2010; Thomas, 2013). Coordination difficulties and the time required for response and identifying solutions through these tools have been highlighted in these studies. However, Thomas (2013) observed that the use of tools such as e-mail improves NPD efficiency through the effective sharing of knowledge. This confirms previous qualitative research findings on software product development projects (Boutellier et al., 1998). However, a research focusing on the indirect impact of overall ICT usage on time performance of new product through collaboration performance was not found. Uncertain projects may take longer times to complete due to information ambiguities and more project revisions required (Lakemond et al., 2013). However, variations in the effectiveness of information sharing using ICT in achieving CPD performance, based on uncertainty or other project characteristics, have not been sufficiently investigated in past studies.

In conclusion, the following limitations have been identified in previous research models evaluating the impact of ICT usage on collaborative product development performance.

- Less-informative single-item ICT usage measures have been adopted.
- ICT impact on new product performance rather than CPD performance has been addressed. Research focused on collaboration outcomes of ICT usage such as information/knowledge-sharing and collaboration have paid little attention to the mediating role of these outcomes in relation to all types of ICT used in CPD.
- Although ICT plays a huge role in CPD, the impact of ICT usage on new product performance aspects: new product quality, speed, and financial

performance as revealed in prior studies is significantly low or empirically inconclusive.

- Factors moderating the direct and indirect associations between ICT usage and CPD performance have been largely ignored.

3.5 SUMMARY

Use of information and communication technology tools improves a company's ability with regard to frequent communication and information sharing which itself drives CPD performance and simulates other performance drivers such as collaborative competence, trust, market orientation, innovative climate, and senior management support. Based on the functions facilitated in CPD, ICT tools are classified as communication and collaboration tools, product development tools, project management tools, information and knowledge management tools, and market research and analysis tools. This chapter primarily focused on reviewing literature related to the impact of ICT usage on collaborative product development performance. Prior studies addressing the association between ICT usage and CPD performance from different perspectives were discussed in detail to understand significant gaps in the area of study. Inefficient measurement criteria for ICT usage and limited empirical evidence available for the direct, indirect, and moderated effects of ICT usage on various aspects of CPD performance have been identified. In order to fill these gaps in the literature, a conceptual research model is developed in the next chapter based on the relational resource-based view and organizational information theory. In addition, it presents the overall design of the research and explains the methodologies adopted in each phase of the study.

4. Conceptual Model and Methodology

4.1 Introduction

Abridging the identified gaps in the literature (Chapter 3), this chapter develops a conceptual research model to evaluate the impact of ICT usage on collaborative product development performance in manufacturing firms. It explains the two theoretical perspectives, the relational resource-based view (RRBV) and the organizational information processing theory (OIPT), that provide the basis for arguments made by the research. Then the chapter describes the complete research methodology followed throughout the study. First, it presents the research paradigm or the broad philosophical stance of the study with reviews on alternative paradigms. Second, it explains the strategy adopted in designing the research and presents the mixed methods design of the study for answering the three research questions: (1) How do manufacturing firms manage ICT usage in terms of frequency, proficiency, and intensity for improving their collaborative product development activities? (2) Does ICT usage have a significant impact on CPD performance? (3) Do the project characteristics representing the information processing requirement in CPD projects significantly moderate the relationship between ICT usage and CPD performance? In subsequent sections, qualitative and quantitative phases of the study are described with details on the validity and reliability of these studies, sample selection and data collection approaches, and the main tools and techniques utilized in the data analyses. Finally, ethical considerations of the study and procedures followed in each research phase for the ethical conduct are explained.

4.2 Developing a Conceptual Model to Evaluate the Impact of ICT Usage on CPD Performance

Addressing the limitations identified in extant literature, this study develops a conceptual model to comprehensively study the impact of ICT usage on CPD performance. This is an initial conceptual model proposed based on existing literature and it addresses the gaps identified in the previous literature review chapter. The mixed-methods research design presented later in this chapter was selected due to the novelty of some constructs and relationships proposed for this model. The model helps exploring some uncovered aspects of the effectiveness of ICT usage in a CPD setting. First, through the identification of different dimensions for ICT usage and CPD performance, the model suggests direct and indirect relationships between these. Furthermore, recently several researchers have highlighted the significance of examining the factors moderating the effectiveness of ICT usage in product development projects in order to uncover more details related to the impact of ICT usage (e.g. Durmusoglu & Barczak, 2011; Kleinschmidt, De Brentani, & Salomo, 2010; Peng et al., 2014; Thomas, 2013). Therefore, based on available theoretical evidence, moderating factors for the ICT-CPD performance relationship are identified and included in the model. The following sections discuss the theoretical context and key literature that supported the development of the conceptual model, explaining the basis for selection of each model construct. Results of the model evaluation with qualitative and quantitative data are provided in chapter 5 and 7 respectively.

4.2.1 ICT usage

Available empirical evidence for the impact of ICT usage on CPD performance are not sufficient as they suggest low or insignificant effects of ICT on performance dimensions such as market performance (Barczak et al., 2007; Durmusoglu & Barczak, 2011), speed-to-market (Barczak et al., 2007), new product quality (Durmusoglu & Barczak, 2011), and NPD collaboration (Peng et al., 2014). One possible reason for this could be limitations in measuring ICT usage in CPD projects. For example, Barczak et al. (2007) operationalized ICT usage as the number of tools used in a selected NPD project. Although their study considered a broader ICT tools classification based on the activities in the product development process (communication and collaboration, product design and development, project management, information and knowledge management, and market research and analysis), the respondents were simply asked to check the tools used in the product development stages. The total number of checks had been considered as the total ICT usage in the project. A similar approach was employed by Durmusoglu & Barczak (2011) with a list of eleven ICT tools used in CPD. In a study on the impact of ICT tools on NPD collaboration, Peng et al. (2014) used a Likert scale to evaluate the overall usage of six tools: e-mail, groupware, CAPP, CAD, simulation modeling, project management software, and shared parts databases in a CPD project. However, this evaluation still had the limitation of considering a single item for each ICT tool although it measured the extent of usage using a Likert scale. Overall, the above ICT usage measurements indicate the difficulty of estimating the actual usage of ICT in a product development project. Therefore, evaluating the extent of ICT usage with a comprehensive measurement scale that represents the different attributes of using ICT will make an essential contribution towards extending these literatures.

Highlighting their limitation in evaluating ICT usage explained above, Durmusoglu & Barczak (2011) suggested frequency and proficiency as possible criteria for better uncovering the impact of ICT usage. In addition, the present study argues that CPD projects can be different in terms of the extent of using features and functionalities in the ICT tools (Kern & Kersten, 2007) and identifies this as another dimension of ICT usage (intensity). Since aggregation of measures helps in increasing robustness and generalizability which leads to increased predictive validity (Fichman, 2001) the study selects three dimensions: *proficiency*, *frequency*, and *intensity of ICT use* to represent the broader concept of 'ICT usage'.

4.2.1.1 Frequency of ICT use

The number of times information is exchanged between partners or frequency of communication has been often considered as a measure of ICT usage (Fisher, Maltz, & Jaworski, 1997; Montoya et al., 2009). Increased communication frequency leads to – better information use (Fisher et al., 1997), improved financial performance (Hoegl, 2005) and intangible CPD outcomes such as higher knowledge acquisition and trust (Badrinarayanan & Arnett, 2008). The significance of frequent consultation between CPD partners throughout the development process for achieving higher CPD performance in terms of quality and market success has been highlighted in several qualitative studies (Bosch-Sijtsema & Bosch, 2015; Littler et al., 1995). However, as recent research suggests, the frequency of using all ICT tools (including communication tools) in CPD projects positively influences some performance aspects (e.g. NPD task proficiency) of NPD projects (Kawakami et al., 2015). According to the PDMA's most recent CPAS (2012) survey, the best firms use ICT tools more frequently in their NPD projects than the rest of the firms (Markham & Lee, 2013). Therefore, in order to investigate the impact of ICT usage on CPD performance comprising both collaboration and project-related outcomes, the present conceptual research model suggests frequency of ICT use as an important dimension of overall ICT usage.

4.2.1.2 Proficiency of ICT use

Human ICT skills or the ICT knowledge of staff is an essential element for achieving high ICT competency in an organization (Bharadwaj, 2000; Ravinchandran & Lertwongsatien, 2005; Tippins & Sohi, 2003). In order to achieve high performance standards through virtual teams, the ability of members to use appropriate ICT tools efficiently and effectively is more important than making a variety of sophisticated tools available (Dube & Pare, 2004). This implies that the ICT proficiency of team members is important in order to utilize the optimum capacity of an ICT tool. Usually, the more proficient users choose the best option (in terms of convenience, time, and quality) out of the various functionalities available in an ICT tool for executing a certain NPD task. Since the impact of ICT usage could vary based on the competency level of the R&D staff in using CPD-supporting ICT tools, ICT usage in a CPD project could be more informatively measured by considering the proficiency of use (Durmusoglu & Barczak, 2011). Based on this argument, the present study selects proficiency of use as another dimension of ICT usage in investigating ICT impact on CPD performance.

4.2.1.3 Intensity of ICT use

The ICT infrastructure that provides the platform to competitively launch innovative ICT applications in firms, is not sufficient to ensure performance (Bharadwaj, 2000). Confirming this, Barczak et al. (2007) found that infrastructure has no significant influence on ICT usage in NPD activities and suggested that the total availability of ICT facilities may not show the actual usage of the tools within the project. Therefore, it is important to reflect on the utilized percentage of available features and functionalities of ICT tools in CPD projects (Aldea, Popescu, Draghici, & Draghici, 2012) when evaluating ICT usage, rather than focusing on ICT infrastructure availability. Prior research suggest a positive association between intensity of communication and CPD performance (e.g. Hoegl, 2005). Intensive use of functionalities ICT tools is required for increasing communication and collaboration within CPD teams particularly when the members are located beyond organizational boundaries (Bhatt & Ved, 2013; Kern & Kersten, 2007). For example, the use of features in collaborative CAD systems such as a collaborative framework to access the same design concurrently (NIC India, 2016) may be lower in projects where designers are in the same location or are situated close by. Video functionalities in Web conferencing may not be heavily used in projects where team members have sufficient opportunities to meet face-to-face in finalizing critical designs. According to Montoya et al. (2009), heavy or lean use of ICT tools can have varied impacts on the performance of CPD teams. Therefore, this study adopts intensity of use as another ICT usage dimension which refers to the utilized proportion of available features, and functionalities of an ICT tool, in order to indicate whether the tool has been heavily used in a project or not.

4.2.2 CPD performance

In addition to the selection of meaningful and informative constructs for the ICT usage, adopting broad performance criteria for the CPD process would be necessary to ensure effective investigation of the impact of ICT usage on CPD performance. As highlighted in the previous literature review (section 3.3), past research addressing the ICT-CPD performance relationship mostly focused on the effect of ICT usage on performance described by financial and quality outcomes of the new product. Some examples of previously used performance indicators are: (1) new product effectiveness (market performance, innovativeness, and new product quality) (Durmusoglu & Barczak, 2011), (2) speed-to-market (Barczak et al., 2007), (3) new product success (meeting targeted sales, volume, and profit) (4) new product creativity (Akgün, Dayan, & Di Benedetto, 2008), (5) product design cycle time, (6) product quality, and (7) product development cost (Banker et al., 2006). However, the performance indicators used in these studies frequently captured the final NPD project success in terms of financial performance, quality, and time performance. These project performance indicators are still appropriate in the evaluation of the impact of overall ICT usage in terms of frequency, proficiency, and intensity of ICT use, proposed in the present research model. Therefore, based on the performance criteria used in past PD research, this study proposes *new product quality* (Luo, Mallick, & Schroeder, 2010; Thomas, 2013), *commercial success* (Najafi Tavani, Sharifi, Soleimanof, & Najmi, 2013; Thomas, 2013), and *time performance* (Barczak et al., 2007; Thomas, 2013), for the conceptual model that evaluates the impact of ICT usage on new product performance, which is the major part of overall CPD performance.

According to Bruce, Leverick, Littler, and Wilson (1995), criteria for assessing the success of CPD projects not only include project performance (e.g. profits, time, and quality), but also the level of success in partnerships, sharing of knowledge and benefits. Efficient processing of information is important to create shared knowledge in CPD which in turn improves project performance (Kleinsmann, Buijs, & Valkenburg, 2010). However, no prior study suggesting collaboration performance as a dimension of CPD performance that represents outcomes achieved through collaboration, or evaluating the indirect impact of overall ICT usage through this aspect of CPD performance, was found. Previous qualitative research emphasize that the use of ICT offers collaboration outcomes such as development of an informal network, coordination support, and information/knowledge transfer, which could lead to a positive or negative impact on long-term project performance (Boutellier et al., 1998; Coenen & Kok, 2014; Corso & Paolucci, 2001). In these premises, it would be worthwhile to empirically confirm the impact of ICT usage on CPD performance comprising both new product performance and collaboration performance.

Büyüközkan and Arsenyan (2012) defined collaboration process within the main CPD domain suggesting that its success is mainly dependent on trust, coordination, co-learning, and co-innovation between partners. Therefore, considering all of the above literature, the present research model introduces a new construct representing the intangible aspect of CPD performance labelled as ‘collaboration performance’ and evaluates the ICT impact on this. According to Littler et al. (1995), the success of product development collaborations is primarily determined by the following factors – how much collaborating partners contributed as expected, how successfully knowledge was shared between partners, how successfully important ideas and information were shared, how successfully the benefits of the project were shared, how successfully the risks were shared, and how much trust was between partners. Since the above six concepts essentially cover the collaboration process performance dimensions defined by Büyüközkan and Arsenyan (2012), these measures are suggested as possible indicators for the proposed collaboration performance construct.

4.2.3 Project characteristics representing the information processing requirement of CPD projects

Effective communication amongst product development team members is a great challenge in CPD where product development team members are dispersed across different functions or organizations. Communication effectiveness could be characterized by the transfer of relevant information resulting from the correct processing of information. The process of information exchange could be critical and complex in terms of amount, quality, and time in various collaborative settings (Bendoly, Bharadwaj, & Bharadwaj, 2012; Dube & Pare, 2004). As the 2003 PDMA best practices survey indicates, the majority of manufacturing companies develop their new products through collaborations and this is more common in radical or more innovative projects (Barczak, Griffin, & Kahn, 2009). Requirements for processing information in CPD could vary across various project and organizational characteristics (Kleinschmidt et al., 2010; Veldhuizen et al., 2006). As this information processing is mainly performed via ICTs, it is important to examine the effectiveness of managing the ICT usage according to the information processing requirements of the projects. In this investigation, it would be important to capture the impact of frequency (Kawakami et al., 2015) and proficiency in using ICT tools (Chen, Tsou, & Huang, 2009) and utilizing the available features and functionalities in the tools (Aldea et al., 2012) on CPD outcomes.

Koufteros, Vonderembse, and Doll (2002) suggested that the use of ICT tools increases product innovation, whereas higher uncertainty and complexity lead to the use of more ICT in product development activities. However, variations in the effectiveness of using ICT tools based on these project characteristics have still not been paid sufficient attention by researchers. Swink (1999) suggested that project characteristics such as complexity, product newness, technological uncertainty, design outsourcing, and project urgency do not decrease new product manufacturability, in the presence of proper external and internal integration of the development teams. ICT usage in a manufacturing CPD project could reflect the degree of integration of their R&D teams within the project. Thus, the moderating effect of project characteristics would be important to study for extending current understanding on the impact of ICT usage on CPD performance. Therefore, the present model initially suggests three project characteristics: *project uncertainty*, *project complexity*, and *project urgency* that represent the information processing requirements in a CPD project. The following reviews elaborate on each of these concepts in the evaluation of the ICT impact on collaborative product development performance.

4.2.3.1 Project uncertainty

Newness in product design, market, product technology, or process technology makes a CPD projects uncertain (Heim et al., 2012). The negative effect of uncertainty on NPD performance is mostly evident in extant literature. Tatikonda and Rosenthal (2000) found a negative effect of task uncertainty (due to product and process technological novelty) on cost and time related NPD outcomes. Product newness has a significant negative impact on new product manufacturability (Swink, 1999). Souder, Sherman, and Davies-Cooper (1998) observed that technological and market uncertainties influence NPD effectiveness aspects such as prototype development proficiency. When uncertainty in the market is high, manufacturing firms tend to introduce more innovative products through collaborations (Lau et al., 2010). As the uncertainty of a task increases, the amount of information to be processed during execution of the task also increases (Galbraith, 1984). The greater the degree of uncertainty in the marketplace and in technology, the greater the need for more valuable information to help make quality decisions, especially in the early product development phases (Achiche et al., 2012). In CPD projects, this decision-making process is mainly facilitated by ICT tools through the transfer of information among relevant parties such as suppliers, customers, and cross-functional teams. However, no prior study addressing the moderating effect of project uncertainty over the direct and indirect relationships between ICT usage and CPD performance was found.

4.2.3.2 Project complexity

The number of tasks involved in the project, and the degree of interdependency of the tasks, have been identified as contributors to NPD project complexity (Ahmad, Mallick, & Schroeder, 2013; Heim et al., 2012). However, in some studies the degree of departmental/partner involvement and team composition have been considered as a complexity dimension (e.g. Ahmad et al., 2013; Swink, 1999). Dube and Pare (2004) identified eight characteristics that make virtual teams more complex. These comprise team size, geographic dispersion, task or project duration, prior shared work experience, members' assignments, membership stability, task interdependence, and cultural diversity. Therefore, in CPD projects, the degree of integration between partners also represents the level of complexity (Danese, 2011). The negative effect of project complexity on unit-cost (Tatikonda & Rosenthal, 2000), and new product manufacturability (Swink, 1999) was previously evident. This is possible because large or more complex projects need more effort to coordinate due to the large number of interfaces and interdependencies (Paashuis, 2013). However, contradicting these literatures, Ahmad et al. (2013) found a direct positive effect of the complexity on overall NPD performance. The researchers identified both complexity and uncertainty as significant conditions for competitiveness. The firms handling such difficult projects successfully, relative to their competitors, are likely to achieve higher project performance.

The higher the complexity of a CPD project, the higher the use of ICT tools within the project as ICT is the major means of communication, coordination, and product development (Heim et al., 2012). Some studies have considered usage of ICT tools as a measure of virtuality in CPD teams (e.g. Bierly, Stark, & Kessler, 2009; Ebrahim, Ahmed, & Taha, 2009). Dayan and Di Benedetto (2010) stressed that proximity of team members is positively related to the formation of trust in product development teams. However, in a dispersed CPD team structure, ICT tools enable partner firms to work closely with each other. Therefore, studying how the impact of ICT usage on collaboration performance (including trust creation, sharing of knowledge, risks and benefits) varies across different levels of project complexities would generate important practical and theoretical implications. Drawing on the literature reviewed, project complexity construct proposed for the current conceptual model comprises both product complexity and the complexity of CPD network.

4.2.3.3 Project urgency

In a study, Veldhuizen et al. (2006) modeled the processing of market information in NPD and identified project urgency as a significant determinant of an information processing need in NPD. In their study, project urgency has been assessed in terms of the priority given to the project and the time pressure felt during the project. Project priority indicates the degree of importance of the NPD project and may increase the requirement to process information during development. Supporting this view, a research that considered priority given to a project as project risk, found that the risk increases the ICT usage in NPD (Barczak et al., 2007). Limited evidence for the moderating role of project urgency in the association between ICT usage and CPD performance dimensions were found. For example, Swink (2003) found that the impact of shared CAD systems on a project's time performance is positive when the project is accelerated. According to the author's argument, although reducing communication and time for design changes is possible with these systems, they are effectively used by CPD teams for completing projects on time when they actually feel that the project is urgent. However, any empirical evidence for the moderating effects related to the other performance dimensions such as quality and commercial success was not found.

In conclusion, increased uncertainty, complexity, and the urgency of a CPD project may increase the need for processing information during product development. Since ICT provides the basic means of processing information in CPD, using these project characteristics as determinants of the information requirement in a CPD project is useful to study their moderating impact on the relationship between ICT usage and CPD performance, based on the following theoretical views.

4.2.4 Theoretical basis of the conceptual research model

Two main theoretical perspectives are considered in the development of the research model for this study. These are the relational resource-based view and the organizational information processing theory.

4.2.4.1 Relational resource-based view (RRBV)

The resource-based view (RBV) emphasizes the contribution of a firm's resources and capabilities in achieving competitive advantage (Grant, 1991; Y. Lin & Wu, 2014; Wernerfelt, 1984). Identifying ICT as a research area that could benefit from incorporation of the RBV insights, Barney, Wright, and Ketchen Jr (2001) highlighted the significance of considering inimitable aspects such as the deployment of new tools and proficiencies. The relational view, an extension to the traditional resource-based view, considers achieving competitive advantage through collaborations. The theory identifies four potential sources of competitive advantage for interconnected firms: relation-specific assets, effective governance, knowledge-sharing routines, and complementary resources and capabilities (Dyer & Singh, 1998; Lavie, 2006).

According to the RBV, ICTs themselves do not generate rents while specific ICT knowledgeable personnel could generate a sustainable competitive advantage (Barney et al., 2001). CPD is a joint business activity connecting distributed R&D teams, suppliers, customers, and various other external partners. As per the RRBV, ownership of synergy sensitive resources (resources that are more valuable after combining with a partner's resources) is important for connected firms to be competitive in the market. In addition, those organizations that are capable of aligning governance structures with inter-firm transactions are likely to achieve better performance through minimizing transaction costs and maximizing value. Investments in improving mechanisms for facilitating knowledge exchange between partners such as suppliers and customers enable organizations to gather superior ideas leading to successful innovations. According to this view, investments in relation-specific assets such as sites (locating immobile production stages close to each other), physical resources (e.g. customized processes and tools for exchange partners), and human resources (accumulated know-how through long-term relationships) are important to reduce costs, increase quality, and increase speed-to-market (Dyer & Singh, 1998). In high-tech manufacturing CPD contexts, a number of geographically distributed partners collaborate throughout nearly all the product development stages by sharing resources and capabilities, mainly via ICT tools. The information shared among the partners through frequent, proficient, and intensive use of ICT is a collection of valuable resources that will generate value for the collaborating firms. In addition, the use of ICT tools reflects a firm's investments in knowledge-sharing routines and relational assets that lead to co-development success (Appio, Lazzeri, Corsi, & Di Minin, 2011; Deck & Strom, 2002).

The RRBV suggests that the capability of networked firms to form and maintain valuable collaborative relationships with partners is important to achieve and sustain competitive advantage. Furthermore, the nature of relationships matters more than the nature of resources in achieving better performance (Lavie, 2006). The RRBV believes that shared resources and capabilities generate relational rents to firms. It identifies the duration of self-enforcing safeguards (e.g. the sharing of knowledge unique to partners and trust), the volume of inter-firm transactions, partner-specific absorptive capacity, and encouraging transparency as sub-processes that facilitate relational benefits and emphasizes their contribution to increased competitive advantage (Dyer & Singh, 1998). The collaboration performance construct suggested in the present study reflects the degree of success of CPD projects in creating trust, sharing knowledge, information, risks, and benefits. Therefore, the RRBV offers appropriate theoretical grounds to posit positive direct and indirect effects of ICT usage on new product performance (product quality, commercial success, and time performance) through collaboration performance.

4.2.4.2 Organizational information processing theory (OIPT)

The organizational information processing theory (OIPT) posits that "the greater the task uncertainty, the greater the amount of information that must be processed among decision makers during task execution in order to achieve a given level of performance" (Galbraith, 1974, p. 28). This theory sees uncertainty as the central condition that restricts the organization's ability to plan their activities prior to the execution. According to the information processing model, organizations can select one of three key strategies for achieving success – planning their ability to preplan by reducing task uncertainty, increasing their flexibility to adopt high uncertainty or inability to preplan, or decreasing the expected level of performance for continued feasibility. Cognitive limits theory that identifies human cognitive limits as a basic determinant of organization structures (Simon, 1957) has been the chief guide to define these strategies in the organizational information processing model. Contingency theory (Lawrence & Lorsch, 1967) that relied on flexible structures and mechanisms in organizations to cope with environmental uncertainty, has also provided an evidential support for developing the organizational information processing model (Galbraith, 1984). As the OIPT suggests, for better performance, organizations need to balance their information processing capability to meet the information processing requirements generated by a task's uncertainty (Daft & Lengel, 1986; Galbraith, 1984; Peng et al., 2014). This is possible through either reducing the need for information processing by making task uncertainty lower or by increasing capacity to process more information required by the task.

Studying moderating effects in the light of OIPT is rather common in the area of product development (Ahmad et al., 2013; Patanakul, Chen, & Lynn, 2012). For example, Ahmad et al. (2013) used the OIPT to establish a positive interaction between project complexity and team integration, and a negative interaction between project uncertainty and process concurrency on overall NPD performance. Their study considered project complexity as a determinant of a project's requirement for processing information while process concurrency, integration of teams, and NPD practices reflect the level of capability in information processing or resource utilization. Studies investigating ICT effectiveness under contingent moderating factors have also adopted OIPT as the basic underlying theory. For instance, based on this theory, Kleinschmidt et al. (2010) examined the moderating effect of organizational internal environment on the relationship between IT-communication competency and global NPD programme performance. They found that a firm's internal environment (described by senior management involvement and resource commitment) suppresses the positive effect of IT-communication competency on the performance. However, very limited OIPT-based empirical studies focusing on project characteristics moderating the effect of ICT on CPD performance were found. For example, Peng et al. (2014) found that product size positively moderates the association between ICT tools and NPD collaboration, while project novelty and task interdependency negatively moderate this relationship. However, any evidence for using the OIPT as the theoretical basis to study the moderating effect of project characteristics on the direct and indirect relationship between ICT usage and CPD performance, through collaboration performance, was not found in the literature.

CPD is a major information processing activity in manufacturing organizations that might have varied processing needs depending upon several technical, market, and project-specific factors. Tatikonda and Rosenthal (2000) identified technology novelty and project complexity as key contributors to the uncertainty associated with the task of product development. As urgent projects need relatively higher amounts of information to process (Veldhuizen et al., 2006), project urgency can also be considered as a factor that increases the level of uncertainty in CPD activities. ICT provides a major platform for communication, knowledge transfer, and work synchronization, which are essential in collaborative product development. In addition to the information exchange between collaborative partners, ICT tools help organizations to meet deadlines, ensure quality, and make NPD projects profitable (Bhatt & Ved, 2013).

In a study based on the OIPT, Heim et al. (2012) considered the usage of ICT tools to represent the required information processing capability for NPD. Extending their study that considered the overall usage of some software tools during the NPD project, the present research considers additional dimensions of ICT capability characterizing its human, organizational, and functionalities aspects (Aldea et al., 2012; Bharadwaj, 2000;

Kern & Kersten, 2007; Tippins & Sohi, 2003). Hence, it identifies proficiency of use, frequency of communication, and intensity of use as dimensions of ICT usage so that it better represents the information processing capability of a firm undertaking CPD projects. Based on the OIPT, this research argues that CPD teams should manage their ICT use according to the information processing requirement in the projects for being successful. In section 4.2.3, project complexity, uncertainty, and urgency have been identified as key project characteristics representing the information processing requirement of a CPD project. Therefore, based on the OIPT, these project characteristics are anticipated to moderate the direct and indirect impact of ICT usage on new product performance.

4.2.5 The conceptual research model

Figure 4.1 illustrates the initial conceptual research model including the constructs identified above, based on available literature. As explained in section 4.2.4, the RRBV and the OIPT provide appropriate grounds to study the relationships proposed for this model.

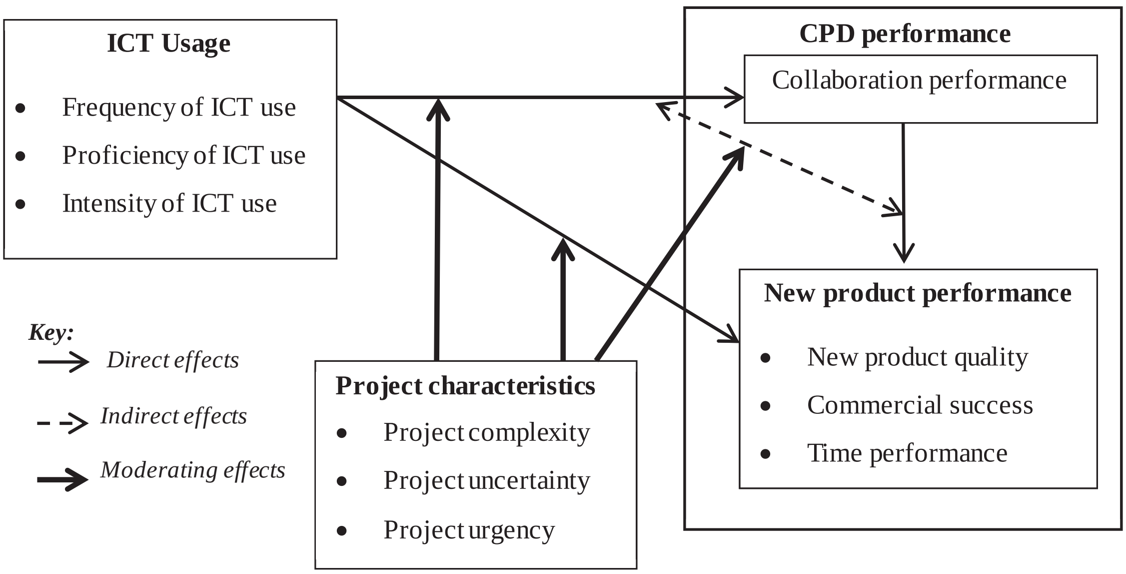

Figure 4.1: Initial conceptual model for the impact of ICT usage on CPD performance

This model includes several constructs and relationships which have not been examined by prior research models addressing the impact of ICT usage on product development performance. Therefore, the subsequent qualitative investigation of industry perspectives would be important as a preliminary evaluation of this initial conceptual model. The findings of this investigation will also answer the first research question on managing ICT usage in manufacturing CPD projects. Basically, the model comprises three types of relationships between ICT and collaborative product development performance. The arrows from ICT usage to CPD performance aspects represent the direct effects of ICT usage on CPD performance in terms of collaboration performance (the degree of success in knowledge/information sharing, risks/benefits sharing, and trust creation in CPD) and new product performance (quality, time, and commercial success). The horizontal arrow from ICT usage to collaboration performance and the vertical arrow from collaboration performance to new product performance, together indicate the indirect effect of ICT usage through collaboration performance (the dashed arrow connecting the two vertical and horizontal arrows denotes this indirect effect). Evaluating these relationships will answer the second research question concerning the impact of ICT usage on CPD performance. The thick arrows from the project characteristics to the direct and indirect (dashed arrow) linkages between ICT usage and CPD performance are the moderating effects of these project characteristics on the direct and indirect associations of ICT usage with new product performance. Examining these relationships will answer the third research question asserting a significant moderating effect of project characteristics on the relationship between ICT usage and CPD performance. Operationalization of the model constructs and the development of specific hypotheses for the conceptualized direct, indirect, and moderating effects are discussed with details in Chapter 7 after presenting the findings of the qualitative evaluation in Chapter 5.

4.2.5.1 Significance of the model

The conceptual research model proposed in this study allows significant extensions to extant literature (Banker et al., 2006; Barczak et al., 2007; Durmusoglu & Barczak, 2011; Kawakami et al., 2015; Peng et al., 2014). Several features of the model make it dissimilar to prior research models that addressed the impact of ICT usage on product innovation performance. First, this model allows examining the effect of various dimensions of ICT usage (frequency of communication, proficiency and intensity of ICT use) on CPD performance whereas previous studies mostly considered a single measure to represent overall ICT usage (Barczak et al., 2007) or individual tools usage

(Durmusoglu & Barczak, 2011; Peng et al., 2014). Second, incorporating collaboration performance which represents the degree of knowledge, information, risks, and benefits sharing, as well as trust creation, and evaluating the impact of overall ICT usage on that aspect of CPD performance, enables the extending of research addressing the impact of some ICT tools on NPD collaboration (Banker et al., 2006; Peng et al., 2014). Third, investigating the proposed moderating effects of project characteristics on the direct and indirect relationships between ICT usage and new product performance dimensions leads to an important contribution to theory since these effects have been rarely addressed in the literature (e.g. Peng et al., 2014). Adopting the RRBV as underlying theory for evaluating the direct and indirect impact of ICT usage on new product performance, through collaboration performance, is another significant contribution of this research model since this is an emerging theoretical view in innovation management and IS (information systems) disciplines.

4.3 Research Paradigm

Paradigms are basic belief systems that shape the practice of a research. Since they define the researcher's view about the nature of the world, his or her place in it, and possible relationships to the world and parts of the world, paradigms are also known as worldviews. Although the beliefs are well argued, no method is available to establish the ultimate truthfulness. Questions related to three fundamentals – the ontology, epistemology, and methodology of a research have significant deviations across paradigms, and dependencies within a single paradigm. The ontology defines the researcher's belief on the nature of reality whereas epistemology defines the nature of the relationship between the researcher and that being studied, the type of knowledge that is accumulated, and justifications. The methodology defines the particular ways that the researcher reaches and reports the findings. There are four main worldviews (paradigms), namely, positivism, postpositivism, constructivism, and critical theory (Denzin & Lincoln, 2011; Guba & Lincoln, 1994). Although postpositivism has been identified as a distinct paradigm, it has many connections with positivism and hence is a modification of positivism. In addition to these paradigms, participatory is recognized as a different worldview which has several connections with other worldviews (Denzin & Lincoln, 2011; Heron & Reason, 1997; Reason & Bradbury, 2001). The following sections describe the above paradigms and their ontological, epistemological, and methodological assumptions (metaphysics).

4.3.1 Positivism and postpositivism

Positivists believe that there is a single apprehendable reality (ontology) that may exist in the form of cause-effect relationships. This implies that the existing truth can be measured and studied. The epistemology of positivists is concerned with the assumption that the researcher and the object being studied are independent. Any influence is regarded as a threat to validity that is eliminated by the researcher through the scientific rigour established. The methodology followed in positivism is stating and testing hypotheses which are believed facts until falsified (Denzin & Lincoln, 2011; Guba & Lincoln, 1994). Mainly, deductive quantitative methods are employed in strictly controlled (for possible confounding effects on outcomes) experimental settings. Verified hypotheses lead to the explanation and prediction of reality (Guba & Lincoln, 1994; Ponterotto, 2005).

Postpositivism evolved as a result of dissatisfaction with some aspects of positivism. Both paradigms are concerned with cause-effect associations and aim to explain and predict reality (Ponterotto, 2005). Although postpositivism also assumes a single reality, the researchers of this worldview believe that the reality is only apprehendable with certain probability. The ontology of postpositivism is also known as critical realism as it relies on broad and critical examination for closely approximating reality (Guba & Lincoln, 1994; Krauss, 2005). In a manner similar to positivism, the epistemology of postpositivism is also concerned with assuming objectivity. However, according to the postpositivists, reality is impossible to comprehend independently of the society as the knowledge about it is a consequence of social conditioning (Krauss, 2005). Validity is established through replication with existing theory and critical community (peers) although falsification of hypothesis is still possible (Guba & Lincoln, 1994). Deductive quantitative research methods are chiefly utilized in the postpositivist paradigm in which qualitative techniques are also applied to better understand the complexities in the real world (Denzin & Lincoln, 2011; Krauss, 2005).

4.3.2 Constructivism

The ontologies of positivism and constructivism are completely different. *Constructivism* assumes the existence of apprehendable multiple subjective realities constructed based on the context formed by the social environment, the individual's experience and perception, and the interaction between the individuals (participants of the study) and the researcher (Denzin & Lincoln, 2011; Ponterotto, 2005). Constructivists believe that reality is constructed by the research participant so it cannot be objectively separated from the actor or participant as assumed in positivism. According to constructivism, quantification captures only a small portion of reality and loses the meaning of the entire phenomenon. Therefore, interpretivists try to collect information, being part of the culture which is investigated and allow for more flexible questioning rather than using a fixed instrument (Krauss, 2005). The ontology and epistemology are not distinct in constructivism because the researcher and the objects of the study are interactively related. The findings are generated as this process of interaction or investigation proceeds (Guba & Lincoln, 1994). More deep interactions lead to more uncovering of reality in the constructivists' research (Krauss, 2005). The methodology of constructivism involves refinement of variables and subjective constructs through recognizing, explanation, detailed interpretation, comparing and contrasting. Naturalistic methods such as interviewing and analysis of available texts are employed and thus qualitative methods provide the major foundation to interpretivists' research. Inductive reasoning is often utilized to develop general principles through broad exploration of the phenomenon of study. Therefore, open-ended questions are usually administered so that the participants can share their views comprehensively (Creswell, 2013; Denzin & Lincoln, 2011; Krauss, 2005).

4.3.3 Critical theory

The ontology of *critical theory* is known as the critical-ideological paradigm or historical realism as it assumes that reality is the structures built within a social-historical setting shaped by oppression and privilege based on ethnic, social, political, economic, cultural, and gender factors (Ponterotto, 2005). The epistemological belief of critical theory is that knowledge is created by the investigator through an interactive relationship with the participant. This involves studying social structures, power and control, and freedom and oppression. The methodology of critical theory is dialogic and dialectical as the dialogue between the researcher and the participants needs to be dialectical in order to influence historically mediated existing structures and eliminate oppression through informed consciousness. The research approach is participatory and the knowledge created empowers participants who work towards a transformation and a democratic change. Qualitative techniques are mainly employed within this paradigm (Denzin & Lincoln, 2011; Guba & Lincoln, 1994; Ponterotto, 2005).

4.3.4 Participatory worldview

Advocacy or participatory worldview is different from other paradigms and may be used when postpositivists impose theories and structural laws that are not well-fitted to marginalized groups or individuals and constructivists do not go up to advocating action to help individuals (Creswell, 2009). The ontological assumption of participatory paradigm is the existence of subjective-objective reality. As argued in constructivism, realities are socially constructed (subjectivity) while being shaped by the experience gained through participation or experimentation (objectivity) (Denzin & Lincoln, 2011; Heron & Reason, 1997). In participatory research, the issues facing these marginalized groups are exposed and studied. The researcher provides a voice for the participants, raising their consciousness and improving their lives through empowerment. The agenda of participatory research is action-oriented because the findings lead to changes in the existing structures. Typically, advocacy worldview exists in qualitative studies, but sometimes can be a foundation for quantitative research as well (Creswell, 2009; Reason & Bradbury, 2001).

4.3.5 Paradigmatic stance of the study

Quantitative researchers focusing on testing and a priori theory with an emphasis on deductive reasoning are more in line with positivism and postpositivism. Postpositivism assumes that researchers should try to approximate reality as best they can, while realizing that their own subjectivity is shaping that reality (Muijs, 2010). Therefore, compared to traditional positivism, postpositivism allows researchers to better explore the phenomenon of study using both quantitative and qualitative techniques. In order to examine the impact of ICT usage on CPD performance, this study conceptualized a research model based on existing theory. Since this model consists of several new constructs, and the available literature on the complex relationships hypothesised is limited, exploring the context of the study through a preliminary qualitative investigation before conducting the major quantitative study (survey) was appropriate. Additionally, secondary data obtained from the PDMA's 2012 Comparative Performance Assessment Study (CPAS) were to be utilized as a preliminary quantitative study that evaluates the impact of ICT usage with a somewhat different set of constructs. Therefore, *postpositivism* has been accepted as the paradigm which defines the theoretical tenets and philosophical principles that support the use of particular methods and associated design in this research.

Although the study utilizes some qualitative methods, constructivism is not its paradigm because the key focus of the research is to empirically verify the hypothesis developed mainly based on the extant literature related to the ICT usage – CPD performance relationship. Moreover, the pre-developed conceptual framework utilized in the qualitative study provided limited freedom for various new constructs to emerge. Critical theory or participatory worldviews do not fit to the present study as it does not aim to create a change in any existing oppressive structures or lives of any group of people through the active participation of the researcher. Postpositivism accepts both qualitative (e.g. in-depth, semi-structured, and unstructured interviews and case studies) and quantitative methods (e.g. structural equation modeling and other statistical techniques) for research (Krauss, 2005). This study adopts a mixed methods approach in order to increase the reliability, validity and relevance of the results obtained, for the extension of theory as well as for the industry. Practising postpositivism chiefly involves the collection of information using instruments, the measures completed by the participants, or observations recorded by the researcher (Creswell, 2009). This study uses hypotheses to evaluate the causal relationships between ICT usage and different aspects of CPD performance. Standard statistical validity and reliability tests performed in the data analyses guarantee the objectivity.

In summary, the present study is characterized by the following features common to postpositivist research – viewing inquiry as a series of logically related steps, believing multiple perspectives from participants rather than a single reality, adopting rigorous methods of data collection and analysis, and employing computer programmes to assist the analysis of quantitative data (Creswell, 2013). The following sections provide details on the overall design of the research, qualitative and quantitative phases of the study, methods applied in each research phase, the alternative methods, and justifications.

4.4 Research Design

There are four important aspects that influence the design of mixed methods studies, namely, timing, weighing, mixing, and theorizing or transforming perspectives (Creswell, 2009). The *timing* factor represents whether the qualitative and quantitative data collections will be carried out one after the other (sequentially) or at the same time (concurrently). In this study timing, is *sequential* as findings of the qualitative study are used to design the survey instrument for the quantitative study. The priority given to the qualitative and quantitative phases in a mixed methods research design is known as *weighing*. This study gave a higher priority to the *quantitative phase* where two types of large datasets (primary and secondary) were utilized and statistically analysed. Preliminary qualitative evaluation was used to provide important background information for the conduct of the primary quantitative study which was set to obtain generalizable results concerning different types of associations (direct, indirect, and moderated) between ICT and collaborative product development performance.

Mixing means when and how the mixing of quantitative and qualitative studies occurs. Mixing can be one of three types: (1) connected (the data analysis phase of the first study connects with the data collection of the second study), (2) integrating (merging qualitative and quantitative datasets into one), and (3) embedding (a secondary form of data within a larger study having a different form of data as the primary database). In the context of the present study, the two studies are *connected*, as the data analysis phase of the qualitative study connects with the data collection phase of the quantitative study (survey). The last feature in mixed-designs is *theorizing* (transforming perspectives) which means whether a larger theoretical perspective guides the entire design. In this study, the relational resource-based view (RRBV) and organizational information processing theory (OIPT) provided the basic foundation to develop the conceptual research model (section 4.2), which guides both the qualitative and quantitative phases.

4.4.1 Strategy of the research design

The four aspects: timing, weighing, mixing, and theorizing shape the procedure of a mixed methods design and help with the understanding of the most appropriate one out of six alternative strategies – (1) sequential explanatory, (2) sequential exploratory, (3) sequential transformative, (4) concurrent triangulation, (5) concurrent embedded, and (6) concurrent transformative (Creswell, 2009). Since the present study conducts qualitative and quantitative data collections sequentially, only sequential designs are possible (concurrent designs perform qualitative and quantitative studies simultaneously whereas transformative designs are based on advocacy worldview). This study conducts qualitative data collection first and its outcomes offer some inputs to the data collection in the quantitative phase (for operationalization of the survey instrument which has some new constructs). According to Creswell (2009), qualitative study followed by quantitative study or sequential exploratory design is particularly appropriate when the researcher needs to develop a survey instrument due to the unavailability or inadequacy of existing instruments. In addition, the study answers the research questions through interpretation of the results of both qualitative and quantitative analyses, which is a major characteristic of sequential exploratory design. Therefore, a *sequential exploratory design* was selected as appropriate for this study.

This study gains several advantages out of the sequential exploratory design strategy implemented. These are: easy implementation and straightforward describing and reporting because the studies are conducted one after the other, greater exploration of the phenomenon of study while expanding the qualitative findings, and the opportunity to develop a new survey instrument (to evaluate the impact of ICT usage on CPD performance). One drawback of this design is the substantial length of time required to complete the two phases of data collection (Creswell, 2009). However, the best effort was made to complete each research phase within scheduled time frames through proper planning and parallel execution of possible activities.

4.4.2 The mixed methods design of the research

Figure 4.2 illustrates the mixed methods research design developed for the study based on the above strategy. It presents both qualitative and quantitative research phases, highlighting the key methods and procedures followed in each phase.

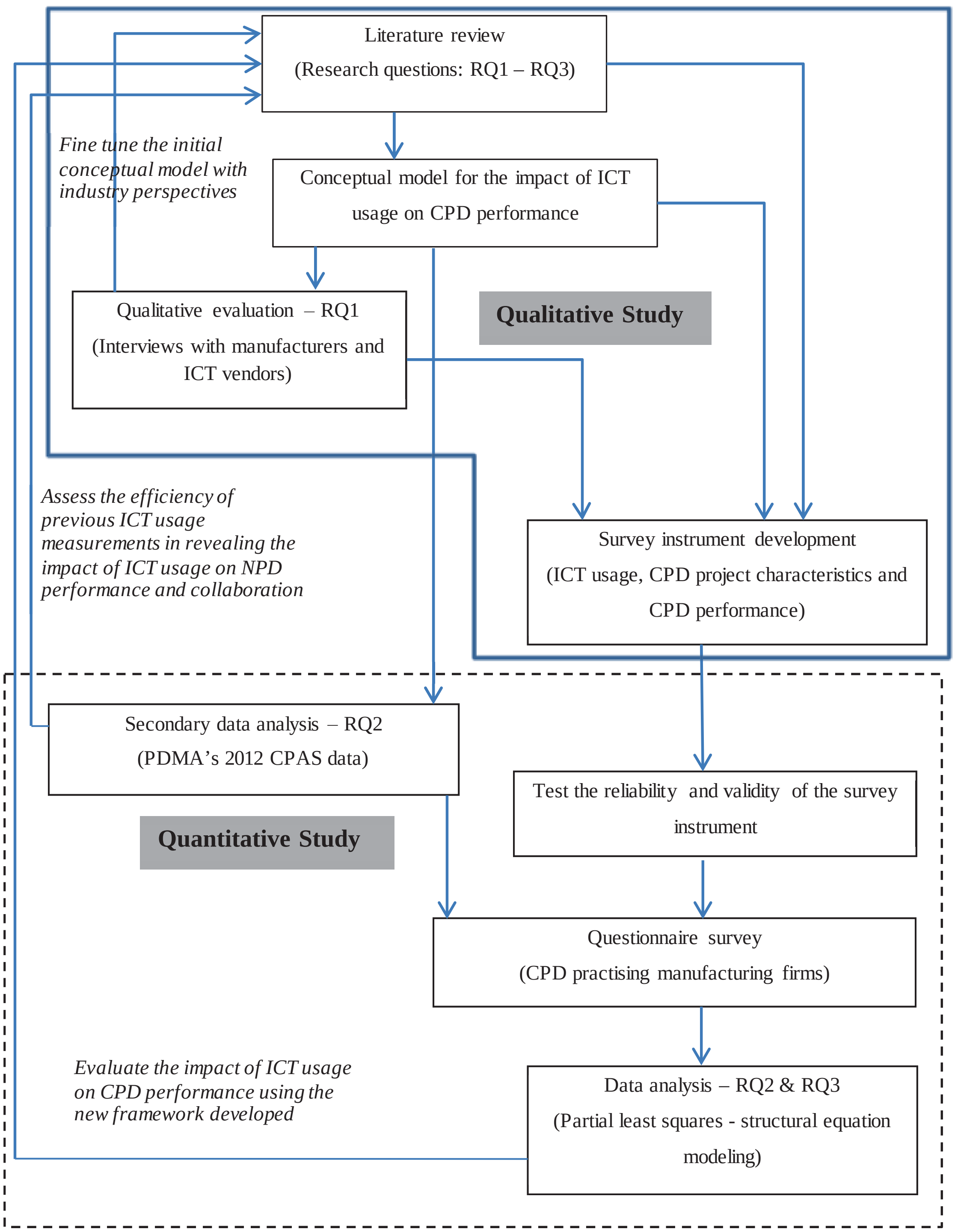

Figure 4.2: Research design

The three research questions formulated based on background literature were addressed in different phases of the study. The in-depth review of literature led to the development of the initial conceptual model for evaluating the impact of ICT usage on collaborative product development performance. First, this model was evaluated and fine-tuned with qualitative data gathered from industry experts (from manufacturing and ICT vendor companies). Findings of this investigation answers the first research question on managing ICT usage in terms of frequency, proficiency, and intensity, in manufacturing firms, for improving their CPD activities. Second, the preliminary quantitative study based on secondary data obtained from the PDMA's (Product Development and Management Association) 2012 Comparative Performance Assessment Study (CPAS) was conducted. This study answers the second research question and assesses the efficiency of previous ICT usage measurements in revealing the impact of ICT usage on overall NPD performance and collaboration. Addressing the second and third research questions based on the finalized conceptual research model, a survey was conducted in the final quantitative phase of the study. This survey collected primary data from CPD projects undertaken in high- and medium-high-tech manufacturing firms. The methods applied for data collection, establishing validity and reliability, and data analysis in the qualitative and quantitative research phases are explained with details in the subsequent sections of this chapter.

4.5 Qualitative Study

The key considerations in executing mixed methods research strategies are the purpose of the study and the amount of time available to collect data (Creswell, 2009). The primary objective of the qualitative evaluation of this study is to answer the first research question by exploring the context of ICT usage in terms of frequency, proficiency, and intensity in manufacturing sector CPD projects. This investigation provided valuable industry perspectives that were important in developing the survey instrument used in the last quantitative phase (survey). There can be trade-offs and choices of methodologies for qualitative studies based on the depth and breadth required. This qualitative investigation required neither a too deep nor a too broad evaluation of the phenomenon of study because it was directed by the conceptual model developed based on the RRBV and OIPT. Moreover, the time and resources available for the qualitative phase were limited because there were two quantitative studies to be conducted subsequently. Hence moderate level depth and breadth were encountered in sampling, data collection, and the data analysis procedures that followed.

4.5.1 Data collection and sampling

There are two broad classifications in qualitative data collection procedures, namely, the one-point-in-time approach and the longitudinal approach (Patton, 2015). In the one-point-in-time method, all required data are collected at one time. Usually, one interview per person or one site visit per place is organized. This method requires a relatively short time and facilitates comparisons across interviewees. The disadvantage of this approach is that it simply captures changes through retrospection rather than changes over time or from more in-depth data that are possible in longitudinal data collections. However, one-point-in-time data collection was satisfactory in this qualitative study which is followed by two large sample quantitative studies (using primary and secondary data) and had strict time and resource constraints.

The six leading methods for collecting qualitative data are: documentation, archival records, interviews, direct observations, participant observation, and physical artefacts (physical evidence) (Yin, 2014). Considering the factors – soft ethical requirements (the research project has been classified as a low risk study for the participants) (section 4.7), the purpose of providing initial support for the survey (which is also directed by the pre-developed conceptual research model), and the potential support from the subsequent quantitative studies – *interviews* was selected as the most suitable method to collect data in the preliminary qualitative study.

There are three common types of interviews, namely, unstructured, structured, and semi-structured (Chow, 2005, p.33-36). In *unstructured* interviews, there is no restriction on how the question is being answered and only open-ended questions are administered. *Structured* interviews are totally the opposite in nature and the researcher asks the interviewee a set of predetermined questions in a predetermined order. However, the interviewer has the freedom to choose the wording for the questions to suit the interviewee. *Semi-structured* interviews that hold both unstructured (open-ended questions) and structured (yes-no or agree-disagree questions) interview formats is the most common approach in research. These interviews are informal but are guided by a certain set of topics to be covered during the interview (Coolican, 2009). Since constructs of the initial theoretical conceptual model (Figure 4.1) provide a guiding outline for the interview, semi-structured was selected as the most appropriate mode of interviewing. Although it was guided by the outline, this method offered flexibility to the interviewer in selecting the order and wording of questioning and a sufficient freedom to the respondent to explore their views. The location of the interview was selected by the participant and it was their workplace for the majority while a few interviews were held on Skype. The average interview time was approximately 45 minutes.

Selecting a random probability sample was not necessary in the qualitative research phase of this study because a survey was planned next to it. Hence, there was no strict need to generalize the results. However, since this study was expected to provide important information for the survey instrument development, selecting a few information rich cases or a *purposive sample* (Creswell, 2009; Patton, 1990) was suitable. Maximum variation or heterogeneity strategy was followed in sampling. According to this method, a variety of cases are selected to obtain diversity on the aspects to be studied. This purposive sampling strategy enables the capturing of common patterns or characteristics common across the groups, using a small sample of great heterogeneity. The chosen sampling technique and the strategy, allowed the selection of highly knowledgeable and experienced managers from five manufacturing firms (with product development experience) and four ICT vendor firms to the sample (specific details are provided in Chapter 5). Different technological levels were represented within the manufacturing group while vendors of different types of ICT tools were in the ICT vendors' group.

4.5.2 Validity and reliability

Criteria for judging the quality of research designs comprise four concepts: internal validity, external validity, construct validity, and reliability (Yin, 2003). In case study research methods, these concepts are known as trustworthiness, transferability, confirmability, and dependability of data (U.S. General Accounting Office, 1990). *Internal validity* is the extent to which the causal relationships derived by a study are valid. This form of validity is mostly relevant for explanatory case studies or quantitative studies that examine relationships among variables. However, descriptive qualitative studies are also able to establish internal validity or trustworthiness using techniques such as pattern matching, explanation building, addressing rival explanations, and using logic models (Yin, 2003). Literature on the relationships proposed in the initial conceptual model were matched and discussed in the data analysis of the qualitative study (Chapter 5) and this supported establishing internal validity through pattern matching. *External validity* or *transferability* is concerned with generalizing the results of a study to a certain domain. Utilizing responses from participants from nine companies implied a satisfactory level of external validity of the preliminary qualitative study, while there was no substantial need to generalize the findings.

Correct reflection of a concept as it claims is known as *construct validity*. The use of multiple sources of evidence is a suitable strategy to establish construct validity in qualitative studies where specific, well-defined statistical techniques are available for quantitative studies (Yin, 2003). The present qualitative study obtained responses from ICT vendors and manufacturers who have different backgrounds in relation to the focus of the study. This helped triangulation of the results and hence confirmed construct validity. *Reliability* of a study assesses whether a test (measurement) produces consistent results on repeated observations of the same condition. Statistical techniques are available for testing the reliability of quantitative studies, whereas the use of study protocol guided by theoretical frameworks and relevant literature assists achieving reliability or dependability of data in qualitative investigations (U.S. General Accounting Office, 1990; Yin, 2003). The interviews conducted in this study were chiefly guided by the initial conceptual model developed based on existing literature, and the procedures followed in the interviews were completely pre-documented and reviewed. Therefore, reliability was adequately confirmed in the qualitative phase of the study through utilizing a study protocol (the information sheet and interview questions provided in Appendix 5.2 and 5.3) and a priori specification of constructs (the conceptual model).

4.5.3 Data analysis

The manufacturing or ICT vendor firm of the interview participant was the unit of analysis in the qualitative study. First, the recorded interviews were transcribed (a full text version of the interviews was prepared) as this is the first step towards analysing interview data. Since this qualitative evaluation aims to explore practitioners' perspectives on the concepts and themes suggested in the literature (for the initial conceptual research model), following a qualitative analytical procedure rather than the counting of words (traditional content analysis) was important (Rubin & Rubin, 2005;

Weber, 1990). Therefore, qualitative content analysis was selected as the appropriate methodology for data analysis. This method allows the classifying of many words of the text into a few content categories. There is freedom to assign a code (category) to a chunk of text of any size, as long as that chunk represents a single theme or issue which is relevant to the research questions (Zhang & Wildemuth, 2009). Therefore, qualitative content analysis allows subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns (Hsieh & Shannon, 2005).

There are three main approaches available in qualitative content analysis – conventional, directed, and summative. Conventional and summative approaches are applied in inductive research where theory emerges from the data gathered. Directed approach in contrast aims to validate or extend a conceptual, theoretical framework or theory and therefore is suitable for deductive research. Usually, in this method open-ended questions are administered concerning predetermined categories (which was the method followed in this qualitative investigation). Directed content analysis in this study started with reading the whole transcript and highlighting important passages in the text, that on first impression appear to represent greater emphasis by the participant. Then the coding of these highlighted passages was carried out using predetermined concepts. Usually, the remaining text that could not be categorized with the initial coding scheme needs to be coded using a new code or a subcategory of an existing code. However, in the present data analysis, all the data, except the barriers to effective ICT use in product development, were able to be categorized within the concepts related to ICT usage, CPD performance, and project characteristics, in the initial conceptual model. Analysing additional data which are not derived from pre-determined categories either offer a contradictory view of the phenomenon or further refine, extend and enrich the theory (Hsieh & Shannon, 2005). In this analysis, the views of the participants on the barriers were extremely useful in refining and improving overall findings obtained by analysing the positive outcomes of ICT use in collaborative product development.

4.6 Quantitative Studies

Quantitative research involves collecting and analysing numerical data using mathematical/statistical methods to explain a particular phenomenon (Muijs, 2010). There are three most common forms of quantitative research, namely, experimental, quasi experimental and non-experimental (Chow, 2005). *Experimental* studies are used to examine the effect of a specific treatment on an outcome. The outcomes of the treated and controlled groups are compared to assess the impact of the treatment. Empirical studies (enquiries designed to answer a well-defined question requiring more than a conceptual analysis) that include all recognized controls and random assignment of participants, are called experiments. In *quasi experiments* random assignment and controlling for some variables, are not possible due to theoretical or practical constraints. *Non-experimental studies*, to which the present study belongs, are of two types, namely, observational and survey (Edmonds & Kennedy, 2012). In *observational* studies the researcher does not control the variables of the study and simply records them to explain relationships between variables and/or predict the outcome based on one or more predictors. *Survey* research uses questionnaires or structured interviews for data collection and generalizes the sample results to the population.

Surveys can be cross-sectional or longitudinal. *Cross-sectional* studies in which data are collected at one point in time are relatively largely applied in research. In contrast, *longitudinal* designs permit the collection of survey data over a selected period of time with the same or different samples drawn from the same population. This approach was not feasible for the present study which had a limited time available for the conduct of the survey. The first quantitative research phase involving secondary data was also a cross-sectional survey conducted by the PDMA in 2012. In the main (final) quantitative phase of the study, a cross-sectional survey was conducted to collect data on CPD projects, from manufacturing firms that are engaged in global CPD. The following sections give more details about the two quantitative research phases of the study.

4.6.1 Use of secondary data

PDMA has conducted world-wide NPD best practices surveys in 1990, 1995, 2004, and 2012. The fourth study conducted in 2012 was named as Comparative Performance Assessment Study (CPAS) (Markham & Lee, 2013). The preliminary quantitative research phase of this study utilized data obtained from the CPAS (2012) as secondary data. All details of the survey and the sample, which are relevant for the present study, are provided in Chapter 6. The primary advantages of using secondary data are: low cost, speed, and the broad scope realized in data collection (Cowton, 1998; McQueen & Knussen, 2006). In this study, there was no cost in obtaining the secondary data from the PDMA and the process took only a short period of time (approximately two weeks). First, the dataset were requested from the PDMA explaining the requirement of the study, and subsequently it was provided subject to an official agreement that the data will only be used for research purposes. The CPAS (2012) survey covered a large number of countries and industries, and this led to an understanding of the appropriate scope for the final survey.

The use of secondary data does have some disadvantages (Cowton, 1998; McQueen & Knussen, 2006). These are highlighted below with explanations on how these affect the preliminary quantitative study which used the data obtained from the PDMA's CPAS (2012).

- The researchers who use secondary data have no control over the generation of the data as they have not been involved in the process of data collection. As a result, there can be many mismatches in measures captured and the range of responses. Therefore, the researchers may not able to adequately address their own theoretical concerns with secondary data. Since the CPAS (2012) has not covered the exact concepts captured in the present study (e.g. collaboration performance, project characteristics), a revised closely related model developed based on data availability was tested in the preliminary quantitative study (Chapter 6). However, this was not an issue since the intention was to simply approximate the findings of the main study while assessing the importance of the concepts included in the main conceptual model for exploring the impact of ICT usage on CPD performance.
- Secondary data are sometimes available as summarized data and this restricts the understanding of the original categories and data editing information. However, secondary data utilized in the present study were not in such a format; they were complete and included all the categories and responses originally gathered in the CPAS (2012).
- The time of secondary data could be a problem as in many cases secondary data are not current and have been collected and reported several years ago. The CPAS (2012) data are three years older than the primary data collected in the main survey (2015) of this study.

4.6.2 The survey

The second phase of the quantitative study involved a questionnaire survey. A measurement instrument was developed to collect primary data to empirically test the main hypotheses developed in the finalized conceptual model (Chapter 7). The instrument included indicators for three dimensions of ICT usage (frequency of communication, proficiency of use, and intensity of use), two CPD project characteristics (complexity and uncertainty), and CPD performance in terms of new product performance and collaborative performance. Due to the absence of scales having been developed that could best fit the scope of the constructs proposed, new scales were developed by modifying or combining suitable existing instruments. Nine-point Likert scale questions were used in the questionnaire items associated with the model constructs. The quality of the survey instrument was established by testing its reliability and validity (section 4.6.4 provides more details).

4.6.2.1 Population and the sample

Since results of this study are expected to generalize to the high- and medium-high-tech manufacturing industries where CPD is widely practised, manufacturing companies from the following industries were selected for the sample – electrical/electronic, automotive, pharmaceutical/biotechnology, medical/dental instruments, machinery, and chemicals. The selection was based on the results obtained in the preliminary quantitative study (secondary data analysis) in relation to the technology level of firms. A collaborative NPD project carried out recently (within last five years) by manufacturing companies from the selected industries was considered as the unit of analysis. The PDMA LinkedIn group was the sampling frame and the respondents for the questionnaire were product development professionals in the group, who have experience in firms that undertake global CPD projects. Since these people are based in various regions of the world, online questionnaire administration method was selected.

4.6.2.2 Planning the online survey

Available time, budget, and ethical issues are the major factors to be considered when selecting a suitable method for creation and conduct of a survey (Sue & Ritter, 2012). As a PhD study supported by partial funding, this research had strict time and budget constraints. Online surveys are created using software such as Google Forms, SurveyMonkey, Zoomerang, or InstantSurvey that are available for free or at a certain cost. Google Forms was used to design the online survey of this study as it is a free, convenient, and reliable online survey designing tool. In Google Forms, the survey link is available to the user after the questionnaire is created. The user can edit the questionnaire and access collected data at any time.

The modes of online surveys are: e-mail surveys, Website surveys, and mobile surveys. In *e-mail surveys*, an e-mail invitation including a link to an online survey is sent to the participants. *Website surveys* are also created using an online survey software application. The survey is posted on a Website, and it appears to the respondents either as a link on the Web page or as a pop-up or crawl-in link. Since it is a Webpage, data collection from a vast community is possible and hence particularly useful when the researcher does not have a sampling frame. In *mobile surveys*, a series of text messages are sent to the participants' mobile electronic devices such as smartphones and tablet computers (Sue & Ritter, 2012). This study used the LinkedIn PDMA group as the sampling frame and e-mail surveys for questionnaire administration. After joining the group, members can be contacted via group messages. However, the group messages did not allow sending Web links to the members who are not in the researcher's own network. Therefore, an initial short e-mail was sent to the members explaining the reason for connecting and subsequently, the connection invitation was sent. Finally, the survey invitation including the survey link was e-mailed to the connected members. Chapter 7 includes more details about execution of the online survey and the responses received.

Several factors affect the response rate to surveys. These are: the topic, survey invitation, appearance and length of the survey, timing and dissemination, perceived security and privacy, relationship with the sender, incentives, and follow-up reminders. In this survey, several techniques were applied to increase the response rate (Sue & Ritter, 2012). Using features available in the software application used, the survey was designed with a good appearance. Topic, ethical approval, and confidentiality details were provided while keeping the length of both the invitation and the survey as short as possible. Full contact details of the researcher were also provided. Thank you messages were promptly sent to the respondents who advised that the survey has been completed. Since material or nonmaterial incentives lead to increased response rates (Sue & Ritter, 2012), the fact that an executive summary of the survey data will be provided to the respondents upon completion of the study, was stated in the survey.

4.6.3 Validity of quantitative studies

Validity implies the accuracy of conclusions drawn from a study. There are four types of validity considered in quantitative studies – statistical conclusion validity, internal validity, construct validity, and external validity (Coolican, 2009; Straub, 1989).

4.6.3.1 Statistical conclusion validity

Statistical conclusion validity concerns the likelihood of errors that are possible when making a conclusion based on statistical tests. In statistical hypothesis tests, researchers may or may not reject what they hypothesised based on evidence available in the sample. An error occurs when they conclude something different from what is in the actual population. The objective of the quantitative researcher is to minimize the likelihood of making false decisions as much as possible. The appearance of a wrong relationship due to inappropriate statistical procedures, or other statistical errors, indicates a lack of statistical conclusion validity (Coolican, 2009; Straub, 1989). In both quantitative phases of the current study, the appropriateness of the statistical procedures selected and the sample adequacies under these procedures were confirmed. In each analysis, several hypotheses were supported at acceptable levels of significance (less than 10%). The samples utilized in each analysis were sufficient to ensure 80% power of the tests performed (more details are provided in Chapters 6 and 7). Therefore, a satisfactory level of statistical conclusion validity has been established in both studies on secondary and primary data.

4.6.3.2 Internal validity

Internal validity is concerned as to whether there is a real causal relationship (direct or indirect) between independent and dependent variables of the study. In cross-sectional studies where subjects are observed at one point in time rather than reporting a sequence of events, inferences on causation are not possible. However, depending on resource and time availability, cross-sectional studies are largely used to infer causal relationships. In these studies the independent variables are identified as possible predictors for the outcome variables (Levin, 2006; Mann, 2003). Sampling bias and non-equivalent groups are the major threats to internal validity. The random allocation of participants to conditions will be useful to eliminate sampling bias. Groups which are different only in the treatment of interest are selected as non-equivalent groups. These arrangements are more practical in experimental studies (Coolican, 2009). In non-experimental research designs, drawing conclusions logically by following an appropriate methodology and the equal treatment of participants, are important to minimize threats to internal validity (Mann, 2003; Trochim, 2006a). In the present quantitative studies, the samples were selected objectively without any personal or organizational bias. Furthermore, fixed, properly developed and validated survey instruments were employed for all the members in the samples to ensure a satisfactory level of internal validity.

4.6.3.3 Construct validity

Construct validity in non-experimental studies can be established by using correct measures that truly measure the constructs. The selection of unrepresentative samples or wrong independent variables (where some other variable or a confounder affects the dependent variable) will also impact the construct validity of quantitative research (Bagozzi, Yi, & Phillips, 1991; Coolican, 2009). Convergent validity and discriminant validity are the two aspects of construct validity in quantitative tests (Campbell & Fiske, 1959). *Convergent validity* considers whether two or more measures of the same concept (construct) are highly related to each other (covary). *Discriminant validity* evaluates the degree to which the measures of different constructs are distinct from each other (Bagozzi et al., 1991).

Principal component-based factor analysis is a recommended technique to assess construct validity (Straub, 1989). It was performed in the preliminary quantitative study on secondary data, to establish the construct validity of the two multidimensional constructs considered – overall NPD performance and collaboration. The results obtained were satisfactory and are presented in Chapter 6. In this analysis, primary product type and technology level were entered into the hierarchical regression analysis as control variables in order to avoid possible confounding effects of these variables. PLS is a widely used component-based structural equation modeling technique to establish construct validity (Hair, Ringle, & Sarstedt, 2011). In the final survey where primary data for the main study were collected, the PLS approach was followed to test the construct validity. Chapter 7 presents these results that have satisfactorily confirmed the convergent and discriminant validity of all the constructs captured in the survey. Homogeneity in the sample in terms of scale of the organization and technology level was maintained in order to reduce the possibility of any confounding effects.

4.6.3.4 External validity

External validity concerns whether the relationships or effects observed in an investigation can be generalized to other people, settings, and periods (Coolican, 2009; Straub, 1989). In the present study, both the primary (285) and secondary (450) samples represent various regions of the world and thus, are large enough to generalize the results to the populations from which the samples were drawn. The primary sample of the study is a collection of CPD projects undertaken in globally operated high-tech manufacturing firms. The population considered in the secondary sample obtained from the CPAS (2012) includes CPD-practising firms (both manufacturing and service sector) rather than projects. Since the two surveys were conducted quite recently (2015 and 2012) the results can be adequately generalized to the current CPD contexts and firms in the respective populations.

4.6.4 Instrument validation

Validity of an instrument is established by assessing whether the instrument tests what was originally intended to measure. The validation process of a survey instrument involves assessments for *face and content validity*, *reliability (internal consistency)*, and *construct validity* (Coolican, 2009; Straub, 1989). Construct validity of the instruments has been explained in a previous section (4.6.3.3) as a major aspect of the validity of quantitative studies.

4.6.4.1 Face and content validity

The face validity of survey constructs evaluates whether it is obvious what the items in the instrument are measuring. There is no technically adequate measure for this validity (Coolican, 2009). The face validity of the constructs used in the primary survey and the constructs adapted from secondary data were reviewed by the researcher and found satisfactory in the context of the current study. Content validity is a sophisticated version of face validity and is established through the instrument evaluated by colleagues for its representation of the area it is intended to cover. The experience of colleagues in the topic area of the research is highly important to assess whether the collection of items accurately measure the concept or construct (Coolican, 2009). In the secondary data analysis, the content validity of the multi-item constructs adopted for overall NPD performance and collaboration was evaluated by the researcher and her supervisors based on their experience and research expertise in the field of study. Content validity of the primary study instrument was satisfactorily confirmed through relevant expert judgement. The process involved is described in Chapter 7 under ‘Instrument Validation’.

4.6.4.2 Internal consistency reliability

Internal consistency reliability ensures that the respondents answer the same or related instrument items consistently. High correlations between alternative measures or Cronbach alpha values greater than 0.7, are the relevant criteria for establishing the reliability of instruments (Coolican, 2009; Cronbach & Meehl, 1955; Straub, 1989). Cronbach alphas of each construct used in both qualitative studies have adequately confirmed the reliability of the measurement instruments and these values are reported in Chapters 6 and 7. However, in PLS-SEM, composite reliability is more appropriate for testing internal consistency as it prioritizes measures based on their reliability during model estimation (Hair et al., 2011). The composite reliability values reported in Chapter 7 are greater than the recommended threshold 0.7, and hence adequately confirm the internal consistency reliability of the instrument developed for the final survey.

4.6.5 Data analysis and interpretation

This section describes the key data analysis tools applied in the two quantitative research phases of the overall study. In the preliminary quantitative study on CPAS (2012) data, hierarchical multiple regression analysis was performed to evaluate the direct and indirect impact of individual ICT tools on overall NPD performance, through collaboration. PLS-SEM path analysis was applied in the primary data analysis to evaluate the direct and indirect impact of ICT usage through collaboration performance on new product performance, and the moderating impact of project characteristics over these associations. In addition to these approaches, correlation analysis, multivariate ANOVA, and principle component-based factor analysis were utilized in supplementary data analysis steps in the quantitative research phases. The main statistical methods used in the study, are briefly explained in the following sections.

4.6.5.1 Hierarchical multiple regression analysis

Multiple regression analysis is a widely-used statistical method for testing hypotheses concerning the relationship between a criterion (dependent) variable and a set of dependent variable (predictors). In hierarchical multiple regression, the predictors are sequentially entered into the model at several steps. The order of entering the predictors should be based on their causal priority. When there are causal relationships among the predictors, the causes need to be entered into the model before their effects. Usually, static variables such as age or gender are entered before the dynamic variables. The reported regression coefficient (β) of a variable entered in step 2 is calculated while controlling statistically for the variables entered in step 1. Therefore, the variance of the response variable attributed to a certain predictor variable depends on the predictor's relationship with the response variable and on the variables that have already been entered into the model. The focus of hierarchical regression analysis is on the change in predictability associated with predictors entered later over the contribution by predictors entered earlier in the analysis. Change in the coefficient of determination or R^2 (ΔR^2) and its corresponding change in F statistic (ΔF) are calculated at each step of entering predictors. A model that shows a significant improvement in the R^2 over its previous model is finally selected (Petrocelli, 2003).

The regression model estimated in the secondary data analysis included 13 ICT tools as predictors, technology level and primary product type as control variables, overall NPD performance as the criterion variable, and NPD collaboration as the mediator. When a multiple regression model between independent variable X and criterion Y contains mediator variables M (Figure 4.3), the analysis needs to follow specific steps (Baron & Kenny, 1986; Kenny, 2015).

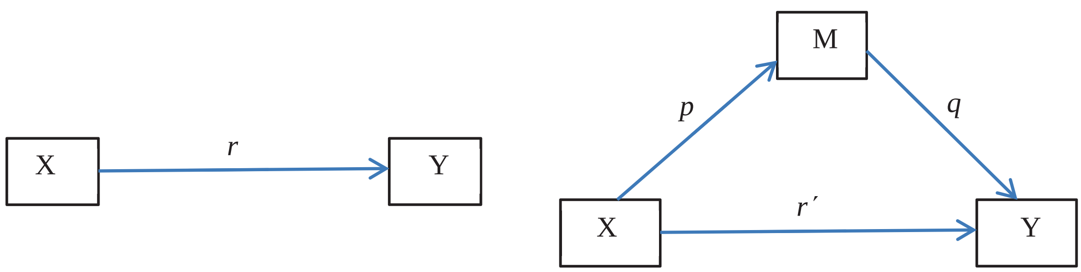

Figure 4.3: Mediator analysis

These steps are: (1) estimate and test the direct path from X to Y [r]; (2) estimate and test the path from X to M [p]; (3) estimate and test the path from M to Y [q]; and (4) estimate the effect of X on Y controlling for M [r']. Since both M and Y are caused by X, the relationships in both steps 3 and 4 are estimated in the same hierarchical regression analysis. If all the effects tested in the four steps are significant, M is identified as to completely mediate the association between X and Y. If only the effects tested in the first three steps are significant, there is a partial mediation. This study used SPSS 22 software to perform the hierarchical regression analysis on the secondary data and all the results and their interpretations are presented in Chapter 6.

4.6.5.2 Partial least squares structural equation modeling (PLS-SEM)

Structural equation modeling (SEM) is a statistical data analytical approach that combines simultaneous regression equations and factor analysis. Factor analysis tests how well sets of observed or manifest variables measure factors or latent constructs (theoretical abstract concepts that cannot be directly measured with single items). Regression models examine hypotheses concerning the strength and direction of relationships between observable predictor variables and a dependent variable. SEM accommodates regression relationships among latent variables measured by a set of observed variables, and between observed and latent variables (Bowen & Guo, 2011).

There are two methods of SEM, namely, covariance-based SEM (CB-SEM) and partial least squares SEM (PLS-SEM). In CB-SEM, a theoretical covariance matrix is developed based on a set of structural equations. The method focuses on estimating a set of model parameters that minimizes the difference between the theoretical covariance matrix and the estimated covariance matrix. PLS-SEM combines features from principal component analysis and multiple regression modeling. First, it iteratively estimates scores of the latent constructs. The iterative process is repeated until the total outer weights' (for formative measurement models) or outer loadings' (for reflective measurement models) differences between two iterations decreases below a predetermined threshold (10^{-5}). Second, final estimates of the outer weights, loadings, and path coefficients of the structural model are calculated using the ordinary least squares method for each partial regression in the SEM model. The significance of these coefficients is evaluated through bootstrapping. In PLS-SEM, the measurement model that shows the unidirectional predictive relationships between each latent construct and its associated manifest variables is known as the outer model. The structural model which shows the paths between the latent constructs is known as the inner model.

The path modeling procedure in PLS-SEM is known as partial since its iterative algorithm estimates the coefficients for the partial ordinary least squares regression models in the measurement models and structural model. In formative measurement models, a multiple regression model is estimated with the latent construct as the dependent variable and the indicators as the independent variables. In reflective measurement models, the regression model contains single regressions with each indicator individually being a dependent variable and the latent construct is always the independent variable. In structural model estimation, each endogenous latent construct represents the dependent variable with its exogenous latent constructs as independent variables in a partial regression model (Hair et al., 2011).

Although CB-SEM provides more precise model estimates due to covariance structure optimization, it has large sample size requirements and multivariate normality assumption to be fulfilled, which are difficult in many empirical research projects. PLS-SEM offers good approximation to CB-SEM even with non-normal data and relatively small samples. In addition, PLS-SEM is applicable for models with reflective or formative constructs whereas CB-SEM has limitations in using formative constructs (Hair et al., 2011). In complex models with mediators and moderators or both, PLS-SEM performs better with relatively small samples (Chin, Marcolin, & Newsted, 2003). Using latent variable scores in subsequent analysis is also possible with the PLS method. PLS-SEM is increasingly applied in marketing, business, and IS research due to its relaxed distributional assumptions, less sample size requirements, and the facilitation of complex model estimation (Chin et al., 2003; Ringle, Sarstedt, & Straub, 2012).

This study involves new product development and IS disciplines and considers a research model that has first and second order constructs. The model tests hypotheses about direct and indirect relationships (through collaboration performance) between ICT usage and new product performance, and the moderating impact of project complexity and uncertainty on these relationships. Figure 4.4 concisely illustrates the effects examined in the study. The PLS-SEM method adequately facilitated testing these effects with the available sample whereas sample size requirement in the alternative

CB-SEM approach is extremely difficult to achieve within the time and budget constraints of the study. SmartPLS 2.0 software was used to perform the PLS path analysis and the complete results are presented and interpreted in Chapter 8.

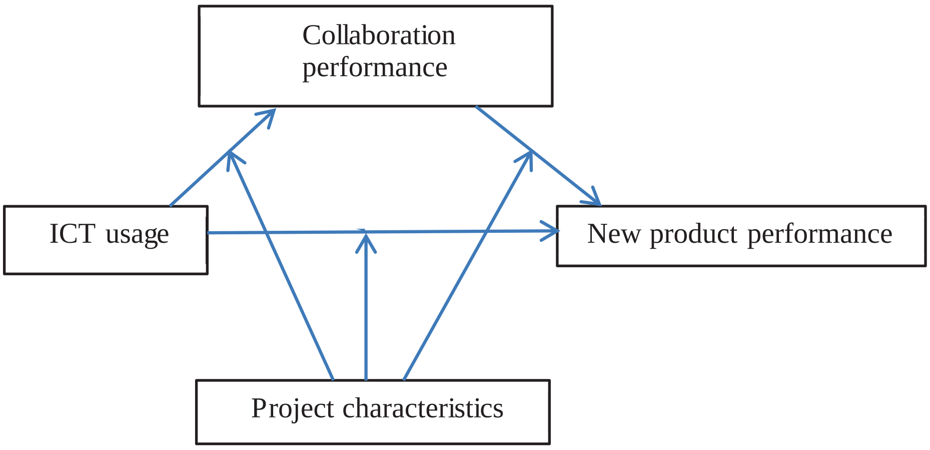

Figure 4.4: The effects tested in the PLS path analysis

4.7 Ethical Considerations

It is the responsibility of a researcher to follow strict ethical principles devised by an appropriate authority, when working with research participants (Coolican, 2009). Massey University has developed a code of ethical conduct of research involving human participants (Massey University, 2015). The major principles in this code of ethics are:

a) respect for persons;
b) minimisation of harm to participants;
c) informed and voluntary consent;
d) respect for privacy and confidentiality;
e) the avoidance of unnecessary deception;
f) avoidance of conflict of interest;
g) social and cultural sensitivity to the age, gender, culture, religion, and social class of the participants; and
h) justice.

Massey University record research projects in which the nature of the harm is minimal and no more than normally encountered in daily life, on the low risk database. After a certain screening process, the researcher receives a low risk notification (Appendix 4.1) which is valid for three years. This study went through that process and was recorded on the low risk database before the start of data collection. This ensured that all three research phases were conducted according to the principles in the Massey University code of research ethics.

In the preliminary qualitative study, the interview participants were clearly informed in advance about the research topic, the purpose of the study, the nature of the interview, approximate time, and ethical approval details, through a detailed information sheet (Appendix 5.2). Full contact details of the researcher were also provided to the respondents. Furthermore, assurance was given that all responses will be kept confidential and company or personal identifiable information will not be disclosed at any point of the study. The interviews were digitally recorded upon a written consent obtained from the participants. Socially or culturally sensitive questions were avoided.

In the preliminary quantitative study which used secondary data, the CPAS (2012) data were obtained from the PDMA upon completion of an official written agreement between the researcher and the PDMA research foundation, with the approval of the PhD supervisors. In accordance with this agreement, a copy was sent to the PDMA each time a paper was submitted for publication based on the data obtained. In the final survey, the participants were clearly informed of the research topic, its purpose, the type of data, the basis for selecting respondents, and the significance of the study. Furthermore, the participants were informed that the data collected will be kept confidential and reported anonymously. The number of questions, the approximate time required for completing the survey, and the incentive for participation (an executive summary) were specified in the survey invitation (Appendix 7.1) and in the online questionnaire (Appendix 7.2). The respondents were asked to contact the researcher if they had any concerns about the conduct of the research, and relevant contact details were provided.

4.8 SUMMARY

In order to fill the gaps identified in the literature (Chapter 3), this research has developed a conceptual research model has been developed based on the relational resource-based view and organizational information theory. This study has been operated in a postpositivist paradigm to explore the impact of ICT usage on CPD performance. The study adopted a sequential exploratory mixed methods research design that included a preliminary qualitative study and two quantitative studies based on secondary and primary data. The three research phases, reason, sequence, and the methods applied in each phase are summarized in Table 4.1 below.

Table 4.1: Methods applied throughout the study

<table>
<tr><th>Research phase</th><th>Process in sequence</th><th>Methods applied</th></tr>
<tr><td rowspan="4">1. Preliminary qualitative study
(To assess the literature-based initial conceptual model with qualitative industry evidence)</td><td>1. Sample selection</td><td>Manufacturing firms involved in CPD and ICT vendors providing ICTs to facilitate manufacturing CPD projects were selected using purposive sampling and maximum variation sampling strategy.</td></tr>
<tr><td>2. Data collection</td><td>Semi-structured interviews with knowledgeable and experienced managers from the selected firms.</td></tr>
<tr><td>3. Validity and reliability</td><td>• Internal validity (trustworthiness) - pattern matching
• External validity (transferability) - responses from nine companies
• Construct validity (confirmability) - responses from two groups (ICT vendors and manufacturers)
• Reliability (dependability) – using a study protocol and priori specification of constructs (the conceptual model)</td></tr>
<tr><td>4. Data analysis</td><td>Directed qualitative content analysis</td></tr>
<tr><td rowspan="4">2. Preliminary quantitative study
(To assess the efficiency of the existing ICT usage measurements using a different set of quantitative data)</td><td>5. Sample selection</td><td>450 CPD practising firms surveyed by PDMA in their 2012 Comparative Performance Assessment Study (CPAS).</td></tr>
<tr><td>6. Data collection</td><td>Secondary data obtained from CPAS (2012)</td></tr>
<tr><td>7. Validity and reliability</td><td>• Statistical conclusion validity- several hypotheses were supported at acceptable levels of significance (less than 10%). The sample was sufficient to ensure 80% power of the hypothesis tests.
• Internal validity – PDMA has selected the sample without any personal or organizational bias and collected data using a fixed, properly developed questionnaire.
• Instrument validity :
o Face and content validity – confirmed through expert judgement
o Construct validity – principal component-based factor analysis
o Internal consistency reliability – Cronbach alpha > 0.7
• External validity – using a large enough sample to generalize the results to various industrial sectors</td></tr>
<tr><td>8. Data analysis</td><td>Hierarchical multiple regression analysis</td></tr>
</table>

3. Final survey *(To evaluate the impact of ICT usage on CPD performance using the new framework developed)*	9. Sample selection	Product development professionals in the PDMA LinkedIn group, who have experience in global CPD projects.
	10. Data collection	Online questionnaire survey
	11. Validity and reliability	• Statistical conclusion validity – several hypotheses were supported at acceptable levels of significance (less than 10%). The sample was sufficient to ensure 80% power of the hypothesis tests. • Internal validity – respondents were selected without any personal or organizational bias, and a fixed, properly developed questionnaire was used. • Instrument validity: o Face and content validity – confirmed through expert judgement o Construct validity - PLS structural equation modeling o Internal consistency reliability – both Cronbach alpha and composite reliability > 0.7 • External validity – using a large enough sample to generalize the results to high and medium-high-tech manufacturing CPD projects.
	12. Data analysis	PLS-SEM path analysis

The qualitative study addresses the first research question while providing industry inputs for supporting and improving the initial conceptual research model developed based on the literature. The preliminary quantitative study which utilized secondary data obtained from PDMA's CPAS (2012) examines the efficiency of previous ICT usage measurements in revealing the impact of ICT usage on performance of CPD projects. The initial conceptual model fine-tuned in the preliminary qualitative study, provided the basis to develop the measurement instrument used for data collection in the final survey. The second research question is addressed in both quantitative studies with different sources of data and the third research question is addressed only in the final quantitative phase. The study has been conducted according to the principles of the code of research ethics of Massey University and recorded as a low risk project in the university research database. The next chapter presents the qualitative preliminary study, which is the first phase of the overall study.

5. Preliminary Qualitative Study

5.1 Introduction

This chapter presents findings of the preliminary qualitative study conducted to explore the practitioners' perspectives on improving manufacturing sector collaborative product development (CPD) programmes through effectively managing ICT use. Earlier quantitative studies focusing on the role of ICT in product development captured ICT usage in terms of the number of ICT tools used in a project (Barczak et al., 2007) or frequency of using the tools (Kawakami et al., 2015) whereas the present research model (Figure 4.1) introduces three dimensions – frequency, proficiency, and intensity to represent overall ICT usage in a CPD project. Most of the studies have focused on the direct impact of ICT usage on an NPD project's final performance rather than collaboration outcomes such as sharing of knowledge, information, risks, and benefits, and trust creation considered in this study. Unlike previously utilized models, the present research model evaluates several direct, indirect, and moderated effects of ICT usage on collaborative product development performance.

The initial conceptual model developed in this study for evaluating the impact of ICT usage on CPD performance identified three main sets of constructs based on the literature. These are: (1) ICT usage (frequency, proficiency, and intensity of ICT use), (2) moderating project characteristics (complexity, uncertainty, and urgency) that represent the information processing requirement in CPD projects, and (3) CPD performance (collaboration performance, new product quality, commercial success, and time performance). The concepts such as collaboration performance, proficiency, and intensity of ICT use are relatively new to the field of study. In addition, there was no qualitative investigation addressing all the concepts captured in the present research model though the existing studies offered many useful insights when incorporating some of the concepts to the present model for better evaluating the ICT impact on CPD performance (e.g. Boutellier et al., 1998; Coenen & Kok, 2014; Kawakami et al., 2011).

Having some new constructs and relationships in the initial conceptual model, which have not been addressed in previous studies focusing on the impact of ICT usage on CPD performance (e.g. Durmusoglu & Barczak, 2011; Kawakami et al., 2015; Peng et al., 2014), was the key reason for this qualitative investigation. This exploration of practitioners' views was also worthwhile in understanding the broad context of the overall study towards improving CPD performance through managing the ICT use (frequency, proficiency, and intensity) and the feasibility of evaluating the initial research model in the final quantitative research phase. Therefore, this study was conducted prior to the final survey using the perspectives of related industry experts, to answer the first main research question through the four sub-questions listed below:

How do manufacturing firms manage ICT usage in terms of frequency, proficiency, and intensity, for improving their collaborative product development activities?

- How do manufacturing firms select ICT tools and use these in their collaborative product development programmes?
- What are the dimensions of ICT usage that contribute to the success of CPD projects? Are frequency, proficiency, and intensity of ICT use relevant ICT usage dimensions?
- Which characteristic of a CPD project predominantly represents the information processing requirement of the project?
- What are the positive CPD performance outcomes expected from ICT usage in manufacturing CPD projects and what are the barriers to achieving these outcomes?

This study uses a sample of nine firms four of whom are ICT vendors that supply software to manufacturers. The remaining five firms are manufacturing companies that use ICT tools in their collaborative product development projects. A product development manager from each manufacturing firm or an experienced manager from each ICT vendor company was selected for the interviews. A similar approach for sample selection using both manufacturers and ICT vendors had been adopted in earlier studies (Kawakami et al., 2011) in order to explore a wide span of industry perception on the phenomenon of the broad study. In this study, the participants' perspectives are qualitatively analysed based on the priori specifications of the concepts in the model. Subsequently, the findings are discussed, connecting with relevant literature, to support the development of: operational definitions for the constructs conceptualised on theoretical grounds (Chapter 4) and the main study hypotheses in Chapter 7 with increased practical relevance.

This study offers a vital understanding on the role of ICT in collaborative product development, based on the descriptive individual perceptions gathered. However, it is important to note that the findings of this study have limited ability to be generalized for the entire manufacturing sector rather than providing some valuable inputs for the main quantitative research phase (survey). Furthermore, the results offer a distinctive advantage by providing real-world justifications to the findings of the quantitative study phases, while deriving some useful implications for CPD practitioners and researchers.

The rest of this chapter is organized as follows. First, the methodology adopted in the qualitative data evaluation, including brief introductions to the nine companies selected for the study, the sampling procedure, research validation, and method of data analysis is explained. Second, the analysis of data and the results obtained in relation to the four sub research questions are presented and discussed in conjunction with the existing literature. The last section presents the conclusions, important implications for the subsequent quantitative research phases, and limitations of the study.

5.2 METHODOLOGY

This preliminary study is broadly identified as deductive since its objectives and research questions are guided by a previously developed conceptual research model. However, qualitative evaluation of the subjective views of the interview participants offers a substantial freedom for suggesting any reforms and adjustments to the main concepts. The following sections describe the specific approaches adopted in sampling, data collection, and data analysis processes.

5.2.1 Sample selection

The selected sampling procedure in this study was purposive sampling as it selects a few information-rich cases which can make a substantial contribution to the qualitative data evaluation (Patton, 1990). Purposive sampling, also known as judgement sampling, can involve developing a framework of the variables of the study based on the researcher’s practical knowledge and available literature evidence in the area of research (Marshall, 1996). Maximum variation sampling strategy that enables the studying of a broad range of subjects (Marshall, 1996; Patton, 1990) was followed in order to capture a great deal of heterogeneity in the views on the conceptual model constructs studied. Accordingly, both ICT vendors and manufacturing firms were selected in the sample to include more varying viewpoints on ICT usage in CPD projects. Since ICT vendors are well aware of functionalities available in the tools they provide and the information processing requirements of manufacturers' CPD programmes, their responses in addition to manufacturers' responses were highly important to establish the confirmability of data. Moreover, all levels of technology (high, medium, and low) were represented in the manufacturers' sample. Similarly, vendors of all types of CPD-enabling ICT tools (communication/collaboration tools, design/development tools, information/knowledge management tools, project management tools, and market research/analysis tools) were included in the ICT vendor group. The admission criteria used to select the firms are:

- be a manufacturing firm collaborating with one or more partners in product development programmes that use ICT tools or
- an ICT vendor company that provides ICT tools to facilitate CPD activities in manufacturing firms and
- has a manager who is well-informed about the company's operations and prepared for responding in the interview.

Five manufacturing firms (M1, M2, M3, M4, and M5) and four ICT vendor companies (V1, V2, V3, and V3) were selected based on the above criteria and resource availability for the preliminary study. Introductions to the selected companies and their CPD operations are given below.

5.2.1.1 M1

M1 is a large, globally-integrated electronics company that manufactures load cells and force measurement solutions for various industries including medical, trade, and agriculture. Around four decades ago, the company was established as a weighing scale design company. In addition to its unique scale designs, M1 started developing load cells (strain gauge-based transducers for the determination of weight) that were a highly innovative product in those times. Load cells produced by the company are used in applications such as medical devices, weighing machinery, process weighing systems, testing and measurement devices, industrial and agricultural machinery, and process automation and control systems. In addition to the load cells, currently M1 has extended its product range to include: force sensors (strain gauge-based transducers for the measurement of force), electronics (amplifiers, A/D converters, and weight indicators) and hardware components that maximize the performance of load cells and force sensors. The company has a number of sales offices and manufacturing plants in Asia, USA, and Europe.

M1 has a strong strategic focus on improving the quality of its products, processes, and customer service while expanding its technology. During the last decade, the company experienced a huge growth in demand and, as a result, both production volumes and the workforce in the international manufacturing plants were expanded significantly. M1 is an innovation-oriented company and every year it invests 10% of its revenues in NPD programmes. The company continuously tries to integrate new technologies and researches possibilities to use new technologies to complement their activities. M1 has R&D teams located in the US, Europe, and Asia, serving customer bases in these regions. The R&D teams have expertise in mechanical design, electronic design, software development, industrial design and strain gauge design and development. In almost all of its product development projects, M1 collaborates with its suppliers and customers as well as cross-functional teams such as manufacturing and marketing. The company plans and selects in advance the external and internal partners to be involved in each project. The size and scope of the project and its compliance with existing processes and technology (the level of uncertainty) are the key factors considered when partners are selected, along with their anticipated degree of involvement in a certain CPD project.

Since most of the partners are located internationally, various ICT tools are intensively used in M1's collaborative product development projects. The engineers located all over the world use a common set of development tools so that product data can be conveniently transferred between sites. SolidWorks is the main product design software used in CPD projects at M1, and this facilitates concurrent product design and development activities of the distributed R&D teams and integrated project management. The company undertakes projects of varied complexities, and according to the manager interviewed, M1 successfully balances ICT tool usage, based on the extent of the information processing requirement in the projects. The company carries out detailed pre-project evaluations for resource requirements including ICT and follows strict procedures for selecting partners for each CPD project undertaken. However, M1 still experiences some problems in relation to people's commitment towards using the right ICT tool for CPD tasks at the right point of time and connecting globally distributed personnel at the time needed.

5.2.1.2 M2

M2 is a medium-scale machinery manufacturer that develops new products through collaborations with suppliers and customers located in different countries. The product range of the company includes welding transformers, battery chargers, step-down transformers, wood-working machines, gas fires, solar hot water systems and wood gas stoves. The main industries that M2 cater to are hardware and agriculture. M2 has a strong innovation orientation and the company recruits many qualified and experienced engineers in order to promote continuous product innovation and improvements to the existing technology. The main strategic goals of the company are offering consistent, customer-satisfied quality, and timely delivery. Consequently, M2 has obtained several quality standards and awards. The firm develops new products or improves existing products through internal cross-functional collaborations such as manufacturing-R&D and R&D-marketing, and external collaborations with suppliers and customers. However, the intensity of involvement of overseas-based external partners in the company's CPD projects is still not up to the level required by the products developed at M2.

Although the development of machinery products needs a great deal of tacit and explicit knowledge to be transferred from technically advanced outside partners, M2's R&D teams largely depend on a few ICT tools which are not too sophisticated. For example, M2 uses MS project for project management, AutoCAD for product design and development, MS Excel for analysing market research data, e-mail, Skype, and telephone for communication. In addition, the company relies on some non-ICT (paper-based) methods for product designing and market research methods. According to the respondent from M2, the company has great potential to improve its CPD projects' performance by improving ICT usage in future since the firm's R&D staff are young, highly committed, and highly motivated to improve their ability to use modern ICT tools. Therefore, management's commitment towards promoting the use of new ICTs needs to be increased for M2 to achieve higher performance standards.

5.2.1.3 M3

M3 is a large manufacturing company that offers fabricated and galvanized steel products, electrical accessories, railway items, and water treatment and supply items to local and international markets in Europe, Asia, and Africa. Apart from manufacturing, M3 is engaged in providing a range of services such as steel fabrication, galvanizing, civil engineering construction (highways and commercial buildings), electrical engineering construction, telecommunication engineering construction, and import and supply services. Therefore, the company is catering to diverse engineering requirements in the mechanical, civil engineering, power, and telecommunication industries. M3 was established in 1980 and over the years the company has increased its production lines from the traditional steel bolt and nut to the present highly-sophisticated items produced to the latest ISO standards. The company has a qualified engineering staff dedicated to research on highly innovative new products and improvements to the existing products. The management of M3 pays considerable attention to acquiring the latest technological advances for their products, thereby increasing the quality valued by their customers. M3 maintains strong long-term collaborative relationships with its broad customer-base including state-sector partners. Collaborations in NPD projects and joint ventures with several internationally-based partners help the firm in transferring new technologies.

The company uses several ICT tools in its CPD projects. M3 has mostly relied on simple tools mainly in the communication, project management, and market research activities of its CPD projects. E-mail and Skype are extensively used in addition to meeting face-to-face wherever possible. A customized MS Excel template is used for managing projects. In comparison with other tools, usage of product design and development ICT tools is higher at M3. The CPD process is entirely carried out with tools such as AutoCAD, Tora Optimization, and MATLAB in which most of the R&D staff possess a high level of proficiency. The company often undertakes projects with different complexities caused by technological and market uncertainties. However, the participant from M3 found some gaps between the firm's ICT usage and information processing requirements in the CPD projects. Although the company has a larger collaborative network, the available ICT tools are not sufficient to share required information between partners even in the projects that overseas partners are intensively involved in. It is believed that increasing ICT tool usage would be significantly helpful in improving collaboration and the final project performance of M3's CPD undertakings.

5.2.1.4 M4

M4 is a large furniture manufacturer that produces cabinets and other furniture for domestic and commercial purposes. The company was started out as a sole proprietorship to fill a gap in the market for high-quality personalised cabinetry. Within a few years, M4 captured a larger market by catering to the demand for domestic and commercial furniture. Currently, the company is capable of providing customized designs in varied volumes and to strict deadlines. A range of commercial furniture for showrooms, stores, offices, counters, conference rooms and shops is designed and manufactured in close collaborations with the company's customers. The domestic product range includes furniture for bathrooms, kitchens, bedrooms, living rooms, and offices, and play tables for children. Most of the customers for domestic products are also business-level customers, such as builders and designers.

Flexibility in terms of variety and volume, speed of delivery, and offering attractive designs (design quality) are the central strategic concerns of M4. The company has selected a few key customers and suppliers who provide the main raw materials for their products, to be involved in its NPD projects. R&D department has been provided with the highest quality ICTs available for furniture designing and manufacturing. In addition to traditional AutoCAD, specially designed tools for furniture designing and programming woodworking machines, such as Aspan CAD-CAM and Pro100, and interior designing software such as PaletteCAD are used. In developing special cabinets and wardrobes with more design complexities, M4 uses highly advanced information management and planning software for furniture product development named Dynalog and Dynaplan. The firm uses an online project management system named Smartsheet for managing the CPD projects. M4 guarantees continuous involvement of external partners and internal cross-functional teams at required stages of its product development projects through the intensive use of modern ICT tools. However, for communication and collaboration requirements in the CPD projects, M4 mostly depends on simple tools such as telephone, e-mail, and Skype. According to the M4 manager interviewed, the firm uses all required ICT tools adequately to match the requirements of the CPD projects. The company initially experienced some difficulties in adoption of

ICT tools due to the insufficient IT background and the reluctance of people to change. However, at present the company has successfully overcome many of these barriers by providing the staff with the tools and the training required.

5.2.1.5 M5

M5 is a large joint venture apparel manufacturing company which has been built upon partnerships with renowned brands in the USA, UK, France, Hong Kong, and India. The company started business in 1987 producing intimate apparel, performance wear, swimwear, and accessories. M5 has the same principles in business ethics as its joint venture partners, and sees this as its key competitive advantage. The company has a dedicated research and innovation unit focusing on introducing new products that will satisfy unmet customer needs in terms of design, fashion, and functionality. The organization provides a work culture that promotes creativity by acquiring capabilities from diverse disciplines. M5 practices lean manufacturing and open, collaborative innovation in order to achieve its key strategic objectives: speed of delivery and quality. M5 maintains collaborative partnerships with its suppliers and customers both within and outside the group. The company also collaborates with universities and research institutions in their CPD programmes, aiming to acquire useful new knowledge through these collaborations. In addition, M5 provides internships to university students from clothing and textile engineering discipline, who explore employment opportunities within their group of companies.

As revealed in the interviews, M5 believes that increased investment in ICT tools is vital for the success of its CPD programmes. Therefore, the company invests in modern ICT tools for apparel product design and development (e.g. Modaris) and in improving the proficiency of staff at using these tools. Newly-recruited R&D staff are trained by allowing them to be involved in the company's latest CPD projects (on-the-job training). However, the company experiences some difficulties in allocating staff for training programmes due to its inflexible work schedules. Since the success of a new apparel product is largely dependent upon its ability to meet exact customer requirements, the role of ICT tools is significant in all stages of CPD programmes in M5. For communication and collaboration, both simple tools (e-mails) as well as rich media ICT tools (video conferencing) are frequently used in early product development stages in order to finalize the correct design specifications. In addition, M5 uses ICT tools such as Dropbox, AutoCAD, MS Project, and online customer satisfaction surveys in their collaborative product development projects. The respondent from M5 agreed that, mostly, the company is successful in balancing its ICT usage based on the information processing requirements of the projects. However, receiving accurate product information before competitors has been challenging to the company, regardless of the intensive use of ICT tools. Therefore, when selecting product development partners, M5 mainly focuses on their strength in terms of ability to provide correct product specification details within a shorter time frame.

5.2.1.6 V1

V1 is a large ICT vendor established in 1984 and has partnered with several world class ICT vendors ensuring high quality in their products and services. The product range of V1 includes CAE, PDM, PLM, document management systems, construction project and contract management systems, and spatial information management solutions. A large number of manufacturing companies use V1's ICT solutions for CAE, PDM, PLM, and document management systems in their CPD programmes. The company offers a full range of finite element analysis services with its engineering design and analysis software (CAE solutions) for increasing manufacturers' ability to reduce time-to-market while improving the quality of the new products. In addition to the implementation service, V1 offers a range of additional services to manufacturers, with its PLM and engineering document management software. These services include: needs analysis, business process re-engineering, integration with ERP or other IT and existing business systems, and training by offering custom or standard courses.

V1 has a strong emphasis on what manufacturers actually expect through advanced ICT tools purchased for their CPD operations. The company always attempts to include new and advanced technological features with ICT solutions so that manufacturers can reduce development cycle times and increase the quality of new products. V1 believes that their advanced ICT tools for information management provide collaboration-based benefits to manufacturers and their partners. According to the V1 manager, the main problem in ICT usage in manufacturing CPD projects is changing ICT tools frequently without a proper analysis of the changing needs of the projects. The company believes that the extra services provided by them such as needs analysis and training assist manufacturers in reducing risks and realising expected profits in CPD.

5.2.1.7 V2

V2 is medium-scale ICT vendor company formed in 2001, to provide custom software to both manufacturing and service sector firms for facilitating collaboration, market research and analysis, and project and document management. In addition, the company provides a range of ICT services such as application integration (according to custom requirements of storing, searching, and retrieving data), Website design and development, Web hosting, and e-mail campaigns (creating and sending eye-catching HTML e-mails to a company's existing or potential clients). The key strategic focus of V2 in their software manufacturing is to maintain a high quality through establishing better integrity, reliability and offer affordable prices through simply meeting exact customer requirements.

V2 maintains a higher level of reliability and transparency in their market research and analysis tools by sourcing reliable industrial databases. It attempts to process some useful extra information that other vendors do not process via their tools in order to enhance the customers' experience. According to the respondent, V2 has a well-experienced, self-motivated, qualified staff to develop collaboration, project and document management software tools that cater for the specific requirements of CPD programmes in manufacturing firms. The company management encourages the staff's autonomy in understanding specific needs of customers and design features and functionalities to simply cater for the identified requirements. The key strategic goal of V2 is to minimize ambiguities to its customers and make their products more user-friendly. This has enabled the company to achieve higher levels of word-of-mouth reputation and profits while offering fairly low prices. The company believes that including many unnecessary features just decreases the affordability and usability of the ICT tools in many collaborative product development projects. Based on this focus, V2 enjoys a very high demand from manufacturing companies that do not handle projects with largely varied complexities.

5.2.1.8 V3

V3 is a large globally-integrated ICT manufacturing and consulting company established in 1911. The company operates in more than 170 countries and offers a vast variety of ICT tools, infrastructure, and services to a large customer base worldwide. V3 has more than 400,000 employees worldwide and maintains collaborative relationships with universities in their research. These collaborations are important for V3 to capture theoretical and technical advancements in the ICT field that can be used for improving its products and services. The company's product range that facilitates manufacturers' CPD activities includes tools for – collaboration and task management, modeling and simulation, product portfolio management, quality management and testing, requirement management, workflow-change and configuration management, product lifecycle management, marketing and merchandising, and information integration and governance. In addition, V3 provides an expertise service for organizations to successfully implement ICT solutions, maximize the value of investments, and address critical business needs. The company's collaboration services and PLM services are the most useful types of services for CPD-practising manufacturing firms.

V3 encourages manufacturing organizations to plan their ICT requirements before implementation. As a large ICT vendor that offers various tools for organizations, V3 faces a huge challenge of introducing customer-required features and functionalities in their products, and offering low prices. Instead, the company supports manufacturers to research and analyse their ICT needs based on availability of staff and other resources and the nature of the innovation projects undertaken. V3 emphasizes the importance of continuous innovation and the need for using ICT tools with advanced features, for maximising the profits of CPD projects. In order to support this, the company provides the required training to R&D personnel in manufacturing firms that implement its advanced information/project management, product evaluation, and collaboration software.

5.2.1.9 V4

V4 is a large-scale ICT vendor that offers a range of communication and collaboration solutions for business customers and general communication services for domestic customers. The company's services include Web hosting, e-mail services, Virtual Private Networks for secure communications, general phone line systems, PBX systems, and broadband. V4 considers innovation as the essential key to differentiate its products and services from those of its competitors. Therefore, the company continuously carries out research and customer feedback surveys to understand new requirements and shortfalls in existing products. V4 provides a comprehensive support service to its customers on installations and analysing time and cost requirements and the benefits of using ICT tools. In addition, the company provides useful information on likely failures and corrective actions and expected resolution times.

The respondent from V4 identified cost as the main factor affecting ICT usage in business organizations. He noted that, regardless of the number of advanced features available in the new ICT tools, many companies simply depend on basic communication and collaboration tools and only large firms obtain the full utilization of advanced ICT tools. Therefore, V4 follows a strategy of increasing the customer value of their ICT tools by introducing low-cost new features. The company considers ICT resource capability of a manufacturing firm as a key to the success of CPD projects. It emphasizes that making manufacturers aware of the real benefits of using a particular ICT tool is the most effective way to introduce that tool to the firm, even for expensive products.

5.2.2 Collection of data

'Interviews' was the selected method of data collection as there was an additional intention to examine industry differences in the perspectives regarding the practical relevance of the main study. R&D managers directly involved in CPD projects in the five manufacturing firms and knowledgeable managers in the four ICT vendor firms were interviewed. Table 5.1 provides the details of the sample studied. By the time of the interview, each participant had more than three years of experience in the selected firm.

Table 5.1: Details of the sample

Company	*Industry (Technological level)*	*Position, background, and role of the respondent in the firm*	*Years of experience in the firm*
M1	Manufacturer - Electronic (High-tech)	R&D Manager (electronic engineering) – product designing, development, and project management	11 ½
M2	Manufacturer – Machinery (Medium-tech)	Factory Manager (mechanical engineering) – product designing, development, and sales	05
M3	Manufacturer – Fabricated metal products (Medium-tech)	Engineer (production engineering) – product designing, development and project management	04
M4	Manufacturer – Furniture (Low-tech)	Operations Manager (manufacturing system engineering) – product designing, development, and project management	04
M5	Manufacturer – Apparel (Low-tech)	Production Manager (engineering and technology management) – product development, project management, and merchandising	10 ½
V1	ICT vendor – engineering design and information management tools)	Owner/Managing Director (engineering and business management) – strategic planning and product development	23
V2	ICT vendor – Web-based/customized, collaboration, market research and analysis tools	R&D Manager (software engineering) – product designing, development, and project management	04
V3	ICT vendor – computer hardware and software for CPD and many other organizational tasks	Manager (information technology) – business analysis, development, and sales for collaboration software	03 ½
V4	ICT vendor – communication/ collaboration ICT infrastructure and Web hosting service provider	Senior software engineer (computer engineering) - Web objects development and project management	03 ½

Using semi-structured interviews, participants' views on managing ICT usage in manufacturing CPD programmes were gathered while examining the appropriateness and relevance of the variables identified in the initial research model for evaluating the ICT impact on CPD performance. Therefore, the questions were posed to explore the selection and use of ICT in manufacturers' CPD projects, the criteria for evaluating ICT usage, project characteristics that determine the information processing requirement of a CPD project, and CPD performance dimensions. Questions on benefits (positive outcomes) and issues associated with ICT usage in CPD projects were administered to validate the relationships conceptualized. Due to the semi-structured nature of the interviews, the questions were primarily directed by the pre-specified constructs in the initial conceptual model. However, the participants were given substantial freedom to express their ideas openly by the administration of open-ended questions. In addition to the main interview questions given in Appendix 5.3, the 'why' questions were probed as the interviews progressed and the answers came forth.

Due to ethical considerations, the confidentiality of the sources of information collected has been maintained. Initially, the participants were contacted through e-mails (Appendix 5.1) and provided all relevant information on the study (Appendix 5.2). Based on their response, a time and venue for the interviews was decided. The interviews were recorded using a digital recorder and the written consent of the participants was obtained at the time of the interview. Each interview (face-to-face or Skype) was of approximately 45 minutes' duration.

5.2.3 Validity and reliability

Responses from manufacturers and ICT vendors triangulated the results; this established construct validity by providing multiple measures for the same phenomenon (Yin, 2003). Using a sample of nine companies justified the external validity (Trochim, 2006b). Matching with relevant literature evidence was extensively supported by the qualitative content analysis performed in the study. This was useful to establish internal validity or the credibility of the study (U.S. General Accounting Office, 1990; Yin, 2003). Reliability was achieved by using a conceptual model developed based on in-depth reviews of current literature, as the guiding framework of the interview protocol (Yin, 2003). Findings of the study were reviewed thoroughly through the transcripts by the researcher to ensure their validity (Harding, 2013).

5.2.4 Data analysis

Directed qualitative content analysis (Hsieh & Shannon, 2005) is the central methodology applied in this interview data analysis. ICT usage dimensions (frequency, proficiency and intensity of use), three project characteristics (complexity, uncertainty, and urgency) and CPD performance dimensions (collaboration performance and new product performance) are the key themes used in coding. In this analysis, the views of the participants on the issues in using ICT tools in CPD programmes, helped in refining and building upon findings on the relationships between ICT usage and CPD performance dimensions.

Once the coding of all the text in each transcript was completed, the consistency of coding was rechecked in order to avoid possible errors in human coding,. Drawing conclusions from the coded data involved exploring the properties and dimensions of categories (i.e. ICT usage, CPD performance etc.) and identifying relationships between these categories so that patterns in the data are made clear (Bradley, 1993). According to Patton (1990), the methods and extent of reporting are finally based on the specific research goals. The central goal of this qualitative study is to validate a previously conceptualized research model and to explore the practical relevance of the main quantitative study that is to be based on the above model. Therefore, matrices displaying the patterns in the participants' views on the constructs in the model and typical quotations to further explore these patterns are used in reporting the findings, as these methods are recommended in qualitative content analysis (Zhang & Wildemuth, 2009). Since the directed qualitative content analysis can support or extend existing theory (Hsieh & Shannon, 2005), prior research evidence was also used in the discussion of findings. Figure 5.1 illustrates the complete roadmap of the qualitative study.

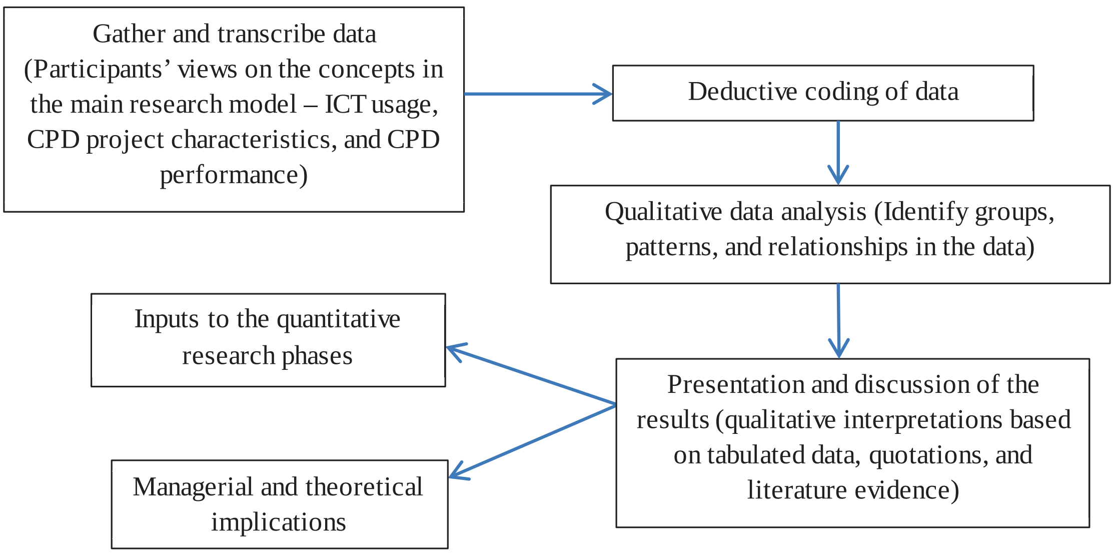

Figure 5.1: Research framework for the preliminary study

5.3 Results and Discussion

The following sections describe how the study reached its findings on each sub-research question developed to answer the first main research question of the study, through the analysis of interview data gathered.

5.3.1 Selection and use of ICT for CPD programmes

In the interviews, the participants were first asked to generally explain their selection and use of ICT tools for CPD activities such as communication, collaboration, product design, Information management and project management. According to the feedback received, the use of ICT tools for all types of CPD activities seems to vary across the levels of technology of the firms. Usage of ICT tools in the five manufacturing firms indicated some pattern in terms of the degree of sophistication of these tools. Use of tools such as e-mail, telephone, and face-to-face face meetings is relatively low in M1 whereas other four firms largely use these tools in their CPD programmes. For instance, the factory manager from M2, noted "*mainly we use telephone for communication and sometimes e-mails as well. In many cases we go for face-to-face communications*". Highlighting the increased convenience, transparency and traceability of simple communication tools, the operations manager at M4, mentioned "w*e use e-mails for communication, that's the main method we prefer. Then we all have full details of whatever we have written. So, it gives references as well. Also, we use telephone calls and Skype because it is easy for our partners and we try to meet face-to-face when needed*".

However, the usage of advanced communication and collaboration tools such as video conferencing and Web-meetings is higher in M1 which is a high-tech firm. The product development professional from M1 noted *"we communicate with our partners throughout the NPD projects and we mostly use Microsoft Lync which enables computer-to-computer communication. This is used more than Skype. In addition, Webinars [Web-meetings] are used. When our customers have difficulty in joining into Lync, we have another alternative called 'GoToMeeting'. It is a website for online meetings, and we book the meeting and we and our partners log on to the website [Web hosting] at the same time and participate. We can share the computer screen and do the meeting. There are significant improvements in our communications because of using these tools"*.

In addition, it was observed that the overall use of advanced communication and collaboration tools in the medium-tech manufacturing firm which has a relatively smaller number of internationally based partners (M2) is lower than that of the low-tech firm which has a larger global CPD network (M5). This is indicated in the previous quote from the M2 interview and the following quote from the interview with the product development manager at M5: "*mostly we use video conferencing. Suppose BS and VS [pseudo names for key customers of M5] are based in the US and Hong Kong, then we definitely have to have a video conference with a designer. But initially, we use e-mail. If the customer cannot understand it only from text e-mails, then we take some photographs and attach them. Sometimes we use Dropbox, and add a video clip to the Dropbox and ask them to watch and review it. Also we write the designs and our alternatives on CD's and send them or ask them to send us their feedback. If these are not enough, then we go for video conferences and discuss face-to-face showing everything on the screen*".

According to the patterns of using the tools and characteristics of the firms, knowledge and the technological intensity of the new products and the close involvement of a large number of distributed R&D teams can result in higher use of sophisticated ICT tools in CPD projects. Some industry-specific reasons were also found for the higher usage of communication tools in low-tech projects. Product developments are more frequent in low-tech industries such as apparel. In addition, making customer-suggested changes during the development process are relatively less costly, less complex, and more frequent in low-tech industries. Therefore, the use of common communication and collaboration ICT tools is more convenient and higher in these industries. Furthermore, low and medium-tech firms still depend considerably on non-ICT or low-tech ICT tools (e.g. CDs) in storing and sharing product-related information.

In contrast, manufacturing firms at all technology levels largely rely on ICT tools for their product designing and development activities. According to the respondents, ability to maintain accuracy, uniformity and ease of precise adherence to the required specifications are the main reasons for the higher use of these tools. The respondents from both low-tech firms (M4 and M5) noted that they use more ICT tools than their competitors. They also emphasized that higher usage of ICT was a key factor behind their considerable level of competitiveness in the market.

The use of advanced CPD-enabling information and project management tools such as PLM and CRM systems was found to be relatively low in all the manufacturing firms interviewed. However, usage of Web-based project and portfolio management systems and integrated project management systems that facilitate the management of CPD projects in a distributed setting was found to be relatively higher in the high-tech firm interviewed. Other firms seemed to be satisfied with simple or customized project management tools with the exception of M4 which uses a Web-based tool for project management. The respondent from M2 noted *"we do not use really good tools for project management but we use Microsoft Excel. Actually, we have developed a customized tool as our own template"*. The M5 respondent noted *"we only use MS Project for project management activities in our new product development projects"*. The participant from M4, the furniture manufacturing firm which performs extremely well in the market, specified that they use a smart sheet online system for project management.

Nearly all manufacturers highlighted the significance of face-to-face meetings as a means of communication in CPD programmes and compared it with other ICT-enabled communication methods. The respondent from M5, the apparel manufacturing company, explained how the current and future CPD projects benefit from face-to-face meetings with customers: *"There are some situations, where we travel to our partner's place to meet them face-to-face and obtain their approval to collaborate in our NPD projects. Also, at events such as roadshows and exhibitions, we get ideas from potential and existing customers for our new products which are developed later in more customized formats"*.

The high-tech manufacturer (M1) interviewed, who has many internationally located partners and uses other ICT tools intensively, similarly highlighted the usefulness of face-to-face meetings while explaining their difficulty with these: *"None of the ICT has ever been able to provide the same quality of face-to-face communication or what we achieve through face-to-face communication. When we start developing a new product, sometimes one of our sales persons goes to find out our customers' needs for this kind of a product and how much is the market potential. Whatever they find at the first point when they go and meet the customer is rather valuable. However, always we need to balance the use of ICT tools and face-to-face meetings, considering if it can be* *managed with the available resources and time because most of our suppliers and customers are overseas"*.

The above observations imply that although face-to-face meetings can provide various benefits to manufacturers at different product development stages (e.g. ideation and product launch), these are extremely difficult for R&D teams that have a number of distributed partners. ICT tools such as video conferencing and Web meetings that facilitate face-to-face communication and collaboration could have a similar or close impact on outcomes of such CPD projects. Table 5.2 summarizes the key results obtained in the above analysis.

Table 5.2: Key findings on selection and use of ICT tools in manufacturing firms

1.	Selection of ICT tools and extent of their sophistication are varied depending on the following factors: - Size and distribution of CPD network - Intensity of involvement of the CPD partners - Knowledge intensity of information to be communicated - Frequency of new product introductions
2.	Increased convenience, transparency, and traceability provided by communication ICT tools are highly valued by manufacturers when selecting and using these tools for CPD.
3.	Technology level of firm is a key factor differentiating the ICT usage in CPD projects (ICT usage seems to increase significantly as the technology level of a firm increases).
4.	The extent to which ICT tools are able to provide benefits that face-to-face communication does, is a major criterion considered by manufacturers when selecting and using ICT for their CPD programmes.

These results provide useful information about the selection and use of ICT in manufacturing CPD projects. Views and experiences of the participants, analysed in this section, provide detailed explanations to various ICT requirements in CPD programmes.

5.3.2 Dimensions of ICT usage

Based on the practitioners' viewpoints, this section assesses the dimensions of ICT usage in the conceptual model of the main study. These dimensions are frequency, proficiency, and intensity of ICT use. Inputs provided by this evaluation are particularly valuable for the operationalization of the new concepts – proficiency and intensity of ICT. The feedback from the ICT vendors weighted more important in relation to intensity of ICT use as they are supposed to be more knowledgeable about the features and functionalities available in the tools. Both responses were equally important for proficiency of ICT use construct as all the respondents are aware of the level of proficiency required for utilizing ICT tools to perform CPD tasks.

5.3.2.1 Frequency of ICT use

Participants' views on their frequency of ICT use were, for the most part, consistent. They particularly emphasized the significance of the frequency of using communication ICT tools in CPD projects. As highlighted by a majority of the manufacturers, frequent communication with external partners in the early development stages is really important for introducing successful new designs. The engineering manager at M1 stated *"when we develop a new product for a particular customer, it is important to communicate with the customer and the component parts suppliers, from time to time. Without frequently contacting them throughout the designing process, it is difficult to have a feasible product design"*. Further, the M3 factory manager noted *"actually, in our product development projects it is highly important to communicate very frequently with our customers and suppliers. This is especially important when setting up the standards with a new client, for a customized hardware item"*. The operations manager at M4 explained *"frequent communication is very important when finalizing specifications for new products. After this, we don't need that much frequent communication, but initially it's really important"*.

Similarly, agreeing upon the importance of frequent communication in the initial development stages for setting up design standards, the product development manager from M5 highlighted a somewhat different viewpoint on the relationship between frequency of communicating via ICT tools and project completion time: *"introducing new products before competitors is highly important in the apparel industry. However, we can reduce development cycle times only if we receive all relevant information in a timely manner. But this rarely happens in our industry because sometimes even our customers are not able to provide right specifications for the products because they have limited information on end-user requirements. So, mostly the trial and error method is applied. That means, we send our design specifications and customers send their options. Then the design is revised and sent back for another review and a very high frequency of communication and exchange of information occurs. Then the development process takes a fairly long time. Actually, using our product development* *software tools, we can develop the product quickly, if we receive all the correct specification details in a shorter time frame".*

According to the above view, more frequent communication with customers leads to bringing the right customer needs to the new product, ensuring greater acceptability in the market, although it does not assure reaching the market at the expected time. This can be critical when project completion time predominantly determines the project success. Therefore, the success of these products in the marketplace seems to be largely dependent on the quality of information received promptly and frequently via market research and analysis ICT tools. However, promptly received incorrect market information or design specifications deviating from actual customer needs would not guarantee high market acceptance although they could help in reaching the market speedily. Therefore, simultaneously achieving both objectives – high market performance and shorter time-to-market – is somewhat difficult and could be supported by frequent ICT use combined with the proper selection and planning of collaborative partnerships.

In high-tech industries where product quality and technical performance primarily determines project success, the frequency of ICT use plays a significant role. The respondent from M1 explained how the frequent use of communication tools as well as information and knowledge management tools help in their CPD projects. "*Receiving frequent and updated product data from customers significantly helps us to align new products with customer requirements. Storing these product data and important technical knowledge received from suppliers is really useful in developing new products in future".*

Furthermore, several respondents highlighted frequency of communication as a significant factor when dealing with novel projects. According to the manager from V4, an ICT vendor company, highly frequent communication is necessary when the market is new to the manufacturing firm. An increasing frequency of information transfer would help product development managers to keep internal and external partners in touch with the project. This would result in higher quality and market acceptability of the product as well as less wastage of resources due to identification of required changes in the early development stages. Making frequent changes as requested by the customers, or a high frequency of using communication/collaboration ICT tools, is likely to increase the frequency of using other types of ICT tools (e.g. design/development) as well. A recent research has observed that frequent use of ICT tools (from all categories) helps in improving NPD task proficiency which, in turn, increases NPD project performance (Kawakami et al., 2015). In this study the NPD task proficiency is referred to as the proficiency of performing product development related tasks in the discovery, development, and commercialization stages. Based on these literature evidence and the results of the preliminary study, frequency of use is identified as a highly relevant measure of ICT usage.

5.3.2.2 Proficiency of ICT use

Some variations were observed in the proficiency of the product development staff in the firms interviewed. Although, no clear pattern was identified across technological levels or industries, background information gathered in the interviews indicated that the overall IT orientation of a firm may affect the proficiency of ICT use in R&D teams. For example, M4, the furniture manufacturing firm, uses ICT tools extensively in all their product development activities. The respondent noted that the firm's attempts to improve the ICT proficiency of staff have been highly successful although some employees demonstrated reluctance at the initial stages. The engineering manager from M1, the electronics manufacturing firm which also has an increased ICT orientation, mentioned that their staff have satisfactory levels of proficiency at the time they are recruited and, therefore, it is not difficult to train them on new tools.

Barczak et al. (2007) identified IT embeddedness, which refers to the degree to which IT plays a significant role in the CPD process, as an antecedent of ICT usage. Regardless of the ICT embeddedness of firms, all the participants from manufacturing firms stressed that proficiency is only relevant for the usage of advanced ICT such as product design/development tools. The M1 manager noted "*usually, in Web handling or conferencing, any specific proficiency would not be required because nowadays it is very rare to give training on the handling of basic tools. For example, in a Web conference, participants know how the volume should be increased or how the screen should be shared, or how to send a personal message to one of the members in that particular conference team and so on. But, in tools like Solid Works or some design or development software, users must have a high level of proficiency*". The manager from M2 suggested "*the importance of proficiency is moderate, because not all ICT tools* *need equally high proficiency in users. I think the design software needs some additional proficiency compared to other types of tools"*. The M4 operations manager also noted *"normally our cabinets are designed using Pro100 drawing, and then converted into Aspan. For this, there should be a proficiency to create Aspan macros according to the requirements. So that's how it goes to the CNC [computerized numerical control] system. This means proficiency is more important in design and product development tools than in other types of tools"*.

These results also reveal that in contemporary globally connected business contexts, sometimes proficiency in using advanced communication and collaboration ICT tools has become a basic requirement for being recruited by a firm. However, some participants stressed the significance of proficiency in some other ICT such as market research and analysis tools. For example, the respondent from V4 highlighted the necessity of some level of proficiency in using online market research tools. Since various alternatives for these tools are available, users need to be well-experienced and knowledgeable to select the best reliable tool. Furthermore, the users are required to be sufficiently capable in handling technical issues such as multi-user problems arising when using ICT tools (Web-based applications) synchronously by several partners. In the interview with the product development specialist from M1, emphasis was placed on the importance of having a high proficiency in handling data analysis software (e.g. Minitab) as well.

Some manufacturer respondents viewed the age of staff (or generation) (M4) and resistance to change (M2) of staff as a barriers to improving their ICT proficiency. However, ICT vendor firms (particularly V1 and V2, the large companies) did not consider proficiency as an important aspect of ICT usage. The point highlighted by these participants was that manufacturing firms can make use of training programmes provided by the ICT vendors on advanced tools. The owner of a leading CPD-enabling ICT vendor (V1) highlighted that the commitment of manufacturing firms to obtain training offered by the ICT vendors is not satisfactory. Therefore, he suggested that 'training effectiveness' and 'perceived ease of adoption' could be suitable measures of the ICT proficiency of staff.

Participants from manufacturing firms also provided some essential information on issues associated with improving the ICT proficiency of product development staff. The product development manager at M5 explained the importance of on-the-job training for increasing the ICT proficiency of R&D staff and the industry-specific barriers to that. *"It takes some time to make them skilled on a particular tool. Since our product development cycle times are relatively low [1-7 days] and the projects go on continuously, it's a bit rare to have all staff during the whole development process. So it is harder for the unskilled staff to get enough proficiency within one or two development projects. Low-skilled people may be involved in some parts of the process and performance of the project may be affected by that. Correct understanding of the specifications sent by the customers is also really important and low-proficient R&D staff is not able to use the available ICT tools effectively to get these details"*. The respondent manager from M4 noted *"we have very old people, some have never used a computer but, actually, I am happy to say that now everybody uses computers and everyone has their own PC at work, a laptop or sometimes a desktop. The company gave good training to them, so that they can involve in product development projects more efficiently than before"*.

Nearly all the participants agreed that the usage of some tools (e.g. product design/development and knowledge/information management ICT) is varied based on the level of proficiency of the users who are the product development staff in manufacturing firms. Therefore, proficiency of use is identified as an important dimension of ICT usage, particularly in evaluating the usage of advanced ICT tools in CPD programmes. Additionally, 'ease of adoption' and 'training effectiveness' could essentially measure the degree of ICT proficiency of staff involved in CPD projects. Therefore, these can be used as indicators of the ICT proficiency construct in the main research model.

5.3.2.3 Intensity of ICT use

Available functionalities and features in ICT tools are utilized in CPD projects to varied degrees (Kern & Kersten, 2007). For example, one CPD team may use '3D design tools' in AutoCAD for generating design ideas as 3D drawings which will be sent for partners' feedback later, while another team use 'design feed feature' where design and conversation occur concurrently. Since this type of ICT usage difference has not been captured in previous studies, the conceptual research model developed in this study introduced a construct named 'intensity of ICT use' which refers to the extent to which the available functionalities in a certain ICT tool were used in a CPD project. As a new measure of ICT usage, views of the preliminary study participants on intensity of use are of higher importance for the development of the survey instrument. Although many participants identified intensity of use as an important dimension of ICT usage, the respondent from a large ICT vendor company (V1) highlighted the difficulty of measuring it. Alternatively, the manager from M3 suggested that: *"ICT tools need to be separately considered when evaluating intensity of use"*.

In comparison with the manufacturers, the ICT vendors in the sample had a stronger view on the importance of intensity of ICT use. As this study interviewed purposefully-selected representatives from ICT vendor firms who are well-informed about all the features and functionalities available in the ICT tools offered by these firms, their perception on the intensity of use construct is valuable. All the ICT vendors emphasized that manufacturing firms who are their customers, do not have sufficient knowledge or commitment to be able to use all of the functionalities available in the ICT tools in CPD programmes. The respondent from V3 emphasized that proficiency of staff as well as the requirements in projects are the important factors related to the intensity of ICT use. He stated *"some users get the benefit of almost all the features available in software packages and it may depend upon the proficiency level of the user as well as the requirement of the tasks in the product development project"*. However, a different perception was observed by the product development manager from M1 who noted *"people's commitment to learn and use new and important features in software tools is highly important"*.

As these views imply, not only the present level of proficiency but also the commitment of R&D people, towards improving their IT knowledge would be essential for intensive use of ICT. According to the manager from V3, different CPD teams may indicate varying levels of intensities of ICT usage based on the degree of project complexities. However, as M1 emphasized, some people are not willing to use additional features and functionalities in the ICT tools, although utilizing these features possibly will add more value to the product development process. Therefore, it will be worthwhile to understand the moderating effect of project complexity on the relationship between ICT usage and CPD performance where ICT usage is captured with intensity of use as a dimension. Therefore 'intensity of use' in the conceptual model is established as one of the dimensions of ICT usage.

The incompleteness of the proposed operational definition of the intensity of ICT use construct has been indicated in some responses. For example, the participant from M5, the apparel manufacturing firm, noted that they use simple ICT tools such as e-mails even for vital product development activities such as sending designs and videos, etc. (the quote is given in section 5.3.1). In contrast, some other firms (e.g. M1) do not fully utilize the storage capacity of e-mails and use them only for lean purposes such as text messaging or sending text files while using more advanced tools for sending drawings and videos. The M1 manager explained *"we use e-mails for communication and sometimes for sending simple documents. We have so many ways to share product information. One is Dropbox; it is also a hosting service that allows our customers to review the products very well. Or otherwise, we have internal servers that can be shared with our partners".*

According to these notions, the utilized capacity of an ICT tool could also provide some meaning to the intensity of ICT use concept. Based on this result, the proposed operational definition of the intensity of use construct is modified incorporating the concept of 'capacity' of an ICT tool. Accordingly, this study defines intensity of ICT use as the degree to which the available capacities, features, and functionalities of ICT tools have been utilised. Use of this measure would enable the capturing of an important piece of information on the central theme of ICT usage. Table 5.3 summarizes the key results obtained from the above analysis on the three ICT usage dimensions, related literature, and implications derived for the model, through a comparison of these.

Table 5.3: ICT usage dimensions based on industry perspectives and literature evidence

Key findings from the interviews	*Literature evidence*	*Implication for the modelled constructs and relationships*
Frequency of ICT use • Frequency of using communication ICT tools would be of relatively higher importance in a CPD project than the frequency of other ICT types [M1, M4, M5, V3]. • Frequent communication is very important in early development stages especially when the customer, technology, or the product is new (uncertain) to the firm [M1, M3, M4]. • Frequent ICT use in collaborative projects helps in resolving complex product and project-related issues and achieving customer required standards in the new products developed [M3, M5].	• Commonly used as a measure of ICT usage (Kawakami et al., 2015; Montoya et al., 2009). • Frequency is used for evaluating usage of all types of CPD-enabling ICT tools (communication/collaboration tools, product design/ development tools, information/knowledge management tools, project management tools, and market research/analysis tools) (Kawakami et al., 2015; Markham & Lee, 2013). • Frequent information exchange between collaborative partners in early product development stages contributes to the success of projects (Boutellier et al., 1998; Littler et al., 1995). • Frequency of ICT use improves the NPD process (Kawakami et al., 2015).	• The findings confirm prior research by identifying frequency as a relevant measure of ICT usage in CPD projects. • The study supports and extends existing literature and suggests a positive effect of ICT usage (including frequency as one dimension) on CPD performance. • Capturing frequency as an ICT usage dimension would be useful in establishing the moderating effect of project complexity and uncertainty suggested in the conceptual model. • The study defines 'frequency of ICT use' in the conceptual model as how often CPD facilitating ICTs (communication/ collaboration tools, product design/ development tools, information/knowledge management tools, project management tools, and market research and analysis tools) have been used in a CPD project.
Proficiency of ICT use • Proficiency is more relevant for advanced ICT tools (e.g. product design software) [M1, M2, M3, M4, M5].	• Durmusoglu and Barczak (2011) have suggested proficiency as a possible measure of ICT usage.	• The study extends the literature by identifying proficiency as a key dimension of ICT usage.

• On-the-job training is vital to achieve high proficiency in advanced product development ICT tools [M2, M5]. • Ease of adoption and training effectiveness of ICT tools could measure the level of proficiency [V1]. • Manufacturers' attention on increasing ICT proficiency of R&D staff is not sufficient and training programmes provided by ICT vendors need to be better utilized [V1, V2]. • Human factors such as the attitude towards improving expertise, and organizational factors such as availability of resources and work environment may affect achieving required proficiency in using ICT [M1, M2, M5, V2].	• Human ICT resources or proficiency of employees in gathering knowledge with the use of ICT, increases the innovation capability of a firm (Chen, Tsou, & Huang, 2009; Svetlik, Stavrou-Costea, & Lin, 2007).	• Training effectiveness and ease of adoption are appropriate indicators of proficiency of ICT use in CPD. • Using proficiency of use as a dimension of ICT usage will enable exploration of the role of ICT in terms of employees' and organizational ICT orientation in CPD. • The study defines 'proficiency of use' in the conceptual model as the degree of expertise of the R&D staff in using ICT tools for CPD.
Intensity of ICT use • Utilizing many features and functionalities available in ICT tools is an important factor for the success of CPD projects [M1, V1, V2, V3, V4]. • Utilized proportion of available capacity of ICT tools is varied based on project requirements [M5]. • Intensity is relevant for evaluating usage of all types of CPD facilitating ICT [M4, V3]. • Intensity of use (or utilized proportion of ICT) could be largely associated with the characteristics of the project [V2]. • Intensity and proficiency of ICT use are interrelated as more proficient users tend to use more features in the tools [V3].	• Different CPD projects utilize the functionalities and features in ICT tools differently (Kern & Kersten, 2007). • Heavy or lean use of ICT tools can have varied impact on performance of CPD teams (Montoya et al., 2009). • The concept 'intensity' has been used in addition to the 'frequency' for measuring amount of communication between CPD partners (e.g. Hoegl, 2005).	• The study extends current literature and identifies intensity as a relevant dimension of ICT usage. • It defines intensity of ICT use in the conceptual model as the extent to which the available capacities, features, and functionalities of ICT tools have been utilized within a CPD project.

5.3.3 Information processing requirement of CPD projects

This section reviews the opinions of the interview participants on the project characteristics that represent the information processing requirement of CPD projects. The results are compared with the appropriate literature and are discussed to explore how manufacturing firms manage their ICT use based on the requirements of the projects. The respondents were asked about the degree of importance of the three project characteristics – complexity, uncertainty, and urgency in terms of information processing requirement of CPD projects in their firms (manufacturers) or their customers' firms (ICT vendors). The views of manufacturing product development professionals were more valued in evaluating these constructs as they are the people who know the actual information processing requirements in CPD projects and the degree of support provided by the ICT tools. However, as experts about the capacity of the tools, ICT vendors are in a position to estimate the information requirements and ICT usage in manufacturing CPD projects. Thus, their feedback is important to further confirm the study findings. All the participants ranked project complexity first, indicating clearly that it is the project characteristic which predominantly determines the information processing requirement of a CPD project. In developing the initial conceptual model, project complexity was recognized as a combination of product complexity and collaborative network complexity. However, the results of the present qualitative study lead to a need to suggest some modifications to the initial definition of CPD project complexity derived based on the literature.

5.3.3.1 Complexity and uncertainty of a CPD project

Prior research suggests product size and interdependency of tasks as indicators of product complexity (Ahmad et al., 2013; Peng et al., 2014). However, the participants in this study emphasized that the number of partners involved is a key factor deciding the information processing requirement in a CPD project. The engineering manager at M1 stated "*suppose we run a project through collaboration with partners located all over the world, it will definitely increase our requirement to use ICT tools during that project. Sometimes we get projects in which we collaborate only with our immediate customer and internal departments, and if they don't involve in many activities, then the requirement is relatively low. This can happen in complex products as well as in simple products*". The manager from M3 noted "*when we have a lot of partners to interact* *with, then the project becomes complex. That means we need to process and transfer much more information"*. Both manufacturers believe the number of collaborative partners involved in a CPD project (or network complexity) is the key to determine the degree of complexity of the project. According to the view of the manager from M1, product complexity would not be as important as network complexity when the requirement to process information is concerned. However, the quote from V2 complies with the literature evidence that product complexity is one aspect of a CPD project's complexity (Peng et al., 2014) although network complexity is the main aspect. He stated *"mainly, the number of people who access certain information will matter. The complexity of the product will also be important"*. These views imply that as the number of participants and the degree of their involvement in a CPD project increases, the need for exchanging information between these partners increases substantially.

As noted in the literature, a CPD project can be uncertain due to lack of market, technological, or competitor information and this is typical when a product, process, or market is new to the firm (Ahmad et al., 2013; Heim et al., 2012). However, several respondents interpreted a lack of clear information available to carry out a product development project, simply as complexity rather than uncertainty of the project. Several studies have identified the concept of project novelty (newness of the product design, market, product technology, and process technology), which is almost similar to the project uncertainty explained above, as one dimension of project complexity (e.g. Kim & Wilemon, 2003; Peng et al., 2014). However, Peng et al. (2014) found that project complexity and uncertainty differently moderates the relationship between ICT tools and NPD collaboration. Relating the available literature to the findings of this qualitative data evaluation, it is clear that project uncertainty lies within the scope of project complexity. However, it is more likely that the two complexity dimensions have different moderating effects on the relationship between ICT usage and CPD performance dimensions.

When all the above evidence on concepts: product complexity and collaborative network complexity (the number of participants involved and the intensity of their involvement) is combined, a more meaningful operational definition for CPD project complexity construct can be derived. Consequently, the complexity of a CPD project is defined as 'the extent to which project information is unavailable due to complications in the product and the collaborative partnership network'. The two large ICT vendors [V1 and V3] view the use of ICT tools as a key means to reduce complexity in CPD projects because these tools help R&D teams to reduce the effect of the absence of information related to product technology, process technology, and the market. According to the highlighted quotes above, participant manufacturers agree upon changes in their ICT usage due to varied project complexities and uncertainties. Therefore, conceptualizing the moderating effects of project complexity and uncertainty in the main research model is valid. Examining these relationships could provide significant implications to product development professionals to become better informed about the impact of ICT usage with varied project characteristics.

5.3.3.2 Project urgency

Four manufacturers (M1, M3, M4, and M5) and three ICT vendors (V1, V2, and V3) noted project urgency as a secondary important indicator of the information processing requirement of a CPD project. According to the M1 manager's point of view, urgency matters only in using some ICT tools (e.g. communication tools) *"definitely we need to communicate more and more with our partners if the project is urgent. But it doesn't mean that usage of all the ICT tools increases accordingly. For example, usage of tools like Solid Works or Minitab would not be changed but e-mail, Lync or telephone calls would be heavily used"*. However, in addition to the use of communication tools, another manufacturer (M5) noted an increase in overall ICT usage in urgent CPD projects; *"a project becomes urgent due to several factors. One is the impact factor which is determined by profit, market share, and competitiveness, etc. Once we receive such an urgent project, we allocate more IT resources and staff to that and also communicate more frequently with our partners"*. The higher effectiveness of ICT usage in more urgent projects is highlighted in the response of V2 *"yes, it [urgency] is really important in terms of the information processing requirement. Since the business is all about money, companies use more ICT tools when their project is urgent. This will help them to reach market more speedily and before competitors"*. As most of the respondents stressed, more ICT resources are allocated for urgent projects due to top management's drive towards these projects which also increases the use of ICT tools in the projects. When people are more committed towards the outcomes of a project, it is possible to utilize the ICT tools more efficiently for achieving the project goals. For example, the V3 participant noted *"when there is push from the company management* *for a certain project, R&D people try their best to complete the project on time. ICT tools may speed up their tasks and provide more benefits".*

According to these results, it is likely to observe a positive moderating effect of project urgency on the relationship between ICT usage and CPD performance in a large sample survey. Overall, this preliminary study predominantly supports project complexity and uncertainty as potential moderators, the effects of which do really need empirical confirmation. Therefore, in order to reduce potential complexity in data collection and analysis, only these two project characteristics are selected for the final research model to be studied in the survey. Table 5.4 summarizes key findings drawn from the above analysis of the interview data, related literature, and the final implications derived for the research model in relation to the project characteristics.

Table 5.4: CPD project characteristics representing the information processing requirement

Key findings from the interviews	*Literature evidence*	*Implications for the modelled constructs and relationships*
Project complexity and uncertainty • Project complexity is usually characterized by the number of participants involved in the project, intensity of their involvement, and product complexity [M1, M2, M4, V2]. • Project uncertainty (or novelty) also indicates the degree of project complexity [M5, V3, V4]. • The amount of information required by a CPD project is primarily determined by the complexity of the project [M1, M5, M3, V2, V4]. • Receiving inadequate information in the early development stages makes projects complex for CPD teams and increased use of ICT helps in reducing the consequences. However, firms rarely balance their ICT usage with the information processing requirement determined by project complexity [M4, M5, V1, V3].	• Project complexity and uncertainty are project characteristics that have often been jointly addressed in product development literature (e.g. Ahmad et al., 2013; Swink, 1999). • Project complexity dimensions: product size, task interdependence, and project novelty have varied moderating effects on ICT-NPD collaboration relationship (Peng et al., 2014). • Project complexity (number of employees involved) and increased design outsourcing reduces a new product's manufacturability (an important factor for the project success) while product newness, and project acceleration improves this (Swink, 1999).	• Project complexity is the characteristic that predominantly represents the information processing requirement of a CPD project. • Collaborative network complexity (number of participants involved and intensity of their involvement) and product complexity are the major dimensions of a CPD project's complexity. • Project uncertainty can have common underpinnings with project complexity. • Based on the observed evidence and contradictory extant literature, exploring the conceptualized moderating effects of project complexity and uncertainty has been identified as important, to extend current understanding on the role of ICT in CPD.
Project urgency • Urgency is a secondary project characteristic compared to project complexity) that also represents the amount of information to be processed in a CPD project [M1, M3, M4, M5, V1, V2, V3]. • Managements and R&D teams tend to use more ICT in urgent projects. This leads to better outcomes in such projects. [V2, V3].	• Project urgency is assessed as the priority given to a CPD project and the time pressure felt during the project (Veldhuizen et al., 2006). • Project acceleration or planned duration for the project relative to a firm's norm (Swink, 1999) is a concept related to project urgency.	• Examining project urgency as a moderator to the ICT usage-CPD performance relationship is less important in comparison with project complexity and uncertainty. • A positive moderating effect of project urgency on the association between ICT usage and CPD performance can be expected.

5.3.4 Outcomes of using ICT tools in CPD projects

In the last stage of the interviews, the participants were questioned on their experience and opinions about positive outcomes or benefits of using ICT tools in CPD programmes and the barriers to the effective use of ICT in these programmes. The respective responses were analysed in order to assess the relevance of the performance constructs captured in the model and to support the building of more appropriate hypotheses (Chapter 7) for the direct, indirect, and moderated relationships of these constructs. The feedback from both manufactures and ICT vendors were considered to be equally important in this analysis as they all are likely to have various experiences regarding outcomes and barriers of ICT use in collaborative product development. This helps to uncover a holistic industry viewpoint on the impact of ICT usage CPD performance.

5.3.4.1 Positive outcomes of ICT usage

The majority of the participants emphasized the significance of ICT usage for achieving higher product quality in CPD projects. This could happen in several ways. First, ICT tools enable R&D teams to gather product ideas from a wider customer base. Second, these tools facilitate the simulation, evaluation, and analysis of the technical, market, and financial feasibility of several design alternatives with customer-desired features. However, as several manufacturers pointed out, knowledge gathered in one project may not to be fully utilized in the same project due to limitations such as – lack of commitment of people [M1]; urgency in introducing the new product to the market due to high competition or management's drive towards the project [M5]; and the unavailability of required resources at the time needed [M2]. According to the respondents, the related knowledge stored using suitable ICT tools (knowledge and information management systems) is extremely useful for increasing competitiveness even in future projects and for introducing high-quality products. In addition, the use of ICT tools supports the achieving of higher quality in the product development process and the technical performance of the final product. The participants noted that proper communication and information management facilitated by ICT tools [M1] and advancement of the design process enabled by product design software [M5] largely help in this.

Although lack of understanding the non-monetary benefits of ICT usage is a major issue identified by many ICT vendors, several manufacturers interviewed had a considerable level of awareness about the contribution of ICT usage towards increasing some aspects of collaboration (e.g. knowledge-sharing). Receiving the expected contribution from partners is a vital feature of NPD collaboration (Littler et al., 1995). According to the manager from M2 (the machinery manufacturing company), providing precise information in a timely manner has helped their firm in receiving the expected contribution from partners, together with the sharing of benefits, as agreed.

The participants from the manufacturing firms particularly valued the information security facilitated by controlled accessibility in some ICT tools. The product development managers at M1 and M4 explained how their main ICT tools facilitate the security of critical product information:

"We use product document management systems mostly, for our mechanical drawings, for modeling, and analysis of performance. The best package that we use is SolidWorks. It is our main enterprise PDM that we use for product document control. What we do with SolidWorks is, for example, if I developed a model and studied something important related to that model, then I can save them and share with other partners through this package. There are so many ways to share. One is Dropbox. Or otherwise we have internal servers that can be shared because Dropbox is kind of public. Although it has a password security it's in somebody else's server. If we have documents which include highly technical and critical information about our products, then we don't like to share them in this way. Then what we do is, we save it in our own server and give the access of that server to only those we need to involve". [M1]

"In our product development projects, we use Pro100 for designing. We've got two keys, one is for the designer and the other is for the showroom. Using the showroom key in that software we can just view designs and draw simple things but only the designer can change macros and the libraries and all those things using the designer key". [M4]

Furthermore, the respondents highlighted that ICT tools help manufacturers in several ways in sharing project risks, which has been considered in the conceptual model as one element of collaboration performance. For instance, the owner of V1, an ICT vendor, mentioned that the transfer of the right information on required changes during the product design and development stages will help manufacturers to reduce the potential risks at the commercialization stage. Respondents from M1, M3, and M4 noted that they get benefits such as identifying new market opportunities and low material prices (discounts) through close and long-term connections with suppliers. As manufacturers (M1 and M4) emphasized, remote access to project information ensures the continuous involvement of distributed R&D teams throughout the project and reduces the risk of project failures for individual teams. Indications of the positive influence of ICT tools in improving trust between partners were also observed. The manager from V1 noted *"a good document management system helps manufacturers in documentation, auditing, and configuration management which are essential for providing a quality service to customers and the secure transfer of important information to suppliers and distributed R&D teams. This is essential for improving trust between manufacturing firms and their partners"*. The manager from M4 explained how the trust created between partners improves final project performance, *"providing frequent updates of project progress to the stakeholders [customers] through our online systems is important to improve their trust in of our operations. This ensures an increased market share and turnover for the new product"*.

All of the above results imply the relevance of the conceptualized indirect effect of ICT usage on a project's commercial success via improving collaboration attributed by the sharing of knowledge, information, risks, benefits, and creating trust. Although manufacturers understand the importance of ICT usage for improving different aspects of collaboration, Table 5.5 indicates that their overall emphasis on collaboration benefits is lower (or nearly equal) compared to that of ICT vendors. Instead, manufacturers are more confident about increasing quality and decreasing product development times as a result of intensive use of ICT tools in their CPD projects. Even though several participants highlighted the importance of ICT usage in increasing the financial performance of CPD projects, compared to the other benefits, less emphasis was observed on financial outcomes. Most of the respondents identified ICT usage as an effective means of reducing or managing costs in CPD projects (M2, M3, M4, V1, and V3) which contributes to increasing profits. Apart from that, some others (M3 and M4) highlighted that increased ICT usage in CPD projects helps manufacturers to open up new markets, which also helps in attaining greater commercial success.

Increased responsiveness to customer requests has been highlighted by many interview participants as a key benefit of using ICT in CPD. Receiving more information from customers increases a firm's ability to produce new products with higher market acceptance which ensures increased sales. According to the manager from M5, many firms in their industry (apparel) use product development software for designing a new product easily with given specifications, but receiving customer information promptly is quite challenging regardless of the extent of the tools used. Therefore, in these industries where finalizing specifications to a new product within a short time is crucial for reaching the marketplace before competitors, some additional measures need to be taken for ensuring the effective use of ICT tools. According to the results of this preliminary study, all three aspects of ICT usage – frequency, proficiency, and intensity of ICT use could help in this. Instead of determining new product specifications based on information received from external collaborators, some companies use ICT tools such as Web portals to quickly search for the necessary information when they need to solve problems with regard to customer requirements. For example the manager from M1 noted *"we have some Web hosting programs for our market, sales, engineering, and production people to know the answers when they get a question. Basically, these Web-based tools are used once we've got problems regarding customer needs. These are kind of discussions going through Web portals where we can post our questions and have answers from a wide community of customers and industry experts within a fairly short time"*. These tools seem to provide fast and satisfactory solutions to critical problems in determining feasible design specifications for new products. However, since the number of firms using these types of tools is limited in this preliminary study, the effectiveness of their use needs to be further investigated in a larger study.

Table 5.5 summarises the positive outcomes of ICT usage identified in the interviews, related literature evidence, and derived implications for the model from both evidence. The performance outcomes have been classified as time, quality, financial, and collaboration-related, to be consistent with the CPD performance dimensions in the conceptual model of the main study.

Table 5.5: Positive outcomes expected from ICT use in collaborative product development

Key findings from the interviews	*Literature evidence*	*Implications for the modelled constructs and relationships*
Collaboration-related outcomes • Sharing of knowledge and skills between partners [M1, M2, M3, V1, V2, V3]. • Information security (controlled access to critical product data) [M1, M4, V4]. • Sharing project risks [M1, M4, V1, V4] and benefits [M1,M3,M4,V3]. • Improved partner trust and relationships through providing continuous project updates [M4, V1, V2, V4]. **Quality-related outcomes** • Increased potential to introduce products with customer-desired features through frequent sharing of quality information/knowledge [M1, M2, M3, M5, V2]. • High conformance to design specifications [M4, M5, V1, V3]. • Increased potential to higher quality in future projects using the knowledge stored [M1,M2,V3]. • Improved quality in the NPD process [M1, M4, V1]. • Increased technical performance [M3].	• Collaboration software (PLM) improves NPD collaboration which in turn improves new product performance (product design cycle time and product quality) (Banker et al., 2006). • Effective management of communication behaviour and adaptation of ICT contributes to creation of trust between CPD partners (Bstieler, 2006; Thomas & Bostrom, 2008). • Use of ICT provides collaboration benefits such as knowledge/information transfer and developing informal network (Boutellier et al., 1998; Corso & Paolucci, 2001). • Level of supplier integration improves the likelihood of collaboration outcomes including risks and reward sharing (Cousins & Lawson, 2007; Figueiredo et al., 2008). • IT-communication strength of a firm has a positive association with global NPD success (Kleinschmidt et al., 2010). • Use of knowledge management ICT improves NPD performance (financial and time) (Vaccaro et al., 2010).	• The study supports conceptualizing the collaboration performance concept in terms of the perceived degree of creation of trust, sharing of knowledge, information, risks, and benefits between CPD partners. • The findings support the propositions concerning the impact of ICT usage on new product performance dimensions (quality, time, and commercial success) and collaboration performance. • Investigating the proposed effects of ICT usage in terms of frequency, proficiency, and intensity on CPD performance is important, since existing literatures are mostly qualitative and inconclusive for the overall ICT usage.

Time-related outcomes • Increased responsiveness via fast engineering changes as customer required [M5, V1, V2, V3]. • Fast finalization of technical specifications of the new product [M4, M5]. • Better time management [M3]. • Efficient marketing of the new product [V1, V2, M3, M4]. • Short product development times [M2, M5]. • Greater speed to market [M5, V1]. **Financial outcomes** • Reducing wastages of resources (money, labour, and material) [M2, M4, V1]. • Better cost management [M3, V3]. • Creating and identifying new market opportunities through external collaborations [M3, M4]. • Increasing financial returns [M4, V2].	• Exchange of technical knowledge with suppliers improves NPD performance (Cousins et al., 2011). • Design/validation software tools have positive influence on product quality and time-to-market (Heim et al., 2012). • Product design tools and project management tools have significant positive effects on NPD collaboration while communication tools have no significant impact (Peng et al., 2014). • Frequency of ICT use has an indirect impact on NPD performance (financial) through NPD task proficiency and no direct impact (Kawakami et al., 2015).	

5.3.4.2 Barriers to the effective use of ICT in CPD programmes

Although many participants agreed upon the positive impact of ICT usage on the four performance aspects (quality, time, commercial success, and collaboration), the study has identified a number of barriers interrupting the achievement of these performance objectives. As several respondents highlighted, CPD teams face many difficulties in maintaining uniformity in their product development processes due to version update problems and frequent changes to the ICT tools used. The manager from M5, the apparel manufacturer, explained the seriousness of these problems in their industry *"when the version of a software tool is updated, sometimes we find situations where our version is not compatible with our partners'. On the other hand, if our competitors have the updated version and if it is quite costly for us to switch to that, then the problem becomes more serious. I wouldn't say it is a problem of technology, but all the files of the previous projects need to be changed to the later version. It takes a longer time and allocation of a huge amount of resources is required, so, quite difficult. Actually, the main problem is in the initial selection of the software, because we buy a suitable one which is available at the moment, but later we realize that it would have been better to have another tool instead of that. When we change our IT tools from time-to-time it is very difficult to maintain uniformity in the available systems and product information"*.

The participant from M4, the furniture manufacturing firm, noted *"if a customer draws something and sends it to me, I can't open the file if both of us are not using the same version of the designing software. For example, if my customer sends me a drawing in Pro100 Version 04, and I have some other version, then I am unable to open that file. So, we have to go for some other way to share this information and face many difficulties of completing projects within the time frame. This usually happens when we get new customers, but actually it's quite rare in our company because we mostly have regular customers who have been with us for many years"*.

According to these findings, technical barriers such as version compatibility problems, could significantly affect achieving quality and time objectives in CPD projects. Since the quality of information management is important for improving collaborative aspects such as risk sharing and trust creation, successful collaborations could also become challenging when external partners use different versions of an ICT tool that the manufacturer uses. One ICT vendor participant (V4) noted the synchronized accessing problem to online tools as an issue in using ICT in collaborative product development. Other technical barriers highlighted by the respondents include less-user friendliness and including many unnecessary features in ICT tools. These issues can be interrelated with human-related issues such as lack of proficiency and outcome-related issues such as high-costs. However, the technical barriers highlighted in this study can be more problematic for manufacturing firms that are largely dependent on ICT tools in simultaneous CPD operations.

A strong emphasis by all the respondents was perceived for the human issues associated with the use of ICT in collaborative product development projects. The engineering manager at M1 explained her experience on the lack of commitment of R&D staff: *"According to the usual setup in our company, every member can use all available ICT resources and there is no need to get help from IT people. Although we have provided superb tools and given all required training on them, projects sometimes fail due to the lack of commitment of teams. For example, depending on the project's requirement sometimes we have weekly regular meetings, but if nobody gets the minutes of that meeting or if the tasks are not executed as discussed, then the project fails regardless of the ICT use in that project. On the other hand, if the team is well-committed to discuss and finalize matters in a certain project, even though some failures exist in a usual tool like Lync, then they may pick up the phone and discuss at least the stuff needed for running the project on that particular day, while keeping the rest for tomorrow or until the problem is resolved. As another example, suppose I upload many important documents of a project to our document management system but other members in our team do not even bother to have a look"*.

According to this response, irrespective of the ICT infrastructure, proficiency, and other organizational practices, people's commitment towards using the right tools at the right time is vital for project success. Furthermore, the low commitment of people may adversely affect product quality, knowledge-sharing and time management (when switching between ICT tools is not done according to the situation). Another respondent from M4 described their success story: *"I think the main problem is that they don't like to change. Yes, it happened in our company, but we managed to get rid of that by providing the required resources, motivations, and training to the staff. In my opinion, this resistance normally comes with the lack of enough IT background"*.

As the respondent emphasized, management's commitment is a significant measure to resolve human-related issues in using ICT in CPD programmes. Firms need to invest in providing adequate resources and training. The M4 respondent and several other participants identified lack of IT background as a key problem of R&D staff in their organizations. The respondent from ICT vendor company V2 emphasized that software manufacturers need to pay more attention to increasing the user-friendliness of their products: *"around half of the users find it difficult to use a software tool while the other half might not find any difficulty. So what we do in our products is we try to minimize the user inputs in the advanced tools and use graphical interfaces as much as possible. In this way, the users don't want to know what is behind them, they only want to give inputs via what they are exposed to, which is very important. Also, with more graphical user interfaces, it's very easy for us to market our products. I believe that user-friendliness is more important than advanced features in a software tool"*. This view explains the role of ICT manufacturers in overcoming the problem of lack of IT proficiency of product development staff in manufacturing firms.

Some other ICT vendors highlighted the opportunities available to manufacturing firms to overcome the proficiency barriers of R&D staff and the low response of manufacturers to these opportunities. The manager from V3 stated *"not only V3, many IT vendors provide training on their products, but it is still doubtful whether user firms get the right benefits from such programmes. Sometimes, firms are not ready to allocate some staff to training and development because I think they are running for day-to-day profits and quantity targets"*. The manager from V1 noted *"normally ICT vendor companies provide required training and support on more advanced tools and I think through these programmes, users in R&D teams can get enough proficiency"*.

Considering the underlying reasons for the issues highlighted, they were categorized under context-specific and organizational barriers. In industries such as apparel, where product development cycle times are relatively shorter, failing to provide on-the-job training (section 5.3.2.2) on some advanced product design ICT tools is a context-specific barrier. Insufficient resources to arrange required training programmes for R&D staff without serious disturbances to regular operations has been classified as an organizational barrier. These context-specific and organizational issues disturb the improving of staff proficiency which is highly important for the effective use of many CPD-enabling ICT tools.

As noted by the V2 participant, the main reason for the higher costs of ICT tools is that modern tools include a lot of advanced features which are never used by most CPD teams. Since this company is a relatively small ICT vendor offering mainly customized collaborative software tools for firms, they could easily reduce unwanted features in their products. However, large ICT vendors that offer a wide variety of products to a huge customer base with various information processing requirements, have little opportunity to do this. As highlighted by the respective respondents, manufacturers' attention to analysing the requirements of ICT features in their CPD projects is not adequate. The manager from V3 emphasized: *"many firms don't do enough assessments before buying new software. In the case of product development, I think manufacturers are almost fully aware of the types of projects they handle and their own capability level. So, unless they have solid plans to expand their project scopes, I think it is not sensible for them to move to advanced tools. Correct forecasting is necessary, though many firms do not do it correctly. The changes in the systems, projects and resources, even people, need to be estimated in advance. Buying new tools only because their competitors use them, is not a good strategy. Usage level of a tool after buying and compatibility of the tool with the project needs should be analysed in detail"*. The manager from V1 noted *"sometimes manufacturers buy different ICT tools with various new features, too frequently. In my opinion, firms need to do a detailed analysis of their needs and the adequacy of existing tools to fulfil those needs, before going for another"*.

The view of these ICT vendors is consistent with that of the respondent from M5 (quoted above), who noted that the initial problem occurs at the selection of the ICT tool stage. Therefore, in order to minimize the consequences of many issues found in this study, manufacturers need to do a detailed analysis of their requirements and capabilities followed by a specific technology plan for ICT.

The outcome-related issues listed in Table 5.6 provide important justifications for the conduct of the main study. Participants from ICT vendors highlighted these issues based on their experience:

"Manufacturing firms may not be able to recover all their costs on the implementation of some IT tools, in one or two projects. They have to think of other benefits as well. For example, these tools may help firms making more accurate decisions via sharing and

analysing information more accurately and efficiently. And ultimately these will support firms in getting more financial benefits and quality improvements". [V1]

"I think the major barrier is the high cost. High performing software is usually high-priced and it depends on how affordable these prices are for firms. If the IT tools are sure to give the benefits that they [manufacturers] need, it'd be better to spend on these tools. However, the main problem is in understanding the actual benefits of using these tools. There are some hidden benefits or non-monetary things that are not assessed. Through IT tools, firms can share many resources and information with their partners and these may not be directly seen in their profits". [V3]

As implied in these views, manufacturers tend to believe that the costs of some advanced tools are not easily recovered. Also, it reflects that they do not value the non-financial or long-term outcomes of ICT usage. Sometimes, manufacturers do not rely on the performance of ICT tools, particularly in terms of providing non-financial or long-term benefits, or they do not fully utilize the available features in the tools purchased.

These insights and the following response of one manufacturer (M4) provide some practical justifications for exploring the mediating role of NPD collaboration in the relationship between IT usage and CPD performance. *"For an example, in developing our new corner drawer unit, we contacted the hardware supplier who has provided the main hardware for our products for many years, because we have to develop the corner drawer according to the hardware specifications. In the commercialization stage, this supplier becomes our customer as well, and continuously shares information with us on ICT tools. They provide sizes and material specifications to us as they have analysed the end customers' demand. This information is valuable for the successful commercialization of our new products".*

From the interview it was noted that company M4 selects a few key partners for their CPD projects and maintains long-term relationships with a high level of trust and proper sharing of risks and benefits with these partners. However, the respondents from high- and medium-tech manufacturing firms (M1, M2, and M3) emphasized that they have several collaboration issues such as low responsiveness and not having the expected contribution from partners. As the participants noted, these problems could be caused by failure to select the best external partners and difficulty in building long-term trustworthy relationships with these partners located dispersedly, with the available

ICTs. Prior research has highlighted the effectiveness of early supplier selection procedures in reducing risks and increasing trust between partners (Humphreys et al., 2007). Firms with higher ICT competency could have a better ability to do such analysis and hence have an increased opportunity to improve collaboration performance. The respondents of this study have also stressed that if CPD teams fail to share information or make the right information available at the right time, then the results are rather likely to be poor (quotes of M5 in section 5.3.2.1 and M1 in section 5.3.4.2). All the above barriers to the effective use of ICT in CPD projects have been classified as technical, human, and other, and summarized in Table 5.6. The barriers categorized under 'others' have been further divided into four groups, namely, context-specific, outcome-related, organizational, and collaboration, indicating their prominent root causes.

Table 5.6: Barriers to the effective use of ICT tools in CPD projects

Technical	*Human*
1. Version updating problems [M2, M3, M4, M5]. 2. Including many unnecessary features [V2, V3, V4]. 3. Less user-friendliness [V2]. 4. Disruptions due to technical or power failures [M5]. 5. Synchronized access problems [V4].	1. Inadequate background and little knowledge in using advanced tools [M2, M3, M4, M5, V2]. 2. Low commitment and less self-motivation to use the right tool at the right time [M1]. 3. Difficulties in connecting required personnel at the time of need [M1]. 4. Resistance to change [M2, M4].
Other	
1. Context-specific • Less effectiveness of ICT tools when customers are unable to provide correct specifications [M5]. • Difficulties of on-the-job training in advanced tools due to inability of having the same staff throughout the development process [M4, M5]. **2. Outcome-related** • Difficulty of recovering high costs of ICT tools [M2, M3, V3, V4]. • Not utilizing the capacity of existing ICT tools [M1, V1, V4]. • Less reliance on performance of advanced features and functionalities of tools [V1, V2]. • Not understanding or valuing non-financial, long-term outcomes of ICT use [V1, V2, V3].	**3. Organizational** • Less staff training due to insufficient staff or interruptions to regular operations [V1, V3]. • Less flexibility in working with tools due to high technology dependency (this restricts switching to simple tools where necessary) [M1, M2]. • Frequent changing of ICT tools [M5, V1]. • Not doing a proper analysis of tools before purchasing (which leads to availability of inappropriate tools) [V3]. **4. Collaboration-based** • Low responsiveness and contribution of the partners [M1, M3]. • Failure in sharing or making information available as required due to not using ICT tools appropriately [M1, M2].

Based on the findings obtained in the analysis of positive outcomes and related issues (Tables 5.5 and 5.6) collaboration performance is confirmed to be tested as a mediator to the relationship between ICT usage and new product performance. The results justify the practical significance of studying the direct impact and indirect impact of ICT usage through collaboration performance on conceptualized CPD performance dimensions – time, quality, and commercial success – in the main research model.

5.4 Conclusions and Implications for the Quantitative Study

Chapter 4 developed an initial conceptual model based on available literature, to empirically explore the impact of ICT usage on collaborative product development performance. This preliminary study qualitatively evaluates the model with practitioners' perspectives in answering the first research question through four sub-questions that examine how manufacturing firms manage ICT use to improve their CPD activities. Data were collected from a sample of nine firms comprising four ICT vendors and five manufacturing firms practising CPD with the use of ICT tools. In answering its first sub research question, this study explored the selecting and using of ICT tools for manufacturers' CPD programmes. The observed lower use of advanced ICT tools in firms can be caused by either a lesser requirement for such tools in CPD projects or a lack of understanding on the impact of using them. As the study suggests, manufacturers mainly consider their product development network and partner involvement in selecting ICT tools for CPD programmes. This implies the relevance of considering these factors under CPD project complexity and examining its moderating effect over the relationship between ICT usage and CPD performance. Answering the second sub research question, the study has provided reasonable justifications to evaluate ICT usage in terms of the three aspects – frequency, proficiency, and intensity of use. It suggests frequency as the most representative dimension of ICT usage while identifying intensity and proficiency of use as two other important dimensions that also determine the degree to which ICT tools are used in a CPD project.

For answering the third sub-research question concerning the moderating project characteristics proposed in the initial conceptual model, this study qualitatively evaluated the three characteristics – project complexity, uncertainty, and urgency that represent the information processing requirement of a CPD project. The results have suggested project complexity as the most important characteristic that represents a project's information processing requirement. According to the participants' perspective, the network complexity of a development team (the number of partners involved and the intensity of their involvement) and product complexity are key elements of CPD project complexity in consideration of the information processing need of the project. Since project uncertainty is a characteristic that can have common underpinnings with overall project complexity, it has also been confirmed for evaluation in the final survey. While project urgency is a project characteristic that also indicates the information processing requirement of a CPD project, its relative importance in being evaluated as a moderator is secondary in comparison to project complexity and uncertainty. Therefore, indicators of project complexity and uncertainty are decided upon to include in the final survey in order to reduce potential complexities in data collection and analysis.

The findings obtained from the investigation into the benefits of ICT usage in CPD, and the barriers, have satisfactorily answered the fourth sub-research question. Increasing quality and reduced time-to-market are the key expectations of manufacturers through the use of ICT tools for performing CPD activities. According to the respondent product development professionals, ICT tools are highly useful in making new products more customized and improving the quality of those products. The ICT vendors stressed that awareness of the impact of using ICT tools helps manufacturers in becoming successful in CPD projects through the effective use of these tools. Although the participants' emphasis on the indirect influence of ICT usage on project success through collaboration performance is inadequate, several participants valued the collaboration-related outcomes of ICT usage (information- and knowledge-sharing, risks and benefits sharing, and trust creation). Since a relatively higher competitiveness and market success was observed in manufacturing firms that showed higher levels of overall ICT usage, a positive association between ICT usage and CPD performance is expected in the subsequent quantitative research phases. However, context-specific issues such as not receiving precise information within a shorter time frame, and human issues such as less commitment in using the right ICT tools at the right time, could disrupt the achievement of the performance objectives of CPD projects.

In conclusion, all the direct, indirect, and moderated relationships conceptualized in the research model need robust empirical confirmation in order to better explore the impact of ICT usage on CPD performance. Figure 5.2 presents the finalised research model based on the findings of the preliminary study. The improvements suggested and the support provided by this qualitative study to the model constructs, are summarized in the next section. Connecting with the relevant literature, these findings are utilized in the operationalization of the survey instrument and the development of hypotheses in Chapter 7. The overall conclusion synthesized from the findings of this qualitative study in relation to the first research question of the main study is presented in Chapter 9.

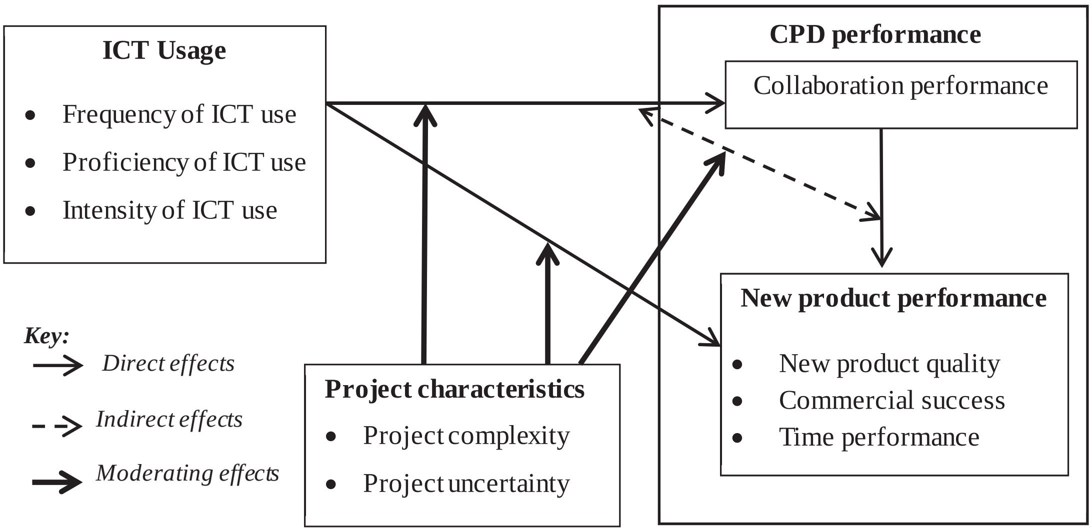

Figure 5.2: Finalized framework for evaluating the impact of ICT usage on CPD performance

5.4.1 Improvements in the finalized research model

The project characteristics (representing the information processing requirement of a CPD project) proposed to the initial conceptual model, have been modified in the final model. The project urgency construct was removed while keeping project complexity and uncertainty due to their relative high importance. Furthermore, CPD project complexity construct was modified including the number of participants involved and the intensity of their involvement as new indicators. Several constructs that have been utilized in prior studies and proposed to the initial model were satisfactorily supported by the qualitative study findings. These are: frequency of ICT use, new product quality, commercial success, and time performance. Two newly introduced ICT usage constructs were supported and improved by introducing important additional dimensions – training effectiveness and ease of adoption. The qualitative findings have helped defining the intensity of ICT usage construct as the extent to which the available capacities, features, and functionalities of ICT tools have been utilized within a CPD project. In addition, this qualitative evaluation has supported in deriving the operational definition for the collaboration performance construct as the degree of achieving collaboration-based CPD performance, while providing adequate justifications for the initially suggested dimensions of the construct (sharing of knowledge, information, risks, and benefits, and creation of trust between partners).

5.4.2 Limitations of the study

Since the scope of this study was defined by the pre-developed conceptual model based on available theory, the ability to explore a broader view on evaluating the impact of ICT usage on CPD performance was limited. However, as a preliminary study, the results provide a satisfactory justification for the model constructs and the relationships conceptualized, and are to be investigated in the final quantitative study phase. Since the sample size of this qualitative investigation is not sufficient for generalizing the findings to the entire manufacturing sector, the suggested relationships between ICT usage and performance aspects need a sound empirical justification in the final large sample survey-based study. Data gathered in the interviews for frequency of ICT usage construct were mostly focused on communication and collaboration ICT, and limited for the other ICT types due to participants' more emphasis and experience on the effects of frequent communication in CPD. However, as this dimension has been previously addressed in studies related to the usage of all ICT types, it is essential to consider it in the main quantitative study. Furthermore, this study has qualitatively evaluated a model that considers broad ICT types used in manufacturing CPD projects rather than individual tools within these ICT categories. Therefore, conduct of in-depth studies focusing on each ICT tool would be required to define more specific dimensions for evaluating the usage of each tool and to explore their impact on CPD performance.

6. Preliminary Quantitative Study

6.1 Introduction

The previous qualitative preliminary study explored the current context of managing ICT use in manufacturers' CPD projects and examined the main research model which comprised several new concepts, based on practitioners' perspectives. Operationalization of ICT usage as a multidimensional construct is a novel approach adopted in the main study to better explore the ICT impact on CPD performance comprising dimensions for both new product performance and collaboration performance. Therefore, this preliminary study was conducted to quantitatively assess the efficiency of previously used ICT usage measurements using secondary data obtained from the Product Development and Management Association's (PDMA's) 2012 comparative performance assessment study (CPAS). This evaluation offers additional justification to exploration of the conceptualized relationships in the main research model by examining some of those associations (direct and indirect effects) with a different source of data. Since the CPAS (2012) has collected data on several NPD-enabling ICT tools with a single measurement for each, this study examines the impact of individual tools rather than the overall ICT usage in terms of frequency, proficiency, and intensity of use, which is the primary concern of the subsequent quantitative research phase. Therefore, this study enables the answering of the second research question of the study (i.e. Does ICT usage have a significant impact on CPD performance?) in relation to the usage of several individual ICT tools in CPD.

Inconclusive findings for some ICT tools (e.g. shared product data management systems) are evident in earlier studies that investigated the impact of different ICT tools (Durmusoglu and Barczak, 2011) on NPD performance or collaboration (Peng et al., 2014). Moreover, the indirect impact of many CPD-enabling ICT tools on NPD performance, through collaboration, has not been examined in these studies. Research that addressed ICT tools such as PLM systems (Banker et al., 2006) and knowledge management software (Vaccaro et al., 2010) have mostly revealed positive effects on project performance dimensions such as profits, speed, and quality. However, the tools such as performance modeling/simulation systems and product portfolio management software have been paid limited attention in evaluating their impact on CPD performance. Furthermore, only case-based literature has been available for the impact of tools such as video conferencing and remote collaborative design systems on NPD performance, (e.g. Boutellier et al., 1998; Salo & Käkölä, 2005). Therefore, evaluating the direct and indirect impact of a variety of ICT tools, through collaboration on NPD performance, using data from a large global survey will have significant contributions to the literature.

This study obtained CPAS (2012) data on 13 ICT tools for examining their impact on CPD success in firms. These tools are: Online focus groups/online surveys (ICT1), Customer needs/requirement analysis software (ICT2), Online communities/net ethnography/virtual shopping/semiotics (ICT3)[1], Rapid prototyping systems (ICT4), Performance modeling and simulation systems (ICT5), Virtual reality/virtual design/cave technology (ICT6), Remote collaborative design systems (ICT7), Product data management systems (ICT8), Product portfolio management software (ICT9), Project management systems (ICT10), Video-conferencing (ICT11), Software systems to connect technology specialists within firms (ICT12), and Groupware (ICT13). The relational resource-based view (RRBV) which relies on achieving competitive advantage through resources, capabilities, and inter-organizational collaborations supports the investigation of the direct and indirect impact of ICT tools, through collaboration on overall NPD performance (Dyer & Singh, 1998; Lavie, 2006).

Understanding important demographics to be considered when conducting the final survey is another objective of this preliminary study. The preliminary qualitative study suggested that a firm’s technology base is a central factor differentiating ICT usage in CPD programmes. Generally, primary product type (good, service, or mix) also decides the tools being used in performing CPD activities. For example, collaborative design tools are less useful for the firms that offer a service as their primary product. The CPAS (2012) database contained data gathered from 453 firms from various industries and technology levels. Organizational information processing theory (OIPT) argues on the effectiveness of balancing the information processing capability of a firm with its information processing requirement for achieving greater performance (Daft & Lengel, 1986). Therefore, based on the OIPT, this study adopts the technology base and primary

[1]It is important to note that online communities, net ethnography, virtual shopping, semiotics specified as ICT3 represent ICT-based market research tools which is an ICT category considered in the current study, rather than methodologies known by these names.

product type as control variables in order to remove any confounding effects of these factors on the relationships examined.

This study provides valuable background information for the final empirical research phase focusing on the direct and indirect ICT impact through collaboration performance on new product performance. In addition, it re-examines and extends existing literature related to the direct and indirect effects of ICT tools on NPD performance. According to the CPAS (2012), best performing firms use ICT tools more than the rest of the firms (Markham & Lee, 2013). Utilizing the same data in a comprehensive analysis, this study evaluates the significance of different ICT tools in achieving CPD performance and offers important practical implications for product developers. However, since the study is based on secondary data obtained from a broad NPD survey which only covers some related concepts addressed in the main study (e.g. NPD collaboration rather than collaboration performance), it can only approximate the relationships hypothesised in the main study (Chapter 7).

The rest of the chapter is organized as follows. First, the theoretical basis for the research model and the development of hypotheses of this preliminary study are presented. Second, the research methodology adopted in the study is explained in detail. Next, the results obtained in the data analysis are presented and discussed providing possible explanations, theoretical, and managerial implications. Finally, limitations of the study and suggestions for the last research phase are presented.

6.2 Research Framework and Development of Hypotheses

This study develops and examines a research model which comprises several concepts related closely to the constructs in the main research model (Figure 5.2). The theoretical basis of the relationships being investigated in the research model and the hypotheses are explained in the following sections.

6.2.1 Theoretical basis of the study

6.2.1.1 Organizational information processing theory

The information processing model states that organizations select one of three key strategies for improving performance – planning their ability to preplan by reducing task uncertainty, increasing their flexibility to adopt high uncertainty or inability to preplan, or decreasing the expected level of performance for continued feasibility (Galbraith, 1974). ICT tools support NPD teams to achieve success, providing increased flexibility to cope with uncertainties in NPD projects. As the organizational information processing theory (OIPT) posits, in order to achieve higher performance, organizations need to balance their information processing capability to meet the information processing requirements generated by a task's uncertainty (Daft & Lengel, 1986).

Continuous new technology developments that quickly make obsolete existing products, shorter product lifecycles due to changing customer requirements, and increased need for involvement of external partners in the NPD process are key characteristics of technologically advanced industries (Gupta & Wilemon, 1990). Since these characteristics lead to increased information processing needs in NPD projects, the usage of ICT tools could be higher as the technology levels increase. Parikh (2001) highlighted the greater importance of various ICT tools in all stages of the knowledge management cycle (knowledge acquisition, knowledge organization, knowledge dissemination, and knowledge application) in high-tech NPD projects. Therefore, the technology base of a firm (high-tech, medium-tech, or low-tech) is suggested as an important factor that could affect the relationship between ICT tools and NPD performance. The kinds of products produced in a firm may also determine which ICT types are more or less used in the NPD programmes of the firm. For example, the use of product design and development tools is likely to be higher in NPD projects that mostly develop physical products. Therefore, the extent of information to be processed within NPD projects can also be based on the type of primary product or percentage of goods offered. Drawing on the OIPT, it can be suggested that firms which successfully balance their ICT usage based on their information processing requirement determined by the technology base and primary product type, have a greater likelihood of achieving higher performance in NPD endeavours. Therefore, based on that theory, this study presumes a positive effect of ICT tools, controlled for the two variables (technology base and primary product type) on NPD performance.

6.2.1.2 Relational resource-based view

As emphasized in the development of the research model of the main study (Chapter 4), the relational resource-based view (RRBV) provides a theoretical foundation for the indirect effects examined in this study. According to the RRBV, firms can generate relational rents through relation-specific investments, complementary resource endowments, knowledge-sharing routines, and effective governance. Usage of ICT tools in CPD programmes reflects investments and resources of firms towards maintaining collaborative relationships with partners and their knowledge and information sharing routines. NPD collaboration is generally known as frequent consultation and open exchange of knowledge and information with external partners and internal cross-functional teams involved in NPD (Banker et al., 2006; Marion et al., 2014; Peng et al., 2014). Therefore, NPD collaboration represents the relationships developed by collaborative firms, which can lead to competitive advantage. Based on the relational resource-based perspective, this study suggests an indirect positive impact of ICT tools usage on the overall NPD performance of firms, through collaboration. The following section presents the details on deriving a research model which is related to the main research model of the study and addresses the direct and indirect effects of specific ICT tools on overall NPD performance.

6.2.2 The impact of ICT tools on NPD performance

6.2.2.1 Market research and analysis ICT tools

Market research tools such as online focus groups and online surveys are primarily used in the front end of the product development process in order to identify customer preferences and problems in existing products (Creusen et al., 2013; Van Kleef et al., 2005). Customer needs/requirements analysis software tools help in both product and service industries to analyse customer experiences and buying behaviours, and integrate them into new designs (Fung, Popplewell, & Xie, 1998; Verma et al., 2012). Precise identification of customer requirements and timely response to these requirements enable the introduction of perfect design configurations and increase the likelihood of market acceptance, ensuring higher project performance. However, studies addressing the association between tools such as online surveys and customer needs/requirements analysis software and NPD performance are limited. Previously, Durmusoglu and Barczak (2011) found that using online customer needs surveys at the new product commercialization stage results in higher NPD effectiveness while having no significant impact at the discovery and development stages.

Online focus groups support open (collaborative) innovation by enabling real-time in-depth discussions among distributed experts and customers (Davis, 2001; Van Kleef et al., 2005). Teo and Choo (2001) emphasized that internet-based market information gathering from external sources increases a firm's competitive intelligence which in turn improves organizational performance. In a study that observed a positive impact of market research tools on cooperation, Vilaseca-Requena et al. (2007) noted that increased use of ICT tools in marketing reduces barriers to innovation, improves integration, and helps in adapting new products to market demands with increased efficiency. Collaboration involves working together while sharing resources and capabilities, and hence is guaranteed by increased cooperation (Camarinha-Matos et al., 2009). Therefore, this study posits that online focus groups/surveys and customer needs analysis software have direct and indirect positive impacts on NPD performance

H_{p1a}: *Online focus groups/online surveys (ICT1) have a direct positive relationship with overall NPD performance.*

H_{p1b}: *Online focus groups/online surveys (ICT1) have an indirect positive relationship with overall NPD performance, through collaboration.*

H_{p2a}: *Customer needs/requirements analysis software (ICT2) has a direct positive relationship with overall NPD performance.*

H_{p2b}: *Customer needs/requirements analysis software (ICT2) has an indirect positive relationship with overall NPD performance, through collaboration.*

There are a large number of online communities such as Weblogs, Twitter, and Facebook available today for business organizations, to be involved with and to monitor potential new product developments (Creusen et al., 2013; Marion et al., 2014). Tools such as net ethnography, virtual shopping, and semiotics are modern virtual market research technologies that offer opportunities to explore in-depth information leading to successful NPD (Catterall & Maclaran, 2002; Wilner, 2008). Use of these tools offers a broad understanding to product and service developers on customer desires based on their culture, brand loyalty, and experience (Catterall & Maclaran, 2002; Horster & Gottschalk, 2012; Robinson & Schulz, 2011) which is important to maintain an organization's competitive position and reputation in the market.

According to Bugshan (2015), online communities enable product developers to share knowledge, information, and ideas with peers, thereby increasing social capital which drives co-innovation. However, these case study findings contradict Marion et al. (2014) who investigated a large sample and found no significant impact of these tools on NPD team collaboration but a positive impact on generating new product concepts and management evaluation (fast management feedback). As a reason for the insignificant impact on collaboration, the researchers highlighted the relatively lower frequency of using these tools (according to their sample) than what is considered to be required to ensure proper collaborative relationships with partners. According to Hess, Randall, Pipek, and Wulf (2013), carefully handling the heterogeneity of the involved partners in broader online communities is crucial in the new product design and development processes. Integration with partners such as suppliers and customers leads to higher NPD project performance (Mishra & Shah, 2009). Since the ICT tools mentioned above are open to a vast community with a wide range of interests, firms gain increased opportunities to generate more innovative and customized designs through the use of these tools for market research. Therefore, it is important to establish a positive direct as well as an indirect association between ICT tools such as online communities, net ethnography, virtual shopping, and semiotics and NPD performance by testing the following hypotheses.

H_{p3a}: Online communities, net ethnography, virtual shopping, semiotics (ICT3) have a direct positive relationship with overall NPD performance.

H_{p3b}: Online communities, net ethnography, virtual shopping, semiotics (ICT3) have an indirect positive relationship with overall NPD performance, through collaboration.

6.2.2.2 Product design and development ICT tools

Rapid prototyping systems enable designers and engineers to create virtual model outputs for a number of design alternatives and select better designs through evaluation of these alternatives (Bryden, 2014). Agile, flexible product development processes facilitated by these tools ensure higher productivity, greater acceptability in the market and higher financial returns on low costs. Some tools facilitate the engagement of multiple dispersed partners in prototyping and provide efficient means to make changes concurrently (Li et al., 2007). This will improve collaboration within teams and guarantee a new product with higher technical performance through improved transparency of design constraints and decisions. Performance modeling and simulation systems are used to simulate product features/functionalities, and evaluate alternative designs. These tools offer low-cost convenient experimentation opportunities for new product developers, which can result in error-free and more profitable new products (Thomke, 1998a). In product development projects undertaken by dispersed R&D teams, the above tasks are facilitated in real time by tools such as virtual reality, virtual design, and cave technology, while ensuring greater ability to design successful new products (Awazu et al., 2009; Ottosson, 2002). Highlighting the greater significance of customer orientation in new product conceptualization, Durmusoglu and Barczak (2011) revealed a positive effect of virtual prototyping tools on NPD effectiveness in the discovery stage and no significant effect in the development stage. The present study considers virtual reality tools including cave technology that are able to provide a better feeling about the real product to the users as well as the designers during development. Remote collaborative design systems facilitate receiving inputs from different partners located dispersedly and sharing visualized models among them (Liu et al., 2007). Previous qualitative research suggesting that these systems increase the efficiency of NPD process are available (e.g. Boutellier et al., 1998). However, generalizable findings derived from representative, large samples on the direct and indirect impact of these tools on NPD performance were not found. Therefore, in order to extend the existing literature, a positive direct and an indirect effect of these tools on NPD performance through collaboration are proposed by the following hypotheses.

H_{p4a}: *Rapid prototyping systems (ICT4) have a direct positive relationship with overall NPD performance.*

H_{p4b}: *Rapid prototyping systems (ICT4) have an indirect positive relationship with overall NPD performance, through collaboration.*

H_{p5a}: *Performance modeling and simulation systems (ICT5) have a direct positive relationship with overall NPD performance.*

H_{p5b}: *Performance modeling and simulation systems (ICT5) have an indirect positive relationship with overall NPD performance, through collaboration.*

H_{p6a}: *Virtual reality/virtual design/cave technology (ICT6) have a direct positive relationship with overall NPD performance.*

H_{p6b}: *Virtual reality/virtual design/cave technology (ICT6) have an indirect positive relationship with overall NPD performance, through collaboration.*

H_{p7a}: *Remote collaborative design systems (ICT7) have a direct positive relationship with overall NPD performance.*

H_{p7b}: *Remote collaborative design systems (ICT7) have an indirect positive relationship with overall NPD performance, through collaboration.*

6.2.2.3 Product data, project, and portfolio management ICT tools

Product data management (PDM) systems process product related engineering data, providing access to these data to relevant members involved in CPD projects. Organizations use these tools for achieving project success through increased product quality and decreased development times (Ahmed, 2011). Improvements in NPD processes are expected through project tracking, planning of resources, and product structure management facilitated by PDM systems. These services support knowledge integration in NPD projects and increase product innovativeness (Durmusoglu & Barczak, 2011). In addition, efficient collaboration through automatic sharing of product data will significantly reduce product development times ensuring greater success in NPD (Son, Na, & Kim, 2011). Therefore, the following hypotheses are tested to establish a positive direct and indirect impact of PDM systems on new product development performance.

H_{p8a}: *Product data management systems (ICT8) have a direct positive relationship with overall NPD performance.*

H_{p8b}: *Product data management systems (ICT8) have an indirect positive relationship with overall NPD performance, through collaboration.*

Portfolio management is used to prioritize NPD projects based on a company's strategic choices on products, markets, and technologies and to allocate resources appropriately to multiple projects (Cooper, Edgett, & Kleinschmidt, 1999). Installing a systematic, formal, rigorous portfolio management system is vital for the success of a firm's NPD programmes (Cooper et al., 2001). Today, in the technologically competitive business environments, many firms simultaneously undertake several NPD projects and use product portfolio management software to systematically prioritize these projects so that the company gets maximum benefits (through eliminating low-value projects and unstructured data management). In addition, these tools support business intelligence and real-time visibility into the status of projects and portfolio (Changepoint, 2015; Sopheon, 2016). Therefore, they help in improving the collaborative decision making process within CPD teams. However, empirical studies investigating the direct and indirect impact of using product portfolio management software on NPD programme success, through collaboration were not available. Therefore, drawing on the RRBV, this study posits the following hypotheses:

H_{p9a}: Product portfolio management software (ICT9) has a direct positive relationship with overall NPD performance.

H_{p9b}: Product portfolio management software (ICT9) has an indirect positive relationship with overall NPD performance, through collaboration.

Project management systems are used to manage tasks, time and resources in NPD projects (Pavlou & Sawy, 2006). These tools have specific features for building work breakdown structures, sequencing tasks, estimating project costs, allocating time and resources, and tracking progress (Pons, 2008). Therefore, firms use these tools to ensure the fast accomplishment of NPD activities and the achievement of project objectives through better management of people, skills, and resources (Boutellier et al., 1998). Advanced tools such as PLM systems enable the project management function in collaborative environments by merging product information and continuously modifying it (Kung, Ho, Hung, & Wu, 2015). These tools process and exchange knowledge between relevant R&D partners and manage dispersed NPD projects. Supporting these views, Banker et al. (2006) found a direct and indirect impact of PLM systems on NPD performance through collaboration. Providing empirical evidence for the direct and indirect positive impact of a broad category of project management tools on new product performance will confirm and extend the above literature.

H_{p10a}: Project management systems (ICT10) have a direct positive relationship with overall NPD performance.

H_{p10b}: Project management systems (ICT10) have an indirect positive relationship with overall NPD performance, through collaboration.

6.2.2.4 Communication and collaboration ICT tools

The extensive use of communication and collaboration ICT tools such as video conferencing, software systems to connect technology specialists within firms, and groupware assures frequent communication and the sharing of information within and between CPD teams. Frequent and close consultation with external and internal partners is a critical factor determining the success of CPD projects (Littler et al., 1995). Video conferencing provides face-to-face-like communication facilities for dispersed R&D teams and helps the building of informal networks between team members (Boutellier et al., 1998). Groupware is a collaborative tool that enables the sharing of knowledge in NPD projects involving many distributed partners (Evans et al., 2015). These tools improve the collaboration of the team members by developing informal networks, providing coordination support, and facilitating information exchange (Boutellier et al., 1998). Collaboration leads to reduced costs, and increased quality and cycle time in NPD (Banker et al., 2006). However, any empirical evidence for the impact of video conferencing and groupware on firms' overall NPD performance was not found in the literature.

Software systems that connect technology specialists within a firm assist the generating of product ideas from a firm's employees. These tools facilitate open communication and collaboration, and improve employee engagement in NPD. Technology specialists within a firm not only have advanced technical knowledge but also greater ability to provide viable ideas for the firm's NPD programmes. However, Durmusoglu and Barczak (2011) found no significant effect of idea generation software on NPD effectiveness. In order to further explore these effects in the light of RRBV, the present study suggests a positive direct and indirect impact of video conferencing, software systems to connect technology specialists within firms, and groupware on overall NPD performance, through collaboration.

H_{p11a}: *Video conferencing (ICT11) has a direct positive relationship with overall NPD performance.*

H_{p11b}: *Video conferencing (ICT11) has an indirect positive relationship with overall NPD performance, through collaboration.*

H_{p12a}: Software systems to connect technology specialists within firms (ICT12) have a direct positive relationship with overall NPD performance.

H_{p12b}: Software systems to connect technology specialists within firms (ICT12) have an indirect positive relationship with overall NPD performance, through collaboration.

H_{p13a}: Groupware (ICT13) has a direct positive relationship with overall NPD performance.

H_{p13b}: Groupware (ICT13) has an indirect positive relationship with overall NPD performance, through collaboration.

The conceptual model developed for investigating the relationships proposed above is illustrated in Figure 6.1.

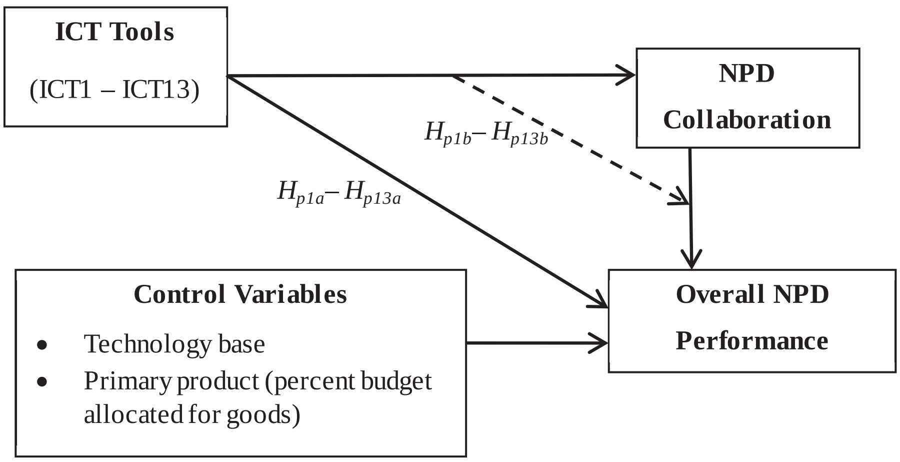

Figure 6.1. Research model for the impact of ICT tools on overall NPD performance

6.3 METHODOLOGY

6.3.1 Secondary data and the sample

In 2011, the PDMA Foundation developed a questionnaire for the fourth NPD best practices study (or CPAS). The CPAS (2012) was a comprehensive benchmarking survey that included 562 questions in ten categories – innovation culture, strategy, portfolio management, new product process, the front end of innovation, development tools, measures and metrics, outcomes, background, and summary and comments

(Markham & Lee, 2013). Out of these, the present study selected and used some items (Appendix 6.1) related to development tools (only ICT tools), new product process (collaboration), outcomes (meeting NPD objectives, overall NPD programme success, and NPD success relative to the primary competitors), and background (technology base, primary product type). The final sample contained 453 surveys after eliminating 382 incomplete surveys. Since this study is based on the RRBV, it focuses on product development in networked firms rather than individual firms. Therefore, the admission criterion for the CPAS data to this study was a responded firm's engagement in collaborative product development. Consequently, three firms that engage in neither global NPD programmes nor collaborations in more innovative NPD projects (CPAS has only considered more innovative projects when collecting data on collaboration) were excluded resulting in final sample of 450 firms. Although the focus of the main study is manufacturing sector, all types of industries in the CPAS sample were considered for this preliminary analysis. The reason for this was the intention to explore potential sector differences in the impact of ICT usage on CPD performance and to understand the relative importance and feasibility of obtaining a sufficient sample only from manufacturing sector, in the final survey. The average annual business unit sales of the selected sample, was $4472 million while 63% of the firms earned less than $100 million revenue. The regional and industrial distributions of the sample are presented in Tables 6.1 and 6.2 respectively.

Table 6.1: Country distribution of the sample

Country	*North America*	*Asia*	*Europe*	*Others*	*Total*
Number	197	148	60	45	450
%	43.8	32.9	13.3	10.0	100

Table 6.2: Industry distribution of the sample (secondary)

Industry	*Total*	*Percentage (%)*
Capital goods	97	21.6
Chemicals and materials	74	16.4
Industrial services	44	9.8
Software and services	49	10.9
Consumer services	51	11.3
Technology hardware	62	13.8
Health care	41	9.1
Fast moving consumer goods	32	7.1
Total	450	100

Table 6.3 presents the composition of the sample based on the technology base (12 data are missing) and primary product type (53 data are missing) of the firm. Technology levels (Appendix 6.1) 1 and 2 were combined and named as low-tech, 3 was taken as medium-tech, and 4 and 5 were grouped as high-tech. Primary product types of firms were identified as goods, mix, or services based on the percent budget spent on goods (Markham & Lee, 2013).

Table 6.3: Composition of the sample (secondary) based on technology base and primary product

Criterion	*Category*	*Total (%)*
Technology base	High-tech	199 (45.4%)
	Medium-tech	114 (26.0%)
	Low-tech	125 (28.6%)
Primary product	Goods (% budget on goods > 66.7%)	223 (56.2%)
	Mix (33.3% < % budget on goods < 66.7%)	67 (16.9%)
	Services (% of goods < 33.3%)	107 (26.9%)

6.3.2 Measures

The survey (CPAS) has measured the usage of each ICT tool using a 5-point Likert scale (Table A1 in Appendix 6.1). The scales for NPD performance and collaboration constructs were developed using two principal component analyses performed on the items selected (Table A2 in Appendix 6.1). The items PERF1-PERF3 that indicate overall performance of NPD programmes in firms were used in the first analysis. All the items were loaded into a single factor (each indicator loading > 0.7) with an eigenvalue greater than 1 indicating the existence of one unidimensional representative construct for the three survey items (Table 6.4). Since this factor sufficiently explains the variability (72.2%) in data, convergent validity of the construct is adequately confirmed. Cronbach alpha calculated for the items was 0.78. Since it is greater than the recommended threshold (0.7), internal consistency and reliability of the construct is confirmed. The factor scores were used as the scale of the NPD performance construct.

Table 6.4: Principal component analysis 1

Survey item	*Factor loading*
PERF1 (NPD program meeting the performance objectives)	0.908
PERF2 (NPD program's overall success)	0.918
PERF3 (NPD program's success relative to competitors)	0.706
Cumulative % of variance explained (Eigenvalue)	72.20 (2.166)

For developing the scale for the NPD collaboration construct, eight items were selected (Table A2 in Appendix 6.1) from the survey (CPAS, 2012) based on theoretical considerations of the construct (Banker et al., 2006; Marion et al., 2014; Peng et al., 2014). Then a principal component factor analysis was performed on these items. Initially, the items were loaded into two factors with eigenvalues greater than one. Then the one item (COLL8) loaded into the second factor was dropped as it does not largely affect the content validity of the collaboration construct. The principal component analysis performed on the remaining seven items generated a single factor explaining 55% of variability and suggesting a sufficient level of convergent validity of the construct. According to the results given in Table 6.5, all the indicator loadings are above 0.7 except one (COLL1) with a loading of 0.622 which is also acceptable (Carmines and Zeller, 1979). Cronbach alpha calculated for the items was 0.86. Since this value is greater than the recommended threshold (0.7), internal consistency and reliability of the construct is satisfactorily confirmed. The scores of the factor were used as the scale of the NPD collaboration construct.

Table 6.5: Principal component analysis 2

Survey item	*Factor loading*
COLL1 (Facilitating internal collaboration)	0.622
COLL2 (Facilitating external collaboration)	0.718
COLL3 (Joint team-building and training)	0.697
COLL4 (Assessing co-development projects and quality of partner relationships)	0.826
COLL5 (Contract structures for sharing risk, reward and performance)	0.757
COLL6 (Concurrent development)	0.822
COLL7 (Clearly sharing internal processes and having common language and common deliverables)	0.704
Cumulative % of variance explained (Eigenvalue)	54.52 (3.817)

The original scale for the first control variable (i.e. technology base) (1 = high-tech and 5 = low-tech) was reversed as shown in Appendix 6.1, for the convenience in interpreting statistical outputs. The NPD budget spent on goods was directly adopted as the second control variable (i.e. primary product type).

6.3.2.1 Common method bias

The risk of common method bias caused by the use of data collected in a single survey including self-reported measures of project success had been reduced in CPAS (2012), by adopting different scales for variables (Appendix 6.1) and allowing respondents to gather information from multiple people in their business unit. Furthermore, as a post-hoc remedy, the present study performed Harman's one factor test for common method variance (Podsakoff & Organ, 1986) considering all the variables selected. The unrotated factor solution included five factors explaining 64% of variability and there was no general factor that accounts for a majority of the variance (the largest was 37%). Therefore, no considerable common method bias was evident.

6.3.3 Sample size requirements

As explained in section 6.3.1, the size of the final sample was 450. The adequacy of the sample was tested according to the criteria defined by (Cohen, 1992). Cohen's f^2 statistic of the effect size for multiple regression models is calculated using the following formula:

$$f^2 = \frac{R^2}{1-R^2}$$

Effect sizes 0.02, 0.15, and 0.35 are considered as small, medium, and large respectively (Cohen, 1992). Barczak et al. (2007) obtained an R^2 value of 6% for a regression of overall ICT usage on market performance. In a study examining the association between several ICT tools on NPD collaboration Peng et al. (2014) attained an R^2 value of 26%. The minimum of these two R^2 values is 6% and approximate effect size based on this value is 0.064 (small effect). The present sample is sufficient to detect an effect of size 0.045 in a hierarchical regression analysis (the minimum required sample size is 421) (Soper, 2006a) which was the method used in this data analysis.

6.4 Results

This section presents important descriptive statistics of variables in the study and results obtained in the hierarchical regression analyses performed to test the hypotheses specified in the model (Figure 6.1). Hypotheses H_{p1a} – H_{p13a} test the direct positive effects of ICT tools on overall NPD performance (NPDP) while hypotheses H_{p1b} – H_{p13b} test the positive indirect effects of ICT tools on overall NPD performance, through collaboration (COLL). Table 6.6 includes the descriptive statistics (means and standard deviations) of the variables, and Pearson correlation coefficients between them. According to the table, the mean values have not substantially deviated from the centre of the scale used and the standard deviation values imply that there is a sufficient variability in the data to perform a further statistical analysis. All the ICT tools have positive and significant (p values < 0.01) correlations with overall NPD performance and collaboration. In addition, collaboration and overall NPD performance has a significant positive correlation. These results indicate no conflict with the direct and indirect relationships hypothesised. Furthermore, the correlations of each ICT tool with NPD performance is less than the correlation with NPD collaboration, suggesting a relatively stronger impact of all the ICT tools on collaboration. The positive significant coefficients of correlations between ICT tools imply that the usages of these tools in CPD projects are also correlated. This is usual since usage of all types of ICT could be increased based on the degree of ICT orientation of a firm. However, in the regression analysis for evaluating the impact of the usage of ICT tools, a specific procedure (stepwise regression) is followed in order to avoid the potential multicollinearity issues.

Table 6.6: Descriptive statistics and Pearson correlations of the variables

	Mean	Std. Deviation	*ICT1*	*ICT2*	*ICT3*	*ICT4*	*ICT5*	*ICT6*	*ICT7*	*ICT8*	*ICT9*	*ICT10*	*ICT11*	*ICT12*	*ICT13*	*NPDP*	*COLL*
ICT1	2.26	1.19	1														
ICT2	2.12	1.25	.445**	1													
ICT3	1.83	1.09	.690**	.480**	1												
ICT4	2.60	1.36	.241**	.295**	.269**	1											
ICT5	2.61	1.36	.270**	.414**	.274**	.577**	1										
ICT6	1.99	1.23	.325**	.517**	.421**	.439**	.526**	1									
ICT7	1.98	1.16	.373**	.494**	.451**	.407**	.483**	.623**	1								
ICT8	2.59	1.43	.370**	.543**	.331**	.385**	.545**	.458**	.545**	1							
ICT9	2.28	1.34	.380**	.645**	.408**	.281**	.352**	.466**	.474**	.624**	1						
ICT10	3.08	1.40	.230**	.438**	.228**	.354**	.435**	.293**	.399**	.543**	.505**	1					
ICT11	2.67	1.31	.325**	.284**	.267**	.326**	.329**	.205**	.353**	.333**	.256**	.327**	1				
ICT12	2.40	1.38	.375**	.461**	.408**	.379**	.436**	.423**	.491**	.478**	.460**	.476**	.408**	1			
ICT13	2.50	1.45	.400**	.426**	.447**	.272**	.384**	.339**	.410**	.367**	.402**	.405**	.393**	.565**	1		
NPDP	0.00	1.00	.174**	.259**	.179**	.219**	.261**	.172**	.232**	.329**	.243**	.293**	.237**	.256**	.245**	1	
COLL	0.00	1.00	.463**	.514**	.496**	.308**	.401**	.445**	.500**	.480**	.469**	.343**	.341**	.467**	.447**	.369**	1

** Correlation is significant at the 0.01 level

6.4.1 ICT usage based on technology base and primary product type

Confidence interval (95%) plots of the ICT tools were obtained to explore the usage of ICT tools based on the technology base and primary product type of firms. As shown in Figure 6.2, high-tech firms have the highest ICT usage. This difference is large for customer requirement analysis software (ICT2), rapid prototyping systems (ICT4), and remote collaborative design systems (ICT7). Both high-tech and medium-tech firms are largely deviated from low-tech firms in the usage of several ICT tools. These are: performance modeling and simulation systems (ICT5), virtual design tools (ICT6), portfolio management software (ICT9), software systems to connect technology specialists within firms (ICT12), and groupware (ICT13). However, use of online surveys (ICT1) is not significantly different across technology levels.

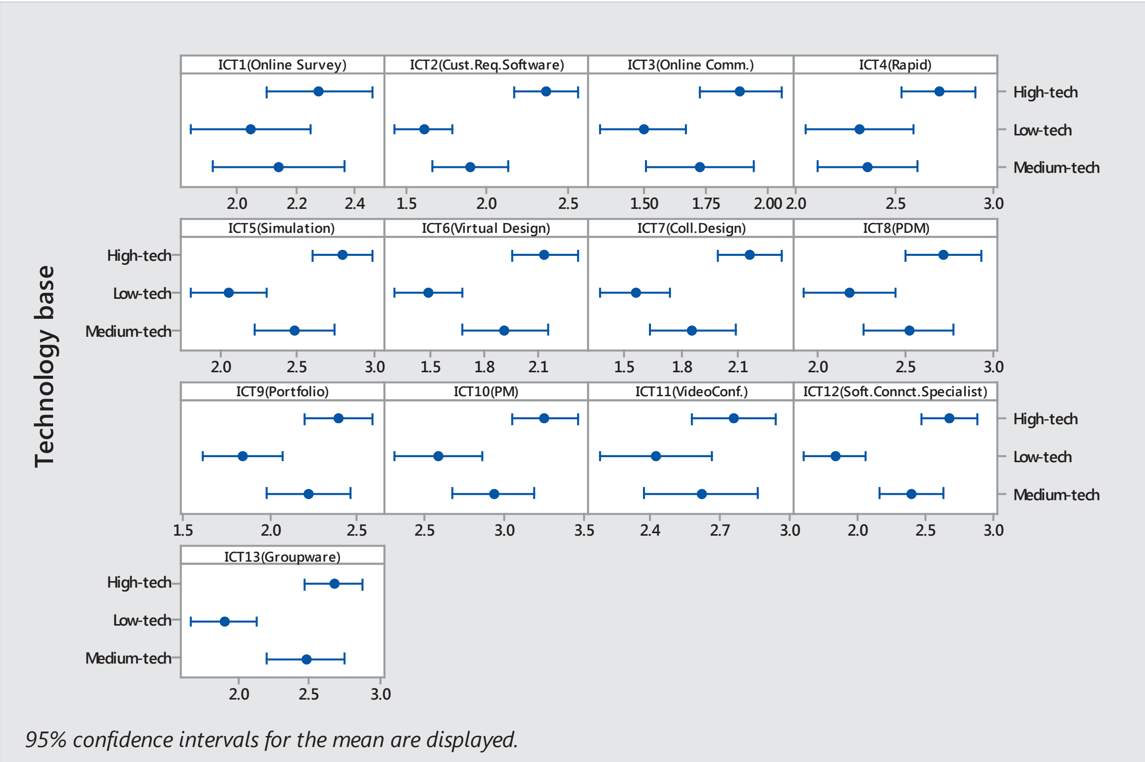

Figure 6.2. Interval plot of the usage of ICT tools by technology base

According to the plot related to the primary product type (Figure 6.3), the usage of several ICT tools in both goods and mix product manufacturing firms, is significantly higher than that of service firms. These tools are: performance modeling and simulation systems (ICT5), virtual design systems (ICT6), collaborative design systems (ICT7), product data management systems (ICT8), portfolio management systems, software systems to connect technology specialists within firms (ICT12), and groupware (ICT13). Many of these tools primarily assist CPD teams in product designing and development. The use of some ICT tools is increasing as the percentage of goods increases. These are: online focus groups/online surveys (ICT1), rapid prototyping systems (ICT4), project management systems (ICT10), and video conferencing (ICT11). Customer requirement analysis software (ICT2), online communities/net ethnography etc. (ICT3), virtual design tools (ICT6), collaborative design systems (ICT7), and software systems to connect technology specialists within firms (ICT12) are mostly used in firms producing mix products. Results of this interval plot analysis indicate significant variations in usage of ICT tools based on the technology base and primary product type of firms. Therefore, including these as control variables in the subsequent hierarchical regression analysis is useful to remove any confounding effects due to them.

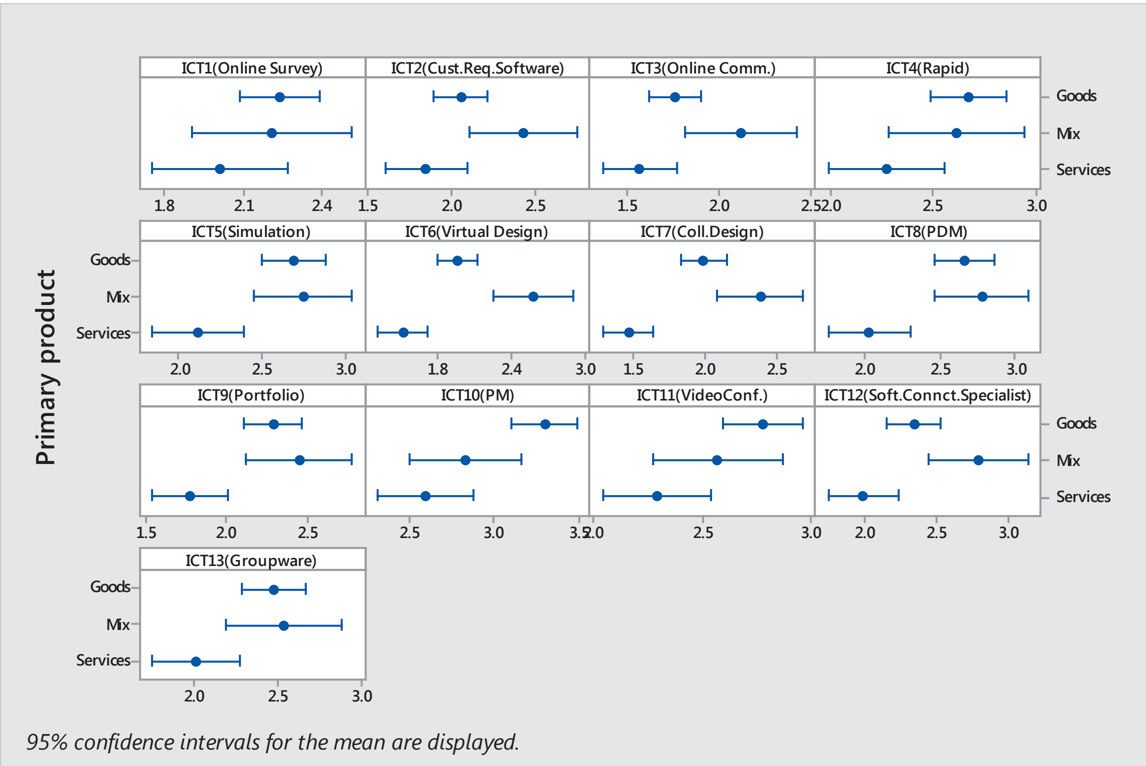

Figure 6.3. Interval plot of the usage of ICT tools by primary product type

6.4.2 Regression analysis

Estimating regression models including mediators involves several steps (section 4.6.5.1) as it should estimate both direct and indirect paths. Usually, two regression models with only predictors and both predictors and mediator are conducted (Baron & Kenny, 1986; Kenny, 2015). The hierarchical regression method allows this model fitting in a single step. First, technology base (TECH) and percentage new product budget spent on goods (GOOD) were entered as the control variables. Since this study hypothesises that ICT usage has both direct and indirect relationships with NPD performance through collaboration (or partial mediation) (Figure 6.1), NPD collaboration was entered into the regression after controlling for the ICT tools. Therefore, after entering the control variables, the 13 ICT tools were entered using the stepwise procedure to select only the best fitting variables and to reduce the potential multicollinearity issues. Significance of the R^2 change was used to test the acceptability of the models generated by the hierarchical regression analysis. Variance inflation factor (*VIF*) scores were obtained to test for any multicollinearity in the models. All these results are summarized in Table 6.7.

Table 6.7. Hierarchical regression model estimation for overall NPD performance

	NPDP		
	Model 1	*Model 2*	*Model 3*
Intercept	-0.761***	-1.269***	-0.952***
GOOD (Primary product)	0.002	0.000	0.000
TECH (Technology base)	0.199***	0.140***	0.107***
ICT8 (PDM systems)		0.135***	0.085**
ICT10 (Project management systems)		0.080**	0.072*
ICT11 (Video conferencing)		0.086**	0.059
COLL (NPD collaboration)			0.208***
F	13.632***	16.622***	17.008***
R^2	0.057	0.158	0.187
Adjusted R^2	0.053	0.148	0.176
ΔR^2	0.057	0.101	0.030
ΔF	13.632***	4.479**	16.111***
Max *VIF*	1.001	1.504	1.649

***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.10$

According to the results of Model 1, the control variables technology base (TECH) and primary product (GOOD) (only the effect of technology base is significant), account for 6% of variability in overall NPD performance (NPDP). Both models 2 and 3 indicate significant improvements over their preceding models as their R^2 changes (ΔR^2) are significant. All the *VIF* values are below the maximum recommended value (2.5) for weaker models (Braunstein, 2007) indicating no multicollinearity issues interrupting the regression result. Model 2 with ICT tools implies significant positive direct effects of three tools: PDM systems (ICT8), project management systems (ICT10) and video conferencing (ICT11) on overall NPD performance. These tools explain 12% of variability (R^2) in NPDP. After entering NPD collaboration (COLL) into the model (Model 3), only two ICT tools (ICT8 and ICT10) remain significant while indicating reductions in their regression coefficients. In this model, NPD collaboration shows a significant positive effect on NPD performance. However, the direct path from ICT tools to NPD collaboration (Figure 6.1) needs to be established in order to determine the nature of the mediation effect of NPD collaboration. Therefore, a regression model between collaboration and the ICT tools was estimated in the next stage. Table 6.8 presents the results obtained.

Table 6.8: Hierarchical regression model estimation for NPD collaboration

	COLL	
	Model 1	*Model 2*
Intercept	-0.845***	-1.762***
GOOD (Primary product)	0.001	-0.001
TECH (Technology base)	0.238***	0.117***
ICT1 (Online focus groups/online surveys)		0.104**
ICT2 (Customer needs analysis software)		0.090**
ICT3 (Online communities/net ethnography)		0.136***
ICT7 (Remote collaborative design systems)		0.127***
ICT8 (PDM systems)		0.111***
ICT13 (Groupware)		0.082***
F	19.861***	40.150***
R^2	0.082	0.421
Adjusted R^2	0.078	0.411
ΔR^2	0.082	0.339
ΔF	19.861***	5.413**
Max *VIF*	1.001	2.175

***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.10$

Similarly, as in the previous estimation, the second model is accepted as it indicates significant improvement in the R^2 over the previous model and shows no multicollinearity issue (the maximum *VIF* value is less than 2.5). The effect of the same control variable (i.e. technology base) is significant and it accounts for 8% of the variability in NPD collaboration (COLL). Six ICT types: online focus groups/online surveys (ICT1), customer requirement analysis software (ICT2), online communities (ICT3), collaborative design systems (ICT7), PDM systems (ICT8), and groupware (ICT13) indicate significant positive direct effects on NPD collaboration. Table 6.9 presents the final results of the two hierarchical regression analyses performed to test the hypotheses of this preliminary study.

Table 6.9: Results of the hypothesis tests (preliminary quantitative study)

Hypothesis	*Result of the regression analysis*
H_{p1a}: Online focus groups/online surveys (ICT1) have a direct positive relationship with overall NPD performance	Not supported
H_{p1b}: Online focus groups/online surveys (ICT1) have an indirect positive relationship with overall NPD performance, through collaboration.	Supported
H_{p2a}: Customer needs/requirements analysis software (ICT2) has a direct positive relationship with overall NPD performance.	Not supported
H_{p2b}: Customer requirements analysis software (ICT2) has an indirect positive relationship with overall NPD performance, through collaboration.	Supported
H_{p3a}: Online communities, net ethnography, virtual shopping, semiotics (ICT3) have a direct positive relationship with overall NPD performance.	Not supported
H_{p3b}: Online communities, net ethnography, virtual shopping, semiotics (ICT3) have an indirect positive relationship with overall NPD performance, through collaboration.	Supported
H_{p4a}: Rapid prototyping systems (ICT4) have a direct positive relationship with overall NPD performance.	Not supported
H_{p4b}: Rapid prototyping systems (ICT4) have an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p5a}: Performance modeling and simulation systems (ICT5) have a direct positive relationship with overall NPD performance.	Not supported
H_{p5b}: Performance modeling and simulation systems (ICT5) have an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p6a}: Virtual reality/virtual design/cave technology (ICT6) have a direct positive relationship with overall NPD performance.	Not supported
H_{p6b}: Virtual reality/virtual design/cave technology (ICT6) have an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p7a}: Remote collaborative design systems (ICT7) have a direct positive relationship with overall NPD performance.	Not supported
H_{p7b}: Remote collaborative design systems (ICT7) have an indirect positive relationship with overall NPD performance, through collaboration.	Supported
H_{p8a}: Product data management systems (ICT8) have a direct positive relationship with overall NPD performance.	Supported

H_{p8b}: Product data management systems (ICT8) have an indirect positive relationship with overall NPD performance, through collaboration.	Supported
H_{p9a}: Product portfolio management software (ICT9) has a direct positive relationship with overall NPD performance.	Not supported
H_{p9b}: Product portfolio management software (ICT9) has an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p10a}: Project management systems (ICT10) have a direct positive relationship with overall NPD performance.	Supported
H_{p10b}: Project management systems (ICT10) have an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p11a}: Video conferencing (ICT11) has a direct positive relationship with overall NPD performance.	Not supported
H_{p11b}: Video conferencing (ICT11) has an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p12a}: Software systems to connect technology specialists within firms (ICT12) have a direct positive relationship with overall NPD performance.	Not supported
H_{p12b}: Software systems to connect technology specialists within firms (ICT12) have an indirect positive relationship with overall NPD performance, through collaboration.	Not supported
H_{p13a}: Groupware (ICT13) has a direct positive relationship with overall NPD performance.	Not supported
H_{p13b}: Groupware (ICT13) has an indirect positive relationship with overall NPD performance, through collaboration.	Supported

These results confirm the hypotheses H_{p8a} and H_{p10a} related to the direct effects and H_{p1b}, H_{p2b}, H_{p3b}, H_{p7b}, H_{p8b}, and H_{p13b} related to the indirect effects through collaboration on overall NPD performance. Since both analyses indicated the significance of PDM systems (ICT8), NPD collaboration partially mediates the relationship between these tools and overall NPD performance. Project management tools (ICT10) have significant direct impact on NPD performance. Five ICT types, namely, online focus groups/online surveys (ICT1), customer requirement analysis software (ICT2), online communities (ICT3), collaborative design systems (ICT7), and groupware (ICT13) indicate direct impact on NPD collaboration which in turn increases overall NPD performance. The following section further discusses the above results providing possible explanations and implications for the final research phase.

6.5 Discussion and Conclusions

This preliminary study utilized the data collected by PDMA in CPAS (2012) as secondary data to examine the direct and indirect impact of 13 NPD-enabling ICT tools, through collaboration on overall NPD success. This study was conducted in order to provide empirical justifications to the relationships addressed in the main study while highlighting the inefficiencies of the previous frameworks in evaluating the impact of ICT usage on CPD performance. A hierarchical regression analysis was performed to answer the second research question of the main study, concerning the impact of ICT usage on CPD performance. The study has revealed a significant positive direct impact of two ICT types: PDM systems and project management tools on overall NPD success. The effect of PDM systems is relatively higher than the effects of the other ICT types. In addition, online communities/net ethnography/virtual shopping/semiotics, PDM systems, collaborative design systems, groupware, customer requirement analysis software, and online focus groups/online surveys indicate significant positive impact on NPD collaboration which in turn improves overall NPD performance.

The process of PDM systems basically include tracking and controlling product related data such as product specifications, engineering drawings, part files, project plans, assembly diagrams, and engineering change orders. System features such as data warehousing, product structure definition module, information management module helps product developers reuse components in multiple products and develop a range of product configurations. Therefore the use of PDM software support product developers in reducing NPD costs and development cycle times while increasing quality and innovativeness of the new products. This ensures a higher rate of achieving project objectives and overall NPD success. Increased use of project management tools ensures that the budget, time, and other resources are properly planned and managed throughout the CPD project. This leads to meeting financial, time, and market objectives set for the projects and hence warrants a high level of overall success. As implied by the revealed indirect effects of online communities, online focus groups/online surveys and customer requirement analysis software, it is very effective when R&D practitioners utilize market research ICT tools in their innovative NPD projects. These tools enable the capturing of customer preferences from a wide community within a relatively short time, which will lead to customized innovative designs.

Tools such as net ethnography/virtual shopping, and customer requirement analysis software, facilitate in-depth research towards understanding customer desires and related cultural and socio-economic factors. Therefore, use of the above tools improves integration and collaboration with customers that helps in bringing knowledge and the assistance required to introduce more acceptable products to the market. This study also informs managers about the effectiveness of using collaborative ICT tools such as remote collaborative design systems and groupware. Remote CAD tools help product designers based in multiple sites to share visualized models, and enable simultaneous, real-time product designing and development. According to the results of the study, these tools provide effective means for collaboration which helps in achieving greater overall performance in NPD programmes. Use of groupware improves collaboration by sharing knowledge and providing extensive support for coordination among partners involved in CPD. Although several ICT tools did not indicate a significant effect on NPD collaboration in this study, all the 13 ICT tools had moderately high positive correlations with collaboration (Table 6.6).

Since the technology base of a firm has been identified as a significant control variable in the hierarchical regression analysis performed, a descriptive statistical analysis was performed to further explore the differences in the effects of ICT tools, based on the technology base. Means and standard deviations of the ICT tools usage in firms indicating high and low overall NPD success (above and below the mean NPDP) were calculated. Table 6.10 presents these values.

Table 6.10: Descriptive statistics of ICT use in firms with high/low overall NPD performance

	Low-tech (Mean and SD)		*Mean Difference*	*Medium-tech (Mean and SD)*		*Mean Difference*	*High-tech (Mean and SD)*		*Mean Difference*
	NPDP (High) (N=49)	*NPDP (Low) (N=78)*		*NPDP (High) (N=56)*	*NPDP (Low) (N=58)*		*NPDP (High) (N=121)*	*NPDP (Low) (N=79)*	
ICT1	2.37 (1.25)	1.95 (0.98)	0.42	2.35 (1.20)	2.26 (1.05)	0.09	2.49 (1.32)	2.12 (1.13)	0.37
ICT2	1.88 (1.03)	1.52 (0.87)	0.36	2.24 (1.33)	1.91 (1.06)	0.33	2.62 (1.37)	2.08 (1.26)	0.54
ICT3	1.81 (1.03)	1.42 (0.81)	0.39	1.96 (1.16)	1.83 (1.02)	0.13	2.07 (1.26)	1.71 (0.93)	0.36
ICT4	2.55 (1.49)	2.32 (1.50)	0.23	2.71 (1.42)	2.29 (1.15)	0.42	2.96 (1.32)	2.50 (1.18)	0.46
ICT5	2.43 (1.35)	1.94 (1.35)	0.49	2.90 (1.37)	2.46 (1.16)	0.44	3.11 (1.31)	2.48 (1.32)	0.63
ICT6	1.65 (1.06)	1.51 (1.01)	0.14	2.20 (1.34)	1.98 (1.18)	0.22	2.34 (1.34)	1.93 (1.16)	0.41
ICT7	1.81 (1.04)	1.47 (0.95)	0.34	2.20 (1.34)	1.85 (0.93)	0.35	2.30 (1.28)	2.01 (1.04)	0.29
ICT8	2.57 (1.55)	2.01 (1.33)	0.56	2.91 (1.348)	2.42 (1.197)	0.49	3.03 (1.53)	2.37 (1.30)	0.66
ICT9	2.16 (1.37)	1.73 (1.19)	0.43	2.58 (1.40)	2.14 (1.07)	0.44	2.59 (1.41)	2.29 (1.28)	0.30
ICT10	3.09 (1.49)	2.45 (1.45)	0.64	3.33 (1.29)	2.82 (1.20)	0.51	3.56 (1.35)	2.92 (1.39)	0.64
ICT11	2.67 (1.36)	2.36 (1.28)	0.31	2.85 (1.38)	2.54 (1.17)	0.31	2.98 (1.32)	2.50 (1.29)	0.48
ICT12	2.02 (1.26)	1.81 (1.23)	0.21	2.69 (1.37)	2.19 (1.12)	0.5	2.83 (1.45)	2.49 (1.45)	0.34
ICT13	2.12 (1.30)	1.86 (1.27)	0.26	2.82 (1.55)	2.37 (1.30)	0.45	2.98 (1.55)	2.41 (1.28)	0.57

According to the above analysis, different ICT tools indicate different levels of importance across technology levels while the tools – PDM systems (ICT8) and project management systems (ICT10) (which were found to be significant in the hierarchical regression analysis) – indicate almost equal importance in all three types of industries. In high-tech industry, all the ICT tools show considerably high positive mean differences between high and low performing firms. This indicates a relatively higher contribution of all the tools in achieving success in high-tech NPD projects. Particularly, intensive use of advanced design and development tools such as performance modeling and simulation systems (ICT5), rapid prototyping systems (ICT4), and virtual design tools (ICT6), collaboration tools such as groupware (ICT13), and market analysis tools such as customer needs analysis software (ICT2) seem to be effective in achieving NPD project success in high-tech industry.

In low- and medium-tech industries, high mean differences are observed for some ICT tools in addition to the tools (PDM systems and project management software) that showed significant direct effects on NPD performance in the regression analysis. For example, tools such as online focus groups/online surveys (ICT1), online communities/net ethnography/virtual shopping/semiotics (ICT3) seem to be highly useful in low-tech industries. Software systems to connect technology specialists within a firm (ICT12) offer better results in medium-tech NPD projects. Performance modeling and simulation systems (ICT5) seem to contribute considerably to the success in low- and medium-tech NPD projects, although its importance is less than that in high-tech industry. These results provide useful implications to the product development practitioners in high-, medium-, and low-tech industries. For example, online surveys and online communities are conveniently available, inexpensive means for low-tech firms for bringing the voice of the customer to the new products. Software systems to connect technology specialists within firms provide better ways for idea generation in medium-tech NPD projects where the technically advanced knowledge requirement is high, and the collaborative networks of externally involved technology experts are not as wide as in high-tech industries. Product lifecycles are relatively short and the frequencies of new product introductions are higher in high-tech industries (Gupta & Wilemon, 1990; Parikh, 2001). Therefore, selecting the best project and killing unimportant projects can be more critical for overall NPD performance in low- and medium-tech firms that handle limited numbers of simultaneous projects. This is indicated in the mean differences of ICT9, and hence facilitating portfolio management using software tools can be more useful for these firms.

In summary, the above discussion suggests that the impact of ICT usage can be varied across technology levels of firms whereas a positive impact of ICT tools is mostly anticipated in high-technological CPD contexts.

6.5.1 Theoretical implications

Findings of this study contribute to current literature by exploring both the direct and indirect impact of ICT tools, through collaboration on overall NPD performance. The revealed positive direct and indirect impact of PDM systems supports and extends the study of Durmusoglu and Barczak (2011) who suggested that the use of shared drives increases new product innovativeness. Introducing innovative designs can improve the competitiveness, guaranteeing overall success in NPD projects. Furthermore, sharing of valuable product-related data among collaborative partners leads to improved collaboration which in turn increases the ability of CPD teams in achieving project objectives and higher competitiveness in the market. The positive impact of project management tools found in this study supports Marion et al. (2014) who found a positive impact of these tools on NPD outcomes. Previous qualitative research suggest that project management tools increase efficiency in NPD project execution by providing proper project planning opportunities and reflecting project status continuously (Boutellier et al., 1998; Pons, 2008). The present study further confirms these findings with appropriate quantitative evidence from a large number of firms around the world.

Kawakami et al. (2015) found that frequency of ICT use has an indirect impact on NPD performance through NPD task proficiency. Extending this literature, the present study suggests that ICT usage has an indirect impact through collaboration on overall NPD performance. By providing empirical evidence for the positive impact of several ICT tools (online communities, collaborative design systems, groupware, customer requirement analysis software, and online focus groups/surveys) on NPD collaboration, this study supports and extends prior research that found a similar impact in relation to the tools such as collaborative PLM systems (Banker et al., 2006) and product design and project management software (Peng et al., 2014).

This study finds a significant positive impact of tools – online communities, net ethnography, virtual shopping, and semiotics – on NPD collaboration which in turn improves a firm’s overall NPD performance. While this finding contradicts Marion et al. (2014) who found no significant impact of online communities on NPD collaboration, it supports and improves recent qualitative research (e.g. Bugshan, 2015) suggesting that interconnectivity of people generates social capital for firms (value of a firm generated by community), which drives collaborative innovation. The indirect positive impact of collaborative design systems on overall NPD performance provides empirical justifications to the research highlighting the advantages of modern advanced collaborative CAD tools (Fuh & Li, 2005; Goel, Vattam, Wiltgen, & Helms, 2012). Furthermore, the revealed indirect positive effect of groupware on overall NPD performance contributes to literature that is mainly available as qualitative research findings (e.g. Boutellier et al., 1998; Evans et al., 2015). By exploring an indirect positive impact (through collaboration) of online focus groups/online surveys and customer requirement analysis software on overall NPD performance, this study supports and extends Durmusoglu and Barczak (2011) that found a significant positive impact of online needs surveys on NPD effectiveness.

6.5.2 Limitations and suggestions for the final research phase

Although this preliminary study provides significant implications concerning the impact of individual ICT tools on NPD performance, it has some limitations mainly due to the use of secondary data. Many of these limitations could be overcome in the final research phase which utilizes primary data and performs more comprehensive evaluations of the impact of ICT usage on collaborative product development performance. For example, this study has measured the usage of each ICT tool using a single item of a 5-point Likert scale (Table A1 in Appendix 6.1). Therefore, extending the scale and adopting multi-item measures of ICT usage (e.g. proficiency and intensity of use) identified in the main study would evaluate the impact of ICT use on CPD performance with better accuracy. Furthermore, the descriptive statistical results of this preliminary study offer valuable practical implications for the conduct of the final survey. For instance, insufficient statistical evidence in the regression analysis, for primary product type as a significant factor affecting the relationship between ICT tools usage and NPD performance is a limitation of this study. However, according to the confidence intervals analysis, usage of several ICT tools (e.g., collaborative and virtual design tools and PDM systems) is significantly low in service sector organizations. Therefore, both technology base and primary product type are suggested as vital organizational demographics to be considered when conducting the final survey. No attempt was made in this study to examine the effects of other categorical variables: geographical region or specific industry of firms (capital goods, chemicals etc.). The main reason for this was the sample size requirement of the hierarchical regression analysis performed. However, this would not seriously affect the results since most firms are operated in various regions, and technology base and primary product type adequately represent the information processing requirements of different industries. More specific and accurate results on the impact of ICT usage can be expected in the final survey by limiting it to a certain level of technology and a primary product type (manufacturing industry). While the study found no significant direct or indirect impact of some ICT tools (e.g. rapid prototyping systems, performance modeling and simulation systems, virtual design tools, portfolio management software, and software systems to connect technology specialists within firms) on NPD performance, these tools may have indirect impact through other collaboration outcomes such as knowledge exchange. Due to the unavailability of required data in the secondary data source (CPAS 2012), this study could not fully address the collaboration performance construct conceptualized in the main research model which comprises several collaboration outcomes (sharing of benefits, knowledge, information, and risks and trust creation). However, the study has observed significant correlations between all the ICT tools and NPD collaboration. Therefore, it is further expected that the final quantitative study could reveal a significant positive indirect impact of overall ICT usage through collaboration performance on new product performance. Although the survey instrument with self-reported measures of project success is a limitation of this study, using a post hoc test, it has been confirmed that the resulting risk of common method bias is not considerable.

7. Development of Hypotheses and Survey Instrument

7.1 Introduction

Drawing on the relational resource-based view (RRBV) and the organizational information processing theory (OIPT), a research model was initially developed based on the available literature (Chapter 4). Next, a preliminary study (Chapter 5) was conducted to qualitatively assess the constructs and relationships in the initial conceptual model and to finalize a model to be tested in this final quantitative study. This chapter develops the research hypotheses and the survey instrument based on the finalized model (Figure 5.2). In addition, it presents the details on conduct of the survey and composition of the sample. Finally, the data are utilized to validate the survey instrument using the partial least squares (PLS) approach.

7.2 Development of Hypothesis

This section develops hypotheses to answer the last two research questions of the study using appropriate literature and industry evidence gathered in the previous qualitative research phase. These questions are:

- Does ICT usage have a significant impact on CPD performance?
- Do the project characteristics representing the information processing requirement in CPD projects significantly moderate the relationship between ICT usage and CPD performance?

The RRBV emphasizes achieving competitive advantage through collaborations (Wang & Li-Ying, 2015). As explained in Chapter 4, RRBV provides the underlying theoretical foundation for hypothesising a direct and indirect positive impact of ICT usage on new product performance through collaboration performance. Furthermore, the OIPT which argues the need for balancing information processing capability with information requirements to achieve organizational performance (Daft & Lengel, 1986; Galbraith, 1984) enables the theorizing of varied degrees of performance for CPD projects with different levels of complexity and uncertainty, based on the ICT usage in these projects (i.e. the moderating effects of project characteristics). The development of specific hypotheses for the above effects is presented in the following sections.

7.2.1 Direct and indirect impact of ICT usage on CPD performance

According to Bstieler and Hemmert (2008), communication quality is an antecedent of trust creation in CPD teams. Proper management of ICT ensures improved quality of communication. ICT is the major enabler of intra-/inter-organizational integration and collaboration of dispersed R&D teams (Camarinha-Matos et al., 2009; Lockwood et al., 2013). Therefore, some studies have shed light on the impact of ICT usage on intangible outcomes such as NPD collaboration (Peng et al., 2014), knowledge transfer (Corso & Paolucci, 2001), and creation of trust (Lockwood & Massey, 2012). However, these studies have not suggested collaboration performance as a dimension of CPD performance that represents outcomes achieved through collaboration, or examined the indirect impact of overall ICT usage on new product success through collaboration performance. Banker et al. (2006) who found a direct and indirect positive impact of collaboration software on NPD performance through collaboration did not consider overall ICT usage or all facets of collaboration performance captured in the present study. Previous qualitative research emphasized that the use of ICT offers collaboration outcomes such as the development of an informal network, coordination support, and information/knowledge transfer that could lead to positive or negative impact on long-term project performance (e.g. Boutellier et al., 1998; Corso & Paolucci, 2001). According to the product development and ICT professionals participated in the qualitative preliminary study, using ICT in CPD provides various collaboration-related benefits to manufacturing firms. These are: sharing knowledge and skills between partners, information security, sharing project risks and benefits, and improved partner trust through continuous project updates. However, the same study identified the low responsiveness and contribution of partners, and failing to make required information available as potential barriers to acquiring these benefits from the use of ICT in CPD. In these premises, it is worthwhile to empirically investigate the association between ICT usage and collaboration performance, by testing the following hypothesis:

H_{1a}: ICT usage has a positive direct effect on collaboration performance of a CPD project.

Quality of product innovation is characterised by technical performance, conformance to design specifications, meeting projected product scope, customer satisfaction, and relative quality compared to competitors' products (Durmusoglu & Barczak, 2011;

Thomas, 2013). Information integration in R&D teams has a positive association with new product quality (Sethi, 2000). As ICT tools largely support information integration and overall NPD performance in high-tech CPD projects (preliminary quantitative study), a positive impact of ICT usage is expected on a new product's quality. Supporting this hypothesis, the preliminary qualitative study suggested that ICT usage increases manufacturer' potential to: include customer-desired features in new products, enhance quality in future products, and ensure high design conformance and technical performance. However, the study also found that various technical and human issues as well as context-specific issues such as inability of customers to provide correct information about the end user requirements and organizational issues such as frequent changing of ICT tools may disturb achieving the expected quality in new products.

Bhatt and Ved (2013) state that communication tools enable the gathering of fast and real-time customer feedback which offers important inputs for introducing customized features to new products. According to Steinmueller (2000), codified knowledge from past projects that is stored and accessible with information and knowledge management systems, helps in improving technical performance through a fewer number of failures. Such qualitative research findings need more systematic empirical justifications for the effect of ICT usage on new product quality. Using a large sample survey, Durmusoglu and Barczak (2011) found a positive direct impact of tools such as e-mail, decision support systems, file transfer protocols, online needs surveys, virtual prototyping, and concept testing software on new product quality and no significant impact of several other tools (Web-meetings, shared drives, secondary data). Since the above study simply evaluated whether or not using the ICT tools in a CPD project, the findings could be improved though examining the direct impact on new product quality using the three-dimensional (frequency, proficiency, and intensity) ICT usage construct proposed.

H_{1b}: ICT usage has a positive direct effect on new product quality.

Furthermore, tools such as PLM systems support collaboration by facilitating increased visibility into the product data and the process of design iteration (Banker et al., 2006). This leads to reducing possible defects in product designs which, in turn improves quality. Tools such as e-mail facilitate knowledge exchange with suppliers, which helps in improving a new product's technical performance (Thomas, 2013). Recently in a qualitative study, Coenen and Kok (2014) suggested that the use of ICTs in distributed

CPD teams results in collaboration-based outcomes including knowledge-sharing and trust creation, which in turn improves new product quality. Therefore, establishing the indirect effect of overall ICT usage on new product quality, through collaboration performance comprising several collaboration outcomes – sharing of knowledge, risks, benefits and creation of trust, in a large quantitative study will significantly contribute to the literature.

H_{2a}: ICT usage has a positive indirect effect on new product quality, through collaboration performance.

ICT is a critical strategic success factor that has a significant impact on a firm's overall financial performance (Gursoy & Swanger, 2007; Melville, Kraemer, & Gurbaxani, 2004). With regard to CPD projects in manufacturing firms, the qualitative preliminary study identified reducing wastages of money, labour, and material, better cost management, finding new market opportunities, and increasing financial returns as positive outcomes of ICT usage. In product innovations, ICTs directly reduce product design staff costs through increased automation, and reduced telecommunication and travelling costs by facilitating real-time communication (Banker et al., 2006). Therefore, higher profits are likely from an increased use of ICT in collaborative product development. However, according to the industry viewpoint explored in the preliminary study, manufacturing firms sometimes fail to achieve expected level of commercial success in CPD projects due to difficulty in recovering high costs of ICT tools implemented and not utilizing the capacity of existing tools.

ICT tools improve CPD teams' ability to adopt customer desires in the new products and enable the collection of important market information from relevant sources (e.g., secondary databases). This leads to higher market share and greater opportunity to achieve price targets. Vaccaro et al. (2010) found that increased reliance on knowledge management ICT tools improves CPD projects' financial performance. Supporting these findings, a few other research revealed a positive direct association between overall ICT usage or several ICT tools and a new product's market performance (e.g. Barczak et al., 2007; Durmusoglu & Barczak, 2011). However, a relatively low or insignificant impact of overall ICT usage or some ICT tools has been revealed in these studies as well as in the preliminary quantitative study conducted using PDMA's 2012 CPAS survey as secondary data. Therefore, in order to support these literatures and preliminary findings using an aggregate measure of overall ICT usage, the present study suggests a positive direct impact of ICT usage in terms of frequency, proficiency, and intensity of use on a CPD project's commercial success.

H_{1c}: ICT usage has a positive direct effect on a new product's commercial success.

High-technological firms have an increased need for the involvement of customers, suppliers, and strategic partners to share relatively higher product development costs and risks (Gupta & Wilemon, 1990). In high-tech CPD projects, some manufacturers have experienced that collaboration outcomes including sharing of knowledge, benefits, and risks help in attaining higher financial returns and quality improvements (e.g. Figueiredo et al., 2008). However, as many CPD practitioners believe, collaborations lead to high costs due to the time and effort required to manage the complications associated (Bruce, Leverick, Littler, et al., 1995). The contribution of ICT in reducing such collaboration complexities can be substantial and the frequent, proficient, and intensive use of ICT tools would assist in this. According to Kleinschmidt et al. (2010), sharing benefits such as opening new markets, which leads to high overall project performance, is possible with increased use of ICT in global CPD projects. Proper use of ICT helps in the creation of trust between virtually engaged product development partners (Thomas & Bostrom, 2008; Coenen & Kok, 2014). In a qualitative investigation, Fawcett, Jones, and Fawcett (2012) suggest that trust created through collaborative innovations helps in achieving higher competitive performance including cost competitiveness. Based on these arguments, the present study attempts to empirically establish a positive indirect association of ICT usage with CPD projects' commercial success, through collaboration performance.

H_{2b}: ICT usage has a positive indirect effect on a new product's commercial success, through collaboration performance.

Fast communication and concept testing and concurrency of design/development activities are facilitated by many modern ICT tools. According to the preliminary qualitative study, usage of ICT provides a number of benefits related to CPD project's time performance. These are: increased responsiveness to engineering changes suggested, fast finalization of technical specifications, and efficient marketing of the new products. However, existing literature does not support a strong argument regarding the positive direct effect of overall ICT usage on CPD projects' time performance. For example, Barczak et al. (2007) found no significant direct effect of ICT usage on speed-to-market. Heim et al. (2012) observed strong and weak positive associations of design/validation software tools with product performance quality and time-to-market respectively. In a study focusing on knowledge management ICT tools Vaccaro et al. (2010) found that higher use of these tools improves speed-to-market. Advanced collaborative functionalities available in ICT tools such as PLM systems can significantly reduce development cycle times, enabling real-time communication between partners (Banker et al., 2006). A negative impact of Web-based communication and collaboration ICT on time performance was evident in some studies (e.g. Oke & Idiagbon-Oke, 2010; Thomas, 2013). The preliminary qualitative study also revealed that technical issues such as disruptions due to technical or power failures and synchronized access problems, as well as human issues such as low commitment and less self-motivation to use the right tool at the right time, are some ICT-related barriers to achieving time objectives of CPD projects. According to these literatures, further examination of the relationship between overall ICT usage and time performance is essential. The improved ICT usage measurement used in this study is expected to reveal more reliable findings on this association. Therefore, a hypothesis which posits a positive direct impact of ICT usage on CPD time performance is tested in this study.

H_{1d}: ICT usage has a positive direct effect on a new product's time performance.

Furthermore, a collaboration process facilitated by ICT increases the ability to review past designs, make rapid changes to new products and hence reduce the development cycle times (Banker et al., 2006). Fawcett et al. (2012) emphasized that collaboration outcomes such as knowledge-sharing and trust creation lead to improving CPD project performance including time performance. However, from the CPD practitioners' point of view, managing collaborations may make product development projects longer (Bruce, Leverick, Littler, et al., 1995). In high-tech industries where technologies become obsolete quickly, sharing designs, investment, and market risks and benefits among external partners would be relatively more important in achieving time targets (Figueiredo et al., 2008; Gupta & Wilemon, 1990). These firms are often engaged in virtual collaborations and essentially are dependent on ICT tools even for face-to-face communication. It is common that dispersed CPD teams use ICT tools for most product development activities to gain collaborative advantages such as knowledge-sharing and cross-functional and inter-organizational involvement, which in turn improve a CPD project's time performance (Coenen & Kok, 2014). Since most existing literatures are based on case studies, and others have not considered different aspects of collaboration performance, a significant positive indirect impact of ICT usage through collaboration performance on CPD projects' time performance is hypothesised in view of the RRBV.

H_{2c}: ICT usage has a positive indirect effect on a new product's time performance through collaboration performance.

7.2.2 Moderating effect of project complexity

Based on extant literature and appropriate industry evidence gathered in the qualitative preliminary phase, the present study conceptualizes and operationalizes CPD project complexity as a single construct which has product and network complexity dimensions. The collaboration performance represents outcomes gained through collaboration between CPD team members. In a study which captured project complexity nearly similar to this study, Kim and Wilemon (2003) emphasized that CPD teams engaged in more complex projects gain from the learning experienced during the process of CPD through struggling and collaborating to manage the complexities. When a product involves a large number of tasks and interdependencies among those tasks, the product becomes more complex. Complex products with many parts to be designed or many design constraints, need to process relatively large amounts of information using ICT tools in product designing, information management, market research and analysis (Heim et al., 2012; Peng et al., 2014).

In CPD projects with many members involved from various locations, the exchange of existing structured information, and information related to the newly-designed parts, is relatively difficult. Peng et al. (2014) found different moderating effects of different complexity dimensions on the association between ICT usage and NPD collaboration. According to their study, ICT tools have a stronger effect on NPD collaboration when the product is large, but a smaller effect when interdependence of tasks is relatively high. However, in projects with relatively higher project and network complexities, the final product is an outcome of the collective effort and inputs received from the large number of partners involved. Participants in the qualitative preliminary study emphasized that ICT tools support successful collaborations in terms of the sharing of knowledge, risks, and benefits among CPD partners, particularly in complex projects. The practitioners were of the opinion that this occurs through facilitating frequent communication, the sharing of updated information, and timely access to relevant critical market and product-related data. Therefore, in the light of the OIPT, this study argues that there is a greater possibility of achieving higher collaboration performance through increased ICT usage in complex CPD projects.

H_{3a}: The direct relationship between ICT usage and collaboration performance will be stronger in CPD projects with greater complexity.

According to the CPD practitioners' viewpoint in the preliminary study, firms rarely manage the use of ICT tools up to the increased requirement of information processing in more complex or uncertain projects. However, a study looking into the variance of the direct impact of ICT usage on new product success across different levels of CPD project complexity or uncertainty was not found in the literature. Due to the difficulty in coordinating information from a large variety of sources, achieving greater quality can be challenging in complex global CPD projects (Kim and Wilemon, 2003). Therefore, the hypothesised positive association between ICT usage and new product quality can be lower when the product becomes more complex.

H_{3b}: The direct relationship between ICT usage and new product quality will be lower in CPD projects with greater complexity.

However, this moderating effect on the direct impact could be different in respect of the indirect relationship between ICT usage and new product quality through collaboration performance. Recently Açıkgöz, Günsel, Bayyurt, and Kuzey (2014) found that team cognition improves product quality particularly in relatively complex products. Although this study focused on software products, the association can be relevant for physical products with greater technological and knowledge intensity and involving a number of partners in the development process. Ability to gather information from inside and outside of the organization characterizes team cognition and greater use of ICT tools essentially helps in this. Proper documentation of lessons learned in previous projects is important to reduce failures in future development projects (Kim & Wilemon, 2003). Firms handling complex projects with higher use of ICT tools have a better ability to maintain product related information and knowledge, and to share them appropriately. For this reason, they can gain greater collaboration success and achieve higher quality through the improved collaboration performance. Therefore, a positive moderation of project complexity for the indirect impact of ICT usage on new product quality is posited.

H_{4a}: The indirect relationship between ICT usage and new product quality through collaboration performance will be stronger in CPD projects with greater complexity.

ICT tools mainly support the handling of structured information and facilitate systematic procedures in CPD. More complex CPD projects need organizations to have more systematic and structured plans than low-complex projects. Therefore, with some level of ICT usage, achieving a higher level of profitability will be easier for a low-complex CPD project compared to a high-complex project. Supporting this argument, Ignatius, Leen, Ramayah, Hin, and Jantan (2012) found that the association between information interpretation and an NPD project's commercial success is higher in low-complex projects. Explaining this relationship, the authors made the point that low-complex projects are low in project risks and the interpretation of information received is easier than that is in high-complex projects. Particularly, R&D staffs having higher ICT proficiency are better able to interpret information since they have greater knowledge and experience in acquiring relevant information and using it within a CPD project. Therefore, a negative moderating effect of project complexity is expected on the direct relationship between ICT usage (which also incorporates a proficiency dimension) and the commercial success of a CPD project.

H_{3c}: The direct relationship between ICT usage and a new product's commercial success will be lower in CPD projects with greater complexity.

However, previous research suggests a higher significance of collaboration in achieving greater project success in more complex projects (Açıkgöz et al., 2014; Ahmad et al., 2013). This is possible through the better sharing of information on new market opportunities and uncovering easier ways to include customer requirements in new products. In their study based on the OIPT, Ahmad et al. (2013) found a positive interaction effect of project complexity and team integration on overall NPD performance including financial returns. As integration of projects with higher collaboration performance is likely to be high, a positive moderation of project complexity is expected on the direct path from collaboration performance to a new product's commercial success. Complex products are not easily duplicated by competitors (Kim & Wilemon, 2003). Greater collaboration performance means successfulness in sharing knowledge, risks, and benefits and building trust. Teams that are capable of higher performance in terms of these aspects can maintain better control over the leakage of technological information through increased integration, and hence retain their competitive position in the market. Also, the previously hypothesised moderating impact of project complexity on the direct effect of ICT usage on collaboration performance is positive. Therefore, the indirect association between ICT usage and commercial success through collaboration performance is expected to be positively moderated by a CPD project's complexity.

H_{4b}: The indirect relationship between ICT usage and a new product's commercial success through collaboration performance will be stronger in CPD projects with greater complexity.

Greater degrees of partner involvement in complex projects usually make the conceptualization stage longer. A larger number of parts, design constraints, and dependencies take up more time in the development stage (Kim & Wilemon, 2003). Iterations make the scheduling process difficult as the outcome of some of those iterations is uncertain. In complex CPD projects where several iterations need to be carried out before finalizing a design, the estimation of time frames is difficult due to these scheduling problems (Chen, Ling, & Chen, 2003). Thus, CPD projects with low complexities are easily managed since the lesser number of partners involved can be informed and coordinated speedily with the use of ICT. Therefore, a negative moderating effect of project complexity is hypothesised for the direct impact of ICT usage on a new product's time performance. However, the earlier hypothesised positive moderating effect of project complexity over the relationship between ICT usage and collaboration performance implies that in complex projects ICT contributes more to increasing collaboration performance. Furthermore, collaboration outcomes such as knowledge-sharing and shared problem solving enabled by effective ICT use improve the time efficiency of CPD projects (Coenen & Kok, 2014). Therefore, a positive moderating effect of project complexity is proposed for the indirect relationship between ICT usage and time performance, through collaboration performance.

H_{3d}: The direct relationship between ICT usage and a new product's time performance will be lower in CPD projects with greater complexity.

H_{4c}: The indirect relationship between ICT usage and a new product's time performance through collaboration performance will be stronger in CPD projects with greater complexity.

7.2.3 Moderating effect of project uncertainty

The uncertainty of a CPD project increases if the product, process, or market is new to the firm (Heim et al., 2012). Firms using ICT tools in CPD projects with varied levels of uncertainty may experience different effects of ICT usage on performance dimensions. However, research that has studied the moderating effect of project uncertainty on the relationship between ICT usage and CPD performance is rare to find. In a study, Peng et al. (2014) found a negative moderating effect of project novelty on the relationship between ICT usage and NPD collaboration. They argue that ICT tools facilitate the transfer of more explicit structured information rather than new unestablished knowledge on product and process technologies and the market. Since the transfer of clear information is essential for improving collaboration outcomes such as sharing of knowledge, risks, benefits, and trust creation, a negative moderating impact of project uncertainty on the direct association between ICT usage and collaboration performance is proposed.

H_{5a}: The direct relationship between ICT usage and collaboration performance will be lower in CPD projects with greater uncertainty.

Although it was not statistically supported, Song and Montoya-Weiss (2001) hypothesised a positive moderating effect of an NPD project's technological uncertainty on the relationship between development process proficiency and project outcomes. In high-technological industries, a higher use of ICT tools implies that R&D people have a greater proficiency in the CPD process because these tools are the primary means for developing new products in these industries. In addition, Tatikonda and Rosenthal (2000) revealed a positive association between product technology novelty and technical performance of the new product, and a positive association between market newness and customer satisfaction. Supporting these literatures, Sicotte and Bourgault (2008) found that market uncertainty positively moderates the association between project methods and project performance in terms of efficiency and effectiveness. In addition Salomo, Steinhoff, and Trommsdorff (2003) emphasized that increased market orientation better contributes towards NPD success when the product is new. These literatures support the proposition that CPD teams handling novel (uncertain) projects make more intensive use of ICT for managing and planning project activities, gathering and analysing market information, product designing, and prototyping. Then there would be a greater possibility for achieving customer-desired quality and higher commercial success in these projects.

Furthermore, Bstieler (2005) empirically established a positive moderating effect of technological uncertainty on the relationship between the technological proficiency and time efficiency of CPD projects. The ICT usage construct operationalized in the present study broadly represents information processing capability in terms of frequency, proficiency, and intensity of ICT use. Also, uncertainty in product and process technologies are the key dimensions of project uncertainty considered in this study. Therefore, addressing the respective gaps in the literature, this study posits a positive moderating effect of project uncertainty on the direct relationship between ICT usage and new product performance represented by quality, commercial success, and time performance.

H_{5b}: *The direct relationship between ICT usage and new product quality will be stronger in CPD projects with greater uncertainty.*

H_{5c}: *The direct relationship between ICT usage and a new product's commercial success will be stronger in CPD projects with greater uncertainty.*

H_{5d}: *The direct relationship between ICT usage and a new product's time performance will be stronger in CPD projects with greater uncertainty.*

Song and Montoya-Weiss (2001) found that the positive effect of cross-functional integration on a CPD project's financial performance is stronger in conditions of high technological uncertainty. In contrast, Brettel, Heinemann, Engelen, and Neubauer (2011) found that the impact of cross-functional integration on NPD effectiveness and efficiency is lower in more uncertain and radical project conditions. Furthermore, they suggested that the relationships between different types of integrations and NPD performance are complex and varied across project phases. According to Dayan and Di Benedetto (2010), in CPD projects where the tasks are relatively new and not defined clearly, trust created among partners better helps in achieving project success. Overall, these literatures provide inconclusive evidence for the interaction effect of project uncertainty with some collaboration outcomes (e.g. trust and team integration) on NPD performance. Thus, sufficient empirical evidence for the moderating effect of project uncertainty, in relation to all collaboration performance elements conceptualized in the present study, was not found. As emphasized in the earlier hypothesised negative moderating effect of project uncertainty on the association between ICT usage and collaboration performance, opportunities to reach collaboration-related outcomes by increasing ICT usage is relatively low when the project is highly uncertain. Therefore, a negative moderation of project uncertainty over the indirect relationship between ICT usage and new product performance (quality, commercial success, and time performance) is expected.

H_{6a}: *The indirect relationship between ICT usage and new product quality through collaboration performance will be lower in CPD projects with greater uncertainty.*

H_{6b}: *The indirect relationship between ICT usage and a new product's commercial success through collaboration performance will be lower in CPD projects with greater uncertainty.*

H_{6c}: *The indirect relationship between ICT usage and a new product's time performance through collaboration performance will be lower in CPD projects with greater uncertainty.*

Table 7.1 summarizes all the hypotheses developed above and Figure 7.1 shows the conceptual research model including these hypotheses.

Table 7.1: Hypotheses of the main study

Direct effects
H_{1a}: ICT usage has a positive direct effect on collaboration performance of a CPD project.
H_{1b}: ICT usage has a positive direct effect on new product quality.
H_{1c}: ICT usage has a positive direct effect on a new product's commercial success.
H_{1d}: ICT usage has a positive direct effect on a new product's time performance.
Indirect effects
H_{2a}: ICT usage has a positive indirect effect on new product quality, through collaboration performance.
H_{2b}: ICT usage has a positive indirect effect on a new product's commercial success, through collaboration performance.
H_{2c}: ICT usage has a positive indirect effect on a new product's time performance through collaboration performance.
Moderating effects on the direct effects
H_{3a}: The direct relationship between ICT usage and collaboration performance will be stronger in CPD projects with greater complexity.
H_{3b}: The direct relationship between ICT usage and new product quality will be lower in CPD projects with greater complexity.
H_{3c}: The direct relationship between ICT usage and a new product's commercial success will be lower in CPD projects with greater complexity.
H_{3d}: The direct relationship between ICT usage and a new product's time performance will be lower in CPD projects with greater complexity.
H_{5a}: The direct relationship between ICT usage and collaboration performance will be lower in CPD projects with greater uncertainty.
H_{5b}: The direct relationship between ICT usage and new product quality will be stronger in CPD projects with greater uncertainty.
H_{5c}: The direct relationship between ICT usage and a new product's commercial success will be stronger in CPD projects with greater uncertainty.
H_{5d}: The direct relationship between ICT usage and a new product's time performance will be stronger in CPD projects with greater uncertainty.
Moderating effects on the indirect effects
H_{4a}: The indirect relationship between ICT usage and new product quality through collaboration performance will be stronger in CPD projects with greater complexity.
H_{4b}: The indirect relationship between ICT usage and a new product's commercial success through collaboration performance will be stronger in CPD projects with greater complexity.
H_{4c}: The indirect relationship between ICT usage and a new product's time performance through collaboration performance will be stronger in CPD projects with greater complexity.
H_{6a}: The indirect relationship between ICT usage and new product quality through collaboration performance will be lower in CPD projects with greater uncertainty.
H_{6b}: The indirect relationship between ICT usage and a new product's commercial success through collaboration performance will be lower in CPD projects with greater uncertainty.
H_{6c}: The indirect relationship between ICT usage and a new product's time performance through collaboration performance will be lower in CPD projects with greater uncertainty.

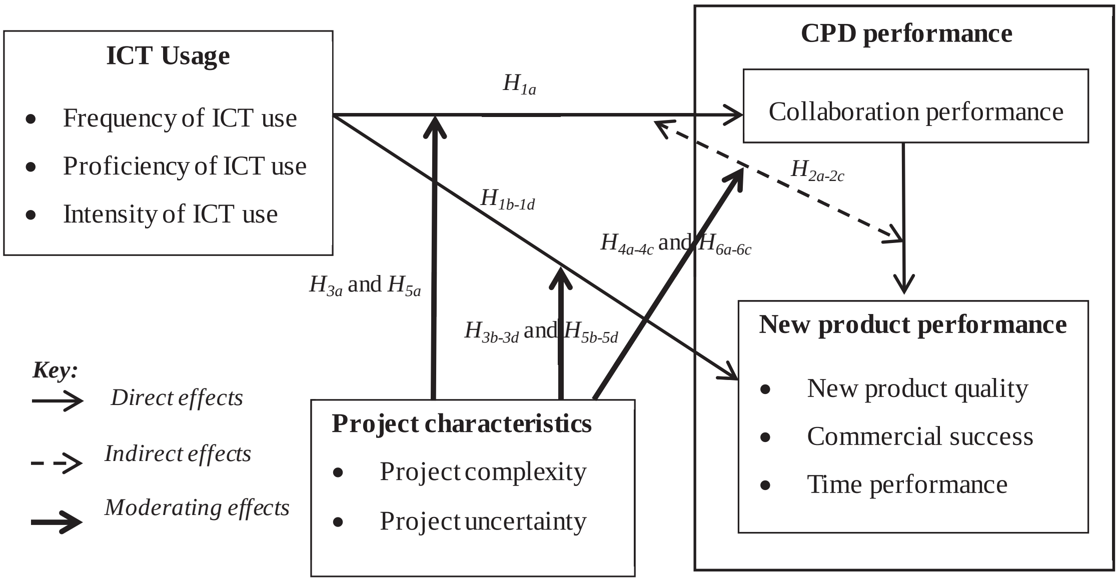

Figure 7.1: Conceptual research model and hypotheses

7.3 Measurement Instrument Development

The major constructs included in the conceptual model (Figure 7.1) are: ICT usage, project characteristics, collaboration performance, and new product performance. ICT usage comprises frequency, proficiency, and intensity of use as its dimensions. CPD performance is represented by collaboration performance and three constructs for new product performance – quality, commercial success, and time performance. Although some of these constructs (e.g. quality, project complexity) have been used in previous studies, the present study adopts these constructs with several modifications (explained in the following paragraphs) being in line with the aims and scope of the study. Although prior research has suggested some dimensions of ICT usage (e.g. frequency and proficiency) in order to better understand the effect of ICT on product development performance, (e.g. Durmusoglu & Barczak, 2011) only a few (e.g. frequency) have been considered so far (Kawakami et al., 2015). Drawing on these literatures, and considering other possible indicators of ICT usage, this study adopts three ICT usage measures, namely, frequency, proficiency, and intensity. In addition to the direct effects of ICT usage on key NPD performance aspects for which sufficient empirical evidence is unavailable (Barczak et al., 2007; Kawakami et al., 2015), some research have highlighted the significance of exploring indirect impact through collaboration-based outcomes (Coenen & Kok, 2014) and moderating factors affecting the ICT usage-CPD performance relationship (Thomas, 2013). Therefore, this study conceptualized (Chapter 4 and Chapter 5) collaboration performance comprising several collaboration outcomes as a mediator, and project complexity and uncertainty as important moderators to be examined.

Drawing the operational definitions or defining constructs with more concrete and quantifiable indicators is the core of a measurement instrument development (Kimberlin & Winterstein, 2008). Therefore, operational definitions and suitable measurement items for each individual model construct were carefully synthesized through in-depth reviews of related constructs utilized in past studies and the results of the preliminary qualitative investigation. The following paragraphs discuss the development of the measurement instrument used in the survey. In order to avoid examining only the effects of a few key ICT tools on CPD performance, this study adopts a broad ICT classification (communication/collaboration tools, product design/development tools, project management tools, information/knowledge management tools, and market research/analysis tools) (Barczak et al., 2007; Peng et al., 2014), so that any ICT tool used in CPD would be classified under one of these categories.

Frequency of ICT use:

Frequency of use is an ICT usage aspect adopted in past surveys in the product development discipline. In one study, Montoya et al. (2009) considered the frequency of using several ICT tools for specific tasks such as gathering and exchanging work-related information, problem solving, and decision making. In their study, the responding team members had been asked to rate the frequency of ICT use in a five-point Likert scale (1=never to 5=all the time). However, this study only addressed communication and collaboration ICTs such as video conferencing, telephone/teleconferencing, e-mail, and shared document repositories. Recently Kawakami et al. (2015) used frequency of ICT use for evaluating how often (1=not at all; 5=very often) ICTs (e.g. video conferencing, online customer needs surveys, shared files and drives) have facilitated a variety of CPD tasks such as communication, collaboration, designing, and market research. Furthermore, the respondents of the qualitative preliminary study (Chapter 5) highlighted that the use of communication/collaboration ICTs in early product development stages is a vital factor for achieving higher performance in CPD projects. Therefore, the present study operationalizes frequency of ICT use as the rate of using: (1) communication and collaboration ICT tools in early product development stages, (2) communication and collaboration ICT tools in development and commercialization stages, (3) product design and development ICT tools, (4) knowledge and information management ICT tools, (5) project management ICT tools, and (6) market research and analysis ICT tools, in a CPD project.

Proficiency of ICT use:

Prior research adopting proficiency of use as an ICT usage dimension was not found in CPD literature. However, Durmusoglu and Barczak (2011) suggested proficiency as a suitable measure of ICT usage in CPD projects. In addition, the qualitative preliminary study provided several important inputs for developing proficiency as a sub-construct of the main ICT usage construct. Drawing on the views of participants of the qualitative investigation, proficiency of ICT use is operationalized as the level of proficiency attained by R&D staff (1) in using simple ICT tools, (2) in using advanced ICT tools, (3) through effective training given on the new ICT tools, (4) by easily adopting the new tools, and (5) via considering ICT proficiency as a major factor when recruiting R&D staff.

Intensity of ICT use:

Intensity of use has not been previously adopted in CPD studies for evaluating overall ICT usage in projects. Based on available literature on utilization of functionalities in ICT tools in CPD activities (Bhatt & Ved, 2013; Kern & Kersten, 2007), this study has put forward an argument that overall ICT usage could depend on the utilized proportion of functionalities in the ICT tools or intensity of use. Due to insufficient evidence on the suggested ICT usage dimension, findings of the qualitative preliminary study were incorporated to operationalize intensity of ICT use as the utilized percentages of capacities, features, and functionalities of: (1) communication and collaboration ICT tools, (2) product design and development ICT tools, (3) knowledge and information management ICT tools, (4) project management ICT tools, and (5) market research and analysis ICT tools, in a CPD project.

Project complexity:

Project complexity is not a new construct and has been adopted in a number of CPD studies. Most of the studies addressed the complexity of a new product in terms of the product scope, size, and interdependence of tasks (Ahmad et al., 2013; Heim et al., 2012; Peng et al., 2014). Based on limited research considering participant involvement in defining the complexity of a CPD project (e.g. Swink, Talluri, & Pandejpong, 2006), this study further investigated project complexity with the qualitative data gathered prior to the main survey. Based on findings of the qualitative study (Chapter 5) and related literature, project complexity is operationalized as the degree of complexity of a CPD project characterized by collaborative network complexity (the number of participants involved in the project and the intensity of their involvement) and product complexity (the number of tasks involved, interdependence of tasks, total number of parts, number of parts to be designed, and the number of design constraints).

Project uncertainty:

Project uncertainty is a project characteristic which has been widely adopted in past survey-based CPD studies (Ahmad et al., 2013; Heim et al., 2012). Newness of the product, process, and the market has been focused on in these studies within the scope of project uncertainty. However, the qualitative study conducted prior to the main survey suggested uncertainty as a project characteristic which has common underpinnings with project complexity. Recent literature supporting this argument was also found (Peng et al., 2014). Therefore, the survey instrument adapts the following items: (1) newness of the product technology, (2) newness of the process technology, and (3) newness of the market for operationalizing project uncertainty. An exploratory factor analysis performed on all the items developed for the two project characteristics (complexity and uncertainty) resulted in two dimensions, clearly identifying project uncertainty and complexity as two separate factors (results of the analysis are presented later in this chapter).

Collaboration performance:

Collaboration performance is a new construct included in this survey while NPD collaboration which refers to the frequency of partner interactions and the extent and openness of information sharing, has been adopted in prior studies (Banker et al., 2006;

Peng et al., 2014). Extant literature suggests that the performance of CPD projects should cover collaboration outcomes in addition to the financial, quality, and time-related project outcomes (Bruce, Leverick, & Littler, 1995; Büyüközkan & Arsenyan, 2012). Based on this understanding, the present study aimed to evaluate the impact of ICT usage on collaboration-specific outcomes rather than collaboration itself. Therefore, findings of the preliminary qualitative study are essentially taken into consideration for developing the collaboration performance as a new performance aspect that could be influenced by ICT usage. Drawing on both the qualitative study and key literature on the outcomes of collaboration in product development (Littler et al., 1995), collaboration performance is defined as the level of success of a CPD project in terms of (1) sharing project benefits, (2) sharing important ideas and information, (3) knowledge-sharing, (4) risks-sharing, (5) contributing partners as expected, and (6) creation of trust between partners.

New product quality:

Quality is a performance indicator considered in many past product development studies. The preliminary qualitative study suggested quality as the main new product performance aspect that would be influenced by ICT use. Since the study conceptualizes the direct and indirect impact of ICT usage on new product quality, the measures used in past studies addressing the role of ICT or NPD collaborations were mainly considered in developing survey items for the new product quality construct. In order to assess the quality improvement, Luo, Mallick, and Schroeder (2010) used technical performance as a measure within CPD performance. Thomas (2013) considered technical performance and extent of meeting customer requirements as measures concerned with the final product quality, which was referred to as NPD effectiveness. Banker et al. (2006) evaluated product quality in terms of the number of product design errors, defects, and engineering change orders. According to Durmusoglu and Barczak (2011), relative quality in comparison with competing products and past products developed by the firm itself are appropriate indicators of the new product quality. Participants in the preliminary qualitative study highlighted that increased potential for new products with customer-desired features, high conformance to design specifications, and improved technical performance is possible with higher use of ICTs in CPD projects. Based on these findings and related measures used in prior studies, this survey operationalizes new product quality as the degree of (1) customer satisfaction,

(2) conformance quality, (3) quality relative to competing products, (4) technical performance, and (5) meeting the target scope of the new product.

Commercial success:

Many survey instruments evaluating NPD project performance essentially included indicators for financial performance (e.g. Blindenbach-Driessen, Van Dalen, & Van Den Ende, 2010; Kawakami et al., 2015; Kleinschmidt et al., 2010; Najafi Tavani, Sharifi, Soleimanof, & Najmi, 2013). The items used in these studies are the extents to which a project meets the goals related to – revenue, market share, profitability, return on investment, and development costs. Adopting similar or closely related items and other measures such as likelihood of market success, some research evaluated the market performance of NPD projects instead (Barczak et al., 2008; Durmusoglu & Barczak, 2011). Participants in the preliminary qualitative investigation agreed upon the increased chance of financial returns, cost reductions, and market success through ICT use. Based on these observations and refining existing measures of a new product's financial or market success, the present survey instrument operationalizes the commercial success construct as the level of success of a new product in meeting its (1) sales objectives, (2) profit objectives, (3) market share objectives, and (4) price targets.

Time performance:

Average product development time, average development speed, speed-to-market, and time-to-market are some time-based performance measures adopted in past product development research (Banker et al., 2006; Barczak et al., 2008; Kessler & Chakrabarti, 1999). The degree of meeting development time goals and time-to-market goals has also been adopted in some studies (Swink, 2003; Thomas, 2013). According to the perspectives of the preliminary study respondents, time-related performance is a major performance aspect affected by increased ICT usage because ICT tools facilitate the fast completion of many activities from design and development, to product launch stages. Such activities include making engineering changes, receiving updated market information, finalizing technical specifications, delivering project updates to partners, and new product marketing. Based on these responses and the measures used in past studies, this survey defines time performance as the degree to which a new product meets the time targets set for (1) concept formation, (2) development, and (3) commercialization stages, and for (4) reaching the market.

Table 7.2 presents the detailed instrument corresponding to the framework developed for evaluating the impact of ICT usage on CPD performance. It also includes the variable indices that are referred throughout the rest of this chapter and the next chapter.

Table 7.2: Measurement instrument for evaluating the impact of ICT usage on CPD performance

*FRQ (Frequency)**	
FRQ1	Frequency of using communication and collaboration ICT tools in early stages of the project.
FRQ2**	Frequency of using communication and collaboration ICT tools in development and commercialization stages of the project.
FRQ3**	Frequency of using product design and development ICT tools in the project.
FRQ4	Frequency of using knowledge and information management ICT tools in the project.
FRQ5	Frequency of using project management ICT tools in the project.
FRQ6	Frequency of using market research and analysis ICT tools in the project.
*PRO (Proficiency)**	
PRO1	Proficiency of R&D staff in simple ICT tools used in the project.
PRO2	Proficiency of R&D staff in advanced ICT tools used in the project.
PRO3	Effectiveness of training provided to staff on new ICT tools.
PRO4	Ease of adoption of the new ICT tools implemented.
PRO5**	Considering ICT proficiency as a major factor when recruiting R&D staff.
INT (Intensity)†	
INT1**	Intensity of using communication and collaboration ICT tools in the project.
INT2**	Intensity of using product design and development ICT tools in the project.
INT3	Intensity of using knowledge and information management ICT tools in the project.
INT4	Intensity of using project management ICT tools in the project.
INT5	Intensity of using market research and analysis ICT tools in the project.
*COLP (Collaboration performance)**	
COLP1	Sharing benefits between partners.
COLP2	Sharing knowledge between partners.
COLP3	Sharing important ideas and information openly between partners.
COLP4	Sharing project risks between partners.
COLP5	Contributing partners as expected.
COLP6	Creation of trust between partners.

*QUAL (New product quality)**	
QUAL1	Customer satisfaction.
QUAL2	Compliance with the specifications.
QUAL3	Quality relative to competing products.
QUAL5	Technical performance of the product.
QUAL6	Meeting the target scope of the product.
*COMS (Commercial success)**	
COMS1	Meeting sales objectives.
COMS2	Meeting profit objectives.
COMS3	Meeting market share objectives.
COMS4	Achieving the product's price targets.
*TIME (Time performance)**	
TIME1	Achieving time targets in the conceptualization phase.
TIME2	Achieving time targets in the product development phase.
TIME3	Achieving time targets in the product commercialization phase.
TIME4	Achieving time targets to reach the market.
*CMP (Project complexity)**	
CMP1	Involving many tasks.
CMP2**	Interdependency of the tasks.
CMP3	Requiring many parts to make one unit of the product.
CMP4	Having many parts to be designed.
CMP5	Having many design constraints.
CMP6	Involving many external and internal partners.
CMP7	Intensity of involvement of the partners.
*UNC (Project uncertainty)**	
UNC1	The product newness to the firm.
UNC2	The production process newness to the firm.
UNC3	Newness of the market for the product.

Note: Nine point Likert scales were used in the survey (*1= Strongly disagree, 5 = Neither agree nor disagree, 9=Strongly agree; †1= 0%, 5 = 50%, 9=100%)
**Item was removed during purification.

7.4 The Survey

This section presents details on the conduct of the survey and the sample structure, based on important qualitative variables. First, the questionnaire was reviewed by two academic experts (with appropriate research experience in the industrial engineering discipline) who were not involved in the research, for clarity and internal consistency. Next, the online questionnaire (Appendix 7.2) was prepared using Google Forms and pre-tested with two CPD practitioners from the electronics and hardware manufacturing industries. After making minor revisions to some parts of the questions based on the feedback received, a pilot survey was conducted with 50 product development professionals selected from the Product Development and Management Association (PDMA) LinkedIn group, based on their CPD experience in the manufacturing sector (according to the LinkedIn profiles of the professionals). Subsequently, an initial e-mail invitation for being connected on LinkedIn to receive the survey link, was sent to all the group members (2173) (except a few who had not activated the group messages option in their profiles) from high-tech and medium-high-tech manufacturing industries (Jaegers, Lipp-Lingua, & Amil, 2013), and had more than one year CPD experience in the current company. The profiles of these managers were not reviewed for any specific ICT-related experience. Therefore, no pro-ICT bias could influence the results. It was also ensured that the firms of the selected survey participants operate in multiple countries. The online survey link was sent to 686 managers who responded to the initial e-mail and 288 completed surveys were received resulting in a 13% total response rate. A CPD project that the respondent was recently involved in (within the last five years) was the unit of analysis.

7.4.1 Sample of the study

In the questionnaire, the participants were asked to specify the scale of their organization in the industry, according to their knowledge. In addition, two questions on the organization's annual sales and number of employees were included and these have been answered by 85% and 93% of the respondents respectively. Table 7.3 presents the median values of the average annual sales of firms in US dollars (millions) and number of employees. The table also includes the number of survey participants who answered the questionnaire and the total number of firms in each category. Additionally, the small firms were low in the usage of some ICT tools (more details on these differences are provided in Chapter 8 under descriptive statistics). Therefore, in order to avoid the impact of sample heterogeneities, three responses with industry differences (participants currently employed in low-tech industries and had not updated this in their LinkedIn profiles) and 41 (small) firms that have extremely low annual sales and number of employees relative to the industry averages were excluded.

Table 7.3: Average annual sales and number of employees in companies

Organization size		*Small**		*Medium*		*Large*		*Total*	
Industry		*Avg. annual sales ($M)*	*No. of employees*	*Avg. annual sales ($M)*	*No. of employees*	*Avg. annual sales ($M)*	*No. of employees*	*Avg. annual sales ($M)*	*No. of employees*
Automotive	Median	0.2	110	200.0	1000	4100.0	14000	705.0	5000
	N/Total	2/3	2/3	8/9	9/9	24/32	27/32	34/44	38/44
Chemicals	Median	13.5	31	600.0	700	3000.0	13500	1000.0	1350
	N/Total	2/2	2/2	6/6	5/6	11/11	11/11	19/19	18/19
Electrical/ electronic	Median	10.0	25	70.0	300	2000.0	7000	200.0	850
	N/Total	19/ 20	19/ 20	27/ 34	33/ 34	47/ 57	50/ 57	93/ 111	102/ 111
Machinery	Median	15.0	60	125.0	500	6000.0	10000	625.0	2000
	N/Total	3/6	4/6	16/ 19	19/ 19	23/ 23	22/ 23	42/ 48	45/ 48
Medical/dental instruments	Median	16.0	55	100.0	1030	2350.0	8500	250.0	830
	N/Total	4/8	8/8	11/ 14	14/ 14	12/ 13	12/ 13	27/ 35	34/ 35
Pharmaceuticals /biotechnology	Median	1.0	10	50.0	300	2000.0	5750	250.0	600
	N/Total	1/2	1/2	9/11	11/ 11	13/ 15	14/ 15	23/ 28	26/ 28
Total	Median	10.0	45	100.0	500	3000.0	10000	406.0	1300
	N/Total	31/ 41	36/ 41	77/ 93	91/ 93	130/ 151	136/ 151	238/ 285	263/ 285

*Not included in the final sample

According to the above table, the small firms in all industries have average annual sales of less than $20M. The number of employees in small firms is less than 120 whereas medium and large firms of all industries except electrical/electronic and pharmaceutical/biotechnology have more than 500 employees. Differences in annual sales and number of employees across organization sizes imply that the size of the organization mentioned by the respondents is satisfactorily reliable. Therefore, the firms that did not answer the two questions on annual sales and number of employees were assigned to one of the three scales: small, medium, or large based on their answers given to the question on the scale of the organization. After excluding the small firms as explained in the previous paragraph, there were 93 medium and 151 large companies in the final sample of 244 cases (details on the sample adequacy and relevant statistics are presented in Chapter 8).

The final sample of 244 surveys were from product developers based in 39 countries (Australia, Bangladesh, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Denmark, France, Germany, Hong Kong, India, Indonesia, Ireland, Israel, Italy, Japan, Luxembourg, Malaysia, Mexico, Netherlands, New Zealand, Nigeria, Pakistan, Philippines, Portugal, Saudi Arabia, Serbia, Singapore, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Thailand, UK, and USA). Figure 7.2 shows the industry composition of the sample.

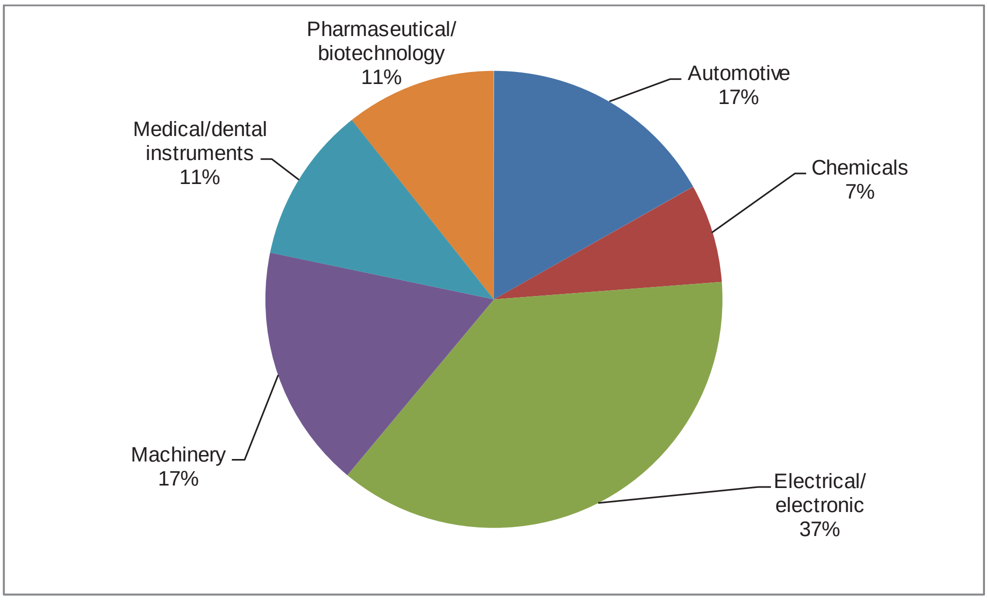

Figure 7.2: Industry composition of the sample

Figure 7.3 presents the structure of the sample based on the region and functional division of the respondents. As explained in section 7.4, it was ensured that all the respondents are from global firms and have actively participated in the CPD projects that they considered when responding to the survey, so that there is no significant effect of the functional or regional categories on the study results.

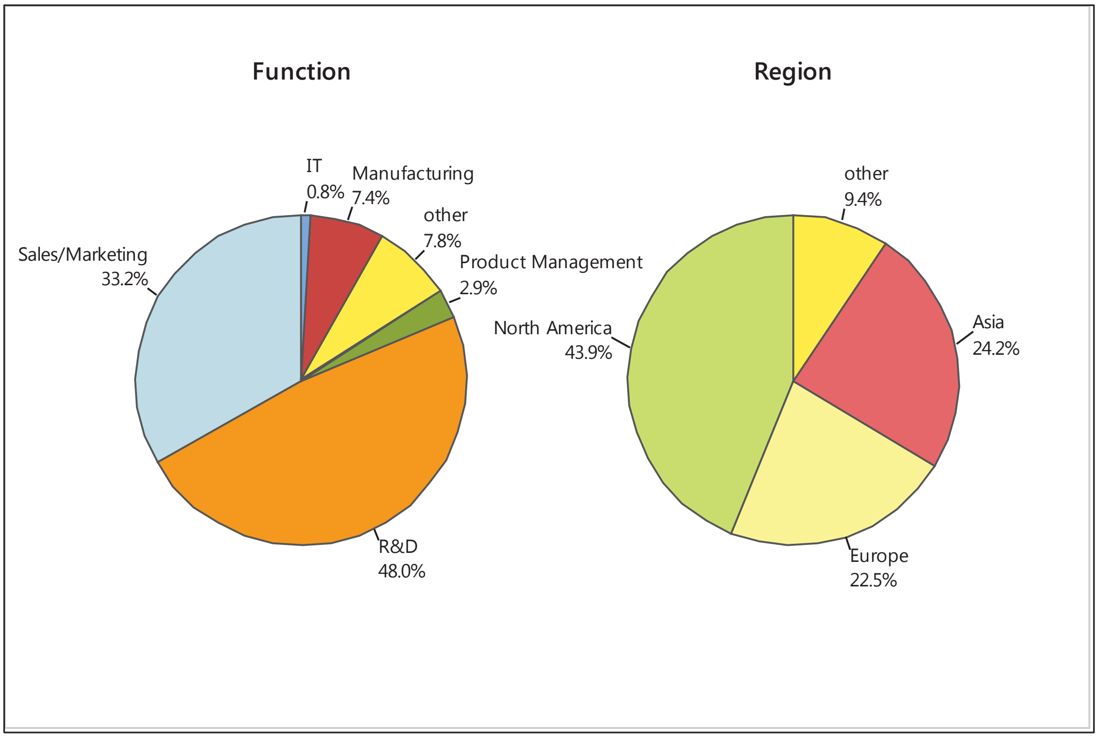

Figure 7.3: Region and function of the respondents

7.4.2 Common method bias

As the data were self-reported by individual CPD practitioners in the firms selected, there was a potential common-method bias. As a post hoc remedy to this (Podsakoff & Organ, 1986), Harman's one-factor test was performed on all the scales of the latent constructs. The unrotated exploratory factor analysis resulted in ten factors that explain 71.7% variability in the data. Since there was more than one factor and no single general factor that accounted for the majority of the variance (the largest was 32.6%), a substantial common method bias was not evident. To make the result more interpretable the rotated (Varimax) solution of the factor analysis is presented in Table 7.4. The names of variables in this table have been detailed in Table 7.2.

Table 7.4: Exploratory factor analysis on all the survey items

Item	*Factor loadings*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
FRQ1	.244	.217	.188	.044	.027	.111	.149	.805	.001	.017
FRQ2	.106	.177	.095	.036	.027	.170	.059	.850	-.004	-.026
FRQ3	.059	.307	.165	.115	.013	.222	.057	.218	-.037	.759
FRQ4	.047	.205	.122	.120	-.011	.271	.416	.528	-.051	.284
FRQ5	.094	.130	.148	-.082	.211	.243	.429	.376	.199	.334
FRQ6	.111	.282	.111	.255	-.032	.317	.503	.193	.315	-.041
PRO1	.145	.180	.113	.097	.315	.520	.026	.515	-.039	.179
PRO2	.070	.137	.139	.198	.190	.697	.135	.264	-.037	.249
PRO3	.315	.050	.166	.054	.091	.732	.255	.075	.088	.078
PRO4	.186	.162	.047	.134	.200	.712	.161	.221	.047	.070
PRO5	.113	.192	.142	.167	.011	.691	.218	-.019	.097	.096
INT1	.207	.133	.088	.114	.188	-.037	.478	.444	-.050	.044
INT2	.076	.255	.070	.065	.146	.164	.258	-.075	.021	.789
INT3	.124	.227	.041	.136	.104	.190	.755	.110	-.012	.155
INT4	.253	.009	.090	.024	.262	.193	.679	.064	.067	.217
INT5	.187	.144	.110	.227	.012	.291	.630	.044	.222	-.074
CMP1	.185	.582	-.172	-.001	.293	.095	.009	.243	.013	.174
CMP2	.058	.454	-.034	.029	.110	-.085	.009	.263	.212	.151
CMP3	.071	.780	.179	-.011	.094	.174	.217	.046	.032	-.031
CMP4	.117	.760	.234	-.057	.041	.189	.173	-.050	.084	.177
CMP5	.142	.649	-.055	-.014	.155	.154	.032	.185	.046	.360
CMP6	.251	.710	.129	.054	-.021	.078	.130	.141	.137	.024
CMP7	.417	.593	.102	.044	-.041	.087	.058	.180	.091	.056
UNC1	.093	.082	.052	-.053	.028	.015	.049	.025	.846	.033
UNC2	.117	.047	.064	-.027	.088	-.051	.081	-.048	.839	.074
UNC3	.026	.214	.027	.138	.029	.198	.060	-.005	.703	-.116
COLP1	.667	.261	.165	.081	.208	.053	.117	.142	.087	.004
COLP2	.782	.109	.085	.059	.164	.178	.087	.203	.152	.013
COLP3	.786	.086	.127	.116	.185	.200	.080	.119	.074	.047
COLP4	.716	.122	.222	.156	-.126	-.024	.228	.114	.081	.039
COLP5	.730	.212	-.007	.209	.239	.113	.132	-.008	-.047	.035
COLP6	.681	.203	.106	.279	.134	.217	.076	.009	.041	.106
QUAL1	.188	.137	.482	.252	.579	.178	.135	.085	.058	.074
QUAL2	.134	.006	.328	.253	.661	.019	.223	.053	.032	.092
QUAL3	.269	.074	.256	.054	.730	.148	.098	.115	.085	.028
QUAL4	.138	.195	.293	.159	.723	.145	.016	.078	.061	.090
QUAL5	.119	.117	.387	.305	.647	.141	.127	-.055	.040	.006
COMS1	.143	.096	.780	.142	.338	.135	.109	.114	.040	.069
COMS2	.161	.075	.827	.155	.301	.141	.052	.118	.065	.058
COMS3	.108	.068	.772	.238	.240	.085	.178	.149	.034	.044
COMS4	.149	.108	.744	.213	.165	.096	-.010	.067	.060	.069
TIME1	.211	-.027	.088	.778	.113	.195	.049	.063	.042	.166
TIME2	.169	.017	.151	.861	.137	.162	.088	.059	-.042	-.074
TIME3	.173	-.024	.320	.771	.142	.004	.132	.073	.059	.066
TIME4	.139	.026	.229	.839	.223	.114	.146	.001	.004	.024
Cum.Var. %	32.6	41.4	46.9	52.0	56.7	60.4	63.8	66.8	69.4	71.7

7.5 Instrument Validation

The quality of a survey instrument needs to be established through examination of relevant reliability and validity criteria (Kimberlin & Winterstein, 2008). The detailed validation process of a survey instrument comprises assessments for: content validity, reliability, and construct validity. Instrument validation is highly important in MIS research since it often leads to internal validity and statistical conclusion validity (Straub, 1989) (Chapter 4). Reliability and validity of the measurement scales were tested using partial least square structural equation modeling (PLS-SEM). PLS is a promising method applied in marketing and IS (information systems) research as it performs well even with small samples, non-normal data, and complex models including higher order (formative or reflective) constructs, mediators, and moderators (Chin et al., 2003; Hair et al., 2011; Ringle et al., 2012). Therefore, recently, PLS-SEM has been adopted widely by product development researchers for testing complex research models with relatively small samples (e.g. Banker et al., 2006; Brettel et al., 2011; Jun, Qiuzhen, & Qingguo, 2011; Peng et al., 2014).

Some variables under this study were not normally distributed and had skewness coefficients larger than one (e.g. FRQ1=-1.5, PRO1=-1.4) (the complete set of measures and their coding which will be referred to from this point onwards has been presented in Table 7.2. In addition, ICT usage is a second order molar construct (Chin, 2010) of the three first order constructs: frequency, proficiency, and intensity of ICT use. Overall, the model is complex in the sense that it has several direct, indirect, and moderating effects to be tested. Therefore, variance-based partial least square structural equation modeling (PLS-SEM) is more appropriate than covariance-based structural equation modeling (CB-SEM) for data analysis in this study which has data and model characteristics highlighted above.

Since the preliminary qualitative study suggested that project complexity and project uncertainty have common underpinnings, the items of the two constructs were first tried as a single latent variable in the PLS analysis. All the uncertainty items held small loadings (below 0.5) in the common construct. Additionally, an exploratory factor analysis with orthogonal rotation (method: Varimax) was performed on all the measures of the two constructs, which also resulted in two factors as shown in Table 7.5. These results clearly show that project complexity and uncertainty are two separate constructs which need to be regarded as moderators specified in the conceptual model (Figure 7.1).

Table 7.5: The factor structure of complexity and uncertainty measures

Item	*Factor loadings*	
	Factor 1	*Factor 2*
CMP1	**0.693**	0.006
CMP2	**0.504**	0.171
CMP3	**0.791**	0.099
CMP4	**0.791**	0.140
CMP5	**0.780**	0.037
CMP6	**0.771**	0.174
CMP7	**0.719**	0.128
UNC1	0.093	**0.856**
UNC2	0.074	**0.855**
UNC3	0.182	**0.743**
Eigenvalue	3.753	2.122
Cumulative variance explained (%)	37.53	58.75

7.5.1 Content validity

Content validity needs to be established in order to confirm that the instrument measures provide an adequate and representative sample of all possible measures of the construct of interest (Kimberlin & Winterstein, 2008). Reviews of literature and expert judgement are the methods available for establishing content validity (Boudreau, Gefen, & Straub, 2001). After finalizing the survey instrument based on in-depth reviews of literature and the feedback from two experts in the field, it was further assessed by two external academic experts (section 7.4) for content validity. The judgements of these professionals confirmed that the items developed to operationalize the construct sufficiently cover the content area.

7.5.2 Reliability

Reliability evaluates whether the measurement error is so high as to discredit the findings (Straub, 1989). Internal consistency reliability coefficients provide estimates of the measurement reliability (Boudreau et al., 2001). While Cronbach's alpha is the most widely used method of establishing internal consistency, composite reliability is more appropriate in PLS-SEM (Hair et al., 2011). Composite reliability values higher than 0.6 are considered as satisfactory for new constructs or exploratory research whereas values above 0.7 are needed for more established constructs (Nunnally & Bernstein, 1994). Table 7.6 reports both Cronbach's alpha and composite reliability values. All the values are above 0.7 indicating a satisfactory level of reliability of the construct measurement.

Table 7.6: Reliability assessment

Construct	*Composite reliability*	*Cronbach's alpha*
Frequency (FRQ)	0.8624	0.7868
Proficiency (PRO)	0.9108	0.8691
Intensity (INT)	0.8640	0.7629
ICT usage (ICTU)	0.9168	0.8999
Collaboration performance (COLP)	0.9220	0.8982
New product quality (QUAL)	0.9261	0.9005
Commercial success (COMS)	0.9422	0.9175
Time performance (TIME)	0.9408	0.9158
Project complexity (CMP)	0.8971	0.8622
Project uncertainty (UNC)	0.8658	0.7712

Indicator reliability was established using the indicator loadings of the items in each construct (loadings were greater than 0.7). Five items (FRQ2, FRQ3, PRO5, INT1, and INT2) with loadings below 0.6 on the second order construct (ICT usage) were removed. Three items (FRQ1, FRQ6, and INT5) with loadings between 0.6 and 0.7 on the ICT usage construct were retained considering their acceptability in exploratory studies and contribution to the construct's content validity (Hair et al., 2011). Table 7.7 presents the indicator reliability values (loadings) of the selected items for the constructs.

Table 7.7: Indicator loadings and cross loadings

Construct / *Item*	*FRQ*	*PRO*	*INT*	*ICTU*	*COLP*	*QUAL*	*COMS*	*TIME*	*CMP*	*UNC*
FRQ1	**0.746**	0.463	0.345	**0.610**	0.434	0.298	0.353	0.204	0.438	0.086
FRQ4	**0.838**	0.536	0.549	**0.732**	0.318	0.275	0.308	0.262	0.424	0.056
FRQ5	**0.804**	0.514	0.562	**0.716**	0.329	0.385	0.351	0.171	0.436	0.252
FRQ6	**0.734**	0.474	0.619	**0.693**	0.395	0.330	0.302	0.347	0.434	0.366
PRO1	0.591	**0.821**	0.384	**0.729**	0.400	0.480	0.396	0.311	0.448	0.064
PRO2	0.535	**0.883**	0.472	**0.761**	0.348	0.424	0.405	0.392	0.393	0.087
PRO3	0.508	**0.826**	0.546	**0.748**	0.489	0.394	0.371	0.315	0.350	0.197
PRO4	0.528	**0.860**	0.490	**0.753**	0.424	0.404	0.326	0.342	0.406	0.166
INT3	0.580	0.459	**0.863**	**0.695**	0.372	0.325	0.285	0.294	0.414	0.163
INT4	0.541	0.474	**0.836**	**0.683**	0.420	0.402	0.339	0.299	0.330	0.184
INT5	0.538	0.448	**0.771**	**0.653**	0.405	0.353	0.286	0.351	0.319	0.279
COLP1	0.380	0.384	0.382	0.444	**0.776**	0.447	0.380	0.330	0.494	0.218
COLP2	0.421	0.457	0.379	0.492	**0.856**	0.416	0.330	0.301	0.414	0.264
COLP3	0.386	0.442	0.400	0.478	**0.865**	0.451	0.370	0.367	0.396	0.214
COLP4	0.358	0.288	0.406	0.397	**0.748**	0.270	0.328	0.328	0.350	0.171
COLP5	0.342	0.374	0.387	0.426	**0.818**	0.436	0.285	0.389	0.424	0.094
COLP6	0.396	0.431	0.412	0.479	**0.821**	0.437	0.378	0.443	0.430	0.189
QUAL1	0.434	0.488	0.413	0.521	0.477	**0.878**	0.706	0.505	0.348	0.180
QUAL2	0.328	0.354	0.382	0.408	0.376	**0.827**	0.566	0.454	0.208	0.113
QUAL3	0.327	0.444	0.381	0.451	0.469	**0.821**	0.546	0.340	0.313	0.187
QUAL4	0.335	0.434	0.299	0.423	0.406	**0.846**	0.567	0.377	0.350	0.160
QUAL5	0.301	0.384	0.358	0.405	0.402	**0.856**	0.623	0.487	0.255	0.157
COMS1	0.384	0.433	0.358	0.459	0.395	0.694	**0.921**	0.427	0.309	0.153
COMS2	0.375	0.430	0.321	0.443	0.406	0.687	**0.944**	0.442	0.287	0.178
COMS3	0.409	0.392	0.386	0.459	0.367	0.626	**0.904**	0.487	0.269	0.135
COMS4	0.330	0.318	0.241	0.348	0.356	0.546	**0.810**	0.433	0.274	0.158
TIME1	0.294	0.399	0.330	0.400	0.408	0.392	0.382	**0.852**	0.140	0.102
TIME2	0.254	0.369	0.332	0.372	0.386	0.434	0.410	**0.924**	0.144	0.059
TIME3	0.303	0.304	0.323	0.357	0.393	0.487	0.511	**0.873**	0.146	0.123
TIME4	0.279	0.356	0.377	0.389	0.397	0.533	0.486	**0.924**	0.161	0.104
CMP1	0.414	0.344	0.250	0.394	0.362	0.265	0.130	0.092	**0.676**	0.130
CMP3	0.438	0.367	0.379	0.454	0.344	0.297	0.303	0.135	**0.801**	0.215
CMP4	0.421	0.369	0.354	0.441	0.372	0.299	0.325	0.096	**0.805**	0.256
CMP5	0.425	0.389	0.309	0.437	0.346	0.262	0.168	0.099	**0.754**	0.167
CMP6	0.453	0.340	0.360	0.443	0.421	0.261	0.253	0.163	**0.820**	0.266
CMP7	0.410	0.371	0.323	0.429	0.511	0.245	0.255	0.165	**0.757**	0.215
UNC1	0.194	0.106	0.188	0.183	0.180	0.121	0.122	0.020	0.212	**0.817**
UNC2	0.170	0.064	0.198	0.156	0.193	0.158	0.151	0.061	0.195	**0.838**
UNC3	0.236	0.192	0.231	0.250	0.208	0.182	0.152	0.161	0.265	**0.824**

7.5.3 Construct validity

Construct validity is the degree to which an instrument measures what it expects to measure (Straub, 1989). Convergent validity and discriminant validity are the two basic components of construct validity. Coefficients of *convergent validity* represent the degree to which the operationalized measurement items of each construct correlate with each other and converge to a single construct. In the PLS-SEM, average variance extracted (AVE) values are used to establish convergent validity. Table 7.8 presents the respective values obtained, and all these are greater than the minimum recommended threshold 0.5 indicating an adequate level of convergent validity.

Table 7.8: Convergent validity assessment

Construct	*AVE*
Frequency (FRQ)	0.6111
Proficiency (PRO)	0.7186
Intensity (INT)	0.6797
ICT usage (ICTU)	0.5013
Collaboration performance (COLP)	0.6639
Quality (QUAL)	0.7151
Commercial success (COMS)	0.8034
Time performance (TIME)	0.7993
Project complexity (CMP)	0.5932
Project uncertainty (UNC)	0.6825

Since ICT usage is a formative second-order construct of frequency, proficiency, and intensity, it is also important to ensure that there is no multicollinearity between the first order constructs, affecting its validity. The *VIF* values calculated for frequency, proficiency, and intensity are: 2.19, 1.78, and 1.89 respectively. Since all these values are below the recommended threshold 5 (Hair et al., 2011), there is no multicollinearity problem affecting the validity of ICT usage construct.

Discriminant validity tests whether the relationship between measurement items of different constructs is relatively lower than the relationship between items of the same construct. The Fornell and Larcker criterion (1981) was used to test the discriminant validity of all the first order constructs. According to this criterion, the AVE of each latent construct needs to be larger than the construct's highest squared correlation with any other latent construct. Table 7.9 presents the results that are satisfactory for the path model tested. In addition, indicator loadings of each construct have been compared with cross-loadings in Table 7.7 to test the discriminant validity. Since all the indicator loadings are higher than the cross-loadings, no violation of discriminant validity is evident.

Table 7.9: Discriminant validity assessment

Construct	*COLP*	*COMS*	*FRQ*	*INT*	*PRO*	*QUAL*	*TIME*	*CMP*	*UNC*
COLP	**0.6639**								
COMS	0.1808	**0.8034**							
FRQ	0.2186	0.1753	**0.6111**						
INT	0.2339	0.1351	0.4502	**0.6797**					
PRO	0.2397	0.1952	0.4059	0.3120	**0.7186**				
QUAL	0.2576	0.5119	0.1698	0.1904	0.2514	**0.7151**			
TIME	0.1966	0.2473	0.0995	0.1452	0.1615	0.2639	**0.7993**		
CMP	0.2652	0.1006	0.3058	0.1852	0.2213	0.0000	0.0000	**0.5932**	
UNC	0.0556	0.0301	0.0598	0.0633	0.0231	0.0362	0.0116	0.0757	**0.6825**

Note: Diagonal values represent the AVE whereas the cell values are the squared correlations between first-order latent constructs.

7.6 SUMMARY

Drawing on the RRBV and OIPT, hypotheses of the main study were developed to answer the last two research questions which examine the direct, indirect, and moderated impact of ICT usage on CPD performance. In addition, this chapter presented the development of the operational definitions for the constructs in the main conceptual model based on the literature and findings of the previous qualitative phase of the study. The results of the validity and reliability tests performed have adequately confirmed the content validity, internal consistency reliability, and construct validity of the survey instrument developed. Therefore, data collected by the instrument are appropriate for testing the hypotheses formulated. The descriptive statistics, results of the power analysis performed to test the adequacy of the sample used for the PLS analysis, complete results of the hypotheses tests, and discussion on the results are presented in the next chapter.

8 Results and Discussion of Primary Data Analysis

8.1 Introduction

This chapter presents the results obtained in the statistical analysis performed on primary data collected by the survey. This data analysis was performed to achieve the two research objectives of the study. These are: (1) to examine the direct and indirect impact of ICT usage in terms of frequency, proficiency, and intensity of use on new product performance (quality, time, and commercial success), through collaboration performance, and (2) to examine the moderating effect of project characteristics on the direct and indirect associations between ICT usage and CPD performance. Therefore, the results obtained in this data analysis will answer the last two research questions addressing the impact of ICT usage on collaborative product development performance. The instrument developed in the previous chapter (Chapter 7) based on in-depth reviews of literature (Chapters 2 and 3) and preliminary qualitative investigation (Chapter 5) was used in the survey for collecting data from CPD projects in manufacturing firms. First, this chapter explains descriptive statistics of the data highlighting the patterns that are important for exploring hypothesised relationships. Then it presents results of the power analysis performed for testing the adequacy of the sample. Next, details on the path analysis performed and results of the hypothesis tests are provided. In addition, results of the correlation analysis conducted for a detailed evaluation of the impact of each individual ICT usage component are presented. The final section provides possible explanations for the results obtained and discusses how do the current findings differ from or confirm the existing literature.

8.2 Descriptive Statistics

Descriptive statistics on ICT usage, performance variables, and moderators were obtained using SPSS version 22. Unstandardized latent variable scores generated by the SmartPLS version 2.0 were also used where appropriate. Figure 8.1 shows the means of the items used for three ICT usage components: frequency, proficiency, and intensity across different scales of organizations. The full sample of 285 CPD projects including small, medium, and large firms was used in this analysis.

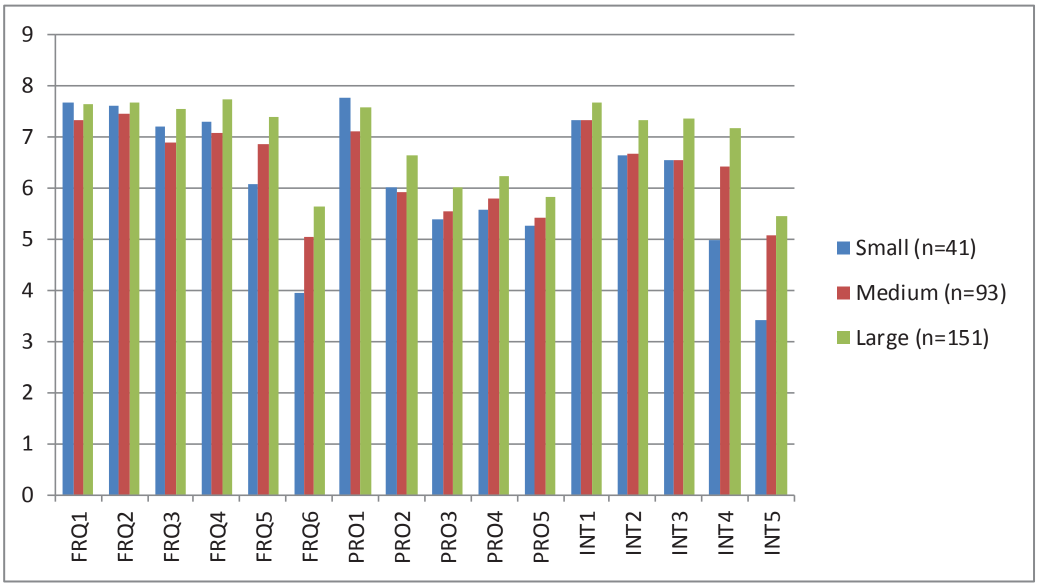

Figure 8.1: Average frequency, proficiency, and intensity of ICT use by organization size

Several mean values are above the centre of the scale (1–9) indicating relatively higher usage of ICT which is usual in high-tech manufacturing industries where various CPD activities of distributed teams are coordinated and executed via ICT tools (Durmusoglu, Calantone, & Sambamurthy, 2006). As per the graph, average scores of ICT usage components related to market research and analysis tools (i.e. FRQ6 and INT5) are noticeably low in small firms. Relatively low usage and the late adoption of modern market research tools such as social networking sites (e.g. Wikis, blogs) in small firms (Kim, Lee, & Lee, 2013) is a possible reason for the above difference. In addition, the frequency and intensity of using project management ICT tools (FRQ5 and INT4) in small firms are low compared to those of other firms. Low implementation rates of advanced tools for project management and planning (e.g. PLM systems) are often observed in small firms due to their high cost and the relatively low requirement of such tools in the CPD projects of these firms (Cantamessa, Montagna, & Neirotti, 2012; Durmusoglu et al., 2006). The differences between the bars (averages) of other ICT usage components are not substantial.

Figure 8.2 shows the standard deviations of ICT usage components based on the size of firms. Since there is no standard deviation close to zero, the data have sufficient variability to perform a statistical analysis. According to the graph, the variability of several ICT usage components (FRQ1, FRQ2, FRQ3, FRQ5, FRQ6, PRO2, INT2, INT3, and INT4) is relatively high in small firms. The differences in FRQ5 and INT2 items are somewhat larger.

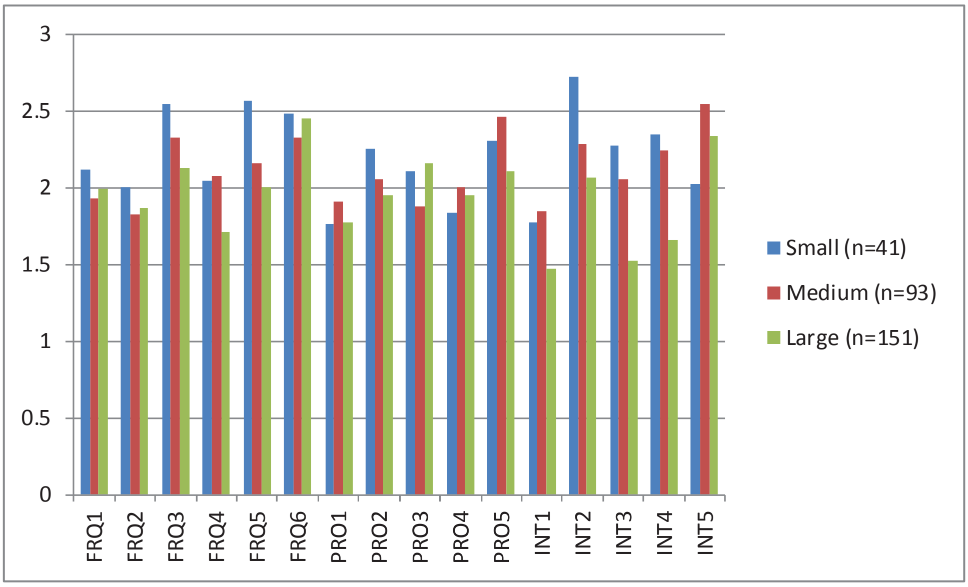

Figure 8.2: Standard deviations of ICT usage components

Overall, the above statistics indicate that ICT usage patterns are different in small firms in comparison with medium and large firms. In addition, these firms have comparatively low annual sales and number of employees relative to the industry averages (Table 7.3). Therefore, small firms were removed and the final sample of 244 CPD projects was used in the main statistical analysis, because including them could increase heterogeneity in the sample causing low accuracy in the path model estimation. In this sample, substantial deviations in average ICT usage components except FRQ3 and INT2 were not observed across industries (Figure 8.3). However, these components were removed in the instrument validation process due to the low indicator loadings obtained (details in Chapter 7). Therefore, any industrial difference may not affect results of the subsequent path analysis.

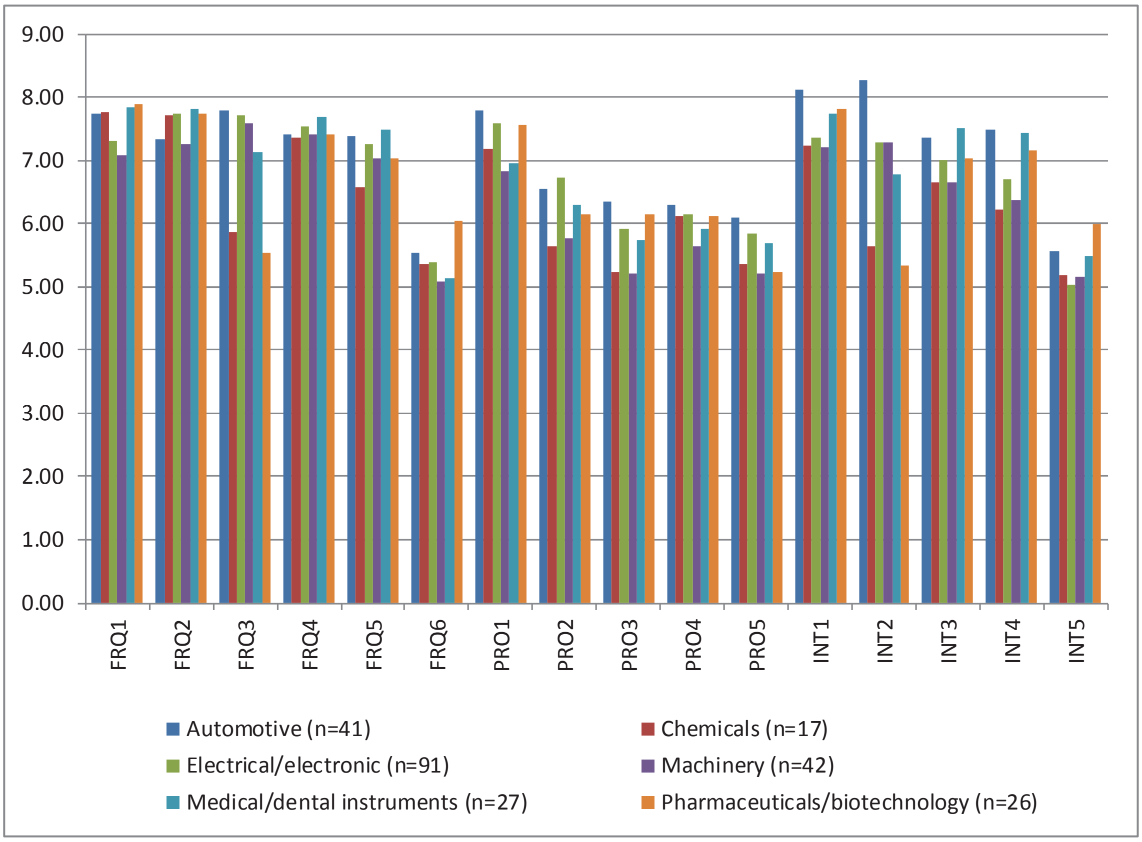

Figure 8.3: Average frequency, proficiency, and intensity of ICT usage by industry [n=244]

Table 8.1 presents overall sample means and standard deviations of all the questionnaire items obtained for the final sample of 244 cases. No missing value was observed in these items because all the questions except those on company's background information were made compulsory in the online questionnaire. Since all the values on the scale (1–9) had been answered by several participants, none of the values were removed as outliers. According to the table, some of the skewness values are greater than 1.0 indicating that the probability distributions of these indicators are deviated from normality. Therefore, it is important to use a method free from distributional assumptions for analysing the data. PLS has relaxed distributional assumptions for data and is more appropriate for structural models with higher order latent constructs or new constructs (Hair et al., 2011). Therefore, it was selected for testing hypotheses of this study (more details on the method of selection are given in Chapters 4 and 7).

Table 8.1: Descriptive statistics of all the questionnaire items

Item	*Mean*	*SD*	*Skewness*
FRQ1	7.50	1.97	-1.51
FRQ2*	7.59	1.86	-1.68
FRQ3*	7.29	2.22	-1.32
FRQ4	7.49	1.89	-1.35
FRQ5	7.19	2.07	-1.17
FRQ6	5.40	2.42	-0.12
PRO1	7.40	1.84	-1.46
PRO2	6.35	2.01	-0.73
PRO3	5.82	2.07	-0.41
PRO4	6.06	1.98	-0.54
PRO5*	5.66	2.26	-0.36
INT1*	7.54	1.63	-1.41
INT2*	7.08	2.17	-1.30
INT3	7.04	1.78	-1.04
INT4	6.88	1.93	-1.08
INT5	5.31	2.42	-0.19
CMP1	8.14	1.25	-1.91
CMP2*	7.34	1.91	-1.59
CMP3	7.01	2.08	-0.92
CMP4	6.92	2.15	-1.04
CMP5	7.22	1.81	-1.06
CMP6	6.73	2.09	-0.82
CMP7	6.66	1.99	-0.93
UNC1	5.69	2.62	-0.32
UNC2	4.73	2.66	0.13
UNC3	4.43	2.70	0.26
COLP1	6.73	1.88	-0.94
COLP2	6.69	1.81	-0.87
COLP3	6.64	1.91	-0.91
COLP4	5.99	2.22	-0.49
COLP5	6.51	1.77	-0.78
COLP6	6.68	1.85	-0.94
QUAL1	7.45	1.42	-1.51
QUAL2	7.41	1.46	-1.16
QUAL3	7.42	1.51	-1.19
QUAL4	7.59	1.36	-1.25
QUAL5	7.40	1.54	-1.45
CMSC1	7.05	1.72	-1.37
CMSC2	6.90	1.76	-1.32
CMSC3	6.88	1.73	-1.15
CMSC4	6.93	1.66	-0.89
TIME1	6.52	1.94	-0.91
TIME2	6.07	2.20	-0.67
TIME3	6.45	2.03	-0.96
TIME4	6.33	2.16	-0.98

*Item was removed during purification

Table 8.2 presents the means, standard deviations, and Pearson correlation coefficients between the latent constructs (unstandardized latent variable scores generated by the SmartPLS software were used).

Table 8.2: Correlations and descriptive statistics of the model constructs

Construct	*FRQ*	*PRO*	*INT*	*ICTU*	*CMP*	*UNC*	*COLP*	*QUAL*	*COMS*	*TIME*
FRQ	1									
PRO	.636**	1								
INT	.664**	.557**	1							
ICTU	.885**	.878**	.822**	1						
CMP	.553**	.471**	.430**	.563**	1					
UNC	.234**	.145*	.246**	.236**	.269**	1				
COLP	.468**	.487**	.482**	.554**	.506**	.233**	1			
QUAL	.407**	.498**	.433**	.520**	.350**	.184**	.501**	1		
COMS	.419**	.440**	.366**	.477**	.315**	.171**	.423**	.711**	1	
TIME	.312**	.399**	.380**	.422**	.163*	.098	.440**	.516**	.501**	1
Mean	7.00	6.43	6.54	6.64	7.18	4.96	6.56	7.46	6.94	6.34
St.Dev.	1.61	1.67	1.65	1.43	1.43	2.20	1.54	1.23	1.54	1.86

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

The study hypothesised a positive direct impact of ICT usage on CPD performance (collaboration performance and new product performance) and a positive indirect impact on new product performance through collaboration performance. According to the table, correlations between ICT usage and four performance variables (collaboration performance, quality, commercial success, and time performance) indicate a correspondence with the hypothesised direct positive relationships between ICT usage and the performance dimensions. Since the correlations of ICT usage (ICTU) with collaboration performance (COLP) and quality (QUAL) are relatively higher, stronger effects of ICT usage on these performance aspects are expected. In addition, significantly high correlation coefficients between collaboration performance and three new product performance indices (quality, commercial success, and time performance) suggest the relevance of the hypothesised indirect impact of ICT usage. Furthermore, individual ICT usage components: frequency, proficiency, and intensity, indicate significant correlations with CPD performance dimensions. However, the correlations of these ICT usage components and overall ICT usage with time performance are mostly lower in comparison to the correlations with other performance dimensions. Therefore, a relatively lower impact of ICT usage on time performance is expected. Furthermore, project complexity has a fairly high correlation coefficient with collaboration performance. Thus, collaboration performance may increase when the product is more complex and the partner involvement is higher. However, correlations between uncertainty and performance indices are not substantial. Therefore, any direct effects of project uncertainty on CPD performance may not be observed in the path analysis.

In order to explore the relevance of the moderating effects of project complexity and uncertainty, the correlation analysis was extended to high and low levels of complexities and uncertainties. Table 8.3 includes descriptive statistics of the two moderator variables, considered in grouping the dataset based on these variables.

Table 8.3: Descriptive statistics of the moderator variables

Statistic	*Complexity*	*Uncertainty*
Mean	7.18	4.96
Median	7.51	5.01
Std. Deviation	1.43	2.20
Skewness	-1.11	-0.03

Since complexity shows some negative skewness (the coefficient of skewness is lower than -1), the dataset was grouped based on medians. Mean and median of uncertainty are nearly equal as it is symmetrically distributed (zero skewness and the approximately symmetric histogram observed). Next, correlations between ICT usage and the four performance indices – collaboration performance, quality, commercial success, and time performance – were calculated for the groups. Table 8.4 presents these results.

Table 8.4: Pearson correlations by project complexity and uncertainty levels

	Low complexity group (N=122)					*High complexity group (N=122)*				
	ICTU	*COLP*	*QUAL*	*COMS*	*TIME*	*ICTU*	*COLP*	*QUAL*	*COMS*	*TIME*
ICTU	1					1				
COLP	.498**	1				.427**	1			
QUAL	.553**	.425**	1			.288**	.461**	1		
COMS	.508**	.456**	.686**	1		.264**	.248**	.684**	1	
TIME	.469**	.407**	.478**	.505**	1	.366**	.475**	.571**	.488**	1
	Low uncertainty group (N=123)					*High uncertainty group (N=121)*				
	ICTU	*COLP*	*QUAL*	*COMS*	*TIME*	*ICTU*	*COLP*	*QUAL*	*COMS*	*TIME*
ICTU	1					1				
COLP	.543**	1				.529**	1			
QUAL	.506**	.478**	1			.501**	.470**	1		
COMS	.469**	.396**	.701**	1		.455**	.407**	.703**	1	
TIME	.379**	.409**	.525**	.494**	1	.473**	.475**	.503**	.503**	1

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Correlations between ICT usage and the four performance dimensions are lower in the high complexity group than in the low complexity group. The gaps are higher for quality and commercial success variables. Therefore, as hypothesised, negative moderating effects of project complexity on the direct relationship between ICT usage and new product quality and commercial success are likely to be observed in the path analysis. Differences between correlations of ICT usage with performance dimensions in low and high uncertainty groups are not substantial except the value of time performance which is slightly higher. Therefore, there is a possibility to detect a positive moderating effect of project uncertainty on the direct association between ICT usage and time performance. The differences in correlations of collaboration performance with the three new product performance aspects are not too large across two levels of project uncertainty. Between the two complexity levels, these correlations show fairly high value for commercial success. However, since the mediation effect involves two paths (one from ICT usage to collaboration performance and the other from collaboration performance to new product performance dimensions) correlation values are not adequate to suggest moderated mediation effects.

The associations suggested in the above descriptive statistical analysis need to be confirmed with the results obtained in the PLS-SEM analysis performed (section 8.4).

8.3 Adequacy of the Sample

As explained earlier, since this study involves several moderating and mediating effects, PLS was applied for testing hypotheses. Sample size requirements for testing the moderating effects with PLS-SEM are lower than in the corresponding covariance-based SEM (Chin et al., 2003). The adequacy of the final sample of 244 was tested using the criteria defined by Cohen (1992). According to these criteria, the effect size (f^2) for a multiple regression model is calculated as follows, based on the coefficient of determination value (R^2) of the model:

$$f^2 = \frac{R^2}{1-R^2}$$

Effect sizes 0.02, 0.15, and 0.35 are considered as small, medium, and large respectively. Using anticipated effect sizes for CPD performance indices (collaboration performance, new product quality, commercial success, and time performance), the required sample size was calculated for attaining 0.8 power and two levels of significance (0.05 and 0.1) of the test. The online calculator developed (Soper, 2006b), based on Cohen (1992), was used in this calculation. Table 8.5 presents R^2 values obtained from past studies for criterion variables related to the variables considered in this study. It also includes anticipated effect sizes and minimum required sample sizes, computed. The largest sample size obtained in this analysis is 242 and hence, the current sample of 244 is adequate to detect all the hypothesised effects of ICT usage (Figure 7.1). The sample is sufficient to detect a small to medium effect of ICT usage on each CPD performance dimension (the minimum effects that can be detected on the three new product performance dimensions using the current sample are 0.065 and 0.055 at α =0.05 and α=0.10 respectively. The respective values for the collaboration performance are 0.055 and 0.045).

Table 8.5: Sample size requirements

Source	*Criterion variable and R^2*	*Related criterion variable in the present model and anticipated effect size (f^2)*	*Minimum required sample size*	
			(α = 0.05)	*(α = 0.10)*
Secondary data analysis (Chapter 06)	Overall NPD performance (0.13)*	New product quality, commercial success, and time performance (0.15)	108	89
Barczak et al. (2007)	Market performance (0.060)	Commercial success (0.064)	242	199
Heim et al. (2012)	Product performance quality (0.205)†	New product quality (0.26)	66	55
Heim et al. (2012)	Time-to-market (0.235)†	Time performance (0.31)	57	47
Secondary data analysis (Chapter 06)	NPD collaboration (0.257)**	Collaboration performance (0.34)	44	36
Peng et al. (2014)	NPD collaboration (0.260)†	Collaboration performance (0.35)	43	35
Marion et al. (2014)	Team collaboration (0.171)	Collaboration performance (0.21)	67	55

Note: *R^2 in the final model estimated for overall NPD performance, including predictors: ICT tools (ICT1 – ICT13) usage and NPD collaboration was 0.187. After deducting the R^2 of the models with only the control variables 0.057, the resulting value was 0.13.
**R^2 in the final model estimated for NPD collaboration with 13 ICT tools as predictors was 0.339. After deducting the R^2 of the models with only the control variables 0.082, the resulting value was 0.257.
†Includes the effect of NPD practices as another predictor in addition to the ICT tools examined.

8.4 Path Analysis

PLS-SEM analysis performed on SmartPLS 2.0 software was used to test the research hypotheses. First, results of the hypotheses tests for the direct ($H_{1a\text{-}1d}$) and indirect ($H_{2a\text{-}2c}$) impact of ICT usage are presented (mediator analysis). Next, results of the hypothesis tests for the moderating effect of project complexity ($H_{3a\text{-}3d}$, $H_{4a\text{-}4c}$) and uncertainty ($H_{5a\text{-}5d}$, $H_{6a\text{-}6c}$) are presented. In addition, the impact of individual ICT usage components are evaluated using the path model estimated. Finally, the strength of the structural model is evaluated using relevant statistical measures.

8.4.1 Direct and indirect impact of ICT usage

This study mainly hypothesised the direct positive effect of ICT usage on CPD performance in terms of collaboration performance (H_{1a}) and new product performance (quality - H_{1b}, commercial success – H_{1c}, and time performance – H_{1d}). In addition, it hypothesised collaboration performance as a mediator for the relationship between ICT usage and new product performance. Hypotheses H_{2a}, H_{2b}, and H_{2c} posit a positive indirect effect of ICT usage through collaboration performance on new product quality, commercial success, and time performance, respectively. If collaboration performance actually mediates the relationship between ICT usage and new product performance, the direct effects of ICT usage must be significantly decreased by adding collaboration performance as an intermediate variable. Figure 8.4 shows the direct effect model without the mediator (i.e. collaboration performance) (the main latent variables are represented by the blue ellipses in the diagram). The model also includes the moderators (project complexity and uncertainty), and their effects (purple ellipses in the diagram) will be discussed later in this chapter (section 8.4.3). The path coefficients between ICT usage and new product quality, commercial success, and time performance are 0.436, 0.394, and 0.467 respectively. The full model with the mediator variable (collaboration performance) is shown in Figure 8.5, and it presents all the path coefficients and their significance. In this model the respective path coefficients are 0.304, 0.312, and 0.315. These values show clear reductions in the three direct path coefficients after adding the mediator variable, suggesting a mediating effect of collaboration performance on the association between ICT usage and new product performance.

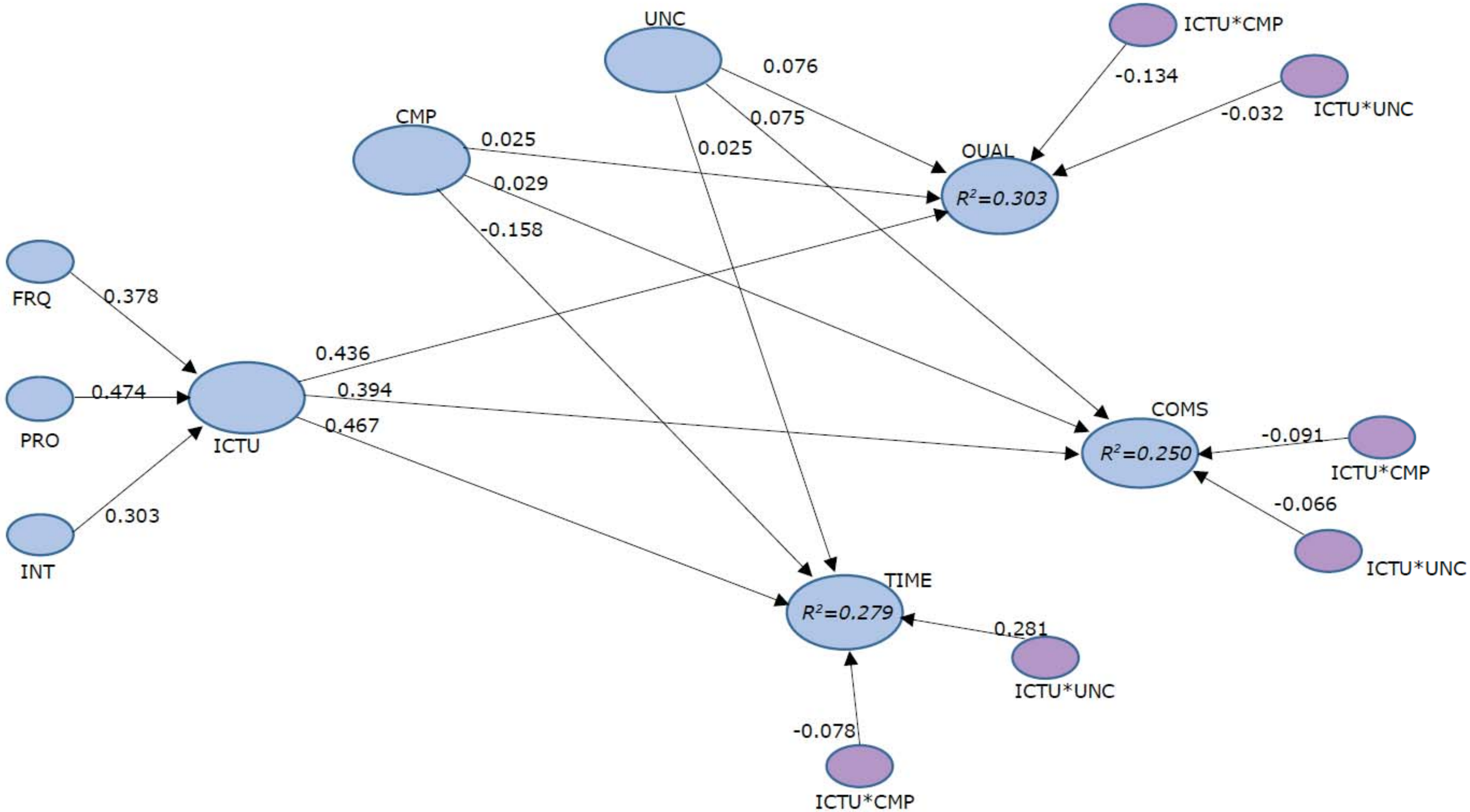

Figure 8.4: The direct effect model (excluding collaboration performance)

(FRQ-Frequency, PRO-Proficiency, INT-Intensity, ICTU-ICT usage, CMP-Project complexity, UNC-Project uncertainty, QUAL-Quality, COMS-Commercial success, TIME-Time performance)

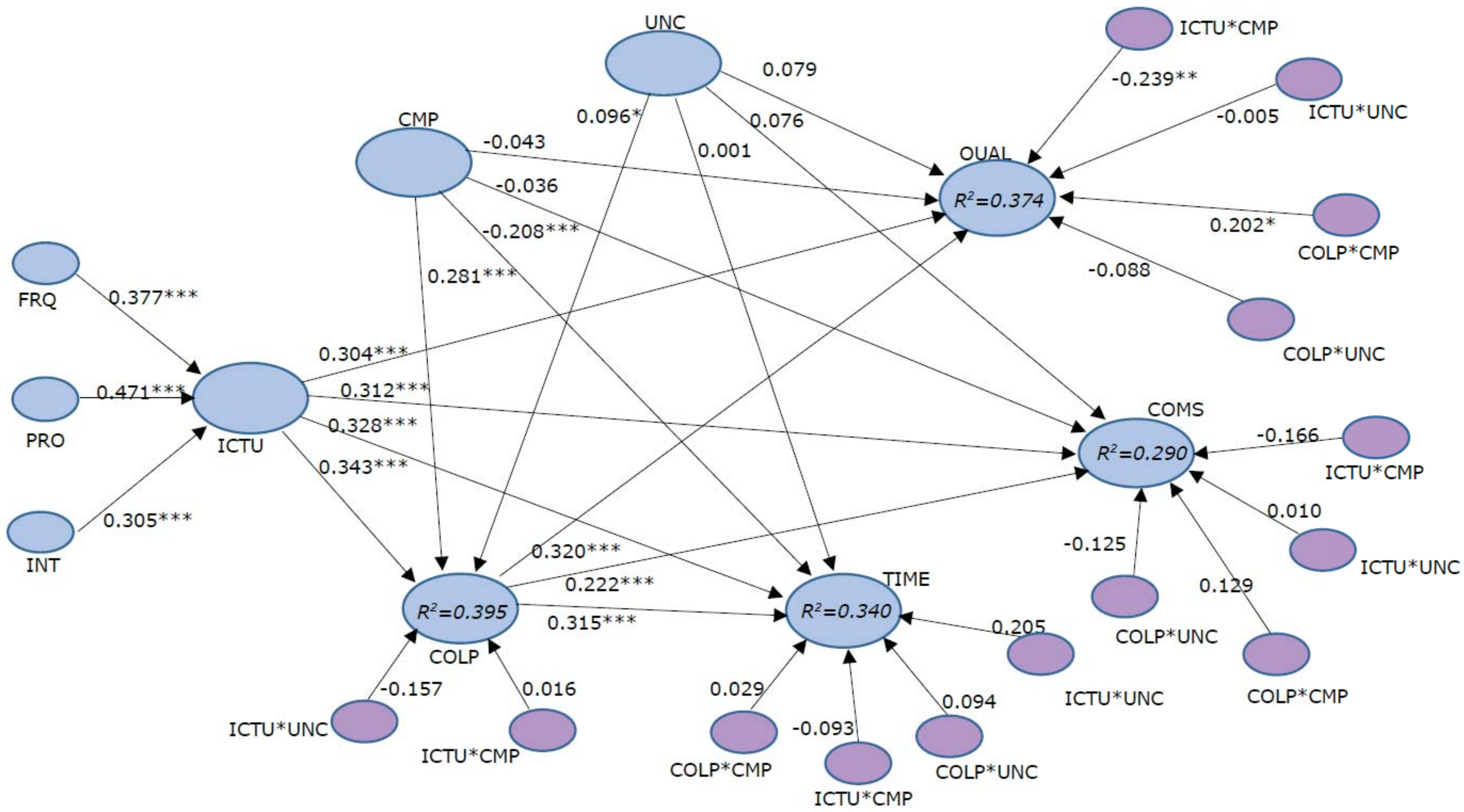

Figure 8.5: Full path model

(***Effect is significant at the 0.01 level; ** Effect is significant at the 0.05 level; *Effect is significant at the 0.10 level)

(FRQ-Frequency, PRO-Proficiency, INT-Intensity, ICTU-ICT usage, CMP-Project complexity, UNC-Project uncertainty, COLP-Collaboration performance, QUAL-Quality, COMS-Commercial success, TIME-Time performance)

In order to test the significance of the mediation effects, the Sobel (1982) test was applied. The Sobel test statistic (z) is calculated using the following formula:

$$z = \frac{ab}{\sqrt{b^2 SE_a^2 + a^2 SE_b^2}}$$

Where a is the path coefficient from the independent variable (ICT usage) to the mediator (collaboration performance), b is the path coefficient from the mediator to the dependent variable (new product quality/commercial success/time performance), SE_a is the standard error of the relationship between the independent variable and the mediator, and SE_b is the standard error of the relationship between the mediator and the dependent variable. The results are given in Table 8.6.

Table 8.6: Sobel mediation test results

Performance dimension	a	b	SE_a	SE_b	z	*P-value*
COMS	0.3364	0.2084	0.0784	0.0790	2.2472	0.025
QUAL	0.3364	0.3092	0.0784	0.0630	3.2303	0.001
TIME	0.3364	0.3168	0.0784	0.0785	2.9397	0.003

According to the results, both direct and indirect paths are significant at the 0.05 level (i.e. all p-values < 0.05). Thus, collaboration performance is considered to partially mediate the association between ICT usage and new product performance. Subsequently, *VAF* (variance accounted for) value was calculated for each of the three performance dimensions to estimate the indirect effects as a ratio of the total effects. Table 8.7 presents path analysis results for the direct and indirect effects examined and the *VAF* values computed.

Table 8.7 Results of the hypothesis tests (direct and indirect effects)

Path	*Total effect (T-value)*	*Direct effect (T-value)*	*Indirect effect (Sobel Z)*	*VAF*	*Result*
ICTU → COLP	0.343** (4.374)	0.343** (4.374)			H_{1a} is supported
ICTU → QUAL	0.414** (6.164)	0.304** (4.186)	0.110** (3.230)	0.266	H_{1b} and H_{2a} are supported
ICTU → COMS	0.388** (5.042)	0.312** (3.816)	0.076* (2.247)	0.196	H_{1c} and H_{2b} are supported
ICTU → TIME	0.436** (5.627)	0.328** (4.289)	0.108** (2.940)	0.248	H_{1d} and H_{2c} are supported

**Effect is significant at the 0.01 level
* Effect is significant at the 0.05 level

The results support all the seven hypotheses stating the positive direct and indirect impacts of ICT usage on CPD performance. The *VAF* values indicate that the indirect effects of ICT usage through collaboration performance on quality, commercial success, and time performance account for 27%, 20%, and 25% of total effects. The indirect effect on commercial success is low compared to those on quality and time performance.

Additionally, a multivariate general linear model analysis (ANOVA) was performed on all the ICT usage items (FRQ1 – INT5) in order to examine whether a significant difference in ICT usage exists across industries, which may lead to different effects on CPD performance. A similar approach was followed by Tidd and Thuriaux-Alemán (2016) in a study focusing on the association between innovation management practices and innovation outcomes. Only three components (FRQ3, INT2, and INT4) out of 16 items indicated significant differences across industries (p value < 0.05). However, since two of these items (FRQ3 and INT2) have already been removed in the instrument validation process, no industrial difference in ICT usage will affect the results obtained (Figure 8.3 also suggested this). Therefore, the revealed positive effects can be generalized into all the six industries considered. The associations were not examined for any regional differences as all the surveyed projects were collaborative in nature and involved participants from several countries.

8.4.2 Effects of individual ICT usage components

This study uses three aspects – frequency, proficiency, and intensity of ICT use – to evaluate overall usage of ICT tools in CPD projects. The path analysis that deployed overall ICT usage as a second order molar construct of the three ICT usage component constructs enables the revealing of indirect effects of frequency, proficiency, and intensity of ICT use on the CPD performance dimensions. As shown earlier in Figure 8.5, proficiency of ICT use (β = 0.471) has a larger impact relative to frequency (β = 0.377) and intensity of ICT use (β = 0.305) on CPD performance. Total indirect effects of frequency, proficiency, and intensity of ICT use on different CPD performance dimensions and their significance (*t*-values obtained using the bootstrapping procedure) are presented in Table 8.8.

Table 8.8 Indirect effects of frequency, proficiency, and intensity of ICT use

Path from ICT usage component	*Indirect effect*	*T- value*
Frequency → Collaboration Performance	0.129*	4.374
Frequency → Comm. Success	0.147*	4.902
Frequency → Quality	0.156*	6.113
Frequency → Time Performance	0.164*	5.533
Intensity → Collaboration Performance	0.105*	4.122
Intensity → Comm. Success	0.119*	5.023
Intensity → Quality	0.126*	5.706
Intensity → Time Performance	0.133*	5.514
Proficiency → Collaboration Performance	0.161*	4.303
Proficiency → Comm. Success	0.183*	5.021
Proficiency → Quality	0.195*	6.116
Proficiency → Time Performance	0.205*	5.728

*Effect is significant at the 0.01 level

Correlations between all the ICT usage items and performance variables were obtained to explore the impact in relation to individual ICT types and usage aspects. Table 8.9 presents these values compared with each other using the test for dependent correlations (Steiger, 1980).

Table 8.9 Correlations between ICT usage items and CPD performance dimensions

ICT usage item	*COLP*	*COMS*	*QUAL*	*TIME*
FRQ1	0.434[cd]	0.366[d]	0.294[a]	0.204[ab]
FRQ2	0.298[d]	0.257	0.224	0.146[a]
FRQ3	0.270	0.279	0.299	0.215
FRQ4	0.318	0.321	0.274	0.261
FRQ5	0.328[d]	0.366[d]	0.380[d]	0.172[abc]
FRQ6	0.395	0.319	0.328	0.346
PRO1	0.399	0.410	0.476[d]	0.309[c]
PRO2	0.347	0.410	0.421	0.389
PRO3	0.489[d]	0.390	0.389	0.312[a]
PRO4	0.422	0.344	0.403	0.340
PRO5	0.352	0.308	0.318	0.319
INT1	0.383	0.308	0.330	0.268
INT2	0.256	0.213[c]	0.335[bd]	0.186[c]
INT3	0.370	0.288	0.324	0.293
INT4	0.419	0.346	0.398	0.300
INT5	0.406[b]	0.281[a]	0.351	0.352

Note: All the correlations are significant at the 0.01 level.
[a]Correlation is different from the correlation with collaboration performance at the 0.05 level.
[b]Correlation is different from the correlation with commercial success at the 0.05 level.
[c]Correlation is different from the correlation with new product quality at the 0.05 level.
[d]Correlation is different from the correlation with time performance at the 0.05 level.

All the correlation coefficients indicate that it is reasonable to assume a positive association for each type of ICT tool and the CPD performance dimensions considered (all the correlations are positive and significant at 0.01 level). However, significant differences are observed between some correlations. For example, frequency of using communication/collaboration tools (FRQ1 and FRQ2) has a relatively large impact on collaboration performance. In addition, proficiency in simple ICT (PRO1) has a higher impact on quality in comparison with the impact on time performance. Also, training provided on new ICT tools (PRO3) has been more effective in improving collaboration performance than time performance. The impact of the two proficiency aspects (PRO1 and PRO3) on other performance dimensions is also not trivial. Although the frequency of using design and development tools (FRQ3) has a relatively equal impact on all performance dimensions, the intensity of using these tools (INT2) seems to be particularly important for improving new product quality. Frequent use of project management tools (FRQ5) has a relatively lower impact on time performance. The correlations also indicate that the intensity of using market research and analysis tools (INT5) helps more in achieving collaboration outcomes than financial outcomes (i.e. commercial success).

8.4.3 Moderating effects of project complexity and uncertainty

The study hypothesised significant moderating effects of project complexity and uncertainty on the direct and indirect effects of ICT usage on CPD performance. Multiple group comparison and product-indicator approach are the two methods available for testing moderating effects in PLS-SEM.

8.4.3.1 Multiple group comparison for moderating effects

For multiple group comparison, there should be two groups of observations representing two levels of the moderator variable. Path coefficients of the effects which are expected to be affected by the moderator are compared across the groups. Significant differences between the path coefficients are interpreted as moderating effects. Multiple group comparison is generally recommended for categorical moderating variables since they can be directly used as grouping variables. The product-indicator approach is the best approach for testing continuous moderators whereas group comparison with dichotomization based on the mean or median of the moderating variable is also possible (Henseler & Fassott, 2010; Sarstedt, Henseler, & Ringle, 2011). Although this study primarily uses the product-indicator approach, a multiple group comparison was performed before that, to obtain an overview of possible moderator effects (Henseler & Fassott, 2010) of the two project characteristics. Since project complexity has shown some skewness as per Table 8.3, grouping for both moderators (complexity and uncertainty) was done based on their median, so that the two groups are almost equal in size. Observations having latent construct scores larger than the median were assigned to the high group and the rest were assigned as low. Accordingly, the following groups (Table 8.10) were obtained.

Table 8.10: Grouping based on medians of latent constructs for project characteristics

Variable (X)	*Median*	*High (X > Median)*	*Low (X < Median)*	*Total*
Project complexity	7.51	122	122	244
Project uncertainty	5.01	123	121	244

The path coefficients required for detecting direct effect moderation and indirect effect moderation (moderated mediation) were compared across high and low groups. For this comparison, Henseler's (2007) non-parametric approach was used since the accuracy of the parametric approach usually depends on normality of data and measurement model invariance (Chin, 2000). Normality is rather unlikely as most of the variables in the study showed skewness (Table 8.1) and thus, the non-parametric method is more appropriate. In this test, if the p-value or $1 - p$-value is below the level of significance, the null hypothesis which assumes that a certain path coefficient across two groups is equal (i.e. the difference between two path coefficients is zero) is rejected. Results obtained for the moderating effects of project complexity and uncertainty are given in Table 8.11 and Table 8.12 respectively.

Table 8.11: Multiple group comparison for the moderating effect of project complexity

Path	*Path coefficient $b^{(1)}$ (Complexity–High)*	*Path coefficient $b^{(2)}$ (Complexity–Low)*	*Difference (d) $d = b^{(1)} - b^{(2)}$*	*Henseler (2007) test P-value*
ICTU → COLP	0.4547	0.4983	-0.0436	0.6625
ICTU → QUAL	0.1355	0.4416	-0.3061**	0.9864
ICTU → COMS	0.2357	0.3794	-0.1437	0.8099
ICTU → TIME	0.2324	0.3212	-0.0888	0.7352
COLP → QUAL	0.4054	0.2218	0.1836*	0.9198
COLP → COMS	0.0952	0.2711	-0.1759	0.1675
COLP → TIME	0.3653	0.2589	0.1064	0.7696

**Difference between path coefficients is significant at the 0.05 level
*Difference between path coefficients is significant at the 0.10 level

The results in Table 8.11 indicate that the direct path coefficients from ICT usage to new product quality are significantly different across high and low complexity groups. Therefore, H_{3a} is supported (p-value < 0.05). In addition, the path from collaboration performance to quality is marginally significant (p-value < 0.10) indicating that H_{4a} is supported. Therefore, project complexity significantly moderates the direct and indirect effect of ICT usage on new product quality.

Table 8.12: Multiple group comparison for the moderating effect of project uncertainty

Path	*Path coefficient $b^{(1)}$ (Uncertainty–High)*	*Path coefficient $b^{(2)}$ (Uncertainty–Low)*	*Difference (d) $d = b^{(1)} - b^{(2)}$*	*Henseler (2007) test P-value*
ICTU → COLP	0.5618	0.5429	0.0189	0.4200
ICTU → QUAL	0.3679	0.3419	0.0260	0.5544
ICTU → COMS	0.3417	0.3534	-0.0117	0.4242
ICTU → TIME	0.3109	0.2358	0.0751	0.7031
COLP → QUAL	0.3236	0.2812	0.0424	0.6291
COLP → COMS	0.2465	0.2046	0.0419	0.6164
COLP → TIME	0.3214	0.2766	0.0448	0.6264

The results in Table 8.12 do not support any hypothesis concerning the moderating effect of project uncertainty on the association between ICT usage and CPD performance. The path from ICT usage to time performance holds the largest difference across the groups and the highest *p*-value. Since dichotomization in the multiple group analysis leads to decreases of information in data, all the moderator effects suggested above need further justification with the product-indicator approach which provides superior results when the variables are continuous (Henseler & Fassott, 2010). Results of this analysis are presented in the following section.

8.4.3.2 Product-indicator approach for testing moderating effects

In the product-indicator approach for moderating effects, indicators of the predictor and the moderator are used to create product indicators. First, all the indicators of each moderator and predictor were standardized (so that each indicator's mean is zero and variance is one). This avoids computational errors (due to higher correlations between product indicators and their individual components), increases the accuracy of estimating the underlying interaction construct, and makes the interpretation of effects easier. Subsequently, the product indicators reflecting the underlying latent interaction variable ($X*Z$) were developed by creating all possible products of the standardized indicators of the predictor (X) and the moderator (Z) (Chin et al., 2003). In testing direct effects moderation, ICT usage (ICTU) was the predictor whereas project complexity (CMP) and uncertainty (UNC) were the moderators. For the moderated mediation effects, this study considers the moderation of both paths [i.e. the path from the independent variable (ICT usage) to the mediator (collaboration performance) and the mediator to the dependent variables (quality, commercial success, and time performance)]. In testing the first path, ICT usage was the predictor where complexity and uncertainty were the moderators. In testing the second path, collaboration performance was used the predictor where complexity and uncertainty were the moderators. The complete model with all the latent constructs developed for moderating effects was shown earlier in Figure 8.5. Table 8.13 summarizes the results of the hypothesis tests for moderating effects.

Table 8.13: Results of the moderator analysis (product-indicator approach)

Moderating effect	*Path coefficient/T-value*	*Result*
ICTU*CMP → COLP	0.016 (0.2435)	H_{3a} is not supported
ICTU*CMP → QUAL	-0.239** (2.2333)	H_{3b} is supported
ICTU*CMP → COMS	-0.166 (1.5277)	H_{3c} is not supported
ICTU*CMP → TIME	-0.092 (0.7729)	H_{3d} is not supported
COLP*CMP → QUAL	0.202* (1.7162)	H_{4a} is supported
COLP*CMP → COMS	0.129 (0.9606)	H_{4b} is not supported
COLP*CMP → TIME	0.029 (0.2045)	H_{4c} is not supported
ICTU*UNC → COLP	-0.157 (0.9985)	H_{5a} is not supported
ICTU*UNC → QUAL	-0.005 (0.0528)	H_{5b} is not supported
ICTU*UNC → COMS	0.010 (0.0740)	H_{5c} is not supported
ICTU*UNC → TIME	0.205 (1.0473)	H_{5d} is not supported
COLP*UNC → QUAL	-0.088 (0.7086)	H_{6a} is not supported
COLP*UNC → COMS	-0.125 (0.8632)	H_{6b} is not supported
COLP*UNC → TIME	0.094 (0.8786)	H_{6c} is not supported

**Effect is significant at the 0.05 level

* Effect is significant at the 0.10 level

According to the above analysis, only H_{3b} and H_{4a} are supported. As implied by H_{3b}, project complexity significantly moderates the direct effect of ICT usage on new product quality. According to the coefficient of the moderating effect of project complexity over the direct path from ICT usage to quality (ICTU*CMP → QUAL= -0.239), the contribution of ICT usage in improving new product quality is increasing as the complexity of the project decreases. The moderated effect of project complexity over the path from ICT usage to collaboration performance is not significant while the moderated effect from collaboration performance to product quality (COLP*CMP → QUAL = 0.202) is positive and marginally significant. This supports H_{4a} implying that project complexity significantly moderates the indirect effect of ICT usage on new product quality. These results on the moderating effect of project complexity obtained by the product-indictor approach are consistent with the multiple group comparison results in Table 8.11.

However, none of the hypotheses concerning the moderating effect of project uncertainty is supported by either moderator analyses (product-indicator approach or multiple group comparison). Therefore, this analysis does not identify project uncertainty as a significant moderator for the association between ICT usage and any of the new product performance dimensions. However, it is important to note that path coefficients of the interaction terms ICTU*UNC → TIME (0.205), ICTU*CMP → COMS (-0.166), ICTU*UNC → COLP (-0.157), COLP*CMP → COMS (0.129), and COLP*UNC → COMS (-0.125) are quite high, though the bootstrap results (*t*-values) are not sufficient to conclude any statistical significance. The following analysis on strength of the moderating effects further examines the above observations.

8.4.3.3 Strength of moderating effects

Strength of a moderating effect can be evaluated by assessing the improvement made to the proportion of variance explained after including the moderator variable. Henseler and Fassott (2010) have suggested the following ratio of coefficient of determination values (R^2) for the size of the moderating effect (f^2) based on Cohen (1988, p.410-414):

$$f^2 = \frac{R^2_{model\,with\,moderator} - R^2_{model\,without\,moderator}}{1 - R^2_{model\,with\,moderator}}$$

The effect size $f^2$of 0.02, 0.15, and 0.35 are regarded as weak, moderate, and strong moderating effects (Cohen, 1992). Figure 8.6 shows the path model without the moderating effects of project complexity. R^2 values in this model and the full model (Figure 8.5) were used to calculate the effect sizes presented in Table 8.14.

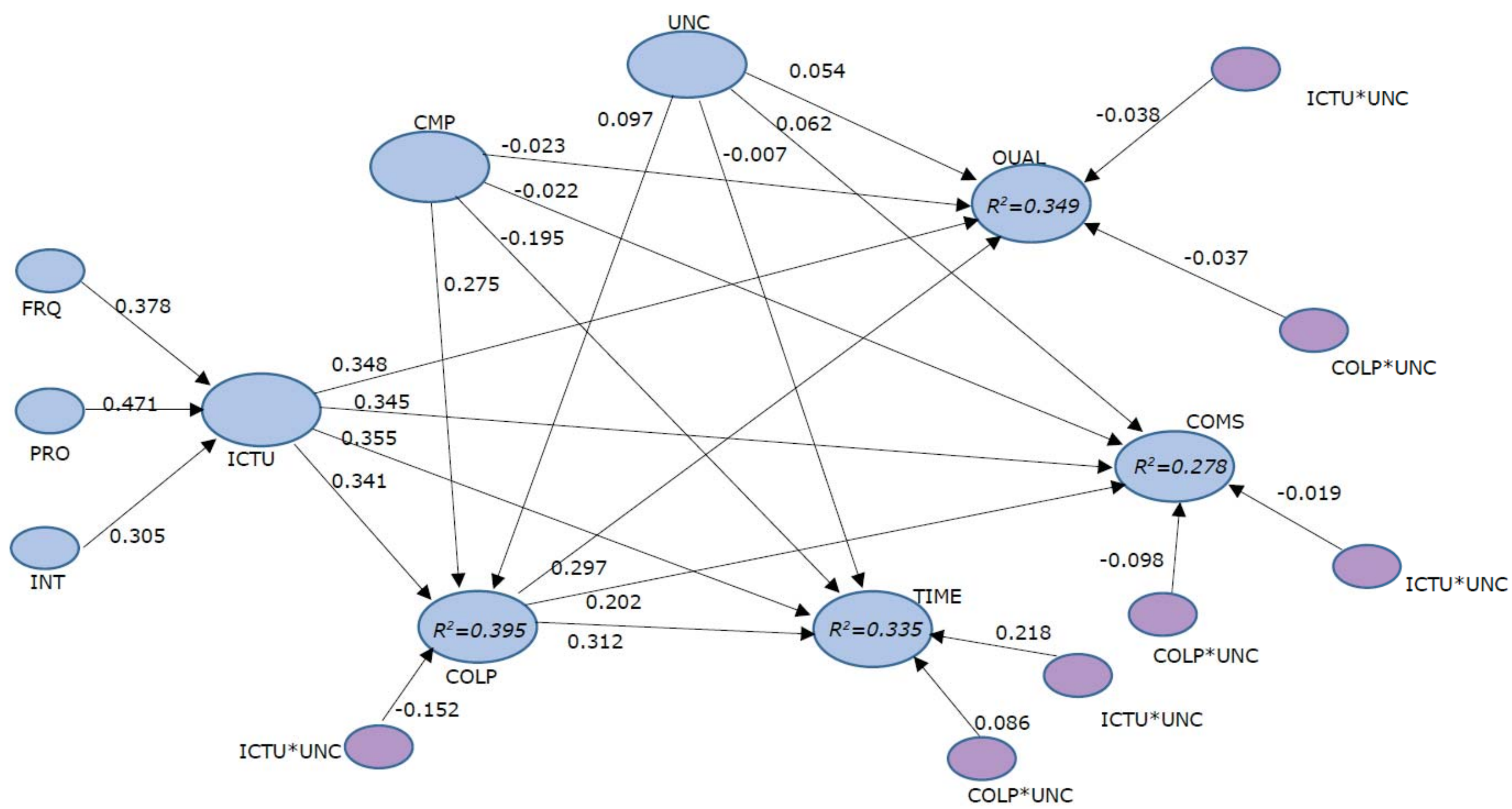

Figure 8.6: Path model excluding the moderating effect of project complexity
(FRQ-Frequency, PRO-Proficiency, INT-Intensity, ICTU-ICT usage, CMP-Project complexity, UNC-Project uncertainty, COLP-Collaboration performance, QUAL-Quality, COMS-Commercial success, TIME-Time performance)

Table 8.14: Strength of the moderating effect of project complexity

Performance construct	*R^2 (full model)*	*R^2 (excluding moderator)*	*f^2*
Collaboration performance	0.395	0.395	0.00
New product quality	0.374	0.349	0.04
Commercial success	0.290	0.278	0.02
Time performance	0.340	0.335	0.01

The calculated effect sizes indicate that project complexity has weak moderating effects on the association between ICT usage and two performance dimensions – new product quality and commercial success. However, according to the moderator analysis results presented in sections 8.4.3.1 and 8.4.3.2, only the moderating effect on product quality is statistically significant. The *t*-value (1.53) of the moderating effect of project complexity on the association between ICT usage and commercial success is only slightly less than 1% critical value of 1.64. Therefore, even though the analysis does not strongly support it, a weak negative moderating effect of project complexity (-0.166) may exist on the association between ICT usage and the commercial success of a new product.

The path model without the moderating effect of project uncertainty is shown in Figure 8.7. Table 8.15 presents the strength of the moderating effects of project uncertainty on the association between ICT usage and the four CPD performance dimensions.

Table 8.15: Strength of the moderating effect of project uncertainty

Performance construct	*R^2 (full model)*	*R^2 (excluding moderator)*	*f^2*
Collaboration performance	0.395	0.375	0.03
New product quality	0.374	0.370	0.01
Commercial success	0.290	0.279	0.01
Time performance	0.340	0.282	0.09

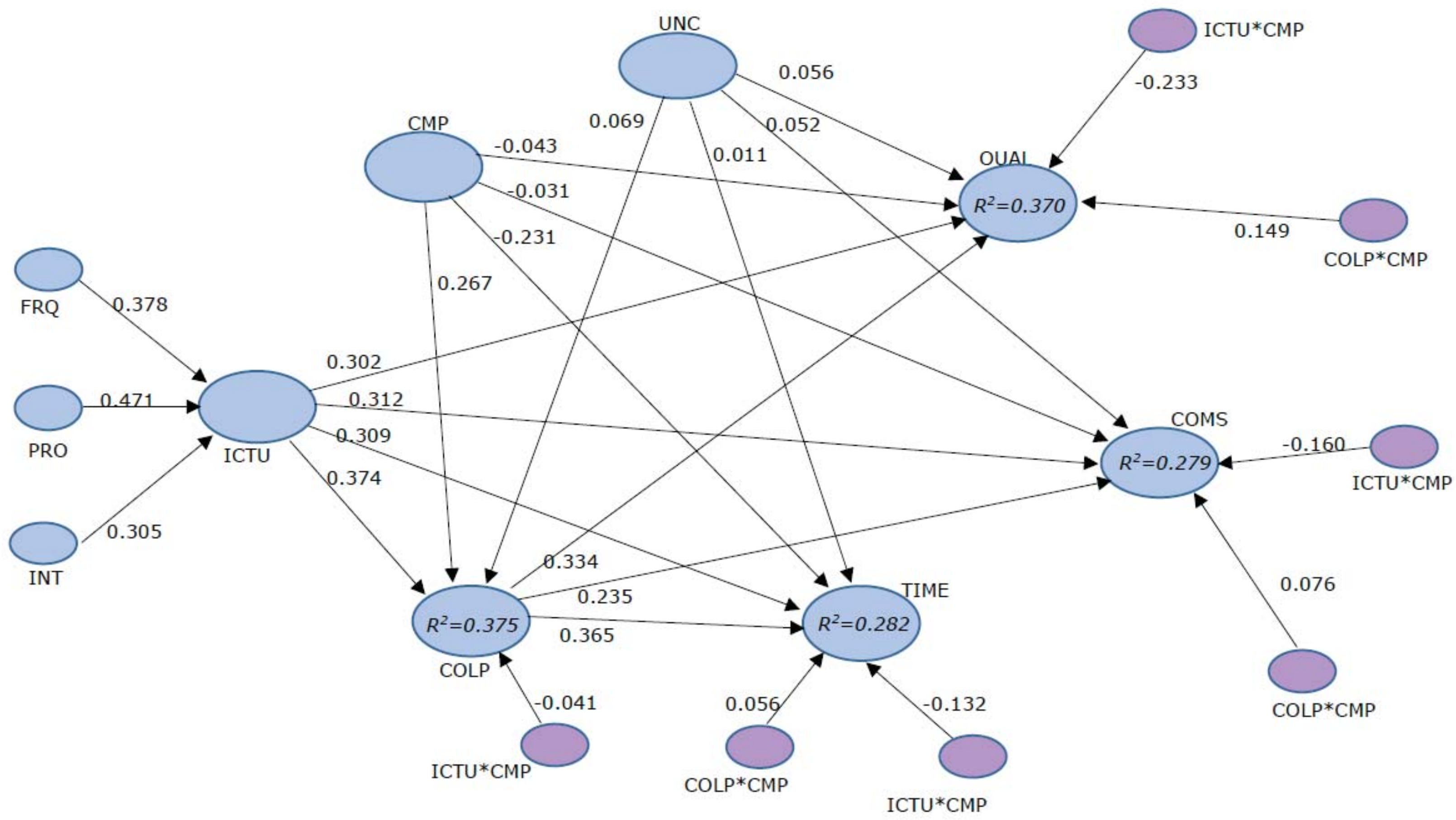

Figure 8.7: Path model excluding the moderating effect of project uncertainty

(FRQ-Frequency, PRO-Proficiency, INT-Intensity, ICTU-ICT usage, CMP-Project complexity, UNC-Project uncertainty, COLP-Collaboration performance, QUAL-Quality, COMS-Commercial success, TIME-Time performance)

As the f^2 values indicate, weak moderating effects of project uncertainty on the relationships between ICT usage and a CPD project's collaboration performance and time performance, exist. However, the results in Table 8.13 do not show statistical significance of any of these moderating effects. Significant moderating effects tend to be detected in PLS when sample size and number of indicators is relatively large (Chin et al., 2003). Although this analysis uses a sufficiently large sample, using three indicators for project uncertainty (moderator) may not be sufficient to detect statistical significance. Since the moderating effect of project uncertainty on the relationship between ICT usage and time performance (0.205) and its effect size (0.09) are relatively high, a positive moderating effect of project uncertainty could exist, although it is not well-supported by the path analysis result.

8.4.4 Performance of the structural model

The proportion of the explained variation in the endogenous latent variables is denoted by the R^2 and used as key criterion for assessing the predictability of a structural model. The values of 0.25, 0.50, or 0.75 are known as weak, moderate, or substantial, respectively (Hair et al., 2011). A structural model's capability to predict is also evaluated by construct cross-validated redundancy measure Q^2 (Geisser, 1974; Stone, 1974). The blindfolding procedure available in SmartPLS estimates these measures. Since omission distance (D) between 5 and 10 is feasible for large samples (Chin, 2010), 7 was selected (D must be a prime integer) for the blindfolding analysis in this study. If the Q^2 value of a certain endogenous latent construct is greater than zero, then its explanatory latent variables are said to have predictive relevance. Table 8.16 presents R^2 values and construct cross-validated redundancy measures of the four CPD performance dimensions – collaboration performance, quality, commercial success, and time performance. The R^2 values indicate weak to moderate impact of ICT usage on CPD performance. As all the Q^2 values are greater than zero, the structural model with ICT usage as a predictor of CPD performance holds sufficient, but moderate, predictive relevance (Q^2 values are greater than 0.5 for highly predictive models).

Table 8.16: Structural model evaluation

Performance construct	*R^2 (%)*	*Construct cross-validated redundancy (Q^2)*
Collaboration performance	0.395	0.2582
Commercial success	0.290	0.2353
New product quality	0.374	0.2595
Time performance	0.340	0.2660

In addition to the above predictability performance measures, a global criterion of goodness of fit (*GoF* index) (Tenenhaus, Amato, & Esposito Vinzi, 2004) was calculated to evaluate the overall performance of the structural model. Unlike CB-SEM, PLS-SEM is not based on a global optimization procedure. Therefore, *GoF* is not suitable for model validation in PLS though it is useful in multiple group comparisons to assess how well a particular PLS path model explains different sets of data (Henseler & Sarstedt, 2013). This study calculated a *GoF* index for the whole dataset and for the groups specified in multiple group comparisons used for moderator analysis (section 8.4.3.1). The following formula was used to calculate the *GoF* index:

$$GoF = \sqrt{\varnothing\ Com \times \varnothing\ R^2_{inner}}$$

where, $\varnothing\ Com$ = The average communality and $\varnothing\ R^2_{inner}$ = Average R^2 of the endogenous latent variables. Table 8.17 includes results of the *GoF* calculation for different groups of data. Wetzels, Odekerken-Schröder, and Van Oppen (2009) presented *GoF* values for small, medium, and large as 0.1, 0.25, and 0.36 respectively based on Cohen (1988). Thus, the calculated *GoF* values exceeding cut-off value of 0.36 indicate a high level of overall goodness of fit in the PLS model estimated.

Table 8.17: *GoF* index values of the path model

Statistic	*Full dataset*	*High complexity group*	*Low complexity group*	*High uncertainty group*	*Low uncertainty group*
$\varnothing\ R^2_{inner}$	0.480	0.358	0.433	0.454	0.409
$\varnothing\ Com$	0.690	0.591	0.619	0.618	0.646
GoF	0.576	0.460	0.518	0.530	0.514

The *GoF* indices calculated for different groups of data based on complexity and uncertainty levels are not largely varied. Therefore, the grouped data adequately fits to the model. However, the *GoF* index of the complete dataset is the highest indicating a better accuracy when considered the data with no grouping. Therefore, results of the moderator analysis based on the complete data (i.e. product-indicator approach) are of relatively higher reliability than the multiple group comparison result.

8.5 DISCUSSION

According to the accepted hypothesis H_{1a}, this study has revealed that ICT usage significantly improves collaboration performance which indicates the degree of success achieved through collaborations in product development projects of manufacturing firms. Reviewing the impact of individual ICT usage dimensions: frequency, proficiency, and intensity considered in the study, is important in explaining this result. ICT tools significantly support acquiring knowledge that resides outside of the firm, frequent and open exchange of information and ideas, coordination and updating partners, and the sharing of information with varied richness. ICT infrastructure well-supported by management, high-level of proficiency in advanced new tools, frequent consultation with partners, and communicating and distribution of benefits and rewards ensure successful knowledge creation and sharing. Implementing ICT tools with advanced security and controlled-access functionalities and utilizing these features frequently and intensively with improved proficiency, contribute to creation of trust and better sharing of knowledge and information between CPD partners.

According to the hypotheses H_{2a}, H_{2b}, *and* H_{2c} confirmed with the empirical data, this study has revealed a highly important indirect impact of ICT usage on new product performance, through collaboration performance. Since existing research addressing the indirect impact of ICT usage have simply considered some aspects of collaboration such as knowledge sharing and have not focused on overall ICT usage in terms of frequency, proficiency, and intensity, the contribution of the revealed indirect impact through collaboration performance is vital. As the present indirect effect implies, collaboration performance enabled by increased usage of ICT in CPD projects, leads to greater project success in terms of new product quality, commercial success and time performance. Moreover, the results indicated that the indirect impact of ICT usage on commercial success is relatively low compared to that on quality and time performance. In explaining this result, it is noted that inputs from collaboration enhanced by frequent, proficient, and intensive ICT use primarily contribute to improving quality and time performance of CPD projects. However, collaboration outcomes such as knowledge sharing and trust creation facilitated by ICT usage do not always ensure significant improvements in financial returns such as profits, sales, and prices. The finding is further supported by the qualitative preliminary study where the participants mostly emphasized the quality and time related benefits of ICT usage rather than financial outcomes.

ICT-enabled knowledge and information sharing and collaboration help globally distributed CPD teams in gathering better quality ideas, achieving excellent quality in their deliverables, managing time effectively, and successfully meeting project deadlines. With the increased use of modern communication and collaboration ICT tools that include a number of features enabling face-to-face-like communication, CPD teams can gain lots of inputs from various partners to ensure greater quality and time performance in their newly developed products. In high-tech manufacturing industries where a number of dispersed partners are involved in a single product development project, enhanced information sharing essentially assists in changing assumptions and making more accurate decisions, which are vital for improving quality of the final product. Although the contribution of ICT for increasing a CPD projects' commercial success is relatively low, this effect is also highly significant. Therefore, concurrent development of common models and reverse engineering, facilitated by collaborative design tools, significantly improves the sharing project risks among CPD partners while increasing the ability to achieve time targets. The effective sharing of project risks and benefits assists in achieving financial goals of CPD projects. In addition, co-innovation enabled by the sharing of product development experience through frequent consultation with partners using ICT with greater proficiency and intensity, helps to realise cost advantages.

The study supports hypotheses H_{1b}, H_{1c}, and H_{1d} that confirms a significant direct positive impact of ICT usage on new product quality, commercial success, and time performance. Since past research focusing on a few ICT tools or overall ICT usage revealed low direct impacts on many of these performance aspects, the present finding contributes to the existing body of knowledge by revealing the above direct positive effects using a comprehensive ICT usage and CPD performance evaluation framework.

As implied by the present results, proficient use of advanced ICTs such as computer-aided drafting and surface and solid modeling systems are important to develop new products up to the required standards. Managing product configurations and variations are facilitated by systems that store and manage product engineering data. Higher utilization of advanced capacities, features, and functionalities in these tools assists completing projects with greater speed. Increased use of market research and analysis tools such as online surveys and online communities in the front end of the product innovation process helps in gathering important market information and adding customer-desired features in new products that ensure greater commercial success. Rapid prototyping, virtual prototyping, and simulation systems enable designers and engineers to create virtual model outputs for a number of design alternatives and select better designs through evaluation of those alternatives. Such designs are more likely to achieve greater quality as well as time targets set for the product development stages.

Revealing the moderating effects of project characteristics for the direct and indirect associations between ICT usage and new product performance dimensions is a significant contribution of this study to theory since no prior empirical evidence for these effects was available. As explained by the hypothesis H_{3b} supported by the study, in complex projects, ICT usage has a relatively weak association with new product quality. An explanation for this impact is that it is rare for a product with a large number of parts, interdependencies, and design constraints to be clearly understood by CPD teams where many participants are involved. However, since the moderation of project complexity on the indirect impact of ICT usage is positive and significant, when a project is complex, firms tend to manage their ICT resources for strengthening collaborative relationships that offer useful inputs for increasing the quality of the product.

Although the path analysis result does not offer strong support, it provides some evidence (relatively large t values and coefficients of strength of moderating effects) for suggesting a similar moderating impact of project complexity on the direct and indirect associations between ICT usage and CPD projects' commercial success. These findings support Ahmad et al. (2013) who identified team integration as an essential factor for improving the performance of complex projects. Also, in a study on software development projects, Jun et al. (2011) observed that user participation makes a greater contribution to improving product performance when project inherent uncertainty is high (they considered project complexity attributes such as project size and technical complexity under the concept named project inherent uncertainty). Improved collaboration performance through increased ICT usage implies greater integration and user participation in CPD. Therefore, according to the present result, it is emphasized that frequent, proficient, and intensive use of ICT tools facilitates the above collaborative mechanisms resulting in considerable improvements in new product quality and commercial success, while managing complexities in high-tech CPD projects.

The study does not suggest any significant moderating impact of project complexity on the direct or indirect association (through collaboration) between ICT usage and time performance. The finding on the indirect association is in line with the study of Dayan and Di Benedetto (2010) which emphasized that trust created in complex projects better supports project success, except for speed-to-market aspect. Creation of trust is one facet of collaboration performance incorporated in the present study. Therefore, the study suggests that not only trust, but also other collaboration outcomes such as knowledge, risks, and information sharing, need to be improved for better time performance, and ICT tools consistently support improving the time efficiency of CPD projects regardless of their level of complexity. Peng et al. (2014) found significant moderating effects of project complexity dimensions, namely product size, task interdependence, and project novelty, on the direct association between ICT tools and NPD collaboration. Although the non-significant moderating impact of project complexity on the relationship between ICT usage and collaboration performance found in the present study is contrary to this, concepts incorporated in the two studies for project complexity and collaboration performance are not exactly similar. In particular, the project complexity of this study captures both product complexity as well as CPD network complexity, and collaboration performance represents the performance outcomes of collaboration rather than the extent of NPD collaboration.

However, some statistical evidence (relatively large path coefficients and coefficients of strength of moderating effects) for a negative moderating effect of project uncertainty on the direct relationships between ICT usage and collaboration performance was observed in the detailed examination of the results. This offers partial support for the negative moderating effect of project novelty found in the study of Peng et al. (2014) on the relationship between ICT tools and NPD collaboration because project novelty had some conceptual underpinnings with project uncertainty adopted in the present study. Therefore, it is suggested that ICT usage has a relatively stronger impact on CPD projects' time performance and a weaker impact on collaboration performance as the degree of project uncertainty increases. However, further investigations on these moderating effects of project uncertainty and the moderating effect of project complexity on the association between ICT usage and commercial success (Tables 8.13 and 8.14) are highly recommended by this study. The relatively small variance of project complexity in the current sample is a possible reason for not observing a strong moderating impact of project complexity. Furthermore, adopting extended project uncertainty constructs including dimensions such as technological and market turbulences (Chen, Reilly, & Lynn, 2005), would be useful in further studies.

This study does not reveal any statistical significance in the moderating effect of project uncertainty on the associations between ICT usage and new product quality and commercial success. Therefore, the positive impact of ICT usage on these performance aspects of a CPD project is consistent regardless its level of uncertainty. In explaining this result, it is emphasized that the CPD projects with greater uncertainty require transfer of more tacit knowledge and processing of information about new products and markets, which are not easily possible with ICT. In CPD, ICT tools mostly facilitate processing of more explicit and structured information and collaborations with existing customers and suppliers. Therefore, the contribution of ICT towards improving quality and commercial success may not be substantially different in more uncertain projects from the extent that it does in projects with low uncertainty. However, according to the participants of the preliminary qualitative study, non-ICT methods such as visiting overseas CPD partners, face-to-face meetings with them, and exhibitions are helpful in more uncertain projects for achieving greater quality and profitability.

Although the direct effects of project complexity and uncertainty are not primary concerns of this study, the path analysis has indicated that three of the direct effects of these project characteristics are significant (Figure 8.5). Paths from project complexity to collaboration performance and time performance are highly significant (p-values < 0.01). As implied by the positive significant effects of project complexity on collaboration performance, CPD projects with high complex characteristics are more likely to improve collaboration performance. Therefore, CPD teams undertaking projects that involve products with many parts and design constraints, and many partners who are involved intensively in CPD activities, effectively share information, knowledge, risks, and benefits and build trust between partners. However, the negative significant path between project complexity and time performance infers that such complex projects have less likelihood of achieving projected time targets. The relatively longer time taken for learning, communication, and processing information, which may increase the cycle times of complex projects is a possible reason for this .

8.6 SUMMARY

This chapter presented descriptive statistics of data collected in the main survey and results of the path analysis performed to test the hypotheses of study. The final sample of 244 CPD projects undertaken by large and medium scale manufacturing firms was utilized in the path analysis. All the hypotheses on direct and indirect effects of ICT usage on CPD performance dimensions have been supported by the PLS results. In addition, hypothesised moderating effects of project complexity on the direct and indirect relationships between ICT usage and new product quality have been supported. Statistical evidence observed for the moderating effects of project complexity on the association between ICT usage and commercial success and project uncertainty on the association between ICT usage and collaboration performance and time performance, is inadequate though supportive. However, the moderating effects of project complexity on the relationships between ICT usage and collaboration performance and time performance are not significant. Similarly, no evidence for the moderating effects of project uncertainty on the relationships between ICT usage and quality and commercial success was found. The next chapter draws the overall conclusions of the study from the results of this primary data analysis and the preliminary qualitative and quantitative research phases. Furthermore, it discusses the theoretical contribution, managerial implications, and limitations of the study, and gives suggestions for future research.

9. Conclusions

9.1 Introduction

This study was conducted to develop an improved framework for evaluating the impact of ICT usage on the performance of collaborative product development projects in manufacturing firms and for investigating the project characteristics that moderate the above impact. Existing inconclusive evidence for the impact of ICT usage on different performance aspects and not incorporating CPD performance reflecting both final project performance and collaboration performance when evaluating ICT impact were the identified gaps in the literature. In addition, the limited understanding about the contribution of multidimensional aspects of overall ICT usage on achieving better performance, and the moderating effect of project characteristics on the impact of ICT usage and CPD performance, were also prevailing research gaps addressed by the study. Overall, the study was required to answer three research questions:

(1) How do manufacturing firms manage ICT usage in terms of frequency, proficiency, and intensity, for improving their collaborative product development activities?
(2) Does ICT usage have a significant impact on CPD performance?
(3) Do the project characteristics representing the information processing requirement in CPD projects significantly moderate the relationship between ICT usage and CPD performance?

First, this chapter presents answers to the research questions, drawn from the empirical findings of the qualitative and quantitative research phases conducted. Second, the theoretical contribution of the study and managerial implications are explained through detailed reviews on the overall findings. Finally, the limitations of the research are identified and possible directions for future research are suggested.

9.2 Empirical Findings

The empirical findings of the three research phases of the study were summarized and discussed in the respective chapters: qualitative preliminary study (Chapter 5), quantitative preliminary study (Chapter 6), and results and discussion of primary data analysis (Chapter 8). This section synthesizes those findings to answer the three main research questions of the study.

9.2.1 Findings on research question 1

Findings of the qualitative study conducted in the preliminary research phase have adequately answered the first research question focusing on managing manufacturing firms' ICT usage for improving their CPD activities. Since this study was set to explore the present context of the main study and evaluate the relevance of the initially developed conceptual research model, the research question was addressed in four sub-research questions: (i) how do manufacturing firms select ICT tools and use them in their collaborative product development programmes? (ii) what are the dimensions of ICT usage that contribute to the success of CPD projects? Are frequency, proficiency, and intensity of ICT use relevant ICT usage dimensions? (iii) which characteristic of a CPD project predominantly represents the information processing requirement in the project? and (iv) what are the positive CPD performance outcomes expected from ICT usage in manufacturing CPD projects and what are the barriers to achieving these outcomes? The research model and its detailed framework finalized based on the findings on the first research question are given in Figure 7.1 and Table 7.2 respectively.

Selection and use of ICT in manufacturing CPD projects

Today, manufacturing firms in many industries use ICT tools nearly in all stages of the product development process. However, differences in the use of ICT are observed mainly depending on: the technological levels of companies, managements' understanding, and confidence in the positive impact of using these tools in CPD programmes. When selecting ICT tools for CPD, manufacturers primarily consider the size and distribution of their product development network, the degree of partner involvement, the nature of information transferred (knowledge intensity), and the frequency of new product introductions. Although the frequency, proficiency, and intensity of ICT use is relatively high in firms handling more technical- and knowledge-intensive products, manufacturers of all types highly value the convenience, transparency, and traceability offered by simple ICT tools such as e-mail and Skype. Furthermore, the ability of an ICT tool to offer the benefits of face-to-face communication is an important criterion for selecting and using the tool in manufacturers' CPD projects.

ICT usage dimensions contributing to the success of CPD projects

Dimensions of ICT usage other than frequency, proficiency, and intensity did not emerge in the qualitative study. According to the practitioners' viewpoint, all the three aspects of ICT usage are important for improving performance of CPD projects. Increased frequency of using communication and collaborative ICT tools in early product development stages is highly important for manufacturers to reduce technological uncertainties. Proficiency of advanced ICT tools, ease of adoption and training effectiveness on new tools are key factors reflecting the ICT proficiency that helps in improving CPD programmes. Intensity of ICT use or the degree of utilizing available capabilities, features, and functionalities in ICT tools is also a vital aspect of ICT usage for achieving high performance in CPD projects.

Project characteristics representing information processing requirement in CPD

Project complexity is the major determinant of the information processing requirement of a CPD project. Product complexity, the number of partners involved and the intensity of their involvement in a CPD project (network complexity of a development team) are key facets of project complexity that can primarily reflect the amount of ICT use required by the project. Since project uncertainty can have common underpinnings with complexity, it is also an important project characteristic to be considered in managing ICT use for improving CPD programmes.

Positive outcomes of ICT usage

Positive outcomes of using ICT in CPD were addressed under the first research question of the study. Manufacturers can gain many collaboration-related advantages through effective use of ICT tools in CPD projects. CPD teams expect collaboration benefits such as improved trust by providing continuous project status updates and ensuring greater information security through the use of appropriate ICT tools. Manufacturers use ICT tools to maintain close, long-term relationships with partners that enable them to share project risks such as potential technical and market failures and benefits in identifying new market opportunities and gaining low material prices (discounts). Several benefits related to new product performance have also been highlighted by the respondents in the interviews. Frequent and high quality information sharing via ICT tools helps manufacturers in developing more customized products. Transferred and deposited knowledge with ICT tools can be utilized to achieve greater quality in future new product developments. CPD teams use ICT tools for: making product designing and development more efficient, making fast changes to products based on customer requests, collecting and analysing market information, and achieving projected budgets and times. The findings supported hypothesising a positive impact of ICT usage on all the CPD performance aspects (collaboration performance, quality, commercial success, and time performance) in the conceptual research model that was to be tested in the final quantitative study.

Barriers to the effective use of ICT in CPD projects

The preliminary qualitative study identified several technical, human and other barriers which can reduce the effective use of ICT in CPD. Version update problems, less user-friendliness, unnecessary features and functionalities, and technical issues of power failures are the key technical barriers that can affect the ability of CPD teams in achieving their desired outcomes. These can delay the product development process and interrupt effective knowledge and information sharing. Human issues such as inadequate ICT proficiency, low commitment in gaining maximum usage of existing ICT resources, resistance to change, and unavailability when required, can distract the collaboration process and achievement of a higher performance of the new product. Other barriers to effective ICT use in CPD were divided into four categories, namely, context-specific, outcome-related, organizational, and collaboration-based barriers. The use of ICT tools is less effective in contexts where partners (customers) are unable to provide quality information, or there is a lesser availability of staff to participate in training programmes. Outcome-related barriers such as low reliance on ICT tools in achieving project goals and less understanding of the intangible outcomes of using these tools can decrease manufacturers' investments in ICTs. Low flexibility in work structures and high dependency on advanced tools, frequent ICT purchases, and lack of assessment before purchasing tools, are organizational barriers which can degrade effective ICT use. The low commitment to using ICT tools for sharing required information and the low responsiveness and contribution of partners are two barriers associated with collaborations in product development.

9.2.2 Findings on research question 2

This research question has been successfully answered by the two quantitative phases of the study. Based on the availability of data in the secondary source (PDMA's 2012 CPAS), the preliminary quantitative research examined the direct and indirect impact of individual ICT tools on overall NPD performance, through collaboration. This study revealed a significant positive direct impact of PDM systems and project management tools on overall NPD performance. In addition, online communities/net ethnography/ virtual shopping/semiotics, PDM systems, collaborative design systems, groupware, customer requirement analysis software, and online focus groups/online surveys, indicted significant positive effects on NPD collaboration which in turn improves overall NPD performance. However, the descriptive statistical analysis performed after testing the hypotheses suggested that in high-tech industries, all types of ICT tools are likely to have a positive impact on NPD performance. Not adopting an informative multidimensional ICT usage measurement has been suggested as the key reason for the little ICT impact observed in the preliminary quantitative study.

Therefore, in the final quantitative phase of the study, the impact of ICT usage was further evaluated with primary data obtained from 244 global CPD projects through an online survey conducted for six high- and medium-high-tech industries: electronic/electrical, medical/dental instruments, pharmaceutical/biotechnology, machinery, automotive, and chemicals. All the hypotheses asserting the direct and indirect positive impact of ICT usage on new product performance (quality, commercial success, and time performance), through collaboration performance have been supported by the results of the PLS-SEM analysis performed (Chapter 8). Hence, it is concluded that ICT usage comprising frequency, proficiency, and intensity has a significant positive direct and indirect impact through collaboration performance on new product quality, commercial success, and time performance of CPD projects. This confirms the findings of preliminary qualitative study that identified several positive outcomes of ICT usage in relation to collaboration, quality, time and financial success of CPD projects, with more sound statistical evidence. According to the results of primary data analysis, the contribution of ICT towards improving collaboration performance and new product quality is larger than improving financial and time-related outcomes. Collaboration performance enabled by ICT usage mostly helps in improving quality and time performance of CPD projects while having a moderate level positive influence on commercial success.

Furthermore, the impact of each individual ICT usage component (frequency, proficiency, and intensity) on each performance dimension is positive and significant. Most importantly, the main quantitative study has found that proficiency of ICT usage has the largest impact on CPD performance while the initial qualitative study suggested frequency as the most representative ICT usage dimension. This study considered the use of five ICT types – communication/collaboration, product design/development, knowledge/information management, project management, and market research/analysis, in evaluating overall ICT usage in a CPD project. Therefore, the results obtained in the study empirically confirm that all these ICT types assist effectively in increasing the performance of CPD projects. In conclusion, overall ICT tool usage in terms of frequency, intensity, and proficiency of use significantly contributes to increasing new product performance and collaboration performance which also in turn improves new product performance of a CPD project.

9.2.3 Findings on research question 3

The path analysis performed in Chapter 8 on primary data collected through the survey examined two sets of hypotheses (Chapter 7) concerning the moderating effect of project complexity and uncertainty over the direct and indirect relationships between ICT usage and CPD performance dimensions. Supporting the qualitative preliminary study which identified complexity as the key project characteristic that represents the information processing requirement of a CPD project, the quantitative study revealed that project complexity significantly moderates the direct and indirect relationships between ICT usage and new product quality. In particular, the direct impact of ICT usage on new product quality is weaker for more complex projects. However, the indirect impact of ICT usage on new product quality, through collaboration performance, is stronger for the complex projects. Therefore, under the conditions of greater project complexities, achieving higher product quality through increased ICT use is only possible when manufacturing firms effectively collaborate with their internal and external product development partners.

Sufficient statistical evidence for a significant moderating impact of project complexity on the associations of ICT usage with other performance dimensions, or for any moderating impact of project uncertainty was not found in this study. However, a detailed review of the statistical results suggests that there is a possibility of a significant moderating effect of project complexity on the association between ICT usage and commercial success. Based on similar evidence, positive moderating effects of project uncertainty on the associations between ICT usage and collaboration performance, and time performance are also suggested. In particular, under the conditions of high project complexities, the direct impact of ICT usage on commercial success can be weaker, whereas the indirect impact through collaboration performance is stronger. In addition, under greater project uncertainties, ICT usage has a relatively larger impact on CPD projects' time performance. However, the contribution of ICT usage for improving collaboration performance in more uncertain projects seems to be relatively lower than in projects that are familiar to the firms. In conclusion, the results of the final quantitative research phase have satisfactorily answered the third research question that investigated into a significant moderating impact of project characteristics on the direct and indirect associations between ICT usage and CPD performance.

9.3 Contribution to Theory

This study which explored a broad view on the impact of ICT usage on CPD performance with both qualitative and quantitative evidence has several significant contributions to the current body of knowledge. In brief, the overall theoretical contribution of the study includes:

- broadening current understanding on managing ICT usage in terms of frequency, proficiency, and intensity, for improving CPD activities in manufacturing sector,
- developing a framework (Figure 7.1 and Table 7.2) including improved ICT usage and CPD performance measurements and project characteristics to evaluate the direct and indirect impact of ICT usage on new product performance, through collaboration performance
- exploring the moderating effect of project characteristics on the relationship between ICT usage and collaborative product development performance, and
- contribution to the underlying theories of the study: RRBV and OIPT

The following sections elaborate these theoretical contributions with specific details.

9.3.1 The use of ICT in collaborative product development projects

Findings of the qualitative phase of this study build upon the previous exploratory research (e.g. Boutellier et al., 1998; Corso & Paolucci, 2001; de Grosbois et al., 2012) addressing the use of ICT in CPD. Extending current understanding on the criteria for selecting and using ICT tools, benefits, and barriers to the effective use of these tools in manufacturing CPD programmes is notable. In addition, the study emphasizes the importance of adopting a more comprehensive ICT usage measurement in evaluating the impact of ICT usage on collaborative product innovation performance. The findings support prior research suggesting the significance of utilizing ICT tools for: frequent contact with product development partners in early product development stages (Boutellier et al., 1998; Littler et al., 1995), the proficient gathering and processing of relevant information (Svetlik et al., 2007), and ensuring rich communication and information exchange (Montoya et al., 2009). The study extends these literatures by providing appropriate industry evidence for the importance of three ICT usage aspects – frequency, proficiency, and intensity, in relation to five ICT types (communication/collaboration, product design/development, knowledge/information management, project management, and market research/analysis) for improving manufacturing sector CPD activities.

Previous research have highlighted that CPD teams can improve trust and knowledge-sharing through appropriate use of ICT tools for providing frequent updates to CPD partners (Coenen & Kok, 2014; Yu, Lu, & Liu, 2010). In addition, benefits such as savings on high-technology procurements and cost-reductions in future projects are possible in close integrations with strategic suppliers and customers (Cousins & Lawson, 2007). Results of this study confirm the above findings and suggest a new construct for representing performance achieved through NPD collaboration including knowledge and information sharing, risks and benefits sharing, and trust creation. This concept extends prior research (Camarinha-Matos & Abreu, 2007; Awwad & Akroush, 2016; Cousins & Lawson, 2007) incorporating indicators for evaluating outcomes of collaborations in product development. Peng et al. (2014) defined project complexity in terms of product size, project novelty, and task interdependence when investigating its moderating impact on the ICT-NPD collaboration relationship. Extending their work to the ICT usage-CPD performance relationship, this study identifies network complexity of a development team (number of partners involved and intensity of their involvement), and product complexity as key elements of overall CPD project complexity which predominantly represents the information processing requirement of the project.

9.3.2 Improved ICT usage measurement and better evaluation of ICT impact on CPD performance

Prior studies addressing the role of ICT in product development have primarily focused on the direct impact of ICT usage on project outcomes such as quality, market performance, and speed-to-market (Barczak et al., 2007; Durmusoglu & Barczak, 2011) or NPD collaboration (Peng et al., 2014) and found little or no impact on some of the performance aspects. Since most of the insignificant relationships revealed in these studies are counterintuitive, further investigation on the impact of ICT usage was required. Adoption of single-item measures for ICT usage that simply capture the number of ICT tools or the extent of using these tools in a project has been identified as a key limitation in the previous research. Findings of the preliminary quantitative study which was based on the secondary data provided additional empirical justification for this notion. Therefore, the main study adopted more reliable and informative multidimensional ICT usage measurement criteria representing frequency, proficiency, and intensity of ICT use in a CPD project. This helped in extending the above literaure with stronger empirical evidence for the direct positive effects of ICT usage on three new product performance dimensions (quality, commercial success, and time performance), and collaboration performance of CPD projects.

Additionally, the findings confirm and extend the studies that found significant positive impact of ICT on service innovation performance using aggregated measures for ICT capability (Chen et al., 2009) by providing evidence from the manufacturing sector with further improved ICT usage measurement adopted. While a few studies have evaluated the impact of selected ICT tools such as project management tools and design tools on NPD collaboration (Banker et al., 2006; Peng et al., 2014), how the overall ICT usage contributes to achieving overall collaboration outcomes comprising creation of trust, sharing of knowledge, risks, and benefits between collaborative partners, had not been investigated. Therefore, the revealed positive impact of overall ICT usage on collaboration performance which in turn improves quality, commercial success, and time performance of CPD projects, significantly contributes to the existing body of knowledge.

Research suggesting that the impact of ICT usage on NPD project performance is indirect rather than direct (Kawakami et al., 2015) are better informed by the partial mediation effect of collaboration performance (i.e. direct and indirect significant effects of ICT usage) revealed in this study. Furthermore, existing findings on the indirect effect of ICT tools on NPD performance, through factors such as NPD collaboration (Banker et al., 2006), knowledge-sharing or knowledge integration (Akgün et al., 2008; Thomas, 2013), and NPD task performance (Kawakami et al., 2015) are confirmed. In addition, those findings are significantly improved by this study which found a positive indirect impact of overall usage of five ICT types (collaboration/communication, design/ development, etc.) on new product performance, through collaboration performance. Most importantly, the empirically established direct and indirect effects contribute to recent qualitative research (Bosch-Sijtsema & Bosch, 2015; Coenen & Kok, 2014) highlighting the importance of exploring ICT impact on collaboration and project based CPD performance in high-tech industries where the use of ICT tools is crucial throughout the product development projects.

Moreover, no prior empirical evidence was found for the impact of individual ICT usage aspects such as frequency, proficiency, and intensity on CPD performance comprising new product performance and collaboration performance. Contributing to bridging this gap, the present study confirms all the three ICT usage dimensions have significant positive impact on collaboration and new product performance while proficiency of ICT use has a relatively stronger impact. According to Shao and Lin (2016), service organizations need to pay greater attention to improving the ICT knowledge and skills of their staff so as to enhance innovation capability. The revealed positive impact of ICT proficiency confirms this finding with appropriate empirical evidence from manufacturing sector product development projects.

9.3.3 Moderating effect of project characteristics

The examined moderating effects of project characteristics on the relationship between ICT usage and CPD performance adds to little empirical research addressing such effects (Peng et al., 2014) and studies that explored differences in ICT usage based on project characteristics (de Grosbois et al., 2012). For example, this study has established a significant moderating effect of project complexity on the direct association and indirect association (through collaboration performance) between ICT usage and new product quality. Specifically, it suggests a negative moderating effect of project complexity on the direct association between ICT usage and quality. This implies that ICT tools better support achieving quality in less complex projects. Furthermore, the study has revealed a significant moderating effect of project complexity over the indirect relationship between ICT usage and new product quality through collaboration performance. Similar moderating effects of project complexity in relation to the direct and indirect effects of ICT usage on a CPD project's commercial success have also been suggested by this study, with marginal statistical evidence obtained. According to Jun et al. (2011), user participation makes a greater contribution to improving product performance when a software development project is more complex. Ahmad et al. (2013) found that project complexity and team integration has a stronger positive effect on overall NPD performance in more complex projects. Improved collaboration performance enabled by increased use of ICT ensures great integration and user participation in CPD. Therefore, the revealed positive moderating effects of project complexity over the indirect association between ICT usage and new product performance supports and extends the above literature with more emphasis on the quality aspect of new product performance.

Based on limited statistical evidence observed for the moderating impact of project uncertainty on the direct association between ICT usage and collaboration performance, the study supports Peng et al. (2014) that found a negative moderating effect of project novelty (which had connections with the uncertainty concept adopted in this study) on the association between ICT tools and NPD collaboration. Based on similar evidence, this study suggests project uncertainty as a possible moderator to the relationship between ICT usage and an NPD project's time performance. Bstieler (2005) found a positive moderating effect of technological uncertainty on the relationship between technical proficiency in product development and time efficiency. Since proficiency of ICT use construct adopted in the present study represents technical proficiency in product development, the positive moderating effect of project uncertainty suggested in this study supports the above finding with more emphasis on ICT capability of R&D staff.

9.3.4 The use of theory

The contributions of this study to its underlying theories (RRBV and OIPT) are also not trivial. This study follows previous ICT-related product development studies adopting organizational information processing theory (Kleinschmidt et al., 2010; Peng et al., 2014) to examine moderating effects of project or organizational characteristics. Advancing these studies, the present research has developed a framework based on two theories RRBV and OIPT in order to investigate collaboration and project based performance outcomes of ICT usage as well as moderating project characteristics. Adopting the relational-resource-based (RRBV) view as a basic underlying theory to examine the direct and indirect impact of ICT usage is a significant contribution of the study where limited research on this emerging theoretical approach is found in the field of innovation management (e.g. Wang & Li-Ying, 2015). This advances prior resource-based research investigating the usefulness of ICT resources in achieving a firm's financial performance (Bharadwaj, 2000) by evaluating in addition, the collaboration-based outcomes of ICT use based on the RRBV, an extended version of the traditional resource-based view.

9.4 Managerial Implications

The findings of this study provide useful implications for CPD practitioners particularly in high- and medium-high-tech manufacturing industries that typically collaborate internally and externally in product innovation. The following sections discuss these suggestions with details.

9.4.1 Using ICT for increasing performance of CPD projects

Understanding the direct impact of overall ICT usage on three major dimensions of new product performance: quality, commercial success, and time performance, would be important for practitioners in ICT investment decisions and managing ICT resources for the success of product development programmes. According to this study, ICT tools improve manufacturers' ability to innovate products with increased design specification compliance, more customer-desired features, and enhanced technical performance. This occurs because ICT tools significantly exceed human abilities in effective information recall, exchange, and processing which are important to make effective decisions in CPD. In addition, cost reduction mechanisms such as computer-enabled simulation, performance evaluations, communication, and market research, supported by ICT tools ensure higher profits, market share, and overall commercial success in CPD endeavours. Managements that utilize ICT resources to ensure high technical proficiency of their R&D staff will have better ability to achieve time targets in the conceptualization, development, and commercialization stages of CPD projects.

The direct impact of ICT usage on collaboration performance and indirect impact through the collaboration outcomes on new product performance make CPD practitioners better informed about the value of ICT use in their innovation programmes. ICT tools are the key means that facilitates all the design, development, market research, project management, communication, and collaboration activities within contemporary CPD teams. Managers should ensure increased frequency and proficiency of using these tools and effective utilization of their functionalities for maintaining relationships that are more trustworthy and help the sharing of project risks, benefits, information, and knowledge. Implementing ICT tools containing advanced security and controlled-access modules would also be effective in this. Improved collaboration performance with ICT use primarily assists in enhancing quality and increasing product development speed rather than ensuring higher commercial success. Creation of new products within projected time frames and with customer-required quality is possible with improved knowledge and information sharing via ICT. As suggested by the qualitative preliminary study, using ICT tools for increasing face-to-face contact with virtually involved members, obtaining frequent feedback from suppliers, and the exchange of quality information in a timely manner largely help CPD practitioners in achieving better performance. Additionally, sharing of project risks and benefits such as new market opportunities and discounts on key material procurements enable manufacturers to claim good prices for their new products.

In-depth evaluation performed on the impact of individual ICT usage aspects considered in this study offer some key insights to product development managers. Frequent use of communication and collaboration ICT in early product development stages importantly assists managers in reaching greater collaboration performance and financial returns. Manufacturing firms should pay special attention to improving the proficiency of their R&D staff in using advanced ICT tools and to ensuring easy adoption of those tools. In addition, encouraging CPD participants to use various functionalities in knowledge, information, and the project management ICT tools, and the frequent use of ICT for market research activities, are important since these have a higher impact on all CPD performance aspects. These findings further imply that having ICT-proficient R&D people who can use many features of the tools for simultaneous task performance within distributed teams and collecting and analysing market data, contributes to improving efficiency as well as effectiveness of CPD. However, it is noted that increased frequency of using project management tools does not largely help in improving product development times while it significantly improves other performance aspects (collaboration, quality, and commercial success). Managers can significantly increase the quality of new products rather than commercial success and time performance by effectively utilizing the features and functionalities in product design and development ICT tools.

9.4.2 Use of ICT in CPD projects with different information processing requirements

The moderating effects revealed in this study provide valuable implications for effectively managing CPD projects with different information processing requirements. As the study suggests, usage of ICT tools directly contributes to improving quality in simple projects more than in complex projects. In complex CPD projects where many distributed partners are intensively involved, many parts are to be designed, and various design constraints and task interdependencies exist, managers face lots of challenges in achieving performance, due to cultural differences, communication and language barriers, and varied technological proficiencies. Therefore, increasing project performance in terms of quality and commercial success through increased use of ICT tools can be relatively difficult in such complex projects. However, the study also suggests that the collaboration performance enhanced through the use of ICT significantly assists managers in dealing with obstacles related to complexity of projects in achieving quality. Extensive involvement of customers, more responsibility assigned to component suppliers, and including external team members with unique technical skills are typical in complex CPD projects (Clift & Vandenbosch, 1999). In such projects with higher information processing requirements, using ICT tools effectively to increase collaboration with the partners is critical to ensure a high level of customer satisfaction, technical performance, and overall quality of the new product as well as greater success in the market. Since there is no evidence of a moderating impact of project complexity on the association between ICT usage and time performance, it is important for managers to note that increased ICT use is similarly important for achieving time targets in CPD projects with any level of information processing requirement due to complexity,.

Although a strong empirical evidence for the moderating impact of project uncertainty was not found, this study offers some important implications concerning the ICT usage effectiveness in projects with varied uncertainties. When projects involve novel technologies, R&D teams usually have greater information ambiguities and need for tacit knowledge to be transferred. However, there is a little opportunity for transfer of this knowledge since ICT tools mainly support the exchange of knowledge available in codified format. Therefore, achieving higher collaboration performance with the use of ICT can be relatively difficult when running projects with high uncertainty. Nevertheless, CPD teams tend to be more committed and rush to process more information via ICT tools when the product/process technology or market is new to them. Consequently, such uncertain projects will have a greater chance for being completed within the expected timeframes. However, managers cannot expect substantial variations in the contribution of ICT use towards improving new product quality or commercial success of projects based on their uncertainties. Therefore, in order to achieve quality and financial objectives, increased ICT usage in terms of frequency, proficiency, and intensity is equally important for CPD projects involving any level of uncertainty in the product technology, process technology, or market.

9.4.3 Additional implications and recommendations

Additional implications that would be useful for CPD practitioners emerge through integration of the findings of qualitative and quantitative investigations conducted. Although ICT tools provide a range of contributions towards the success of CPD projects, there exist some barriers to the effective use of ICT in CPD, which can lower the positive impact on performance objectives. Therefore, performing a detailed cost-benefit analysis before purchasing ICT tools would be beneficial for manufacturing firms undertaking CPD projects. This will help firms to understand the tangible and intangible performance outcomes of using ICT tools and will reduce the risks of not realizing the results expected from the use of these tools. Implementing a proper technology plan for ICT resources would also help to avoid potential technical, human, and other issues associated with ICT use in CPD. A team with extensive experience and knowledge on the firm's business, culture, working environment, and CPD process, and having a good technological background, could plan future ICT requirements based on the information processing requirements of projected innovation projects. Features in available ICT tools, durations for complete adoption, frequency of updating tools, and costs of training are important factors to be considered in the planning process. The required levels of user-friendliness of the tools based on the proficiency of staff and the degree of access to be allowed to different users also need to be specified in the plan in order to ensure positive results.

9.5 Limitations of the Study

Though this study offers several important implications for the field of product innovation, it has some limitations of which the effect has been minimized to the best of the researcher's ability. Although the preliminary stages of this study considered various industries, the main quantitative study has investigated the ICT usage – CPD performance relationship only in high- and medium-high-tech manufacturing industries. Therefore, the inferences of the study are particularly valid for these industries. Furthermore, the representation of different industries in the current sample could not be sufficient to reveal variations across specific industries considered (automotive, machinery, etc.) in terms of the direct, indirect and moderating effects investigated. The main analysis of this study has primarily focused on the impact of overall ICT usage on CPD performance, rather than evaluating the impact of individual ICT tools in detail. However, it has made some inferences about the impact of different ICT types (communication/collaboration, product design/development, etc.) through a detailed discussion on the statistical results obtained. Statistical evidence found in this study for some of the moderating effects examined is not sufficient. Relatively low variation of project complexity in the sample and adopting inadequate number of indicators for project uncertainty are possible reasons for the small effects observed. Due to existing resource and time constraints, this study implemented a cross-sectional research design which limits its ability to infer causal effects of ICT usage. Even though the self-reported questionnaire survey could lead to a risk of common method bias, a post hoc analysis performed in the study has justified that this risk is not substantial.

Furthermore, this study does not cover the psychological dimension of the subject and thus, it is important to consider the findings exclusive of the psychological aspects of the model constructs.

9.6 Suggestions for Future Research

The industries excluded in the main study (low-tech and service industries) may have different magnitudes and patterns in the direct, indirect and moderating effects investigated, thus require further examination in future studies. Although this study does not suggest significant differences in ICT impact across specific industries considered (electronic, automotive, etc.), future studies could investigate these differences in detail using larger samples from each industry. Comparisons of the results of such studies with the present findings would be worthwhile to explore differences in the effectiveness of ICT usage across technology levels and product types. The findings of this study related to individual ICT types could be further reviewed by way of more focused studies on individual ICT tools, by appropriately adjusting the suggested measurement criteria (frequency, proficiency, and intensity) for evaluating the usage of these tools. Further examination of the moderating effects of project characteristics on the associations between ICT usage and CPD performance dimensions is recommended for future studies as this is the only research that has attempted to evaluate many of these effects. Including projects with more variations in terms of complexity and considering additional dimensions of uncertainty such as technological and market turbulence would be useful in those studies to uncover the moderating effects with improved accuracy. In order to overcome limitations in the present cross-sectional research design, evaluating similar hypotheses using project-based longitudinal data and comparing the results with the current findings are recommended for future studies.

References

Abdalla, H. S. (1999). Concurrent engineering for global manufacturing. *International Journal of Production Economics, 60/61*(3), 251-260.

Achiche, S., Appio, F. P., McAloone, T. C., & Di Minin, A. (2012). Fuzzy decision support for tools selection in the core front end activities of new product development. *Research in Engineering Design, 24*(1), 1-18.

Açıkgöz, A., Günsel, A., Bayyurt, N., & Kuzey, C. (2014). Team Climate, Team Cognition, Team Intuition, and Software Quality: The Moderating Role of Project Complexity. *Group Decision & Negotiation, 23*(5), 1145-1176.

Agile Manifesto. (2001). Retrieved 14 August, 2013, from http://agilemanifesto.org

Ahmad, S., Mallick, D. N., & Schroeder, R. G. (2013). New product development: Impact of project characteristics and development practices on performance. *Journal of Product Innovation Management, 30*(2), 331-348.

Ahmed, Z. (2011). Designing Flexible GUI to Increase the Acceptance Rate of Product Data Management Systems in Industry. *International Journal of Computer Science & Emerging Technologies, 2*(1), 100-109.

Ahmed, Z., & Gerhard, D. (2007). Contributions of PDM Systems in Organizational Technical Data Management. *The First IEEE International Conference On Computer, Control & Communication*.

Akgün, A. E., Dayan, M., & Di Benedetto, A. (2008). New product development team intelligence: Antecedents and consequences. *Information & Management, 45*(4), 221-226.

Al-Ashaab, A., Golob, M., Attia, U. M., Khan, M., Parsons, J., Andino, A., . . . Sopelana, A. (2013). The transformation of product development process into lean environment using set-based concurrent engineering: A case study from an aerospace industry. *Concurrent Engineering, 0*(0), 1-18.

Aldea, C. C., Popescu, A.-D., Draghici, A., & Draghici, G. (2012). ICT Tools Functionalities Analysis for the Decision Making Process of Their Implementation in Virtual Engineering Teams. *Procedia Technology, 5*, 649-658.

Andriessen, J. E. (2012). *Working with groupware: understanding and evaluating collaboration technology*: Springer Science & Business Media.

Androutsopoulos, I., Koutsias, J., Chandrinos, K. V., & Spyropoulos, C. D. (2000). An experimental comparison of naive Bayesian and keyword-based anti-spam filtering with personal e-mail messages *Proceedings of the 23rd annual international ACM SIGIR conference on research and development in information retrieval* (pp. 160-167). New York, USA: ACM.

Appio, F. P., Lazzeri, F., Corsi, S., & Di Minin, A. (2011). *ICT tools enabling collaborative creation and development with customers: the case of Ansaldo Energia*. Paper presented at the VIII Conference of the Italian Chapter of AIS, Italy.

Arsenyan, J., & Büyüközkan, G. (2012). *Information Technology Planning For Collaborative Product Development Through Fuzzy QFD*. Paper presented at the The Sixth International Conference on Digital Society, Spain.

Athaide, G. A., & Klink, R. R. (2009). Managing Seller–Buyer Relationships during New Product Development. *Journal of Product Innovation Management, 26*(5), 566-577.

Atuahene-Gima, K. (1995). An Exploratory Analysis of the Impact of Market Orientation on New Product Performance. *Journal of Product Innovation Management, 12*(4), 275-293.

Awazu, Y., Baloh, P., Desouza, K. C., Wecht, C. H., Kim, J., & Jha, S. (2009). Informationcommunication technologies open up innovation. *Research-Technology Management, 52*(1), 51-58.

Awwad, A., & Akroush, D. M. N. (2016). New product development performance success measures: an exploratory research. *EuroMed Journal of Business, 11*(1), 2-29.

Badrinarayanan, V., & Arnett, D. B. (2008). Effective virtual new product development teams: an integrated framework. *Journal of Business & Industrial Marketing, 23*(4), 242-248.
Bagozzi, R. P., Yi, Y., & Phillips, L. W. (1991). Assessing construct validity in organizational research. *Administrative science quarterly, 36*(3), 421-458.
Banker, R. D., Bardhan, I., & Asdemir, O. (2006). Understanding the impact of collaboration software on product design and development. *Information Systems Research, 17*(4), 352-373.
Barczak, G., Griffin, A., & Kahn, K. B. (2009). PERSPECTIVE: Trends and drivers of success in NPD practices: Results of the 2003 PDMA best practices study. *Journal of Product Innovation Management, 26*(1), 3-23.
Barczak, G., Hultink, E. J., & Sultan, F. (2008). Antecedents and consequences of information technology usage in NPD: A comparison of Dutch and U.S. companies. *Journal of Product Innovation Management, 25*(6), 620-631.
Barczak, G., Sultan, F., & Hultink, E. J. (2007). Determinants of IT usage and new product performance. *The Journal of Product Innovation Management, 24*, 600-613.
Barney, J., Wright, M., & Ketchen Jr, D. J. (2001). The resource-based view of the firm: Ten years after 1991. *Journal of Management*, *27*(6), 625-641.
Baron, N. S. (2013). Instant messaging *Pragmatics of computer-mediated communication* (pp. 135-161).
Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173-1182.
Becker, M. C., Salvatore, P., & Zirpoli, F. (2005). The impact of virtual simulation tools on problem-solving and new product development organization. *Research Policy, 34*(9), 1305-1321.
Bendoly, E., Bharadwaj, A., & Bharadwaj, S. (2012). Complementary drivers of new product development performance: Cross-functional coordination, information system capability, and intelligence quality. *Production and Operations Management, 21*(4), 653-667.
Bharadwaj, A. S. (2000). A resource-based perspective on information technology capability and firm performance: An empirical investigation. *MIS Quarterly, 24*(1), 169-196.
Bhaskaran, S. R., & Krishnan, V. (2009). Effort, revenue, and cost sharing mechanisms for collaborative new product development. *Management Science, 55*(7), 1152-1169.
Bhatt, N., & Ved, A. (2013). ICT in New Product Development: Revulsion to Revolution. In C. Mukhopadhyay, K. B. Akhilesh, R. Srinivasan, A. Gurtoo, P. Ramachandran, P. P. Iyer, M. Mathirajan, & M. H. Bala Subrahmanya (Eds.), *Driving the Economy through Innovation and Entrepreneurship* (pp. 833-845): Springer India.
Bierly, P. E., Stark, E. M., & Kessler, E. H. (2009). The Moderating Effects of Virtuality on the Antecedents and Outcome of NPD Team Trust. *Journal of Product Innovation Management, 26*(5), 551-565.
Blindenbach-Driessen, F., Van Dalen, J., & Van Den Ende, J. (2010). Subjective Performance Assessment of Innovation Projects. *Journal of Product Innovation Management, 27*(4), 572-592.
Blood, R. (2000, 18 September 2013). Weblogs: A History and Perspective. Retrieved 12 February, 2016, from http://www.rebeccablood.net/essays/weblog_history.html
Boehm, B. W. (1988). A spiral model of software development and enhancement. *Computer, 21*(5), 61-72.
Bogers, M., & Horst, W. (2014). Collaborative Prototyping: Cross-Fertilization of Knowledge in Prototype-Driven Problem Solving. *Journal of Product Innovation Management, 31*(4), 744-764.
Bonaccorsi, A., & Lipparini, A. (1994). Strategic partnerships in new product development: An Italian case study. *Journal of Product Innovation Management, 11*(2), 134-145.
Bonner, J. M. (2010). Customer interactivity and new product performance: Moderating effects of product newness and product embeddedness. *Industrial Marketing Management, 39*(3), 485-492.

Bosch-Sijtsema, P., & Bosch, J. (2015). User Involvement throughout the Innovation Process in High-Tech Industries. *Journal of Product Innovation Management*, *32*(5), 793-807.
Boudreau, M.-C., Gefen, D., & Straub, D. W. (2001). Validation in information systems research: a state-of-the-art assessment. *MIS Quarterly*, *25*(1), 1-16.
Boulos, M. N., Maramba, I., & Wheeler, S. (2006). Wikis, blogs and podcasts: a new generation of Web-based tools for virtual collaborative clinical practice and education. *BMC medical education*, *6*(1), 41.
Boutellier, R., Gassmann, O., Macho, H., & Roux, M. (1998). Management of dispersed product development teams: The role of information technologies. *R&D Management*, *28*(1), 13-25.
Bowen, N. K., & Guo, S. (2011). *Structural equation modeling*: Oxford University Press.
Bradley, J. (1993). Methodological issues and practices in qualitative research. *The Library Quarterly*, 431-449.
Braunstein, J. W. (2007). Identifying Multicollinearity in Multiple Regression: Statistics Help for Dissertation Students & Researchers. Retrieved 1 July, 2015, from http://www.researchconsultation.com/multicollinearity-regression-spss-collinearity-diagnostics-vif.asp
Brettel, M., & Cleven, N. J. (2011). Innovation culture, collaboration with external partners and NPD performance. *Creativity and Innovation Management*, *20*(4), 253-272.
Brettel, M., Heinemann, F., Engelen, A., & Neubauer, S. (2011). Cross-Functional Integration of R&D, Marketing, and Manufacturing in Radical and Incremental Product Innovations and Its Effects on Project Effectiveness and Efficiency. *Journal of Product Innovation Management*, *28*(2), 251-269.
Bruce, M., Leverick, F., & Littler, D. (1995). Complexities of collaborative product development. *Technovation*, *15*(9), 535-552.
Bruce, M., Leverick, F., Littler, D., & Wilson, D. (1995). Success factors for collaborative product development: a study of suppliers of information and communication technology. *R&D Management*, *25*(1), 33-44.
Bryden, D. (2014). *CAD and Rapid Prototyping for Product Design*. London: Laurence King Publishing.
Bryman, A., & Bell, E. (2015). *Business research methods*: Oxford University Press, USA.
Bstieler, L. (2005). The moderating effect of environmental uncertainty on new product development and time efficiency. *Journal of Product Innovation Management*, *22*(3), 267-284.
Bstieler, L. (2006). Trust formation in collaborative new product development. *Journal of Product Innovation Management*, *23*, 56-72.
Bstieler, L., & Hemmert, M. (2008). Developing trust in vertical product development partnerships: A comparison of South Korea and Austria. *Journal of World Business*, *43*(1), 35-46.
Bugshan, H. (2015). Co-innovation: The role of online communities. *Journal of Strategic Marketing*, *23*(2), 175-186.
Büyüközkan, G., & Arsenyan, J. (2012). Collaborative product development: a literature overview. *Production Planning & Control*, *23*(1), 47-66.
Calantone, R., & Benedetto, C. (2012). The role of lean launch execution and launch timing on new product performance. *Journal of the Academy of Marketing Science*, *40*(4), 526-538.
Camarinha-Matos, L. M., & Abreu, A. (2007). Performance indicators for collaborative networks based on collaboration benefits. *Production Planning & Control*, *18*(7), 592-609.
Camarinha-Matos, L. M., Afsarmanesh, H., Galeano, N., & Molina, A. (2009). Collaborative networked organizations – Concepts and practice in manufacturing enterprises. *Computers & Industrial Engineering*, *57*(1), 46-60.
Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological bulletin*, *56*(2), 81-105.

Cantamessa, M., Montagna, F., & Neirotti, P. (2012). An empirical analysis of the PLM implementation effects in the aerospace industry. *Computers in Industry, 63*(3), 243-251.
Capterra. (2016). Top Idea Management Software Products. Retrieved 10 Mar., 2016, from http://www.capterra.com/idea-management-software/
Carr, A. S., & Kaynak, H. (2007). Communication methods, information sharing, supplier development and performance: an empirical study of their relationships. *International Journal of Operations & Production Management, 27*(4), 346-370.
Carstensen, P. H., & Schmidt, K. (1999). Computer supported cooperative work: New challenges to systems design. In I. K. Itoh (Ed.), *Handbook of Human Factors*: Citeseer.
Catterall, M., & Maclaran, P. (2002). Researching consumers in virtual worlds: A cyberspace odyssey. *Journal of Consumer Behaviour, 1*(3), 228-237.
Chan, L.-K., & Wu, M.-L. (2002). Quality function deployment: a literature review. *European Journal of Operational Research, 143*(3), 463-497.
Changepoint. (2015). Project Portfolio Management (PPM). Retrieved 25 Mar., 2016, from http://changepoint.com/en-us/solutions/by-need/project-portfolio-management
Chen, C.-H., Ling, S. F., & Chen, W. (2003). Project scheduling for collaborative product development using DSM. *International Journal of Project Management, 21*(4), 291-299.
Chen, J.-S., Tsou, H. T., & Huang, A. Y.-H. (2009). Service delivery innovation antecedents and impact on firm performance. *Journal of Service Research, 12*(1), 36-55.
Chen, J., Reilly, R. R., & Lynn, G. S. (2005). The impacts of speed-to-market on new product success: the moderating effects of uncertainty. *IEEE Transactions on Engineering Management, 52*(2), 199-212.
Chin, W. W. (2000). Frequently Asked Questions – Partial Least Squares & PLS-Graph. Home Page. Retrieved 18 August, 2014, from http://disc-nt.cba.uh.edu/chin/plsfaq.htm
Chin, W. W. (2010). How to write up and report PLS analyses *Handbook of partial least squares* (pp. 655-690): Springer.
Chin, W. W., Marcolin, B. L., & Newsted, P. R. (2003). A Partial Least Squares Latent Variable Modeling Approach for Measuring Interaction Effects: Results from a Monte Carlo Simulation Study and an Electronic-Mail Emotion/Adoption Study. *Information Systems Research, 14*(2), 189-217.
Choi, S. Y., Lee, H., & Yoo, Y. (2010). The impact of information technology and transactive memory systems on knowledge sharing, application, and team performance: a field study. *MIS Quarterly*, 855-870.
Chow, S. L. (2005). *Research methods and statistics : an integrated account for the behavioral sciences*. Calgary, Canada: Detselig Enterprises.
Church, K., & de Oliveira, R. (2013). What's up with whatsapp?: comparing mobile instant messaging behaviors with traditional SMS *Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services* (pp. 352-361). New York, USA: ACM.
Clark, K. B. (1991). *Product development performance: Strategy, organization, and management in the world auto industry*: Harvard Business Press.
Clift, T. B., & Vandenbosch, M. B. (1999). Project complexity and efforts to reduce product development cycle time. *Journal of Business Research, 45*(2), 187-198.
Coenen, M., & Kok, R. A. (2014). Workplace flexibility and new product development performance: The role of telework and flexible work schedules. *European Management Journal, 32*(4), 564-576.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*: Hillsdale, N.J. : L. Erlbaum Associates, 19882nd ed.

Cohen, J. (1992). A power primer. *Psychological bulletin, 112*(1), 155-159.
Coolican, H. (2009). *Research methods and statistics in psychology*. London: Hodder Education.

Cooper, R. G. (1979). The dimensions of industrial new product success and failure. *Journal of Marketing, 43*(3), 93-103.
Cooper, R. G. (2013). New products-What seperates the winners from the losers and what drives success. In Kenneth B. Kahn, Sally Evans Kay, Rebecca J. Slotegraaf, & S. Uban (Eds.), *The PDMA handbook of new product development* (3 ed.). Hoboken, N.J.: Wiley.
Cooper, R. G., Edgett, S., & Kleinschmidt, E. (2001). Portfolio management for new product development: results of an industry practices study. *R&D Management, 31*(4), 361-380.
Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (1999). New product portfolio management: practices and performance. *Journal of Product Innovation Management, 16*(4), 333-351.
Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (2004). Benchmarking best NPD practices-I. *Research Technology Management, 47*(1), 31-43.
Corso, M., & Paolucci, E. (2001). Fostering innovation and knowledge transfer in product development through information technology. *International Journal of Technology Management, 22*(1), 126-148.
Cousins, P. D., & Lawson, B. (2007). The Effect of Socialization Mechanisms and Performance Measurement on Supplier Integration in New Product Development. *British Journal of Management, 18*(3), 311-326.
Cousins, P. D., Lawson, B., Petersen, K. J., & Handfield, R. B. (2011). Breakthrough Scanning, Supplier Knowledge Exchange, and New Product Development Performance. *Journal of Product Innovation Management, 28*(6), 930-942.
Cowton, C. J. (1998). The use of secondary data in business ethics research. *Journal of Business Ethics, 17*(4), 423-434.
Crawford, I. M. (1997). *Marketing Research and Information Systems*. Rome: Food and Agriculture Organization of the United States.
Creswell, J. W. (2009). *Research design : qualitative, quantitative, and mixed methods approaches* (3 ed.). Thousand Oaks, Calif.: SAGE Publications.
Creswell, J. W. (2013). *Qualitative Inquiry & Research Design Choosing Among Five Approaches* (3 ed.). London: SAGE Publications.
Creusen, M. E. H., Hultink, E. J., & Eling, K. (2013). Choice of consumer research methods in the front end of new product development *55*(1), 81-104.
Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological bulletin, 52*(4), 281-302.
Croom, S. R. (2001). The dyadic capabilities concept: examining the processes of key supplier involvement in collaborative product development. *European Journal of Purchasing and Supply Chain Management, 7*(1), 29-37.
Curşeu, P. L., Schalk, R., & Wessel, I. (2008). How do virtual teams process information? A literature review - and implications for management. *Journal of Managerial Psychology, 23*(6), 628-652.
d'Avolio, E., Bandinelli, R., & Rinaldi, R. (2015). Improving new product development in the fashion industry through product lifecycle management: a descriptive analysis. *International Journal of Fashion Design, Technology and Education, 8*(2), 108-121.
Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. *Management Science, 32*(5), 554-571.
Danese, P. (2011). Towards a contingency theory of collaborative planning initiatives in supply networks. *International Journal of Production Research, 49*(4), 1081-1103.
Davis, H. O. (2001). System and method for conducting focus groups using remotely loaded participants over a computer network: Google Patents.
Dayan, M., & Di Benedetto, C. A. (2010). The impact of structural and contextual factors on trust formation in product development teams. *Industrial Marketing Management, 39*(4), 691-703.
De Clercq, D., Thongpapanl, N. T., & Dimov, D. (2011). A Closer Look at Cross-Functional Collaboration and Product Innovativeness: Contingency Effects of Structural and Relational Context. *Journal of Product Innovation Management, 28*(5), 680-697.

de Grosbois, D., Kumar, U., & Kumar, V. (2012). Extent of Internet-based Technology Use in New Product Development Projects in Canada and the United States. *Jindal Journal of Business Research, 1*(1), 1-19.
Deck, M., & Strom, M. (2002). Model of co-development emerges. *Research Technology Management, 45*(3), 47-53.
Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE handbook of qualitative research*: Sage.
Di Benedetto, C. A. (1999). Identifying the Key Success Factors in New Product Launch. *Journal of Product Innovation Management, 16*(6), 530-544.
Djelassi, S., & Decoopman, I. (2013). Customers' participation in product development through crowdsourcing: Issues and implications. *Industrial Marketing Management, 42*(5), 683-692.
Dube, L., & Pare, G. (2004). The Multi-Faceted Nature of Virtual Teams. In D. J. Pauleen (Ed.), *Virtual Teams: Projects, Protocols and Processes* (pp. 1-39). Pennsylvania: IGI Global.
Durmusoglu, S. S., & Barczak, G. (2011). The use of information technology tools in new product development phases: Analysis of effects on new product innovativeness, quality, and market performance. *Industrial Marketing Management, 40*(2), 321-330.
Durmuşoğlu, S. S., & Barczak, G. (2011). The use of information technology tools in new product development phases: Analysis of effects on new product innovativeness, quality, and market performance. *Industrial Marketing Management, 40*(2), 321-330.
Durmusoglu, S. S., Calantone, R. J., & Sambamurthy, V. (2006). Is more information technology better for new product development? *Journal of Product & Brand Management, 15*(7), 435-441.
Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of management review, 23*(4), 660-679.
Ebrahim, N. A., Ahmed, S., & Taha, Z. (2009). Virtual Teams: a Literature Review. *Australian Journal of Basic & Applied Sciences, 3*(3), 2653-2669.
Edmonds, W. A., & Kennedy, T. D. (2012). *An applied reference guide to research designs: Quantitative, qualitative, and mixed methods*. Thousand Oaks, Calif.: SAGE Publications.
Ellis, C. A., Gibbs, S. J., & Rein, G. (1991). Groupware: some issues and experiences. *Communications of the ACM, 34*(1), 39-58.
Eppler, M. J., Hoffmann, F., & Bresciani, S. (2011). New Business Models through Collaborative Idea Generation. *International Journal of Innovation Management, 15*(06), 1323-1341.
Eriksson, I. V., & Dickson, G. W. (2000). Knowledge sharing in high technology companies *AMCIS 2000 Proceedings*.
Evans, R. D., Gao, J. X., Martin, N., & Simmonds, C. (2015). Integrating Social Knowledge and Collaboration Tools into Dispersed Product Development. *International Journal of Advanced Corporate Learning, 8*(2), 20-27.
Fawcett, S. E., Jones, S. L., & Fawcett, A. M. (2012). Supply chain trust: The catalyst for collaborative innovation. *Business Horizons, 55*(2), 163-178.
Felekoglu, B., & Moultrie, J. (2014). Top management involvement in new product development: A review and synthesis. *Journal of Product Innovation Management, 31*(1), 159-175.
Feng, T. (2013). Supply chain involvement for better product development performance. *Industrial Management & Data Systems, 113*(2), 190-206.
Ferrise, F., Bordegoni, M., & Cugini, U. (2013). Interactive virtual prototypes for testing the interaction with new products. *Computer-Aided Design and Applications, 10*(3), 515-525.
Fichman, R. G. (2001). The role of aggregation in the measurement of IT-related organizational innovation. *MIS Quarterly*, 427-455.
Figueiredo, P., Silveira, G., & Sbragia, R. (2008). Risk sharing partnerships with suppliers: The case of Embraer. *Journal of Technology Management & Innovation, 3*(1), 27-37.

Filieri, R. (2013). Consumer co-creation and new product development: a case study in the food industry. *Marketing Intelligence & Planning, 31*(1), 40-53.
Firestone, S., Ramalingam, T., & Fry, S. (2007). *Voice and video conferencing fundamentals*: Cisco Press.
Fisher, R. J., Maltz, E., & Jaworski, B. J. (1997). Enhancing communication between marketing and engineering: The moderating role of relative functional identification. *Journal of Marketing, 61*(3), 54-70.
Flores, M., Boër, C., Huber, C., Plüss, A., Schoch, R., & Pouly, M. (2009). Universities as key enablers to develop new collaborative environments for innovation: successful experiences from Switzerland and India. *International Journal of Production Research, 47*(17), 4935-4953.
Fornell, C., & Larcker, D. F. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *Journal of Marketing Research, 18*(1), 39-50.
Franceschini, F. (2016). *Advanced quality function deployment*: CRC Press.
Frost, S. (2006). World Web Event Services Markets - N100-64.
Fuh, J. Y., & Li, W. (2005). Advances in collaborative CAD: the-state-of-the art. *Computer-Aided Design, 37*(5), 571-581.
Fung, R., Popplewell, K., & Xie, J. (1998). An intelligent hybrid system for customer requirements analysis and product attribute targets determination. *International Journal of Production Research, 36*(1), 13-34.
Galbraith, J. R. (1974). Organization design: An information processing view. *Interfaces, 4*(3), 28-36.
Galbraith, J. R. (1984). Organization design: An information processing view. *Army Organizational Effectiveness Journal, 8*(1), 21-26.
Gautam, N., & Singh, N. (2008). Lean product development: Maximizing the customer perceived value through design change (redesign). *International Journal of Production Economics, 114*(1), 313-332.
Geisser, S. (1974). A predictive approach to the random effect model. *Biometrika, 61*(1), 101-107.
Goel, A. K., Vattam, S., Wiltgen, B., & Helms, M. (2012). Cognitive, collaborative, conceptual and creative—four characteristics of the next generation of knowledge-based CAD systems: a study in biologically inspired design. *Computer-Aided Design, 44*(10), 879-900.
Gologlu, C., & Mizrak, C. (2011). An integrated fuzzy logic approach to customer-oriented product design. *Journal of Engineering Design, 22*(2), 113-127.
Grant, R. M. (1991). The resource-based theory of competitive advantage: implications for strategy formulation. *Knowledge and strategy, 33*(3), 3-23.
Greer, C. R., & Lei, D. (2012). Collaborative Innovation with Customers: A Review of the Literature and Suggestions for Future Research. *International Journal of Management Reviews, 14*(1), 63-84.
Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research *Handbook of qualitative research* (pp. 105-117).
Gunasekaran, A. (1999). Agile manufacturing: A framework for research and development. *International Journal of Production Economics, 62*(1–2), 87-105.
Gupta, A. K., & Wilemon, D. L. (1990). Accelerating The Development Of Technology-Based New Products. *California Management Review, 32*(2), 24-44.
Gursoy, D., & Swanger, N. (2007). Performance-enhancing internal strategic factors and competencies: impacts on financial success. *International Journal of Hospitality Management, 26*(1), 213-227.
Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *The Journal of Marketing Theory and Practice, 19*(2), 139-152.
Hall, H. (2001). Input-friendliness: motivating knowledge sharing across intranets. *Journal of information science, 27*(3), 139-146.

Hambali, A., Sapuan, S. M., Ismail, N., Nukman, Y., & Karim, M. S. A. (2009). The Important Role of Concurrent Engineering in Product Development Process. *Pertanika Journal of Science & Technology, 17*(1), 9-20.
Hamel, G. Y. L. P. C. K. (1989). Collaborate with Your Competitors--and Win. *Harvard Business Review, 67*(1), 133-139.
Handfield, R. B., & Lawson, B. (2007). Integrating Suppliers Into New Product Development. *Research-Technology Management, 50*(5), 44-51.
Handfield, R. B., Ragatz, G. L., Peterson, K., & Monczka, R. M. (1999). Involving suppliers in new product development? *California Management Review, 42*, 59-82.
Harding, J. (2013). *Qualitative data analysis from start to finish*. London: Sage.
Hart, S., & Tzokas, N. (2010). Launch Strategies and New Product Success. In J. Tidd (Ed.), *Gaining Momentum: Managing the Diffusion of Innovations* (Vol. 15, pp. 121). London, UK: Imperial College Press.
Heim, G. R., Mallick, D. N., & Peng, X. D. (2012). Antecedents and Consequences of New Product Development Practices and Software Tools: An Exploratory Study. *IEEE Transactions on Engineering Management, 59*(3), 428-442.
Henseler, J. (2007). A new and simple approach to multi-group analysis in partial least squares path modeling. In T. N. M. M. H. Martens (Ed.), *PLS'07 international symposium on PLS and related methods – causalities explored by indirect observation* (pp. 104-107). Norway: Matforsk, A ˚ s.
Henseler, J., & Fassott, G. (2010). Testing moderating effects in PLS path models: An illustration of available procedures *Handbook of partial least squares* (pp. 713-735): Springer.
Henseler, J., & Sarstedt, M. (2013). Goodness-of-fit indices for partial least squares path modeling. *Computational Statistics, 28*(2), 565-580.
Heron, J., & Reason, P. (1997). A participatory inquiry paradigm. *Qualitative inquiry, 3*(3), 274-294.
Hess, J., Randall, D., Pipek, V., & Wulf, V. (2013). Involving users in the wild—Participatory product development in and with online communities. *International Journal of Human - Computer Studies, 71*(5), 570-589.
Hirunyawipada, T., Beyerlein, M., & Blankson, C. (2010). Cross-functional integration as a knowledge transformation mechanism: Implications for new product development. *Industrial Marketing Management, 39*(4), 650-660.
Hoecht, A., & Trott, P. (2006). Innovation risks of strategic outsourcing. *Technovation, 26*(5), 672-681.
Hoegl, M. (2005). Buyer-supplier collaboration in product development projects. *Journal of Management, 31*(4), 530-548.
Holland, S., Gaston, K., & Gomes, J. (2000). Critical success factors for cross-functional teamwork in new product development. *International Journal of Management Reviews, 2*(3), 231-259.
Hong, Y., & Hartley, J. L. (2011). Managing the supplier-supplier interface in product development: The moderating role of technology newness. *Journal of Supply Chain Management, 47*(3), 43-62.
Horster, E., & Gottschalk, C. (2012). Computer-assisted Webnography A new approach to online reputation management in tourism. *Journal of Vacation Marketing, 18*(3), 229-238.
Hoyer, W. D., Chandy, R., Dorotic, M., Krafft, M., & Singh, S. S. (2010). Consumer Cocreation in New Product Development. *Journal of Service Research, 13*(3), 283-296.
Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research, 15*(9), 1277-1288.
Hultink, E. J., Griffin, A., Hart, S., & Robben, H. S. J. (1997). Industrial New Product Launch Strategies and Product Development Performance. *Journal of Product Innovation Management, 14*(4), 243-257.

Humphreys, P., Huang, G., Cadden, T., & McIvor, R. (2007). Integrating design metrics within the early supplier selection process. *Journal of Purchasing and Supply Management, 13*(1), 42-52.

Ignatius, J., Leen, J. Y. A., Ramayah, T., Hin, C. K., & Jantan, M. (2012). The impact of technological learning on NPD outcomes: The moderating effect of project complexity. *Technovation, 32*(7), 452-463.

Inoue, M., Nahm, Y. E., Tanaka, K., & Ishikawa, H. (2013). Collaborative engineering among designers with different preferences: Application of the preference set-based design to the design problem of an automotive front-side frame. *Concurrent Engineering*.

Jaegers, T., Lipp-Lingua, C., & Amil, D. (2013). High-technology and medium-high technology industries main drivers of EU-27's industrial growth. *Eurostat Statistics in Focus: Industry, Trade and Services. Luxembourg: Eurostat*.

Jassawalla, A. R., & Sashittal, H. C. (1998). An Examination of Collaboration in High-Technology New Product Development Processes. *Journal of Product Innovation Management, 15*(3), 237-254.

Jiao, J. (2006). Customer Requirement Management in Product Development: A Review of Research Issues. *Concurrent Engineering, 14*(3), 173-185.

Jo, H., Parsaei, H., & Sullivan, W. (1993). Principles of concurrent engineering. In H. Parsaei & W. Sullivan (Eds.), *Concurrent Engineering* (pp. 3-23): Springer US.

Jun, L., Qiuzhen, W., & Qingguo, M. (2011). The effects of project uncertainty and risk management on IS development project performance: A vendor perspective. *International Journal of Project Management, 29*(7), 923-933.

Karlsson, C., & Åhlström, P. (1996). The Difficult Path to Lean Product Development. *Journal of Product Innovation Management, 13*(4), 283-295.

Kawakami, T., Barczak, G., & Durmusoglu, S. S. (2015). Information Technology Tools in New Product Development: The Impact of Complementary Resources. *Journal of Product Innovation Management, 32*(4), 622-635.

Kawakami, T., Durmusoglu, S. S., & Barczak, G. (2011). Factors Influencing Information Technology Usage for New Product Development: The Case of Japanese Companies. *Journal of Product Innovation Management, 28*(6), 833-847.

Kayis, B., Zhou, M., Savci, S., Khoo, Y., Ahmed, A., Kusumo, R., & Rispler, A. (2007). IRMAS–development of a risk management tool for collaborative multi-site, multi-partner new product development projects. *Journal of Manufacturing Technology Management, 18*(4), 387-414.

Kennedy, M. N., & Ward, A. (2003). *Product development for the lean enterprise: why Toyota's system is four times more productive and how you can implement it*: Oaklea Press.

Kenny, D. A. (2015). Mediation. Retrieved 07 April, 2016, from http://davidakenny.net/cm/mediate.htm

Kern, E.-M., & Kersten, W. (2007). Framework for internet-supported inter-organizational product development collaboration. *Journal of Enterprise Information Management, 20*(5), 562-577.

Kessler, E. H., & Chakrabarti, A. K. (1999). Speeding up the pace of new product development. *Journal of Product Innovation Management, 16*(3), 231-247.

Kettunen, P. (2009). Adopting key lessons from agile manufacturing to agile software product development—A comparative study. *Technovation, 29*(6-7), 408-422.

Khan, M., Al-Ashaab, A., Doultsinou, A., Shehab, E., Ewers, P., & Sulowski, R. (2011). Set-based concurrent engineering process within the LeanPPD environment *Improving Complex Systems Today* (pp. 433-440): Springer.

Kim, H. D., Lee, I., & Lee, C. K. (2013). Building Web 2.0 enterprises: A study of small and medium enterprises in the United States. *International Small Business Journal, 31*(2), 156-174.

Kim, J., & Wilemon, D. (2003). Sources and assessment of complexity in NPD projects. *R&D Management, 33*(1), 15-30.

Kim, J., & Wilemon, D. (2007). The learning organization as facilitator of complex NPD projects. *Creativity and Innovation Management, 16*(2), 176-191.

Kimberlin, C. L., & Winterstein, A. G. (2008). Validity and reliability of measurement instruments used in research. *Am J Health Syst Pharm*, *65*(23), 2276-2284.
Kleinschmidt, E., De Brentani, U., & Salomo, S. (2010). Information processing and firm-internal environment contingencies: Performance impact on global new product development. *Creativity and Innovation Management, 19*(3), 200-218.
Kleinsmann, M., Buijs, J., & Valkenburg, R. (2010). Understanding the complexity of knowledge integration in collaborative new product development teams: A case study. *Journal of Engineering and Technology Management, 27*(1-2), 20-32.
Koufteros, X., Vonderembse, M., & Doll, W. (2001). Concurrent engineering and its consequences. *Journal of Operations Management, 19*(1), 97-115.
Koufteros, X. A., Vonderembse, M. A., & Doll, W. J. (2002). Integrated product development practices and competitive capabilities: the effects of uncertainty, equivocality, and platform strategy. *Journal of Operations Management, 20*(4), 331-355.
Krauss, S. E. (2005). Research paradigms and meaning making: A primer. *The qualitative report, 10*(4), 758-770.
Kung, K.-H., Ho, C.-F., Hung, W.-H., & Wu, C.-C. (2015). Organizational adaptation for using PLM systems: Group dynamism and management involvement. *Industrial Marketing Management, 44*, 83-97.
LaBahn, D. W., & Krapfel, R. (2000). Early Supplier Involvement in Customer New Product Development: A Contingency Model of Component Supplier Intentions. *Journal of Business Research, 47*(3), 173-190.
Lai, C.-S., Chen, C.-S., Chiu, C.-J., & Pai, D.-C. (2011). The impact of trust on the relationship between inter-organisational collaboration and product innovation performance. *Technology Analysis & Strategic Management, 23*(1), 65-74.
Lakemond, N., Magnusson, T., Johansson, G., & Säfsten, K. (2013). Assessing interface challenges in product development projects. *Research-Technology Management, 56*(1), 40-48.
Lam, P.-K., & Chin, K.-S. (2005). Identifying and prioritizing critical success factors for conflict management in collaborative new product development. *Industrial Marketing Management, 34*(8), 761-772.
Langner, B., & Seidel, V. P. (2009). Collaborative concept development using supplier competitions: Insights from the automotive industry. *Journal of Engineering and Technology Management, 26*(1–2), 1-14.
Lau, A. K. W., Tang, E., & Yam, R. C. M. (2010). Effects of Supplier and Customer Integration on Product Innovation and Performance: Empirical Evidence in Hong Kong Manufacturers. *Journal of Product Innovation Management, 27*(5), 761-777.
Lavie, D. (2006). The competitive advantage of interconnected firms: An extension of the resource-based view. *Academy of management review, 31*(3), 638-658.
Lawrence, P. R., & Lorsch, J. W. (1967). *Organization and environment : managing differentiation and integration*. Boston: Harvard University.
Lawson, M., & Karandikar, H. M. (1994). A Survey of Concurrent Engineering. *Concurrent Engineering, 2*(1), 1-6.
Lee, Y. S. (2012). Networked Collaborative Design and Control for Collaborative Product Development Using Haptic Interface. *Computer-Aided Design and Applications, 9*(3), 327-343.
Letens, G., Farris, J. A., & Aken, E. M. V. (2011). A Multilevel Framework for Lean Product Development System Design. *Engineering Management Journal, 23*(1), 69-85.
Levin, K. A. (2006). Study design III: Cross-sectional studies. *Evidence-based dentistry, 7*(1), 24-25.
Li, M., Gao, S., & Wang, C. C. (2007). Real-time collaborative design with heterogeneous CAD systems based on neutral modeling commands. *Journal of Computing and Information Science in Engineering, 7*(2), 113-125.
Lin, Y.-C., Hsing, M. Y., & Wang, Y.-C. (2008). Research on Business Strategy and Performance Evaluation in Collaborative Design. *IJEBM, 6*(2), 57-69.

Lin, Y., & Wu, L.-Y. (2014). Exploring the role of dynamic capabilities in firm performance under the resource-based view framework. *Journal of Business Research, 67*(3), 407-413.
Lindlöf, L., Söderberg, B., & Persson, M. (2012). Practices supporting knowledge transfer – an analysis of lean product development. *International Journal of Computer Integrated Manufacturing, 26*(12), 1-8.
Littler, D., Leverick, F., & Bruce, M. (1995). Factors affecting the process of collaborative product development: A study of UK manufacturers of information and communications technology products. *Journal of Product Innovation Management, 12*(1), 16-32.
Liu, X. F., Raorane, S., & Leu, M. C. (2007). A web-based intelligent collaborative system for engineering design *Collaborative product design and manufacturing methodologies and applications* (pp. 37-58): Springer.
Lockwood, N. S., & Massey, A. P. (2012). Communicator trust across media: A comparison of audio conferencing, video conferencing, and a 3D virtual environment *Proceedings of the 45th Annual Hawaii International Conference on System Science (HICSS)* (pp. 839-848). Maui, HI: IEEE.
Lockwood, N. S., Montoya, M. M., & Massey, A. P. (2013). Virtual Teams in New Product Development: Characteristics and Challenges. In K. B. Kahn (Ed.), *The PDMA handbook of new product development* (3rd ed.). New Jersey, USA: Wiley.
Luh, Y.-P., Pan, C.-C., & Chu, C.-H. (2011). A hierarchical deployment of distributed product lifecycle management system in collaborative product development. *International Journal of Computer Integrated Manufacturing, 24*(5), 471-483.
Luo, C., Mallick, D. N., & Schroeder, R. G. (2010). Collaborative product development: Exploring the role of internal coordination capability in supplier involvement. *European Journal of Innovation Management, 13*(2), 244-266.
Mann, C. (2003). Observational research methods. Research design II: cohort, cross sectional, and case-control studies. *Emergency Medicine Journal, 20*(1), 54-60.
Marion, T. J., Barczak, G., & Hultink, E. J. (2014). Do Social Media Tools Impact the Development Phase? An Exploratory Study. *Journal of Product Innovation Management, 31*(S1), 18-29.
Markham, S. K., & Lee, H. (2013). Product Development and Management Association's 2012 Comparative Performance Assessment Study. *Journal of Product Innovation Management, 30*(3), 408-429. doi: 10.1111/jpim.12025
Marshall, M. N. (1996). Sampling for qualitative research. *Family practice, 13*(6), 522-526.
Martinsuo, M. (2013). Project portfolio management in practice and in context. *International Journal of Project Management, 31*(6), 794-803.
Mathrani, S. K., & Liu, C. (2015). Success factors for collaborative product development in engineering projects: a monoview study. *IEEE Engineering Management Review, 43*(2), 118-118.
McDonough, E. F. (2000). Investigation of Factors Contributing to the Success of Cross-Functional Teams. *Journal of Product Innovation Management, 17*(3), 221-235.
McGee, M. (2013, 28 March 2013). Email Is Top Activity On Smartphones, Ahead Of Web Browsing & Facebook [Study]. Retrieved 25 Mar, 2016, from http://marketingland.com/smartphone-activities-study-email-web-facebook-37954
McGrath, M. E. (2004). *Next generation product development: How to increase productivity, cut costs, and reduce cycle times*. New York ; London: McGraw-Hill.
McQueen, R. A., & Knussen, C. (2006). *An introduction to research methods and statistics in psychology*. New York: Pearson Education.
Melville, N., Kraemer, K., & Gurbaxani, V. (2004). Review: Information technology and organizational performance: An integrative model of IT business value. *MIS Quarterly, 28*(2), 283-322.
Meybodi, M. Z. (2013). The links between lean manufacturing practices and concurrent engineering method of new product development: an empirical study. *Benchmarking: An International Journal, 20*(3), 362-376.

Microsoft. (2016). Project Top Features. Retrieved 25 Mar., 2016, from https://products.office.com/en-nz/Project/project-top-features?tab=5be62e8e-5c9c-50b2-6d90-fd024de6a69f

Milhim, H. K. B., Deng, X., Schiffauerova, A., & Zeng, Y. (2012). The Role of Product Lifecycle Management Systems in Organizational Innovation. In Louis Rivest, Abdelaziz Bouras, & B. Louhichi (Eds.), *Product lifecycle management: towards knowledge rich enterprises, IFIP WG 5.1 International Conference, PLM 2012, Montreal, QC, Canada* (Vol. Revised selected papers, pp. 322-331). New York, USA: Springer.

Ming, X. G., Yan, J. Q., Lu, W. F., & Ma, D. (2005). Technology solutions for collaborative product lifecycle management–status review and future trend. *Concurrent Engineering, 13*(4), 311-319.

Minitab. (2016). Minitab 17. Retrieved 26 Mar., 2016, from http://www.minitab.com/en-us/products/minitab/

Mishra, A. A., & Shah, R. (2009). In union lies strength: Collaborative competence in new product development and its performance effects. *Journal of Operations Management, 27*(4), 324-338.

Molay, K. (2007, 01 Mar.). Webinar Or Webcast - What's The Difference? Retrieved 10 Jan., 2014, from http://wsuccess.typepad.com/webinarblog/2007/03/webinar_or_webc.html

Montoya, M. M., Massey, A. P., Hung, Y.-T. C., & Crisp, C. B. (2009). Can you hear me now? Communication in virtual product development teams. *Journal of Product Innovation Management, 26*(2), 139-155.

Muethel, M., Siebdrat, F., & Hoegl, M. (2012). When do we really need interpersonal trust in globally dispersed new product development teams? *R & D management, 42*(1), 31-46.

Muijs, D. (2010). *Doing quantitative research in education with SPSS*: Sage.

Murray, J. Y., Gao, G. Y., & Kotabe, M. (2011). Market orientation and performance of export ventures: the process through marketing capabilities and competitive advantages. *Journal of the Academy of Marketing Science, 39*(2), 252-269. doi: 10.1007/s11747-010-0195-4

Mutum, D. W., Qing. (2010). Consumer Generated Advertising in Blogs. In N. M. Burns (Ed.), *Handbook of Research on Digital Media and Advertising: User Generated Content Consumption* (pp. 248–261): IGI Global.

Najafi Tavani, S., Sharifi, H., Soleimanof, S., & Najmi, M. (2013). An empirical study of firm's absorptive capacity dimensions, supplier involvement and new product development performance. *International Journal of Production Research, 51*(11), 3385-3403.

Narver, J. C., Slater, S. F., & MacLachlan, D. L. (2004). Responsive and Proactive Market Orientation and New-Product Success. *Journal of Product Innovation Management, 21*(5), 334-347.

Nevogt, c. (2015). 30 Project Management Software Solutions. Retrieved 20 Jan., 2016, from http://blog.hubstaff.com/project-management-software-solutions/

NIC. (2014, 23 Jan.). Collaborative 2D & 3D CAD/CAM Software. Retrieved 25 Feb., 2015, from http://www.collabcad.com/features_detailed.html

Nieto, M. J., & Santamaría, L. (2007). The importance of diverse collaborative networks for the novelty of product innovation. *Technovation, 27*(6-7), 367-377.

Noël, F., & Azli, M. A. (2013). Experimenting new metaphors for pdm through a model driven engineering scheme *Product Lifecycle Management for Society* (pp. 570-583): Springer.

Nordlund, H., Lempiala, T., & Holopainen, M. (2011). Openness of innovating: the new roles of customers and users in business-to-business context. *International Journal of Entrepreneurship and Innovation Management, 14*(4), 282-297.

Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric Theory: New York: McGraw-Hill.

Oke, A., & Idiagbon-Oke, M. (2010). Communication channels, innovation tasks and NPD project outcomes in innovation-driven horizontal networks. *Journal of Operations Management, 28*(5), 442-453.

Oppenheim, B. W. (2004). Lean product development flow. *Systems Engineering, 7*(4), 352-376.

Ottosson, S. (2002). Virtual reality in the product development process. *Journal of Engineering Design*, *13*(2), 159-172.
Ozer, M. (2000). Information technology and new product development: opportunities and pitfalls. *Industrial Marketing Management, 29*(5), 387-396.
Paashuis, V. (2013). *The organisation of integrated product development*: Springer Science & Business Media.
Parikh, M. (2001). Knowledge management framework for high-tech research and development. *Engineering Management Journal, 13*(3), 27-34.
Park, J., Shin, K., Chang, T.-W., & Park, J. (2010). An integrative framework for supplier relationship management. *Industrial Management & Data Systems, 110*(4), 495-515.
Parker, D. B., Zsidisin, G. A., & Ragatz, G. L. (2008). Timing and extent of supplier integration in new product development: A contingency approach. *Journal of Supply Chain Management, 44*(1), 71-83.
Parker, H. (2000). Interfirm collaboration and the new product development process. *Industrial Management & Data Systems, 100*(6), 255-260.
Parsaei, H. R., & Sullivan, W. G. (2012). *Concurrent engineering: contemporary issues and modern design tools*: Springer Science & Business Media.
Partridge, C. (2008). The technical development of internet email. *IEEE Annals of the History of Computing, 1*(2), 3-29.
Patanakul, P., Chen, J., & Lynn, G. S. (2012). Autonomous Teams and New Product Development. *Journal of Product Innovation Management, 29*(5), 734-750.
Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2 ed.): SAGE Publications, inc.
Patton, M. Q. (2015). *Qualitative research & evaluation methods : integrating theory and practice* (4 ed.). Los Angeles: SAGE Publications, Inc.
Paulraj, A., Lado, A. A., & Chen, I. J. (2008). Inter-organizational communication as a relational competency: Antecedents and performance outcomes in collaborative buyer–supplier relationships. *Journal of Operations Management, 26*(1), 45-64.
Pavlou, P. A., & Sawy, O. A. E. (2006). From IT leveraging competence to competitive advantage in turbulent environments: The case of new product development. *Information Systems Research, 17*(3), 198-227.
Peng, D. X., Heim, G. R., & Mallick, D. N. (2014). Collaborative Product Development: The Effect of Project Complexity on the Use of Information Technology Tools and New Product Development Practices. *Production and Operations Management, 23*(8), 1421–1438.
Petersen, K. J., Handfield, R. B., & Ragatz, G. L. (2005). Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management, 23,* 371-388.
Petrocelli, J. V. (2003). Hierarchical multiple regression in counseling research: Common problems and possible remedies. *Measurement and evaluation in counseling and development, 36*(1), 9-22.
Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: Problems and prospects. *Journal of Management, 12*(4), 531-544.
Pons, D. (2008). Project management for new product development. *Project Management Journal, 39*(2), 82-97.
Ponterotto, J. G. (2005). Qualitative research in counseling psychology: A primer on research paradigms and philosophy of science. *Journal of counseling psychology, 52*(2), 126.
Prabaharan, M. (2013). *Application of CAD/CAE, Reverse Engineering and Rapid Prototyping in New Product Development Industry*. Paper presented at the ASME 2013 International Mechanical Engineering Congress and Exposition.
Ragatz, G. L., Handfield, R. B., & Petersen, K. J. (2002). Benefits associated with supplier integration into new product development under conditions of technology uncertainty. *Journal of Business Research, 55*(5), 389-400.

Ragatz, G. L., Handfield, R. B., & Scannell, T. V. (1997). Success Factors for Integrating Suppliers into New Product Development. *Journal of Product Innovation Management, 14*(3), 190-202.
Rao, M. (2012). *Knowledge management tools and techniques*. Amsterdam ; Boston: Elsevier Butterworth-Heinemann.
Ravinchandran, T., & Lertwongsatien, C. (2005). Effect of information systems resources and capabilities on firm performance: A resource-based perspective. *Journal of Management Information Systems, 21*(4), 237-276.
Reason, P., & Bradbury, H. (2001). *Handbook of action research: Participative inquiry and practice*: Sage.
Red, E., Holyoak, V., Jensen, C. G., Marshall, F., Ryskamp, J., & Xu, Y. (2010). ν-CAx: A Research Agenda for Collaborative Computer-Aided Applications. *Computer-Aided Design and Applications, 7*(3), 387-404.
Reid, S. E., & De Brentani, U. (2004). The Fuzzy Front End of New Product Development for Discontinuous Innovations: A Theoretical Model. *Journal of Product Innovation Management, 21*(3), 170-184. doi: 10.1111/j.0737-6782.2004.00068.x
Ringle, C. M., Sarstedt, M., & Straub, D. (2012). A critical look at the use of PLS-SEM in MIS Quarterly. *MIS Quarterly, 36*(1), 3-14.
Ritter, T., & Gemünden, H. G. (2003). Network competence: Its impact on innovation success and its antecedents. *Journal of Business Research, 56*(9), 745-755.
Robinson, L., & Schulz, J. (2011). New field sites, new methods: new ethnographic opportunities. *The handbook of emergent technologies in social research*, 180-198.
Romano, N. C., Fang, C., & Nunamaker, J. F., Jr. (2002). Collaborative Project Management Software *Proceedings of the 35th Annual Hawaii International Conference on System Sciences* (pp. 233-242). Hawaii: IEEE.
Romero, D., & Molina, A. (2011). Collaborative networked organisations and customer communities: value co-creation and co-innovation in the networking era. *Production Planning & Control, 22*(5-6), 447-472.
Rossi, M., Taisch, M., & Terzi, S. (2012). Lean product development: A five-steps methodology for continuous improvement. In B. Katzy, T. Holzmann, K. Sailer, & K. D. Thoben (Eds.), *ICE 2012 Conference proceedings* (pp. 1-10). Munich IEEE.
Rubin, H. J., & Rubin, I. (2005). *Qualitative interviewing : the art of hearing data* (2 ed.). Thousand Oaks, Calif. : Sage Publications, Inc.
Ruggles, R. L. (2009). *Knowledge management tools*: Butterworth-Heinemann.
Salo, A., & Käkölä, T. K. (2005). Groupware Support for Requirements Management in New Product Development. *Journal of Organizational Computing & Electronic Commerce, 15*(4), 253-284.
Salomo, S., Steinhoff, F., & Trommsdorff, V. (2003). Customer orientation in innovation projects and new product development success-the moderating effect of product innovativeness. *International Journal of Technology Management, 26*(5-6), 442-463.
SAP. (2014). Achieve product excellence in process manufacturing with integrated collaboration and product development software. Retrieved 30 January, 2015, from http://www.sap.com/solution/lob/r-and-d/software/product-development-process/index.html
Sarcar, M., Rao, K. M., & Narayan, K. L. (2008). *Computer aided design and manufacturing*. New Delhi: Prentice-Hall of India Pvt. Ltd.
Sarstedt, M., Henseler, J., & Ringle, C. M. (2011). Multigroup analysis in partial least squares (PLS) path modeling: Alternative methods and empirical results. *Advances in international marketing, 22*(1), 195-218.
Schiele, H. (2010). Early supplier integration: the dual role of purchasing in new product development. *R&D Management, 40*(2), 138-153.
Seimens. (2016). What is PLM Software? Retrieved 26 Mar., 2016, from https://www.plm.automation.siemens.com/en_us/
Seth, A., Vance, J. M., & Oliver, J. H. (2011). Virtual reality for assembly methods prototyping: a review. *Virtual Reality, 15*(1), 5-20. doi: 10.1007/s10055-009-0153-y

Sethi, R. (2000). New product quality and product development teams. *Journal of Marketing, 64*(2), 1-14.
Shao, B. B. M., & Lin, W. T. (2016). Assessing Output Performance of Information Technology Service Industries: Productivity, Innovation and Catch-Up. *International Journal of Production Economics, 172*, 43-53.
Sicotte, H., & Bourgault, M. (2008). Dimensions of uncertainty and their moderating effect on new product development project performance. *R&D Management, 38*(5), 468-479.
Simon, H. A. (1957). *Models of man; social and rational*. Oxford: Wiley.
Sivadas, E., & Dwyer, F. R. (2000). An examination of organizational factors influencing new product success in internal and alliance-based processes. *The Journal of Marketing*, 31-49.
Smals, R. G. M., & Smits, A. A. J. (2012). Value for value—The dynamics of supplier value in collaborative new product development. *Industrial Marketing Management, 41*(1), 156-165. doi: http://dx.doi.org/10.1016/j.indmarman.2011.11.022
Smith, P. G. (2007). *Flexible product development: building agility for changing markets*: John Wiley & Sons.
Smith, R. P., & Eppinger, S. D. (1998). Deciding between sequential and concurrent tasks in engineering design. *Concurrent Engineering: Research and Applications, 6*(1), 15-25.
Snow, C. C., Fjeldstad, Ø. D., Lettl, C., & Miles, R. E. (2011). Organizing continuous product development and commercialization: the collaborative community of firms model. *Journal of Product Innovation Management, 28*(1), 3-16.
Soares, D., Bastos, J., Gavazzo, D., Pereira, J., & Baptista, A. J. (2013). Lean Management Methods in Product Development: A Case Study. In A. Azevedo (Ed.), *Advances in Sustainable and Competitive Manufacturing Systems* (pp. 1385-1399): Springer International Publishing.
Sobek II, D. K., Ward, A. C., & Liker, J. K. (1999). Toyota's principles of set-based concurrent engineering. *MIT Sloan Management Review, 40*(2), 67-83.
Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological methodology, 13*(1982), 290-312.
Son, S., Na, S., & Kim, K. (2011). Product data quality validation system for product development processes in high-tech industry. *International Journal of Production Research, 49*(12), 3751-3766.
Song, L. Z., Song, M., & Benedetto, C. A. D. (2011). Resources, supplier investment, product launch advantages, and first product performance. *Journal of Operations Management, 29*(1–2), 86-104.
Song, M., & Di Benedetto, C. A. (2008). Supplier's involvement and success of radical new product development in new ventures. *Journal of Operations Management, 26*(1), 1-22.
Song, M., & Montoya-Weiss, M. M. (2001). The effect of perceived technological uncertainty on Japanese new product development. *Academy of Management Journal, 44*(1), 61-80.
Song, X. M., Montoya-Weiss, M. M., & Schmidt, J. B. (1997). Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D, Manufacturing, and Marketing Perspectives. *Journal of Product Innovation Management, 14*(1), 35-47.
Song, X. M., Thieme, R. J., & Xie, J. (1998). The Impact of Cross-Functional Joint Involvement Across Product Development Stages: An Exploratory Study. *Journal of Product Inoovation Management, 15*(4), 289–303.
Soper, D. S. (2006a). A-priori Sample Size Calculator for Hierarchical Multiple Regression [Software]. Retrieved 30 May, 2015, from http://www.danielsoper.com/statcalc/calculator.aspx?id=16
Soper, D. S. (2006b). A-priori Sample Size Calculator for Multiple Regression. Retrieved 04 Jul., 2015, from http://www.danielsoper.com/statcalc/calculator.aspx?id=1
Sopheon. (2016). Project and Portfolio Management (PPM) Solutions for Multiple Market Segments. Retrieved 25 Mar., 2016, from https://www.sopheon.com/project-portfolio-management-ppm/

Souder, W. E., Sherman, J. D., & Davies-Cooper, R. (1998). Environmental uncertainty, organizational integration, and new product development effectiveness: A test of contingency theory. *Journal of Product Innovation Management, 15*(6), 520-533.
SPSS. (2016). IBM SPSS Statistics. Retrieved 26 Mar., 2016, from http://www-01.ibm.com/software/analytics/spss/products/statistics/features.html
Stark, J. (2015). Product lifecycle management *Product lifecycle management* (3 ed., Vol. 1, pp. 1-29). Switzerland: Springer.
Stark, J. (2016). The PDM System *Product Lifecycle Management* (3 ed., Vol. 2, pp. 233-252). Switzerland: Springer.
Steiger, J. H. (1980). Tests for comparing elements of a correlation matrix. *Psychological bulletin, 87*(2), 245-251.
Steinmueller, W. E. (2000). Will new information and communication technologies improve the'codification'of knowledge? *Industrial and corporate change, 9*(2), 361-376.
Stock, R. M., Totzauer, F., & Zacharias, N. A. (2014). A Closer Look at Cross-Functional R&D Cooperation for Innovativeness: Innovation-Oriented Leadership and Human Resource Practices as Driving Forces. *Journal of Product Innovation Management, 31*(5), 924-938.
Stone, M. (1974). Cross-validatory choice and assessment of statistical predictions. *Journal of the Royal Statistical Society. Series B (Methodological), 36*, 111-147.
Straub, D. W. (1989). Validating instruments in MIS research. *MIS Quarterly, 13*(2), 147-169.
Study.com. (2003). Secondary Data in Marketing Research: Definition, Sources & Collection. Retrieved 27 Aug., 2014, from http://study.com/academy/lesson/secondary-data-in-marketing-research-definition-sources-collection.html
Sue, V. M., & Ritter, L. A. (2012). *Conducting online surveys*. Thousand Oaks, Calif.: SAGE Publications, Inc.
Suk-Ki, H., & Schniederjans, M. J. (2000). Balancing concurrent engineering environmental factors for improved product development performance. *International Journal of Production Research, 38*(8), 1779-1800.
Sun, H., Fan, W., Shen, W., & Xiao, T. (2012). Ontology-based interoperation model of collaborative product development. *Journal of Network and Computer Applications, 35*(1), 132-144.
Svetlik, I., Stavrou-Costea, E., & Lin, H.-F. (2007). Knowledge sharing and firm innovation capability: an empirical study. *International Journal of Manpower, 28*(3/4), 315-332.
Swink, M. (1999). Threats to new product manufacturability and the effects of development team integration processes. *Journal of Operations Management, 17*(6), 691-709.
Swink, M. (2003). Completing projects on-time: how project acceleration affects new product development. *Journal of Engineering and Technology Management, 20*(4), 319-344.
Swink, M. (2006). Building collaborative innovation capability. *Research Technology Management, 49*(2), 37-47.
Swink, M., Talluri, S., & Pandejpong, T. (2006). Faster, better, cheaper: a study of NPD project efficiency and performance tradeoffs. *Journal of Operations Management, 24*(5), 542-562.
Talke, K., & Hultink, E. J. (2010). The Impact of the Corporate Mind-set on New Product Launch Strategy and Market Performance. *Journal of Product Innovation Management, 27*(2), 220-237.
Tang, H., Guo, S., Huang, L., Li, L., & Li, Y. (2015). Research and development on key models and technology of PDM system. *The International Journal of Advanced Manufacturing Technology, 78*(9-12), 1865-1878.
Tatikonda, M. V., & Rosenthal, S. R. (2000). Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management, 47*(1), 74-87.
Teigland, R., Fey, C. F., & Birkinshaw, J. (2000). Knowledge dissemination in global R&D operations: an empirical study of multinationals in the high technology electronics industry. *Management International Review, 40*(1), 49-77.

Tenenhaus, M., Amato, S., & Esposito Vinzi, V. (2004). A global goodness-of-fit index for PLS structural equation modelling *Proceedings of the XLII SIS scientific meeting* (Vol. Contributed Papers, pp. 739-742). Padova: CLEUP.
Teo, T. S. H., & Choo, W. Y. (2001). Assessing the impact of using the Internet for competitive intelligence. *Information & Management, 39*, 67-83.
Thomas, D., & Bostrom, R. (2008). Building trust and cooperation through technology adaptation in virtual teams: Empirical field evidence. *Information Systems Management, 25*(1), 45-56.
Thomas, E. (2013). Supplier integration in new product development: Computer mediated communication, knowledge exchange and buyer performance. *Industrial Marketing Management, 42*, 890-899.
Thomke, S., & Reinertsen, D. (1998). Agile Product Development: Managing Development Flexibility in Uncertain Environments. *California Management Review, 41*(1), 8-30.
Thomke, S. H. (1998a). Managing experimentation in the design of new products. *Management Science, 44*(6), 743-762.
Thomke, S. H. (1998b). Simulation, learning and R&D performance: Evidence from automotive development. *Research Policy, 27*(1), 55-74.
Tidd, J., & Thuriaux-Alemán, B. (2016). Innovation management practices: cross-sectorial adoption, variation, and effectiveness. *R&D Management*.
Tippins, M. J., & Sohi, R. S. (2003). IT competency and firm performance: Is organizational learning a missing link? *Strategic Management Journal, 24*(8), 745-761.
Tony Liu, D., & William Xu, X. (2001). A review of web-based product data management systems. *Computers in Industry, 44*(3), 251-262.
Trochim, W. M. K. (2006a). Internal Validity. Retrieved 15/02, 2015, from http://www.socialresearchmethods.net/kb/intval.php
Trochim, W. M. K. (2006b, 10/20/2006). Qualitative Validity. Retrieved 15/02, 2015, from http://www.socialresearchmethods.net/kb/qualval.php
Troy, L. C., Hirunyawipada, T., & Paswan, A. K. (2008). Cross-Functional Integration and New Product Success: An Empirical Investigation of the Findings. *Journal of Marketing, 72*(6), 132-146.
Tuli, P., & Shankar, R. (2015). Collaborative and lean new product development approach: a case study in the automotive product design. *International Journal of Production Research, 53*(8), 2457-2471.
Tyndale, P. (2002). A taxonomy of knowledge management software tools: origins and applications. *Evaluation & Program Planning, 25*(2), 183-190.
U.S. General Accounting Office, P. E. a. M. D. (1990). Case study evaluations. Washington DC: Government Printing Office.
Un, C. A., Cuervo-Cazurra, A., & Asakawa, K. (2010). R&D Collaborations and Product Innovation. *Journal of Product Innovation Management, 27*(5), 673–689.
University, M. (2015). Code of Ethical Conduct for Research, Teaching and Evaluations involving Human Participants.
Vaccaro, A., Parente, R., & Veloso, F. M. (2010). Knowledge management tools, inter-organizational relationships, innovation and firm performance. *Technological Forecasting and Social Change, 77*(7), 1076-1089.
Vaccaro, A., Veloso, F., & Brusoni, S. (2009). The impact of virtual technologies on knowledge-based processes: An empirical study. *Research Policy, 38*(8), 1278-1287.
Valle, S., & Vázquez-Bustelo, D. (2009). Concurrent engineering performance: Incremental versus radical innovation. *International Journal of Production Economics, 119*(1), 136-148.
Van Echtelt, F. E. A., Wynstra, F., Van Weele, A. J., & Duysters, G. (2008). Managing Supplier Involvement in New Product Development: A Multiple-Case Study. *Journal of Product Innovation Management, 25*(2), 180-201.
Van Kleef, E., van Trijp, H. C., & Luning, P. (2005). Consumer research in the early stages of new product development: a critical review of methods and techniques. *Food quality and preference, 16*(3), 181-201.

Veldhuizen, E., Hultink, E. J., & Griffin, A. (2006). Modeling market information processing in new product development: An empirical analysis. *Journal of Engineering and Technology Management, 23*(4), 353-373.
Verma, R., Teixeira, J., Patrício, L., Nunes, N. J., Nóbrega, L., Fisk, R. P., & Constantine, L. (2012). Customer experience modeling: from customer experience to service design. *Journal of Service Management, 23*(3), 362-376.
Vilaseca-Requena, J., Torrent-Sellens, J., & Jiménez-Zarco, A. I. (2007). ICT use in marketing as innovation success factor: Enhancing cooperation in new product development processes. *European Journal of Innovation Management, 10*(2), 268-288.
Vinodh, S., Devadasan, S. R., Maheshkumar, S., Aravindakshan, M., Arumugam, M., & Balakrishnan, K. (2009). Agile product development through CAD and rapid prototyping technologies: an examination in a traditional pump-manufacturing company. *The International Journal of Advanced Manufacturing Technology, 46*(5-8), 663-679.
Walter, A. (2003). Relationship-specific factors influencing supplier involvement in customer new product development. *Journal of Business Research, 56*(9), 721-733.
Wang, Y., & Li-Ying, J. (2015). Licensing Foreign Technology and the Moderating Role of Local R&D Collaboration: Extending the Relational View. *Journal of Product Innovation Management, 32*(6), 997-1013.
Weber, R. P. (1990). *Basic content analysis* (2 ed.). California, USA: Sage Publications, Inc.
Weimann, P., Pollock, M., Scott, E., & Brown, I. (2013). Enhancing team performance through tool use: How critical technology-related issues influence the performance of virtual project teams. *Professional Communication, IEEE Transactions on, 56*(4), 332-353.
Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal, 5*(2), 171-180.
Wetzels, M., Odekerken-Schröder, G., & Van Oppen, C. (2009). Using PLS path modeling for assessing hierarchical construct models: Guidelines and empirical illustration. *MIS Quarterly*, 177-195.
Wilner, S. J. (2008). Strangers or Kin? Exploring Marketing's Relationship to Design Ethnography and New Product Development. *Ethnographic Praxis in Industry Conference Proceedings, 2008*(1), 286-301.
Wu, D. D., Kefan, X., Gang, C., & Ping, G. (2010). A risk analysis model in concurrent engineering product development. *Risk Analysis, 30*(9), 1440-1453.
Xu, X. W., & Liu, T. (2003). A web-enabled PDM system in a collaborative design environment. *Robotics and Computer-Integrated Manufacturing, 19*(4), 315-328.
Yan, T., & Dooley, K. (2014). Buyer–supplier collaboration quality in new product development projects. *Journal of Supply Chain Management, 50*(2), 59-83.
Yan, T., & Dooley, K. J. (2013). Communication intensity, goal congruence, and uncertainty in buyer–supplier new product development. *Journal of Operations Management, 31*(7), 523-542.
Yin, R. K. (2003). *Case study research : design and methods* (3 ed.): Thousand Oaks, Calif. : Sage Publications.
Yin, R. K. (2014). *Case Study Research-Design and Methods* (5 ed.). Los Angeles, USA: Sage Publications.
Yu, T.-K., Lu, L.-C., & Liu, T.-F. (2010). Exploring factors that influence knowledge sharing behavior via weblogs. *Computers in Human Behavior, 26*(1), 32-41.
Zhang, Y., & Wildemuth, B. M. (2009). Qualitative analysis of content. In B. M. Wildemuth (Ed.), *Applications of social research methods to questions in information and library science* (pp. 308-319). Portland, US: Book News.

Appendices

Appendix 4.1: Low risk notification

MASSEY UNIVERSITY
ALBANY

27 August 2013

Chitra SILVA
13A, Summerfield Lane
Albany
AUCKLAND 0632

Dear CHITRA

Re: a Framework to Evaluate the Impact of ICT Usage on Collaborative Product Development Performance in Manufacturing Firms

Thank you for your Low Risk Notification which was received on 31 July 2013.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

> *"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.*
>
> *If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz".*

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

J.O'Neill

John G O'Neill (Professor)
Chair, Human Ethics Chairs' Committee and
Director (Research Ethics)

cc Dr S Mathrami
School of Engineering & Technology **Albany CAMPUS**

Prof D Cleland, HoS, **Manawatu campus**

Massey University Human Ethics Committee
Accredited by the Health Research Council

Appendix 5.1: E-mail invitation to the interview participants

Dear Manager,

I am a PhD student at Massey University, Albany campus and conducting interviews as part of my research project studying the impact of Information and Communication Technology (ICT) on collaborative product development performance of manufacturing firms. This will be the preliminary part a broader study and as a manufacturing/an ICT vendor firm you are in an ideal position to give me valuable first-hand information from your own perspective. Therefore, you are kindly invited to take part of this project by participating in an interview.

The interview takes around 45 to 60 minutes and is very informal. I am simply trying to capture your thoughts and perspectives on impact of using ICT for collaborative product development but not any personal or identifiable, confidential information of you or your company. This research has been judged to be low risk for the participants by the Massey University Research Ethics Committee and your responses to the questions will be kept confidential. There is no compensation for participating in this study. However, your participation will be a valuable addition to the research and the findings could lead to improve efficient and effective use of ICT in product development projects of manufacturing firms.

I would be very much grateful to you if you could participate in this interview. However, if you are not in a position to participate, please name a correct person in your company who could participate on behalf of you and suggest a date and time that suits him or her, and I will try my best to be available. If your company will take part the interview, information sheet of the study and a sample of interview questions will be sent to the participant in advance. If you have any question, please do not hesitate to ask and my contact details are as follows:

Chathurani Silva
Doctoral Student
School of Engineering and Advanced Technology
Massey University, Auckland, New Zealand
Office phone: 09 414 0800
Mobile phone: 021 379944

Appendix 5.2: Information sheet of the qualitative preliminary study

A Framework to Evaluate the Impact of ICT Usage on Collaborative Product Development Performance in Manufacturing Firms

This research is being carried out by Chathurani Silva, a doctoral candidate at Massey University, Auckland, New Zealand. Interviews with ICT vendors and manufacturers are carried out for the preliminary study which is a part of a broad study.

Purpose of the study:

This study examines the impact of ICT usage on collaborative product development (CPD) performance in manufacturing firms. How manufacturing companies manage ICT use according to the characteristics of their CPD projects and the outcomes of ICT use are mainly focused upon.

Ethical issues:

This study has been approved by the Massey University Research Ethics Committee as a low risk project to the participants. Any personal or organizational identifiers will not be revealed during the analysis and write-up of findings. The interview will be recorded using a digital recorder and the participant could request switching it off at any time that he/she wants during the interview. The responses to all the interview questions are kept confidential.

Access to participants:

A knowledgeable person in the selected ICT vendor or manufacturing company is first accessed. A face-to-face interview is conducted with him/her or any other member of the same company who was introduced by the first contact. Initially, an e-mail is sent requesting permission of the participating firm. Then the information sheet and a sample of interview questions are sent to the firms who are willing to take part. Clarifications to the terminology used in the questions are provided at the time of the interview. However, the participants could avoid answering any question that they do not understand or like to answer.

Informed consent:

All details about the study are explained to the participant and any question raised by him or her will be answered to their satisfaction. Written consent of the participant, who has been provided all the relevant information, is obtained at the time of the interview.

Contact details:

The investigator and principal contact in this research project is:

Chathurani Silva
Doctoral Student
School of Engineering and Advanced Technology
Massey University, Auckland, New Zealand
Office phone: +64 9 414 0800
Mobile phone: +64 21 379944
E-mail: c.w.c.silva@massey.ac.nz

The principal supervisor of this research is:

Dr Sanjay Mathrani
Senior Lecturer
School of Engineering and Advanced Technology
Massey University, Auckland, New Zealand
Office phone: +64 9 414 0800 Ext: 43331
Mobile phone: +64 21 045 5067
E-mail: S.Mathrani@massey.ac.nz

Appendix 5.3: Interview questions

Questions for manufacturers:

1. Do you collaborate with suppliers, customers, cross functional teams, or any other partner in your product development projects?
2. How does your company select and use ICT tools in collaborative product development projects for facilitating communication, collaboration, product design, development, information and knowledge management, project management, and market research activities?
3. What are the dimensions of ICT usage that are important for the success of collaborative product development projects? Are frequency, proficiency, and intensity of ICT use relevant ICT usage dimensions?
4. What characteristics of projects determine the information processing requirement of collaborative product development projects in your firm? How important project complexity, project uncertainty, and project urgency in terms of representing the information processing requirement?

5. Do you think there is a proper balance between usage of ICT and information processing requirement of collaborative product development projects undertaken by your firm?
6. What are the benefits that you can anticipate through the right use of ICT tools in collaborative product development?
7. According to your experience, what are the major barriers or issues associated with effective ICT usage in collaborative product development projects?

Questions for ICT Vendors

1. How do your ICT products and services facilitate collaborative product development activities in manufacturing firms?
2. What is your view about evaluating ICT usage in collaborative product development projects in terms of frequency, proficiency, and intensity?
3. According to your knowledge, what characteristics of projects determine the information processing requirement of manufacturers' collaborative product development projects? How important project complexity, project uncertainty, and project urgency in terms of representing the information processing requirement?
4. What is your view about selecting and using ICT tools for collaborative product development projects in manufacturing firms? Do you find a proper balance between the ICT usage and information needs in those projects?
5. What benefits can manufacturers obtain through the right use of ICT tools in their collaborative product development projects?
6. According to your experience, what are the issues or barriers to the effective use of ICT in manufacturers' collaborative product development projects?

Appendix 6.1: Questionnaire items and codes (Secondary data)

Table A1: ICT tools studied

Code	*ICT tool(s)*
ICT1	Online focus groups/online surveys, etc.
ICT2	Customer needs/requirements analysis software
ICT3	Online communities, net ethnography, virtual shopping, semiotics
ICT4	Rapid prototyping systems
ICT5	Performance modeling and simulation systems
ICT6	Virtual design/virtual design/cave technology
ICT7	Remote collaborative design systems
ICT8	Product data management systems
ICT9	Product portfolio management software
ICT10	Project management systems
ICT11	Video-conferencing
ICT12	Software system to connect technology specialist within firm
ICT13	Groupware

Note: Usage of the ICT tools were measured on a 5-point Likert scale (1=Never, 2= About 25% of time, 3= About 50% of time, 4=About 75% of time, 5= Virtually always).

Table A2: Performance and collaboration measurements

Code	*Survey item*
PERF1[a]	Our new product program meets the performance objectives set out for it.
PERF2[a]	Overall, our new product program is a success.
PERF3[b]	Business unit's overall new product success as compared with the primary competitors over the past 5 years.
COLL1[c]	Facilitate collaboration internally through an internal focused open innovation system
COLL2[c]	Facilitate collaboration externally through an externally focused open innovation system
COLL3[c]	Joint team-building and training
COLL4[c]	Have performance indicators to assess results of co-development projects and the quality of relationships that exist with our partners
COLL5[c]	Shared risk, reward and performance contract structures
COLL6[c]	Interlocking concurrent development processes
COLL7[c]	We have clearly shared with our partners our internal processes, and have a common language and common deliverables
COLL8[c*]	We meet with partners at critical points in the evolution of the co-development project.

Note: [a]Items were measured on a 7-point Likert scale (1=Disagree, 4= Neutral, 7=Agree). [b] Items were measured on a 4-point scale (1=In the bottom third of our industry, 2=In the middle third of our industry, 3=In the top third of our industry, 4=The most successful in our industry). [c] Items were measured on a 5-point Likert scale (1=Never, 2= About 25% of time, 3= About 50% of time, 4=About 75% of time, 5= Virtually always)

*The item was dropped in the principle component analysis.

Control variables

Technology base:

In terms of technology, my Business Unit is considered to be:

	Scale
High Tech and little, if any, Low Tech	5
75% High Tech and 25% Low Tech	4
50% High Tech and 50% Low Tech	3
25% High Tech and 75% Low Tech	2
Low Tech and little, if any, High Tech.	1

Primary product type:

What percent of your total new product development budget is spent on goods and what percent is spent on services (The total should add to 100%)?

This can be measured in dollars or people.

Percent budget spent on Goods ________%

Percent budget spent on Services ________%

Appendix 7.1: E-mail invitation for the survey

Dear Mr/Ms………………..,

Thank you very much for being connected with me on LinkedIn. I am a PhD student at the School of Engineering and Advanced Technology, Massey University, New Zealand and do research into the impact of ICT (Information and Communication Technology) usage on collaborative product development performance. Since ICT tools are essential elements of product development projects, understanding their impact on product quality, profitability, and development times through a large global study would provide valuable insights to product development practitioners. In this study, I collect responses from professionals who have involved in product development projects in manufacturing industry. The results of the study will assist managers in ICT related investment decisions and effective management of ICT resources in collaborative projects. Upon your participation, you will have an opportunity to receive important findings of this study in the form of an executive summary (by replying to this message or sending me an e-mail).

The survey will take around 20 minutes to complete and no personal or identifiable information of you or your company is collected. As an experienced product development professional, you are kindly invited to participate in this study via the following link:

http://goo.gl/forms/l28hypYMU0

Thank you very much in advance for your invaluable cooperation – you will contribute to increased knowledge in the field of product development.

Sincerely,

Chathurani Silva, BSc (Hons), MBA (Management of Technology)
PhD Student
School of Engineering and Advanced Technology
Massey University,
Albany, Auckland 0632,
New Zealand.
E-mail: c.w.c.silva@massey.ac.nz, chathurani77@gmail.com
Phone: +64 21 379944

Appendix 7.2: Online questionnaire

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

A Questionnaire to Examine the Impact of ICT Usage on Collaborative Product Development Performance

The purpose of this research study is to investigate the impact of ICT usage on performance of collaborative product development projects in manufacturing firms. This study is very important for the product development practitioners as it examines how ICT tools usage can increase product quality, reduce time to market, achieve commercial success, and improve collaboration between partners. The survey comprises 14 main questions including sub-questions for 6 of the main questions. Upon completion of the study, an executive summary of the study will be sent to you, if you would like to send me an e-mail.

This research is being conducted in accordance with human ethics guidelines of Massey University, New Zealand. All the responses will be compiled together and analyzed as a group, and therefore anonymity and confidentiality are assured at all times. If you have any concerns or questions about this questionnaire, please feel free to contact me. If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Director, Research Ethics, e-mail: humanethics@massey.ac.nz.Thank you very much in advance for your valuable time spent on participating in this important Massey University research.

*Required

Section 1: Background information

1. Industry that your business unit belongs to *

- Pharmaceuticals / biotechnology
- Computers / electrical / electronic products
- Chemicals
- Automotive
- Medical / dental instruments
- Machinery
- Other: ______

2. Region of your business unit *

3. Country of your business unit (please write down)

4. According to your knowledge the scale of your organization *

5. Average annual sales of your organization (approximately)

US $

6. Total number of employees in your organization (approximately)

7. Your functional area *

- R&D
- IT
- Sales/Marketing
- Manufacturing
- Other:

Continue »

14% completed

Section 2:

Please select recently completed (within last 05 years) collaborative new product development project that you were involved in, for answering this section.

8. Who were the partners involved in the collaborative product development project? *

(you may select more than one answer)

- In house R&D teams
- Suppliers
- Customers
- Sales/marketing teams
- Purchasing and logistics staff
- Production / quality staff
- Universities or other research organizations
- External consultants
- Competitors
- Other

9. Please rate your level of agreement to the following statements on the frequency of ICT use in this project.

(1= Strongly Disagree, 5 = Neither agree nor disagree, 9=Strongly Agree)

(i) Communication and collaboration ICT tools (e.g., e-mail, video conferencing, or groupware) were frequently used in early stages of this product development project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(ii) Communication and collaboration ICT tools (e.g., e-mail, video conferencing, or groupware) were frequently used in development and commercialization stages of the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iii) Product design and development ICT tools (e.g., CAD, CAE, rapid prototyping systems, or simulation software) were frequently used in the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iv) Knowledge and information management ICT tools (e.g., shared databases/shared drives, MS Excel or MS Access) were frequently used in the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(v) Project management ICT tools (e.g., MS Project, MS Excel templates, web-based project/portfolio management systems, integrated project management systems, or PLM systems) were frequently used in the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(vi) Market research and analysis ICT tools (e.g., online focus groups, online surveys, statistical software, or secondary data such as searchable databases) were frequently used in the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

« Back   Continue »

28% completed

10. Please rate your level of agreement to the following statements on ICT proficiency of R&D staff.
(1 = Strongly Disagree, 5 = Neither agree nor disagree, 9=Strongly Agree)

(i) Our R&D staff is highly proficient in simple ICT tools used in this project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(ii) Our R&D staff is highly proficient in advanced ICT tools used in this project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iii) Training provided to our staff on new IT tools were effective. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iv) Staff involved in the project adopted easily the new ICT tools that we implemented. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(v) ICT proficiency (IT knowledge) is a major factor considered by our firm when recruiting R&D staff. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

« Back Continue »

42% completed

11. Please indicate the extent to which the available capacities, features, and functionalities in each of the following ICT tool were utilized in this product development project.
(1 = 0%, 5 = 50%, 9=100%)

(i) Communication and collaboration ICT tools (e.g., e-mail, video conferencing, or groupware). *

	1	2	3	4	5	6	7	8	9	
0%	○	○	○	○	○	○	○	○	○	100%

(ii) Product design and development ICT tools (e.g., CAD, CAE, rapid prototyping systems, or simulation software). *

	1	2	3	4	5	6	7	8	9	
0%	○	○	○	○	○	○	○	○	○	100%

(iii) Knowledge and information management ICT tools (e.g., shared databases/shared drives, MS Excel or MS Access). *

	1	2	3	4	5	6	7	8	9	
0%	○	○	○	○	○	○	○	○	○	100%

(iv) Project management ICT tools (e.g., MS Project, MS Excel templates, Web-based project/portfolio management systems, integrated project management systems, or PLM systems). *

	1	2	3	4	5	6	7	8	9	
0%	○	○	○	○	○	○	○	○	○	100%

(v) Market research and analysis tools (e.g., online focus groups, online surveys, Statistical software, or Secondary data such as searchable databases). *

	1	2	3	4	5	6	7	8	9	
0%	◯	◯	◯	◯	◯	◯	◯	◯	◯	100%

« Back | Continue »

57% completed

12. Please rate your level of agreement to the following statements on the degree of complexity of the project.
(1 = Strongly Disagree, 5 = Neither agree nor disagree, 9=Strongly Agree)

(i) This project involved many tasks. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(ii) The tasks in this project were highly interdependent. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(iii) The number of parts required to make one unit of this product was high. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(iv) The product included many parts to be designed. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(v) The product had many design constraints. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(vi) Many external and internal partners were involved in this project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(vii) The intensity of involvement of the partners in this project was high. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(viii) This product was new to our firm. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(ix) The production process of the product was new to our firm. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(x) The market for this product was new. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

« Back   Continue »

71% completed

13. Please rate your level of agreement to the following statements on the collaboration outcome of the project.
(1 = Strongly Disagree, 5 = Neither agree nor disagree, 9=Strongly Agree)

(i) The benefits of the project were successfully shared between partners. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(ii) Knowledge was successfully exchanged between partners. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iii) Important ideas and information were exchanged openly between partners. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	○	○	○	○	○	○	○	○	○	Strongly Agree

(iv) The risks of the project were successfully shared between partners. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(v) The partners contributed as expected in the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(vi) Trust was created between partners during the project. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

« Back　　Continue »

85% completed

14. Please rate your agreement to the following statements on the performance of the project.
(1= Strongly Disagree, 5 = Neither agree nor disagree, 9=Strongly Agree)

(i) Customers were satisfied about the product. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(ii) The project outcome fully complies with the specifications. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(iii) The product was of higher quality relative to competing products. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(iv) Technical performance of the product was high. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(v) The project met target scope of the product. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(vi) The product successfully met (or will likely meet) sales objectives. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(vii) The product successfully met (or will likely meet) profit objectives. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(viii) The product successfully met (or will likely meet) market share objectives. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(ix) Price targets for the product have been (will be) achieved. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(x) The product concept formation (i.e. opportunity identification and product design) achieved time targets. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(xi) The product development phase achieved time targets. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(xii) The product commercialization (i.e. market testing, production, distribution, promotion, sales) achieved time targets. *

	1	2	3	4	5	6	7	8	9	
Strongly Disgree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

(xiii) Overall, the product achieved time targets to reach the market. *

	1	2	3	4	5	6	7	8	9	
Strongly Disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strongly Agree

If you would like to receive an executive summary of this study, please send me an e-mail (c.w.c.silva@massey.ac.nz) or a LinkedIn message (Chathurani Silva).

« Back   Submit

100%: You made it.

Appendix 9.1: Publications related to the thesis

DRC 16

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STATEMENT OF CONTRIBUTION
TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Chitra Waduge Chathurani Silva

Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., Jayamaha, N., (2016). The Impact of ICT Usage on Collaborative Product Innovation Performance. International Journal of Innovation Management, 20(5).

In which Chapter is the Published Work: Chapter 7, 8, and 9

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Model development, data collection and preparation, data analysis, and writing

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Principal Supervisor's signature

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Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., & Jayamaha, N. (2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. International Journal of Innovation, Management and Technology, 5(1), 43-49.

In which Chapter is the Published Work: Chapter 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Review of literature, conceptual model development, and writing.

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Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., Jayamaha, N. (March, 2016). The Impact of ICT Usage on Collaborative Product Development Performance: A Conceptual Model and Industry Perspective. Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia.

In which Chapter is the Published Work: Chapter 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

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- Describe the contribution that the candidate has made to the Published Work:

  Conceptual model development, data collection and preparation, data analysis, writing, and presenting in the conference.

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Date: 2016.06.08 09:55:30 +12'00'

Candidate's Signature

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Name of Candidate: Chitra Waduge Chathurani Silva

Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2015). The Impact of ICT Usage on Collaborative Product Innovation Performance. Proceedings of the ISPIM (International Society for Professional Innovation Management) Innovation Summit, Brisbane, Australia.

In which Chapter is the Published Work: Chapter 7, 8, and 9

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Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., Jayamaha, N., (Nov., 2015). Testing Moderating Effects with Higher-order Constructs in PLS. Presented at Joint Conference of the NZ Statistical Association and Operations Research Society of NZ. Christchurch, New Zealand.

In which Chapter is the Published Work: Chapter 8

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Candidate's Signature

08/06/2016

Date

Sanjay Mathrani Digitally signed by Sanjay Mathrani Date: 2016.06.08 11:49:14 +12'00'

Principal Supervisor's signature

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Name of Candidate: Chitra Waduge Chathurani Silva

Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., Jayamaha, N., (Dec., 2014). The Impact of IT Usage on Collaborative New Product Development Performance. Proceedings of the 25th Australasian Conference on Information Systems. Auckland, New Zealand.

In which Chapter is the Published Work: Chapter 6

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- Describe the contribution that the candidate has made to the Published Work:

  Model development, data collection and preparation, data analysis, writing, and presenting in the conference.

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Candidate's Signature

08/06/2016

Date

Sanjay Mathrani Digitally signed by Sanjay Mathrani Date: 2016.06.08 11:49:43 +12'00'

Principal Supervisor's signature

08/06/2016

Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Chitra Waduge Chathurani Silva

Name/Title of Principal Supervisor: Dr Sanjay Mathrani

Name of Published Research Output and full reference:

Silva, C., Mathrani, S., & Jayamaha, N. (Mar., 2014). The role of ICT in collaborative product development: A conceptual model based on information processing theory. Presented at Journal Conference on Innovation Management and Technology. Penang, Malaysia.

In which Chapter is the Published Work: Chapter 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Review of literature, conceptual model development, writing, and presenting in the conference.

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Candidate's Signature

08/06/2016

Date

Sanjay Mathrani Digitally signed by Sanjay Mathrani Date: 2016.06.08 11:50:20 +12'00'

Principal Supervisor's signature

08/06/2016

Date