# Development of a decision support tool for automation adoption and optimisation in precast concrete plants – a New Zealand case study

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## Abstract

In response to the growing demand in the New Zealand construction market, this study aims to develop a decision-support framework for adopting and optimising automation in precast concrete plants, which are increasingly recognised for their numerous benefits. The primary resources required by these plants include labour, equipment, and materials, and their efficient use is essential for maintaining competitiveness. Automation has been identified as a potential solution for improving productivity and profitability in precast concrete manufacturing; however, an appropriate decision-support tool is currently lacking.

The current study commences with a comprehensive literature review, followed by historical data collection, face-to-face interviews, and site observations of precast concrete plants to address this research gap. These methods help identify attributes that affect profitability, leading to developing and validating of a theoretical framework named the Precast Plant Automation System Tool (PPAST) through a case study. The PPAST framework comprises two sequential phases: the strategic phase, which uses the direct rating method for preliminary feasibility evaluation of automation adoption, and the tactical phase, where the AHP method assesses the appropriate automation sequence for the plant.

The study's main findings indicate that the developed decision support system enables decision-makers to articulate their objectives and attitudes towards risk as they explore the feasibility of automation and formulate an optimal automation strategy. Specifically, the system aids in evaluating the impact of automation on cost and quality and identifying necessary process changes before implementing new technologies. The primary contribution of this research is its novel approach to systematically evaluating alternative automation scenarios in precast concrete production plants.

The results demonstrate that the proposed model is a valuable and effective decision-making tool for adopting and optimising automation in precast concrete plants. This research fills a critical knowledge gap concerning the crucial measurements of precast concrete plant profitability and the absence of an automation adoption tool. The developed framework can be extended to investigate automation adoption and optimisation in other precast concrete plants across New Zealand.

This study's practical implications include empowering precast plants to meet their organisation's profitability measures, thus satisfying stakeholder value propositions. A thriving precast concrete industry will lead to more satisfied clients, attract additional investment, and improve the overall construction industry's quality, productivity, and profitability at the national level. Theoretically, this research contributes a reliable benchmark for future studies by developing decision support tools that facilitate selecting optimised automation methods for precast concrete plants and contributing to theoretical knowledge by establishing an optimised automation decision support method that guides researchers in exploring other avenues for maximising profitability.

**Keywords:** Automation, Construction, Precast Concrete Plant, Profitability, Productivity, Decision Support Framework.

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## Copyright

## Definition of terms

**BIM:** Building Information Modelling is a digital representation of the physical and functional characteristics of a building or infrastructure.

**CAD:** Computer-Aided Design is the use of computer systems to assist in the creation, modification, analysis, or optimisation of a design.

**Decision Support System:** A computer-based information system that supports business or organisational decision-making activities.

**JIT:** Just-in-time is a manufacturing strategy that focuses on producing or delivering products or services just in time to meet customer demand.

**KAIZEN:** Kaizen is a Japanese term for continuous improvement, which refers to the philosophy or practice of making small incremental improvements in a business process.

**KPI:** Key Performance Indicator is a measurable value that demonstrates how effectively a company is achieving its key business objectives.

**Lean construction:** Lean construction is a management philosophy and practice that focuses on eliminating waste and maximizing value in construction projects.

**RFID:** Radio Frequency Identification is a technology that uses radio waves to identify and track objects or people automatically.

**TQM:** Total Quality Management is a management approach that aims to provide customers with products and services that meet their needs and expectations.

**VSM:** Value Stream Mapping is a lean manufacturing technique used to analyse, design, and manage the flow of materials and information required to bring a product or service to a customer.

**Archival analysis:** Archival analysis is a research method that involves analysing existing records or documents to answer research questions.

**Case study:** A case study is an in-depth analysis of a particular individual, group, or situation over time.

**Data saturation:** Data saturation is the point in qualitative research where new data no longer provide additional insights or themes.

**Direct observation:** Direct observation is a research method that involves watching and recording behaviours or events as they occur in real-time.

**Methodology:** Methodology is the systematic, theoretical analysis of the methods applied to a field of study.

**Semi-structured interview:** A semi-structured interview is a research method that uses a pre-determined set of open-ended questions while also allowing the interviewer to ask follow-up questions based on the respondent's answers.

**Thematic analysis:** Thematic analysis is a research method used to identify, analyse, and report patterns (themes) within qualitative data.

**Triangulation analysis:** Triangulation analysis is a research method that involves combining multiple data sources and methods to improve the validity and reliability of the findings.

## List of abbreviations

**CAD:** Computer-Aided Design

**BIM:** Building Information Modelling

**KPIs:** Key Performance Indicators

**NZ:** New Zealand

**RFID:** Radio Frequency Identification

**SMEs:** Small and Medium-sized Enterprises

**TA:** Thematic analysis

**VSM:** Value Stream Mapping

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# 1. Introduction

## 1.1. Background

In recent years, the construction industry in New Zealand has faced significant challenges related to labour costs and the recruitment and retention of skilled workers (Dizhur et al., 2021; CITB, 2020). These challenges have driven the need for alternative construction methods, such as prefabrication and off-site manufacturing, to address the increasing demand for efficient and cost-effective building solutions while promoting sustainable development and reducing construction waste (Molavi et al., 2019; Huang et al., 2021). The construction sector has experienced a rapid growth in labour costs over the past decade (PWC, 2019), which has been attributed to factors such as rising demand for construction services, a growing skills gap, and a tight labour market (Ferguson, 2018). Consequently, the industry has been compelled to explore innovative solutions, such as prefabrication, to mitigate the impact of these challenges on construction firms, maintain productivity and quality standards, and respond to the increasing global focus on sustainability (Liu, Yi, & Wang, 2020; Eastman et al., 2011).

BRANZ has identified the construction industry as one of the largest waste-producing industries in New Zealand (Balador, 2020). In 2022, Construction and Demolition (C&D) waste represented up to 50% of all waste generated (Smith, 2023). Recent efforts to reduce C&D waste have focused on implementing waste minimization strategies and promoting the use of recycled materials in construction (Jones et al., 2023). Moreover, the New Zealand government has introduced new regulations to encourage sustainable construction practices and better waste management in the industry (Ministry for the Environment, 2023). Recent research into building consent data by PrefabNZ indicates that, between 2011 and 2021, the rate of prefabrication-intensive residential projects has increased by 300% and non-residential projects by 190% (ACCORD, 2020). With acceleration of construction demand in New Zealand, the construction industry is achieving rapid development, but construction waste is increasing. Construction activities will thus inevitably have adverse effects on the ecological environment.

The construction industry has indeed experienced rapid growth in recent years, with the value of building work put in place increasing by 5.3% in 2021 (Statistics New Zealand, 2022). This growth has led to a surge in construction waste, with an estimated 1.5 million tonnes of construction and demolition waste being generated annually (WasteMINZ, 2022).

Research indicates that the increase in construction waste has led to negative ecological impacts, such as increased landfill space usage, soil contamination, and increased greenhouse gas emissions (Green Building Council, 2022). In 2021, construction waste accounted for 23% of the total waste sent to landfills in New Zealand (Ministry for the Environment, 2022).

Recycling plays a crucial role in mitigating the environmental impact of construction waste. In 2021, 30% of construction and demolition waste was recycled, with materials such as concrete, wood, and metal being the most commonly recovered (WasteMINZ, 2022). Recycling these materials not only reduces landfill usage but also saves resources and energy, as the production of new materials typically requires more energy and raw materials than recycling existing ones (Jones & Williams, 2023). Increased recycling efforts and the adoption of a circular economy within the construction industry can help to reduce the negative ecological impacts of construction waste in New Zealand.

Off-site manufacturing uses particular technology, design principles and manufacturing processes to reduce or eliminate waste. This industry can contribute to the circular economy by minimising waste material and recycling wastes in a controlled factory environment and deconstruction for recycling or reuse at the end of life. For example, it has been reported that replacing in-situ concrete cast panels with prefabricated elements has resulted in a 70% reduction in construction time and a 43% reduction in labour cost (Jaillon, Poon, & Chiang, 2009). Case studies comparing the use of prefabricated with traditional construction methods in Hong Kong identified an average reduction of construction waste by 65% using prefabricated products (Hu, Chong, & Management, 2019).

Precast concrete, as a modern and sustainable construction technology that replaces the conventional cast-in-situ concrete construction, has attracted huge attention from many countries (Li, Shen, & Xue, 2014; Sojobi & Liew, 2022; Yuan et al., 2021; Zhang & Tsai, 2021). The benefits of prefabricated construction technology include construction waste reduction (Cao, Li, Zhu, & Zhang, 2015; Luo et al., 2020; Shen, Tam, Tam, & Ji, 2010), superior quality control (Boyd, Khalfan, & Maqsood, 2012; Navaratnam et al., 2022), noise and dust reduction (Navaratnam et al., 2022; Pons & Wadel, 2011), higher standards for health and safety (Lopez-Mesa, Pitarch, Tomas, & Gallego, 2009; Pons & Wadel, 2011; Yuan et al., 2021), time and cost savings (Chiang, Chan, & Lok, 2006; Gibb & Isack, 2003; Shahzad, 2011; Sojobi & Liew, 2022), reduced labour demand (Nadim & Goulding, 2010; Navaratnam et al., 2022; Yuan et al., 2021), low resource depletion (Aye, Ngo, Crawford, Gammampila, & Mendis, 2012; Luo et al., 2020; Won, Na, Kim, & Kim, 2013), customisation capability (Li, 2021; Pan, Gibb, & Dainty, 2008), swift delivery (Dan, Liu, & Fu, 2021; Moya & Pons, 2014) and others. As a result, prefabrication technology has been suggested as a way to improve the New Zealand construction industry (Shahzad, 2011).

Productivity is a production efficiency which means how much output is obtained from a given set of inputs (Syverson, 2011). Construction productivity has been attracting much attention as an essential indicator of economic growth (Zhai, 2010), although globally, the construction industry has one of the lowest productivity rates compared to other industries (Thomas, 2017). The New Zealand construction industry suffers from poor productivity (Davis, 2007; DBH, 2009) which in fact experienced a steady decline from 1997 to 2008 (Shahzad, 2011). The Ministry of Business, Innovation and Employment (MBIE) focuses on building value across New Zealand's building and construction sector to empower it to become productive, safe, and profitable, so that it can deliver good quality homes and buildings and provide a foundation for strong communities and a prosperous economy (Syverson, 2011).

The profitability of organisations is linked to their productivity level (Nurhendi, Khoiry, & Hamzah, 2022). Some researchers have linked profitability levels to particular technologies, demand, and market structure features. As profit-making is considered essential for the survival of a business, the primary objective of a business undertaking is to earn profits. Profitability analysis measures how a firm will perform to generate profits. The firm's profitability is highly influenced by internal and external variables, such as the size of organisations, liquidity management, growth of organisations, a component of costs and the inflation rate (Pradhan & Das, 2016).

This study developed a decision support tool for automation adoption and optimisation to improve the productivity and profitability of the precast concrete organisations in New Zealand. To achieve this, one of the biggest precast concrete plants based in Auckland was used as a pilot in this study. The decision support tools were planned to be transferred to other New Zealand precast concrete plants and the global market to ensure competitiveness.

Although some countries with an extensive public housing program have increasingly turned to the use of precast building and structural elements and some site automation to increase their productivity (Li et al., 2014), there are some known barriers to the adoption of prefabrication in the NZ construction industry (Shahzad, 2011). Through a nationwide survey of consultants, contractors, employers and manufacturers, the cost, value and productivity was shown to have a high share of 14% compared to the precast concrete industry (Shahzad, 2011).

Production using automation and robotics is advancing (Thomas, 2017). Through the ongoing evolution of research in robotics, new technical capabilities (modularity, lightweight concepts, wearable robot technology, and social robot technology) have been explored and combined with existing manipulation-oriented automation and robot technology. Over time, the ability of robot systems has grown, allowing them to work more within unstructured environments in which human beings work cooperatively with them (Thomas, 2017). Sometimes such large prefabrication plants do not gain the designed output capacity within a short time scale. As a result, the return on investment (ROI) will be delayed by the over-dimensioning or over-automation (Neubauer, 2017a). Therefore, if the initial automation requirement seems to be very high, it could be more appropriate to start with a smaller plant and extend it for a second separate plant, than to build a huge automated factory (Neubauer, 2017a). Large investments are required to automate a precast plant, and significant research is needed before embarking on such a project. This study will fill the research gap between automated precast concrete technology and its implementation in precast plants.

According to Chang and Jieh-Haur et al. (2017), automation as a sustainable method, can increase productivity and profitability, reduce environmental uncertainty during the construction process and satisfy the requirements of process industrialisation and organisational competitiveness (Jieh-Haur, Yan, Tai, & Chang, 2017). Countries such as New Zealand, with an extensive public housing program and housing shortages, have an opportunity to turn to the use of automated building systems and prefabricated structural elements (O'Neill & McDermott, 2021). However, some precast concrete plants are not advanced in meeting the design output capacity and the labour efficiency to meet the required construction demands (Brown et al., 2022).

In conclusion, the New Zealand construction industry has been facing significant challenges relating to labour costs, skill shortages, and productivity, prompting the exploration of alternative construction methods such as prefabrication and off-site manufacturing. These methods have demonstrated considerable potential in enhancing sustainability, reducing construction waste, and promoting a circular economy. Prefabrication technology has been proposed as a viable solution for improving the industry's efficiency and mitigating labour demands, while also delivering numerous benefits, including reduced construction time, cost savings, and improved quality control. Automation and robotics have been advancing rapidly, allowing for the potential of further increasing productivity and profitability in the precast concrete sector. However, substantial investments and research are required before implementing automation in precast plants. This study aims to develop decision support tools to facilitate the adoption and optimisation of automation in precast concrete organisations in New Zealand, addressing the research gap and ultimately enhancing the industry's competitiveness and sustainability.

## 1.2. Research Problem

The primary resources required by the precast plants are labour, equipment, and materials. To maintain their strength in a competitive market, precast plants need to re-examine their existing production procedures to ensure that resources can be used efficiently to produce the desired results (Chen, Yang, & Tai, 2016).

The performance of an organisational system is evaluated according to at least seven criteria. These are market attractiveness, resource efficiency (equipment, labour and time), quality, profitability and gross profit margin (GPM) ability (Cain, 2008; S. Reichenbach & Kromoser, 2021).

A study of service industries shows that most performance indicators that companies have in place are financial ones (Rao, 2006; Sabău-Popa & Lakatos-Fodor, 2021). Managers' immediate question is to establish what should be measured, evaluated, and controlled. The importance of measuring business performance has already been the subject of many academic papers (ERSARI & Naktiyok, 2022; Grafton, Lillis, Widener, & Society, 2010; Kohlbacher, 2010; Malagueño, Lopez-Valeiras, & Gomez-Conde, 2018; Neely; Norton, 2015; Radnor, Barnes, & Management, 2007). Making this decision is a vital function of management that is frequently largely overlooked and ignored (Papulová, Gažová, Šlenker, & Papula, 2021; Sink, Tuttle, & DeVries, 1984). It is essential because a manager can only expect to obtain the results that are explicitly or implicitly measured. If the measurement system is ill-designed, it will likely be a root cause of performance and profitability problems (Sink et al., 1984).

According to the New Zealand Companies official website, at the time of writing this thesis, there were 141 prefabricated manufacturing companies in New Zealand. About 2% of the companies registered in NZ have gone into liquidation, 54% have closed, and only 44% remain in operation across the country (NZ-Companies-Register, 2021). There are some large construction and precast companies which are in receivership because of the company's financial failures. For example, Bagley and Blake Construction's cash flow was insufficient to meet day-to-day operations, and the company was under-capitalised for the rapid growth experienced before bankruptcy (Herald, 2019). Six Stanley Construction Group companies and one of the largest NZ offsite manufacturing companies, were placed into liquidation (Bond, 2019), and four associated Tallwood companies, with 120 staff in Waikato and Auckland laid off in 2019. Grant (Grant, 2019) said that the company under-quoted a large construction job by $2 million which created severe liquidity pressure on the business . There were cost overruns in addition to the $M2, so that this project was the reason for the failure of the Stanley Group (Morrah, 2019). Like so many construction companies that have collapsed in recent years, their demise has been tied to an attempt to undercut competitors to win a lucrative contract in a booming market (Forbes, 2019). Based on the liquidator's reports (Insolvency, 2019), the Matamata based Stanley Group has a long history, going back three generations to the 1920s. But it started to experience problems when it sought to expand beyond its base in the Waikato into the competitive Auckland market. The Auckland expansion was not successful. The business continued to win work, but was unable to maintain control of its profitability and quality (Forbes, 2019). In March 2019 after the collapse of Arrow International and Ebert Construction, and Fletcher Building's well-publicised woes, Auckland Council's chief economist David Norman said the problems were being driven by demand-side pressures (Forbes, 2019).

The large Ebert Construction company was placed into receivership, mainly because of several delays on projects in the Auckland region which adversely affected the company's financial position (Oliver, 2018). Bishop Industries was a precast concrete manufacturer that went to liquidation in April 2017 largely because of poor quality of their products, low profitability, insufficient cash flow, and delays in production. The director attempted to source external funding to pay creditors but could not do so (Kellow, 2017).

The economic and business performance and the quality of the business environment are closely interconnected and influence each other. The global financial and economic crisis and bankruptcy of the businesses have had serious long-term affects on the business environment and led to the economic recession from 2007 to 2009 (Jakóbik, 2011). As earlier discussed, the profitability of the offsite manufacturing industry has been attracting attention as one of the important indicator of economics. Improving profitability is always a priority for construction projects (Besklubova, 2020). However, the profitability of the New Zealand construction industry is poor, as evident in the report of a task force commissioned by the Ministry of Business, Innovation and Employment (MBIE) (Chen et al., 2016; Shahzad, 2011). Automation is reputed to be a reliable mechanism to improve the productivity and profitability of manufacturing companies – especially precast companies. However, the industry lacks an appropriate decision support tool to guide the optimisation of products and processes.

In conclusion, the precast concrete industry faces significant challenges related to resource efficiency, productivity, quality, and profitability. During the growing competitiveness in the market, some construction companies have failed or gone into liquidation. Automation and robotics have been advancing rapidly, allowing for the potential of further increasing productivity and profitability in the precast concrete sector. However, substantial investments and research are required before implementing automation in precast plants. This study aims to develop decision support tools to facilitate the adoption and optimisation of automation in precast concrete organisations in New Zealand, addressing the research gap and ultimately enhancing the industry's competitiveness and sustainability.

## 1.3. Research Questions and Objectives

This thesis aims (1) to develop a decision support tool for automation adoption and optimisation in precast concrete plants. (2) to utilise the developed decision support tool in the selected case study to provide recommendations and pathways towards the implementation of the optimised automation system to enhance the subject firm's overall performance. The research problems have led to the consideration of the following research questions and objectives (table 1.1), to facilitate a realistic and rational investigation into the research problem:

Table 1. 1: Research Questions and Objectives

| Research Questions | | Research Objectives | |
|---|---|---|---|
| RQ1 | What are the challenges associated with the profitability of precast construction plants? | RO1 | To establish the current challenges associated with the profitability of precast construction plants |
| RQ2 | How can adoption of automation improve profitability? | RO2 | To identify the potentials for automated systems to improve profitability within precast construction plants |
| RQ3 | What is the profitability of products in the case study? | RO3 | To measure the profitability of products in precast construction plants |
| RQ4 | What decision support tool can be provided for selection & optimisation of the automation method? | RO4 | To develop a decision support tool that will optimise the implementation of automation in precast construction plants in NZ |
| RQ5 | What automation sequence will improve the profitability of products in the current case study? | RO5 | To provide recommendations and pathways towards the implementation of the optimised automation system in the case study by utilising the RO3 into the developed decision support tool in (RO4) above. |

## 1.4. Overview of Methodology

The variety of data collection methods led to methodological questions, such as, which would be the best method to choose. In survey practice, multiple modes of data collection or mixed-modes have become popular (Czepkiewicz, Heinonen, Næss, Stefansdóttir, & society, 2020; Sahin & Öztürk, 2019). A mixed-mode methodology combines quantitative and qualitative methods to provide robust investigation into the research problem and achieve the research aim. Quantitative research is described by Creswell (2013) as a method for testing an objective theory by examining and measuring the relationship between variables. Using this method, extracted numerical data can be analysed by using statistical procedures. Hennink, Hutter, and Bailey (2010) have described qualitative research as a broad umbrella term covering many different techniques and philosophies. A balance should be reached in describing the nature of the research questions between quantitative and qualitative approaches before choosing a research method (Paton, Bajek, Okada, & McIvor, 2010). A balance is often attained by explaining why a phenomenon occurs and how it occurs against what occurs (Yin, 2017).

The research design for this study adopts a mixed-methods approach, incorporating both quantitative and qualitative methods to provide a robust investigation into the research problem and achieve the research aim. Sequential mixed-methods inquiry procedures were employed based on the exploratory nature of the research problem, combining both quantitative and qualitative approaches to improve the overall strength of the study. The study focuses on reliability and validity to ensure the accuracy and trustworthiness of the findings.

The research objectives adopted for this study will answer both ‘what’ and ‘how’ questions, which means that the study should incorporate both the qualitative and quantitative (i.e. mixed) methodological approaches. This means that the researcher observes the data, examines or analyses it, and interprets it by forming an impression of the meanings that could be teased from the analysed data. The researcher then reports the impressions in a structured and sometimes quantitative form. Accordingly, sequential mixed-methods inquiry procedures were adopted based on the research problem being exploratory in nature, and to provide reliable and valid research findings through combining both quantitative and qualitative approaches to improve the overall strength of the study. Qualitative studies such as literature reviews and direct observations were also employed to identify challenges to the profitability of precast concrete plants – Research Objective One. Therefore, from the findings, the factors affecting the profitability of the precast concrete plant were identified as the first research objective. To illustrate the importance of the automation method to the criteria for the second objective, the qualitative method (literature review) was used. Validation questions analysis was adopted to accomplish Objective Three to develop a decision support framework. The quantitative study, such as historical data analysis and direct observation, answered the fourth research question and the AHP method was employed for the last objective to adopt and optimise the automation system in the case study to get the most profitable result.

The table below summarises the interrelationships between the objectives, methods adopted, the significance of objectives, and how they were achieved for this study.

Table1. 2: Inter-relationships between the objectives, methods adopted, the significance, and how they will be achieved

| | Research Questions | Research Objectives | Research Methods | Significance of research objectives to the overall aim of the study | How would the ROs be achieved with the specified methods and data collection? |
|---|---|---|---|---|---|
| 1 | What are the challenges associated with the profitability of precast construction plants? | To establish the current challenges associated with the profitability of precast construction plants | Qualitative:<br>- Literature review<br>- Interview with Subject Matter Expert (SME)<br>- Direct observation | There is currently no study investigating the challenges in New Zealand precast concrete plants that affect their profitability. Therefore, this objective will fill in the knowledge gap and help the NZ precast concrete industry to improve its profitability. | A comprehensive literature review to justify the construction industry's challenges that affect profitability. Ten Interview with the key staff from the case study to capture the possible and visible problems within the company that affect their profitability. And direct observations and analysing by Value Stream Mapping (VSM) method to investigate the factors causing non-profitable processes for the production lines. And utilising the Thematic Analysis method to categorise challenges that associated with the profitability of precast construction plants. |
| 2 | How can automation adoption improve profitability in precast concrete production? | To identify the potentials for automated systems to improve profitability within precast construction plants | Qualitative:<br>- literature review | Addressing the importance of automation methods on criteria affecting the profitability of a precast concrete plants. | A comprehensive literature review to address the importance of automation on criteria that are affecting the profitability of precast concrete plants |
| 3 | What is the profitability of products in the case study? | To measure the profitability of products in the subject precast construction plant | Qualitative:<br>- Literature review<br>Quantitative:<br>- Archival analysis<br>- Direct observation | There is currently no study to measure the profitability of the NZ precast concrete plants. Therefore, this objective will fill in the knowledge gap and help provide insights to measure the profitability of the companies. | By using historical data (2010 to 2017) from the case study for seven different products in Microsoft excel, the below criteria measured for each product:<br>Market attractiveness, plant utilisation, labour efficiency, market demand and gross profit margin.<br><br>Further by direct observation data collection and value stream mapping analysing method, the researcher measured each production line's non-profitable processes (i.e. time wasted). |
| 4 | What decision support framework can be provided for selection & optimisation of automation method? | To develop a decision support tool that will optimise the implementation of automation in precast construction plants in NZ | Qualitative:<br>- validation question (VQ) | The proposed framework can be provided for the selection & optimisation of automation methods in other precast concrete plants in NZ. | Researcher proposes that higher market demand and wasted time, and the lower plant utilisation, labour efficiency, market attractiveness, and GPM, are directly related with a need for automation for the production line. Total of six validation questions were proposed and validated through questionnaire survey. |
| 5 | What automation sequence will improve profitability of products in the current case study? | To provide recommendations and pathways towards the implementation of the optimised automation system in the case study by utilising the outcome above in (4) into the developed decision support tool in (3) above. | Quantitative:<br>- AHP | To help decision-makers to check if their precast concrete plant is capable of being automated, and if yes, what is the best sequence of automation system for the plant. | Use the AHP method to rank product A to F from the case study based on their profitability attributes (Market attractiveness, wasted time, plant utilisation, labour efficiency, market demand, non-profitable processes, and GPM) between 2010 and 2017.<br>The outcomes are recommendations and pathways toward automation adoption and an optimised system in the subject case study organisation. |

## 1.5. Research Significance

Considering the enormous value of New Zealand's construction industry and its bankruptcy levels, there is a need to understand the bankruptcy reasons and implement a method for its high volatility. Improvement in the performance of this sector would offer a range of benefits to the various stakeholders. For individual firms, this would mean better profitability for owners and more earning opportunities for the workforce. For end-users, this would mean a reduction in construction costs, better quality in terms of the end product, fewer project delays, and better value for money. Recently, some high-profile construction firms have been bankrupted, which has had a negative effect on the overall industry (Rotimi, Wahid, & Shahzad, 2019). This research therefore adds value to the body of knowledge by exploring the issues faced by this industry and finding a solution to the problems that it currently faces.

High labour costs, poor quality of products, low market demand, insufficient cash flow, project delays, labour and skills shortage, low productivity and profitability are the main problems that construction companies are facing (Rotimi et al., 2019; Zhao, Mbachu, Liu, Zhao, & Wang, 2021). Concrete is the primary construction material used worldwide (Reichenbach, Sara, Kromoser, & Benjamin, 2021), and the costs of this resource have risen. Therefore, to maintain the strength of precast companies in a competitive market, these companies must re-examine their existing production procedures to ensure that resources can be used efficiently to produce desirable results. By meeting the profitability measures consistently at the project level, the precast concrete organisation can satisfy the customers or clients and gain market share relative to competitors. Contributions from this thesis form a basis that can assist to analyse and recommend a pathway towards optimising plant profitability in New Zealand precast concrete plants.

### 1.5.1. Practical Significance

The implication of findings and recommendations from this study will improve the profitability levels of precast concrete plants for relevant stakeholders.

- Implications for precast concrete companies

The opportunity to have clarity regarding a company's performance will help the decision-makers to discover its bottlenecks, so as to avoid losing money and increase profitability. This decision support tool will apply to all of NZ's precast concrete plants and to the global market, to ensure the profitability of such firms in the industry.

- Implications for the construction industry

This study will empower precast plants to meet the organisation's profitability measures, thus satisfying the stakeholder value propositions. If several organisations within the precast concrete industry are doing well at the organisational level, this will ensure more satisfied clients. This would attract more investment into the precast concrete industry, improving profitability at the industry level. This, in turn, would feed into the industry nationally and would improve the overall construction industry's quality, productivity and profitability.

### 1.5.2. Theoretical Significance

This study will contribute a reliable benchmark for future related research by developing the decision support tools that can be used to select an optimised automation method for precast concrete plants. This research will also contribute to theoretical knowledge by developing an optimised automation decision support method that will guide researchers in exploring other means of achieving maximum profitability for precast concrete plants.

## 1.6. Risk Analysis

As this study utilises existing empirical data from the case study, any publications based on the thesis will require the company's permission. Hence, no significant risk has been identified in this research.

## 1.7. Brief critical literature review discussions

The following literature review provided a critical analysis of the current state of automation adoption in the precast concrete industry and highlighted the various challenges faced by companies in New Zealand. The review revealed that many precast companies were struggling with profitability due to increasing competition and rising costs, which has led to a growing interest in the adoption of automation technologies. The literature also emphasized the importance of considering pre-screening attributes before the adoption of automation technologies, including technical feasibility, cost-benefit analysis, organisational readiness, and supply chain integration.

Furthermore, the review highlighted the lack of appropriate decision support tools for precast companies to guide them in optimizing automation adoption. The existing tools were found to be inadequate and often based on outdated or incomplete information, which led to ineffective decision-making. The literature pointed out the need for a new, comprehensive decision support tool that could provide up-to-date and accurate information to precast companies to assist them in making informed decisions about automation adoption.

Overall, the literature review demonstrated the significance and urgency of addressing the challenges facing the precast concrete industry in New Zealand and the potential benefits of adopting automation technologies. It also highlighted the need for a more sophisticated decision support tool to guide companies in the adoption process.

## 1.8. Thesis Structure

This thesis is structured in Seven chapters. The chapter outlines are listed below.

**(Chapter 1)** **The introduction** provides a general overview of the research investigation by giving background information on the magnitude of the research problem. The research objectives and the original contributions are stated.

**(Chapter 2)** **Literature review** presents the fundamental concepts associated with the precast concrete plants as to their productivity and profitability. It presents a literature review of automation in the precast concrete industry and its implementation. It finally highlights the importance of automation on criteria affecting the profitability of precast concrete plants.

**(Chapter 3)** **Research methodology** describes the qualitative and quantitative methods employed in this study and outlines the ethical process used.

**(Chapter 4)** **The case study** presents the case study's profile, production lines, profitability challenges; and direct observations based on data collection and analysis.

**(Chapter 5)** **Case study profitability measurement** measures the profitability of the subject case study based on selected themes such as market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin, and non-profitable processes.

**(Chapter 6)** **Findings** develops and validates the decision support tool (PPAST) and presents the outcome from the automation adoption into the subject case study by utilising PPAST.

**(Chapter 7)** **The conclusion** discusses the summary and conclusion of the research investigations. It presents a review of the research objectives, implications of the results for New Zealand's precast concrete plants and recommendations and provides suggestions for further research.

# 2. Literature Review

This literature review introduces the study's fundamental concepts in the research context. It provides partial answers gleaned from the literature to the research objectives. It gives brief explanations of the key concepts embodied in the topic, such as the precast industry, hierarchy process method (AHP), the pareto analysis, and some approaches used to measure profitability and productivity. The chapter summarises the extent to which the research objectives have been accomplished in earlier studies, the gaps, and how this study contributes to filling them.

## 2.1. New Zealand construction and manufacturing trend

New Zealand has a severe housing shortage, with 60,000 houses needing to be built by 2030 to create a balance between demand and supply; and of these 60,000 houses, 35,000 are required in Auckland alone (Johnson, Howden-Chapman, Eaqub, & Employment, 2018; Moradibistouni, Vale, & Isaacs, 2019). The current housing shortage has tainted housing affordability, and median house prices in New Zealand are at their highest (StatsNZ, 2020). In recent years New Zealand's Government undertook a very ambitious initiative of building a thousand houses in 2019 and ten thousand homes in the next ten years under its KiwiBuild scheme. However, the country's construction industry, which was already criticised for its low productive performance (Kestle & van de Linde, 2020), could not deliver the KiwiBuild targets, and the Government had to drop the KiwiBuild scheme after a year (Almughrabi, Samarasinghe, & Rotimi, 2021; Hatton, 2019).

However, the number of building consents issued for new dwellings in New Zealand rose 2.1 percent month-over-month to a new record of 4,207 in July of 2021, following an upwardly revised four percent jump in the previous month. In the year ended July 2021, the actual number of new dwellings consented was 45,119, up twenty percent from the July 2020 year (Fig 2.1). Building permits in New Zealand averaged 2108.62 from 1995 until 2021, reaching an all-time high of 4207 in July of 2021 and a record low of 991 in January of 2009 (Economics, 2021). Therefore, the building of the new dwellings is booming.


Figure2. 1: New Zealand New Dwellings Building Consents

Further, construction output in New Zealand increased 2.70 percent in the fourth quarter of 2020 over the same period in the previous year (Fig 2.2). Construction output in New Zealand averaged 8.74 percent from 1995 until 2020, reaching an all-time high of 40 percent in the first quarter of 2000 and a record low of -25 percent in the second quarter of 2000 (Economics, 2021).

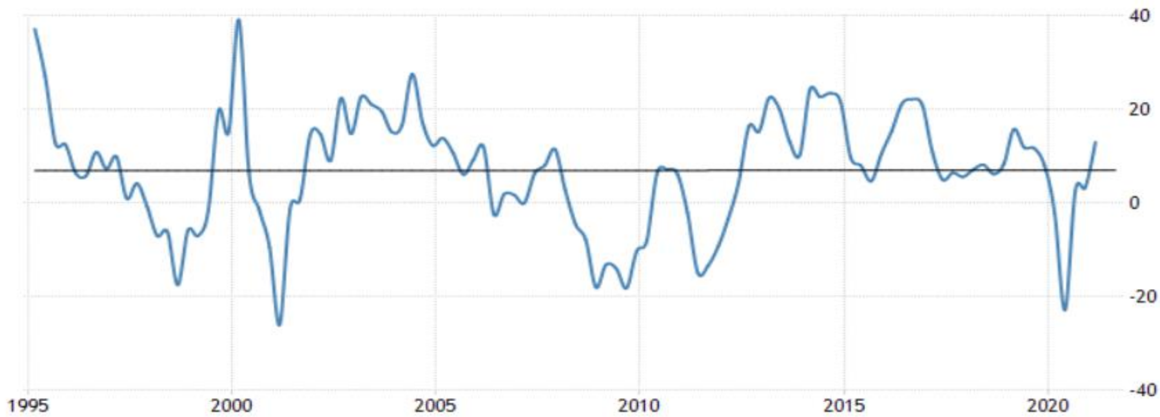



Figure2. 2: New Zealand Construction Output

The period from 2019 to 2021 witnessed significant fluctuations in the construction output in New Zealand, largely due to the impact of the COVID-19 pandemic. In 2019, the construction industry in New Zealand experienced steady growth, with an increase in construction outputs (Statistics New Zealand, 2021). However, the onset of the COVID-19 pandemic in early 2020 led to unprecedented challenges and disruptions for the construction sector. As a result, construction output in 2020 experienced a decline due to lockdown measures, border closures, and supply chain disruptions (New Zealand Treasury, 2021).

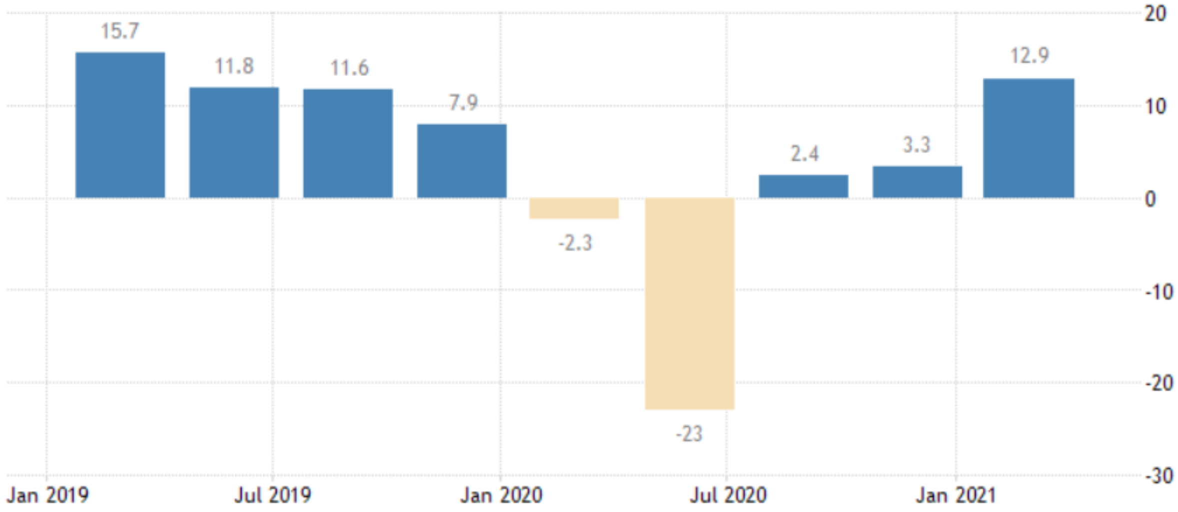



Figure2. 3: New Zealand Construction Output (2019 to 2021 Impact of Covid-19)

Minimum wages in New Zealand averaged 14.51 NZD/Hour from 2006 until 2021, reaching an all-time high of 20 NZD/Hour in 2021 and a record low of 10.25 NZD/Hour in 2006. Minimum wages show a definite increasing trend (Economics, 2021).

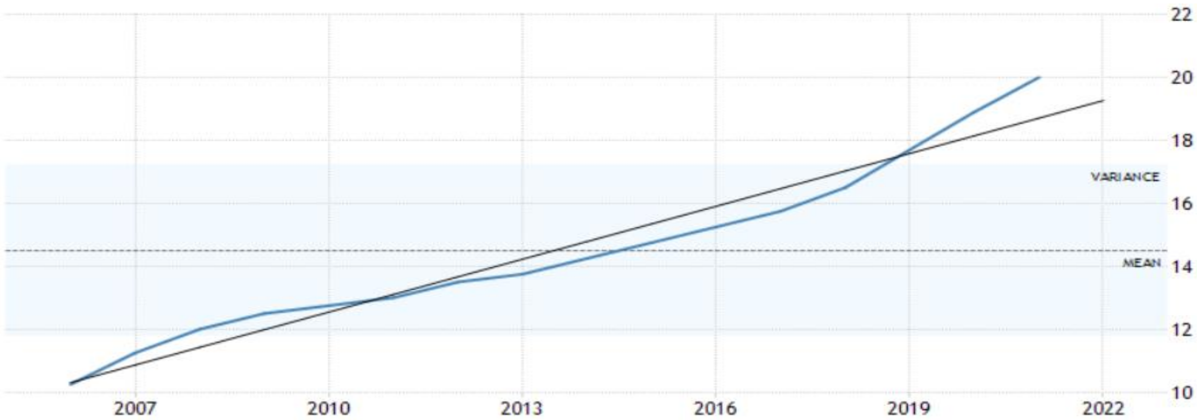



Figure2. 4: New Zealand Gross Minimum Hourly Wage

With the increasing minimum wage, the average hourly wage in manufacturing in New Zealand is increasing every year. Wages in manufacturing in New Zealand averaged 22.5 NZD/Hour from 1995 until 2021, reaching an all-time high of 32.58 NZD/Hour in the second quarter of 2021 and a record low of 14.50 NZD/Hour in the first quarter of 1995 (Economics, 2021).

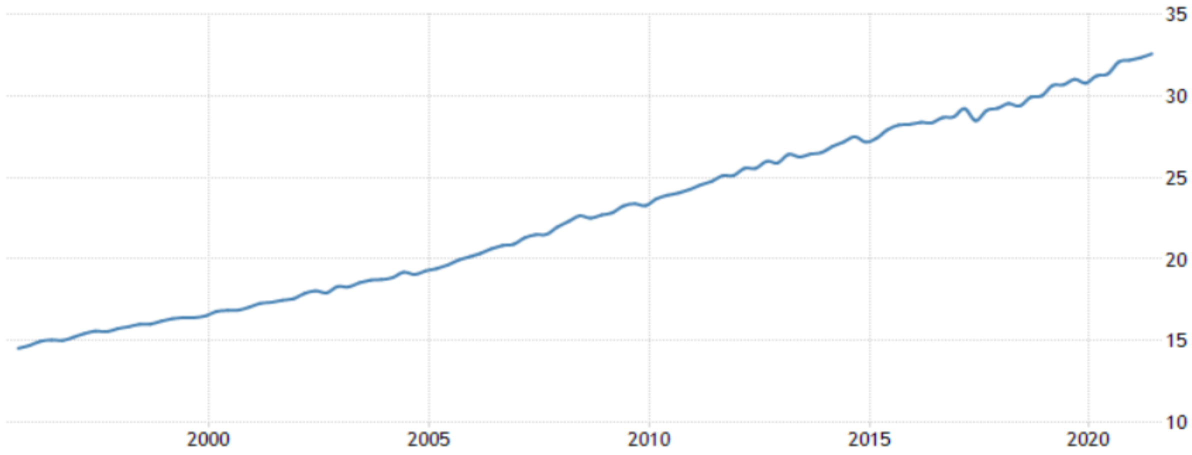



Figure2. 5: New Zealand Average Hourly Wages in Manufacturing

Labour costs in New Zealand averaged 970 points from 1995 until 2021, reaching an all-time high of 1244 points in the second quarter of 2021 and a record low of 720 points in 1995. New Zealand's annual wage inflation, measured by the labour cost index, rose by 2.1 percent in the second quarter of 2021, accelerating from a 1.6 percent increase in the prior period. Public sector wages advanced 1.9 percent, up from a 1.8 percent gain in the previous quarter, while private-sector wages rose 2.2 percent, quickening from 1.6 percent during the previous quarter. Every quarter, wages increased 0.7 percent, following a 0.4 percent rise in the prior period (Economics, 2021).

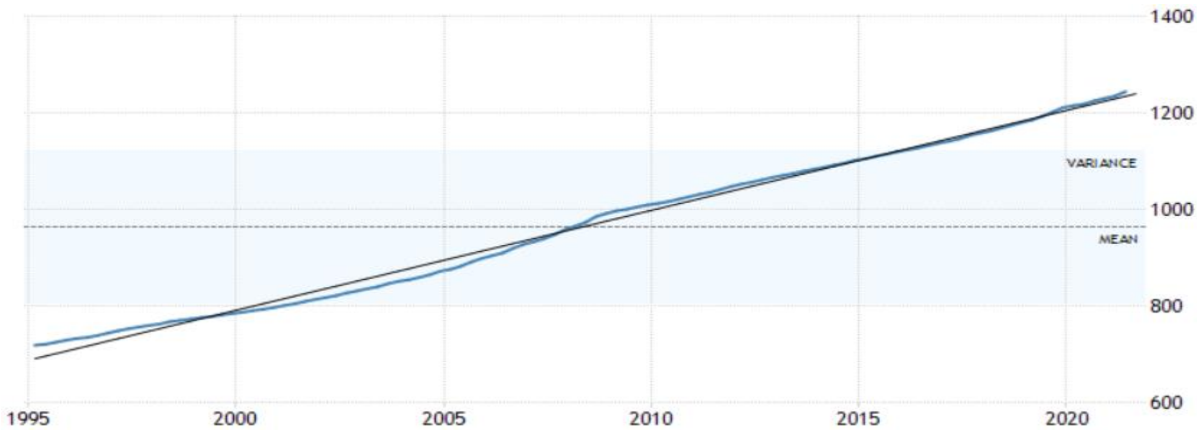



Figure2. 6: New Zealand Labour Cost

The housing index in New Zealand averaged 305781 NZD from 1995 until 2021, reaching an all-time high of 850000 NZD in August of 2021 and a record low of 0.40 NZD in March of 2016 (Economics, 2021).

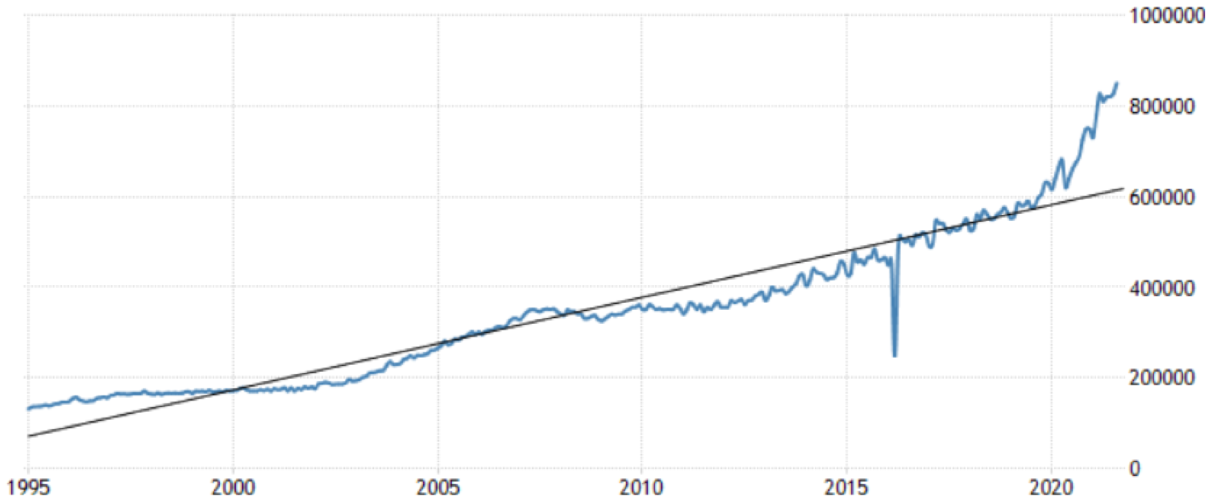



Figure2. 7: New Zealand House Prices MOM Change

## 2.2. Prefabrication industry

In New Zealand, the demand for affordable housing and concerns about the performance of residential buildings provide a strong case for using prefabrication methods (Almughrabi et al., 2021). As a modern and sustainable construction technology, the prefabricated method replaces conventional cast-in-situ concrete construction. It has attracted huge attention in many countries over the past two decades (Z. Li et al., 2014). Prefabrication technology has the potential to improve the reported low productivity of the New Zealand (NZ) construction industry (Shahzad, 2011). The benefits of prefabricated construction technology include, but are not limited to, construction waste reduction (Shen et al., 2010), superior quality control (Almughrabi et al., 2021; Boyd et al., 2012; Lara Jaillon & Poon, 2008) and noise and dust reduction (Pons & Wadel, 2011); higher standards for health and safety (Almughrabi et al., 2021; Blismas, Pasquire, & Gibb, 2006; Lopez-Mesa et al., 2009; Pons & Wadel, 2011) and time and cost savings (Chiang et al., 2006; Gibb & Isack, 2003; Mitchell, 2017; Shahzad, 2011); reduced labour demand (Nadim & Goulding, 2010), low resource depletion (Aye et al., 2012; Won et al., 2013), customisation capability (Pan et al., 2008), swift delivery (Moya & Pons, 2014), and reduced construction time (Mitchell, 2017).

The labour cost in New Zealand is very high. For this reason, precast construction organisations are critical to the construction industry, as they can enable the industry to increase its viability. This study aims to examine the productivity of one case study precast construction plant as well as the firm's profitability. As a result, the whole precast construction industry in NZ will be improved.

### 2.3. Precast production in the construction industry

Compared to in-situ construction, prefabricated elements offer faster production, a reduced overall construction schedule, lower cost, reduced wastage, and more efficient assembly of components (Godbole et al., 2018; Lacey, Chen, Hao, & Bi, 2018; Sacks, Eastman, & Lee, 2004; Shahpari, Saradj, Pishvaee, & Piri, 2020). Moreover, precast concrete elements lead to a cleaner and safer construction environment (L Jaillon et al., 2009; Tam, Tam, Zeng, & Ng, 2007; Teng & Pan, 2019; Wan et al., 2018). In the past two decades, designers or constructors have adopted offsite fabrication means and methods to achieve better quality with a reduced schedule and lower cost (Ku & Broadstone, 2017).

Precast house building (PHB) companies are shaping the future of the built environment in sustainable cities, as most of the construction work moves to offsite to achieve sustainability through innovating house-building (Masood, Lim, González, & Society, 2021). The performance of those companies has become a crucial subject as the dependence on supply chains for building projects using sustainable prefab products and methods has increased. New Zealand is lagging in attaining the full benefit of prefabrication as the market is struggling to promote its existence and vitality (Masood et al., 2021).

The precast concrete industry is a significant supplier of offsite-prefabricated components to the construction industry. The construction of a building can be partially an assembly of hundreds of different designs and delivery dates of precast concrete units. This demand creates difficulty in precast production (Benjaoran & Dawood, 2006). Research into precast concrete projects in Singapore showed that over 95% of project managers with general contracts believed that 20% of projects had problems, such as production scheduling and delivery, quality issues, incorrect quantity, handling space and structural damage in precast components (O'Brien, Formoso, Ruben, & London, 2008; Pheng & Chuan, 2001). Precast production and construction supply chain management aim to solve problems such as production scheduling, handling space, adjusting production resources in response to requirements, or providing fixed production resources that minimise the project completion time (Y. Chen, Okudan, &

Riley, 2010). For the precast industry, current production problems can be divided into two aspects: inside and outside. Inside the plant, components must be produced according to schedule; as early or late production will result in storage problems and delays at the construction site (S. Y. Yin, Tserng, Wang, & Tsai, 2009), especially given that stored components can be time consuming to locate using traditional methods. Outside the plant, the production and installation of precast concrete elements must proceed according to schedule, so it is essential to know which component belongs to which floor and part of the construction (S. Y. Yin et al., 2009). If the inventory elements in stock cannot meet site demand on any given day, delivery is delayed until production meets the demand, thereby incurring the contractual penalty costs associated with a missed delivery (W. Chan & Hu, 2002).

## 2.4. New Zealand Prefabrication Industry

New Zealand is a new country with a small open economy that operates on free-market principles (Shahzad, 2011). The construction industry of New Zealand is regarded as an inefficient industry with a considerable lack of productivity (Scofield, Wilkinson, Potangaroa, & Rotimi, 2009). Historically the New Zealand construction industry has used on-site timber construction. Even though prefabricated is not very well adopted by the New Zealand construction industry, the technology is not a new concept to New Zealanders. New Zealand has a long history of prefabricated housing, starting from importing panelised housing kits from the UK and US in early 1800 (Scofield, Wilkinson, Potangaroa, & Bell, 2009). However, Scofield explains that the construction industry finds it easier to use traditional design and construction approaches to meet market demands while complying with building legislation. This is because the industry is reluctant to try innovative construction methods and prefers to follow the tried and tested traditional methods that appear less risky. However, (Becker, 2005) reports that although the use of prefabrication is low in the New Zealand construction industry, the industry is ready to adopt innovative construction methods. He further adds that the New Zealand building regulations are based on performance and allow alternatives to achieve performance; this brightens the prospects for improved adoption of prefabrication in the future. Bell argues that offsite production can provide a good opportunity for the New Zealand construction industry to develop an environmentally friendly and sustainable culture (Bell, 2009).

## 2.5. Precast concrete production process

In precast construction, the components of projects are prefabricated in production plants instead of on the construction sites before they are transported to the sites for direct assembly. The production workflow presents the work to be performed and the timeframes in which the work will be operated. The flow consists of multiple entities called jobs that need to be processed in order of tasks called operations (Wang, Hu, & Gong, 2018). Through a direct observation from the case study by the researchers, each job has to be processed in the same sequence on all products in the precast plant. In precast production, jobs are represented by different pieces and production processes. Precast production is generally divided into nine processes, as illustrated in the figure below. First, the casting bed always needs to be prepared and customised before the production due to the lack of standardisation of products. Then the fastening of side frames, cleaning, and oiling mould surfaces are processed during assembling operations . After preparing the mould, the strands, reinforcements, inserts, and other embedded parts are placed and assembled in their positions. The moulds will be stripped for reuse after the concrete solidifies, followed by the product's finishing and repair if required. Finally, products will be stored at plants to achieve the delivery date or required strength, and they are transported to construction sites to finish assembly; figure 2.8.

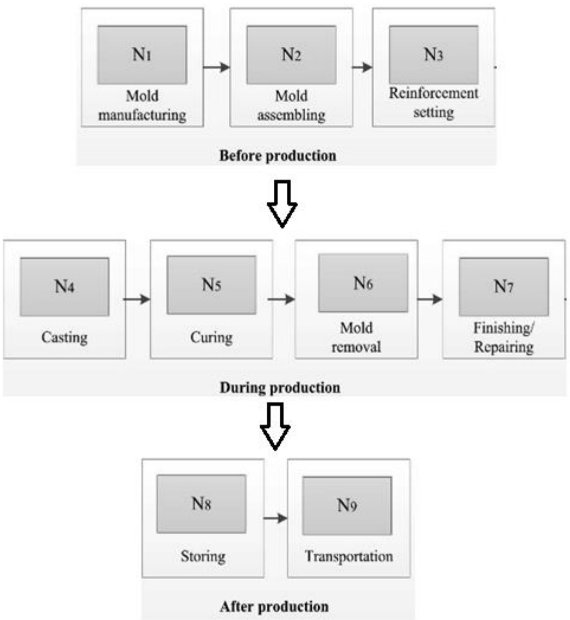



Figure2. 8: Precast concrete production workflow

## 2.6. Challenges of precast concrete plants

### 2.6.1. Supply chain management in the plant

The construction supply chain management in precast production aims to resolve requirements such as production scheduling, handling space and adjusting of production resources (O'Brien et al., 2008). A closer look at the precast industry shows that a considerable amount of the waste produced is rooted in the poor management of the materials supply chain (e.g. delivery services, inventory, communications) (O'Brien et al., 2008).

Productivity is one of the most crucial resources performance indicators to assess the success of a plant (Yi & Chan, 2013). The stages through which project resources, including materials, equipment, and personnel, proceed from supply points to the project site is called the supply chain (O'Brien et al., 2008). The construction supply chain management in precast production aims to solve problems such as production scheduling, handling space and adjusting of production resources (O'Brien et al., 2008). A closer look at the precast industry shows that a considerable amount of material waste produced is rooted in the poor management of the materials supply chain (e.g. delivery services, inventory, communications) (O'Brien et al., 2008).

Therefore, proper supply chain management in the precast concrete plant will increase the plant's profitability by reducing the non-essential inventory cost such as rework, remedial work, and double handling.

### 2.6.2. High level of companies closing down and bankruptcies

Several precast concrete companies recently left the business because of various challenges (Masood et al., 2021). The oldest construction company in liquidation was incorporated for forty-three years, from 1971 to 2014, and the newest ones were incorporated for less than one year, from Nov 2016 to Jul 2017 (Opencorporate, 2021). Even large construction companies are not free of the liquidation threat. Mainzeal Property and Construction Ltd were one of the leading New Zealand property and construction companies until being liquidated on 28 February 2013 (NZ-Companies-Register, 2021). Mainzeal had delivered $7.5 billion of construction projects across New Zealand and employed 400+ people, according to its website. Fletcher's building unit lost nearly a billion dollars between 2016 to 2018 (Gibson, 2018). Some other collapsed construction companies are: Construction Build Limited; Engineering And Construction Services Limited; Parkes Construction Limited; Annex Construction Limited; New Home Construction Limited; Fargher Construction Limited, PRECAST LIMITED, CDH Precast Limited, Rilean Construction (Canterbury) Limited, Rilean Construction (Central Otago), JE Collett Builders Ltd, Stanley Group, Vijay Holdings, Tower Cranes, Welhaus Ltd; and A1 Homes (Gazette.govt.nz, 2021; mondaq.com, 2019; nzherald, 2020; Office, 2021; Opencorporate, 2021; Stuff, 2020). The liquidators' initial investigations in all of these cases indicate that the companies were unable to pay their debts and release their retentions as they felt due.

### 2.6.3. Skilled labour shortages

The skilled construction worker shortage has become a worldwide issue (Zaki, Mohamed, & Yusof, 2012). The New Zealand construction sector suffers from severe labour and skill shortages (Almughrabi et al., 2021). The precast concrete industry is labour-intensive, and different types of skills are required during the manufacturing process (Al-Bazi & Dawood, 2018). New Zealand's unemployment rate rose sharply from the beginning of 2008 to mid-2009 and has remained high ever since (Statistics New Zealand, 2010). Although the definition of a high unemployment rate can vary depending on the context and the historical average for a given country, an unemployment rate exceeding 6% is generally considered high for developed countries (IMF, 2012). In the case of New Zealand, a persistently high unemployment rate above this level could indicate underlying issues in the labour market and the economy. A persistently high unemployment rate in isolation suggests significant drop in the labour market and the economy as a whole (Reserve Bank of New Zealand, 2010). However, that appears inconsistent with some other labour market indicators. Job advertisements reported skill shortages, and wage growth suggests that the excess capacity built up during the recession of 2008-2009 has dissipated gradually over the subsequent three years (Craigie, Gillmore, & Groshenny, 2012). According to (Economics, 2021), lack of research and development, skilled worker shortages, lack of previous work experience, and complexity of prefabricated building components are four major barriers to uptake of employment in prefabrication.

Australia's construction industry benefits from New Zealand's training and the skilled workers New Zealand exports. Also, following the lengthy Covid-19 border closures, there will be pent-up demand in New Zealand for workers, especially in the construction sector. In December 2020, the NZ construction industry, which employs about 260,000 people, estimated before Covid-19 that it would be short about 50,000 workers the following year and had planned to address that through changes in the education sector and by bringing in skilled workers from overseas. However, the estimated shortfall increased to 60,000 due to Covid-19, as vocational training plans had been delayed and skilled workers have not arrived (Morrison, 2020).

## 2.7. Offsite production concepts defined

### 2.7.1. Profitability

In recent years, the global construction industry has suffered from steady increases in wages and materials costs (Almughrabi et al., 2021; StatsNZ, 2020). Profitability is the result of the interaction of controllable and uncontrollable factors. The uncontrollable factors include the economic and political environment, market growth or decline and inflation, among others (Alsyouf, 2007).

The term 'profitability' is the overriding goal for success and growth; it can be defined as the ratio between revenue and cost (Tangen, 2005).

$$\textbf{Profitability} = \frac{Output\ volume\ X\ output\ unit\ price}{input\ volume\ \ X\ unit\ cost}$$

Profitability is a useful complementary or countermeasure to performance and productivity. It helps to identify the effects of economic factors like inflation, price changes, devaluation and currency movements, and distinguish them from 'true' performance and productivity changes (Mtotywa, 2007). A company can increase its profit margin and, at the same time, decrease productivity because of these economic effects. If both productivity and profitability are measured, the valid reasons for increased profits can become clearer (Grünberg, 2004).

#### 2.7.1.1. Companies' financial performance indicators

There are currently many indicators proposed for assessing the profitability of companies. To evaluate its profit, a company must first define its performance indicators with the goals to be achieved by the organisation and by its employees (Lucato, Costa, & de Oliveira Neto, 2017). To meet this need, previous researchers have recommended the use of the following financial performance indicators: gross margin, gross profit margin, net income, ROS (Return on Sales) and ROI (Return on Investment) (Gitman, Juchau, & Flanagan, 2015; Robinson & Phillips McDougall, 2001). Given these considerations, this research proposes to use as financial performance indicators of the company surveyed, the following values: gross margin, gross profit margin, and labour costs.

- Gross margin, gross profit or net profit

The gross margin is an adequate analytical basis for efficient cost management and decision-making (Filipović et al., 2015). Gross margin is a fast and efficient indicator of the profitability of a particular production line (Filipovic, Stankovic, & Ceranic, 2015). The method used to evaluate the case study company's profit (see chapter 5) and costs of production is based on the standard approach to gross margin analysis. A gross margin (GM) is a total income from producing a product minus the variable costs incurred in the production (Swaminathan et al., 2016). A set of 'management strategy' gross-margin budgets is prepared, based on the experience and judgements of experts. According to Filipović (Filipović et al., 2015), a gross margin is a helpful tool for assessing the economic importance of a particular product. Comprising the production value and direct costs solely, it can be easily comprehended even by people with no special training in economics. Moreover, one must remember that GMs of different production lines should not be compared if they have other overhead costs (Rural Solutions, 2012). GM has been used as an indicator narrower than an analytic calculation in previous studies. The gross margin shows the difference between production and direct costs, which makes it an essential tool from the economic aspect (Jankovic, Andjelic, Kuzevski, & Kosanovic, 2009).

$$\boldsymbol{Gross\ margin} = total\ sales\ -\ total\ cost\ of\ goods$$

- Gross profit margin

In 1997, Osisioma saw gross profit margin as a measure of the efficiency of a firm's sales operations, concerning the cost of goods sold (Osisioma, 1997). Using the gross profit margin avoids the distortion caused by non-operating costs and revenue, thus limiting itself to evaluating the trading and manufacturing operations. This ratio is based on the firm's net sales because that is its most important feature. A low gross profit margin indicates that the cost of goods or the direct costs are relatively too high (Barman & Sengupta, 2017).

$$\boldsymbol{Gross\ profit\ margin} = \frac{sales\ -\ cost\ of\ goods}{Sales}\ OR\ \frac{Gross\ profit}{Sales}$$

The gross profit margin measures the relative profitability of a firm's sales after deducting the cost of goods. The higher the gross profit margin, the better, o; the lower the relative cost of the merchandise sold (Pradhan & Das, 2016).

Profit efficiency is an essential measure of a company's performance. Unlike productivity, which a company achieves by maximising the number of units produced in a given time frame, profit efficiency requires costs to be minimised and profits to be maximised for a given level of output (Prokopenko, 1987; Shaaban, 2010; shmula, 2007). Therefore, efficiency enables a business to make the best possible use of the company's resources. For example, an efficient company will produce more quality products with less waste and use less energy and other resources during a given period than an inefficient company (Prokopenko, 1987; Shaaban, 2010; shmula, 2007).

- Economic criteria in the selection of alternatives

Investment appraisal or capital budgeting is the planning process used to determine whether an organisation's long-term investments such as new machinery, replacement of machinery, new plants, new products, and research development projects are worth the funding of cash through the firm's capitalisation structure (debt, equity or retained earnings) (Sheffrin, 2003). Capital budgeting is the process of allocating resources for major capital, or investment, expenditures (Sheffrin, 2003). One of the primary goals of capital budgeting investments is to increase the firm's value to the shareholders (Mona, 2016). The purpose of capital budgeting is to assess the economic prospects of a proposed investment project. It is a methodology for calculating the expected return based on cash-flow forecasts of many, often inter-related, project variables. Risk emanates from the uncertainty encompassing these projected variables. The evaluation of project risk, therefore, depends, on the one hand, on our ability to identify and understand the nature of uncertainty surrounding the key project variables and, on the other, on having the tools and methodology to process its risk implications on the return of the project (Savvides, 1994). In addition, according to the U.S. General Services Administration, Life Cycle Costing (LCC) is a critical economic analysis used in the selection of alternatives that impact both pending and future costs. It compares initial investment options and identifies the lowest cost alternatives for twenty years. Therefore, by implementing the economic analysis before deciding on an alternative, the corporates will guarantee their return on investment (ROI).

In finance, the capital asset pricing model (CAPM) is used to determine a theoretically appropriate required rate of return on an asset. To make decision**s** about adding assets, the CAPM is a model for pricing an individual security or portfolio (Tsuji, 2017). The capital asset pricing model is one of the most famous asset pricing models in finance (Sharpe, 1994). Hence, many studies of stock returns applying this model have been conducted by academicians, and this model is also often used in practice as a primary benchmark model. The application of this model is generally conducted using a linear regression approach such as the ordinary least squares (OLS) method, and this method generally assumes a normal distribution for stock returns (Tsuji, 2017). Modern academic finance is built on the proposition that markets are fundamentally rational. The foundational model of market rationality is the capital asset pricing model (CAPM). The implications of rejecting market rationality as encapsulated by the CAPM are considerable. In adopting the idea that markets are inherently rational, the CAPM has made finance an appropriate subject for econometric studies. The industry has come to rely on the CAPM for determining the discount rate for valuing investments within the firm, for valuing the firm itself, and for setting sales prices in the regulation of utilities, as well as for such purposes as benchmarking fund managers and setting executive bonuses linked to adding economic value. The concept of market rationality has also been used to justify the policy of arm's-length market regulation – on the basis that the market knows best and that it is capable of self-correcting. (Dempsey, 2013). In 2011, (Mehrling & Brown, 2011) considered the CAPM as the ‘revolutionary idea’ that runs through finance theory. He recounts the first significant step in developing modern finance theory as the ‘efficient markets hypothesis’, followed by the CAPM’s second step. While the efficient market hypothesis states that at any time, all available information is imputed into the price of an asset, the CAPM gives context to how such information should be imputed.

- Construction risks

The construction industry is very uncertain, and construction work is one of the well-known risky types (Larsson & Field, 2002). The complexity of the construction industry and its production methods generates enormous risks (Zou, Zhang, & Wang, 2007). No project is risk-free. Risk can be managed, minimised, shared, transferred, or accepted; it cannot be ignored (Latham). Project risks may cause changes in a project, and they are believed to be among the key barriers to meeting project success targets (Dey, 2001). Therefore, risk management is an essential component of construction project management. It is a continuous process of risk identification, risk analysis, risk treatment, risk review and monitoring. Of these, risk analysis is the most difficult (Baloi & Price, 2003).

### 2.7.2. **Productivity**

The interest in New Zealand construction productivity has increased considerably over the last few years, especially since Statistics New Zealand in 2010 first published productivity statistics at the industry level, and these indicate that the construction industry has underperformed other industries in the last few decades, both in terms of productivity levels and of productivity growth (Jaffe, Le, & Chappell, 2016).

Productivity is a multi-dimensional term with a meaning that can vary depending on the context within which it is used. However, the term has a common characteristic (Tangen, 2005). Productivity is generally defined as output (i.e. produced goods) in relation to input (i.e. consumed goods) in precast concrete units in a precast concrete plant. On the other hand, mathematical definitions can be used as the basis of performance measures, where the major aim is to improve (not to explain) productivity. Mtotywa (Mtotywa, 2007) suggested that it is necessary to have a clear distinction between a concept and a mathematical definition attached to the concept to evaluate the characteristics of the mathematical definition effectively.

Previous researchers provided a helpful explanation of productivity related to manufacturing: Productivity means how much and how well we produce from the resources used. If we produce more or better goods from the same resources, we increase productivity. Or, if we produce the same goods from fewer resources, we also increase productivity. 'Resources' means all human and physical resources – the people who produce the goods or provide the services, and the assets with which the people can produce the goods or provide the services.

This definition captures two important characteristics. Firstly, productivity is closely related to the use and availability of resources. This means that a company's productivity is reduced if resources are not correctly used or if there is a shortage of them. Secondly, productivity is also strongly connected to the creation of value. Thus, high productivity is achieved when activities and resources in the manufacturing transformation process add value to the goods produced.

The productivity measures can be divided into three types (Stainer, 1997): total productivity, total factor productivity, and partial productivity measures.

Productivity is a relative concept – it cannot increase or decrease unless a comparison is made, either in a standard variation at a certain point in time or of changes over time. Other authors (Misterek, Dooley, & Anderson, 1992) argue that productivity can be increased or decreased based on the differences in the relationships.

In 1986, Thomas and Mathews (1986) stated that no standardised productivity definition had been established in the construction industry. It is the critical determinant of value and all other factors influencing the value of these goods and services (quality, service, price). Productivity in New Zealand is an important factor that significantly impacts economic growth, the standard of living, and increases in welfare (Black, Guy, & McLellan, 2003). This study is not focused on defining productivity but on the key productivity constraints in the New Zealand context. Generally, productivity measures how resources are leveraged to achieve objectives or desired outputs (Durdyev, 2011). It emphasises creativity and innovativeness, aiming to achieve more output with fewer resources by re-engineering the production or service delivery process and optimising the resource leverage (Durdyev, 2011; Park, Thomas Stephen, & Tucker Richard, 2005). The term 'productivity' has different meanings for different people. The Organisation formally defined European cooperation as the measure obtained by dividing output by one of the factors of production. Or, in other words, The same as efficiency, which is defined as the ratio output energy divided by input energy (Harris

& McCaffer, 2006). Productivity in concept is production efficiency: how much output is obtained from a given set of inputs (Syverson, 2011). As such, it is typically expressed as an output-input ratio. Single-factor productivity measures reflect units of output produced per unit of a particular input.

While productivity is relatively straightforward in concept, many measurement issues arise when constructing productivity measures from actual production data (Syverson, 2011). Although many publications exist on construction productivity, there is no agreed-upon definition of work activities or a standard productivity measurement system. A few researchers have attempted to develop common definitions and a standard productivity system; however, those were not based on harmony between academia and industry. Productivity measures are a series of inputs calculated against a series of outputs. Using the productivity measures formula can help determine how to maximise the use of the company's resources. Utilising the company's resources to the fullest extent can help achieve higher sales and revenue (Harnish, 2006). From an economist's perspective, productivity is the ratio of a measure of output to a measure of resource input (Schreyer (2001). Productivity can also be explained as a measured rate of successful delivery of the leading project objectives with a high level of cost-effectiveness (Chan & Chan, 2004; Mbachu, 2008). The main project objectives in this field can be the rate of achieving the targeted schedule, rate of project cost-effectiveness, and the level of quality achieved. Maximum productivity is achieved by maximising the number of units produced in a given time frame. Therefore, productivity is one of the most important criteria when evaluating a company's success.

Labour productivity is the most common measure of this type, though occasionally capital or even materials productivity measures are used (Syverson, 2011). Several studies have been commissioned to investigate productivity trends, especially labour productivity, in the NZ construction industry (Tran & Tookey, 2011). The main reason for this particular consideration is the nature of the industry. Construction is generally a labour-intensive industry, and improving labour productivity constitutes a prime target. Tran (2011) argued that labour productivity growth in NZ construction has been low, and that productivity has declined over time. Labour productivity measures can be based on either a gross output or the value-added concept. The most straightforward measure of labour productivity is output per worker. An increase in output per worker can be observed either by requiring workers to produce more in the hours they work, or if they work longer hours. The latter is a disadvantage of this definition. The second measure of labour productivity is output per hour worked (Tran & Tookey, 2011).

Overall, an operational definition of productivity that fits well with the various approaches to defining the concept is 'the amount or quantity of output of a process per unit of resource input'. This aligns with similar definitions by (Syverson, 2011), (Park et al., 2005) and (Durdyev, 2011).

#### 2.7.2.1. Productivity in Context

The term 'productivity' has different meanings for different people but was formally defined by the Organisation for Economic Co-operation and Development (OECD, 2001) as the quotient obtained by dividing output by one of the factors of production. Or, in another's words: The same as efficiency, which is defined as the ratio of output energy divided by input energy (Harris & McCaffer, 2006). In concept, productivity is production efficiency: how much output is obtained from a given set of inputs (Syverson, 2011). As such, it is typically expressed as an output-input ratio. Single-factor productivity measures reflect units of output produced per unit of a particular input. Labour productivity is the most common measure of this type, though occasionally capital or even materials productivity measures are used (Syverson, 2011). Two producers may have different labour productivity levels even though they have the same production technology. It is difficult to define a standard productivity measure because companies use their internal systems, which are not standardised (Park et al., 2005). Productivity can be illustrated by an association between an output and an input. Depending on the purpose, different methods are available for explaining productivity. Generally, productivity can be explained to achieve a set of objectives or desired output as a measure of how well resources are leveraged (Durdyev, 2011). Productivity emphasises creativity and innovativeness, which targets achieving more outputs with fewer resources by re-engineering the production or service delivery process and optimising the resource leverage (Durdyev, 2011; Park et al., 2005).

Productivity can be divided into macro-and micro-level (Bureš, Stropková, & Sciences, 2014; Dozzi & AbouRizk, 1993). The macro-level deals with contracting methods, labour legislation, and labour organisation, while the micro-level is focused on the management and operation of a project, mainly at the job site. Productivity, to be improved, must be a measurable concept; the management team must be able to measure the effect of changes adopted, on methods, effort, and systems. The measured productivity values can then be compared to those used to compile the estimate or other production standards.

Further, most of the approaches were developed primarily for the manufacturing sector. Only a few approaches are designed to measure productivity in the service sector. Indeed, there is a need for research in this area in the future to develop approaches that take into account the very different framework conditions and, thus, the requirements of the service sector (Günter, Gopp, & Management, 2021).

This research will focus on micro-level productivity in precast concrete plants. According to (Durdyev & Mbachu, 2011), when using cost as the denominator in the efficiency measure of productivity, the dimensions of effectiveness and efficiency can be combined as one to represent productivity 'cost effectiveness'; cost in this context refers to the optimisation of the use of scarce resources, while effectiveness refers to the achievement of the set objectives. As an indicator of productivity, cost-effectiveness targets maximising the extent of achievement of the set objectives while minimising the scarce resources employed in the process (Durdyev & Mbachu, 2011). Therefore, maximum productivity is achieved by maximising the number of units produced in a given time frame.

Overall, an operational definition of productivity that fits well with the various approaches to defining the concept is 'the amount or quantity of output of a process per unit of resource input'. This aligns with similar definitions by (Durdyev & Mbachu, 2011; Park et al., 2005; Syverson, 2011).

#### 2.7.2.2. Measuring productivity

The standard output rate in precast concrete companies is the volume of work produced per unit of time (Prokopenko, 1987; Shaaban, 2010; shmula, 2007). Serdar has argued that ideally, the measure of overall productivity could be required at any of five levels: (national, industry, organisational, project and resource levels) (Durdyev & Mbachu, 2011). By consistently meeting the productivity measures at the project levels, an organisation can satisfy its customers or clients, achieve repeat purchases, and gain market share relative to its competitors. This will allow the organisation to meet productivity measures at the organisation level. If several organisations within the industry are doing well at the organisation level, this will ensure more satisfied clients; this, in turn, will attract more investment into the industry, thereby improving productivity at the industry level, which feeds into the national productivity stream (Durdyev & Mbachu, 2011).

According to previous researchers, most measurements of productivity in New Zealand are made at the aggregate (whole economy) level (Davis, 2007). There are no official measures of industry productivity within New Zealand (Durdyev & Mbachu, 2011). Many terms are used to measure and describe productivity in the construction industry: performance factors, production rate, unit person-hour (p-h) rate and others. Traditionally, productivity has been defined as the ratio of input and output – the ratio of the input of an associated resource (usually, but not necessarily, expressed in man-hours (mnhr)) to actual output (in creating economic value) (Dozzi & AbouRizk, 1993). To restate this definition for use in the precast concrete industry, labour productivity is the physical progress achieved by man hours per production measurement unit. According to Dozzi (1993), the most important measure of labour productivity is the relative efficiency of labour doing what it is required to do at a given time and place (Dozzi & AbouRizk, 1993).

$$\textbf{labour productivity} = \frac{\textbf{production (Qtys)}}{\textbf{Labour cost (NZD)}}$$

#### 2.7.2.3. Measuring Productivity and Operational Efficiency

While productivity is relatively straightforward in concept, many measurement issues arise when constructing productivity measures from actual production data (Syverson, 2011). Although many publications have discussed construction productivity, there is no agreed-upon definition of work activities or a standard productivity measurement system. Using a productivity measurement formula can help to determine how to maximise a company's resources. Also, utilising the company's resources to the fullest extent can help to achieve higher sales and revenue (Harnish, 2006).

Many terms have been used to measure and describe productivity in the construction industry (Günter et al., 2021). However, an overview of standard definitions of productivity has been defined in the table below (Tangen, 2005).

Table2. 1: Standard definitions of productivity in the construction industry

| | |
|---|---|
| (Littré, 1881) | Productivity is faculty to produce |
| (CHEW, 1988), | Units of output/units of input |
| (Sink, Tuttle, & Shin, 1989) | Actual output/expected resources used |
| (Aspen, Bråthen, Cassel, Ericsson, & Marelius, 1991) | Value-added/input of production factors. |
| (Jackson, 1999) | Efficiency * effectiveness & value adding time/total time |
| (Al-Darrab, 2000) | (output/input) * quality & efficiency * utilisation * quality |
| (Coelli, Rao, O'Donnell, & Battese, 2005) | Outputs/inputs |
| (Oeij et al., 2012) | (output quantity * output quality)/(input quantity * input quality) |
| (Berhe, Abebe, Azene, & Excellence, 2017), | Total outputs/total inputs |
| (Rehman, Usmani, Umer, Alkahtani, & Engineering, 2020) | Actual output per combined unit of labour, machine and overhead, reflecting the contributions of all factors of manufacturing |

To restate the definition of productivity for use in the precast concrete industry:

- Labour productivity is the physical progress achieved by man-hours per linear metres or cubic metres of double tee production. The most important measure of labour productivity is the relative efficiency of labour doing what it is required to do at a given time and place (Dozzi & AbouRizk, 1993). Equation 1 shows labour productivity.

$$\text{labour productivity} = \frac{\text{output}}{\text{input}} \frac{\text{producton quatity}}{\text{actual work hours}} \quad (1)$$

As shown in equation 1, labour productivity is the number of actual work hours required to achieve the appropriate work units. As noted, when defined in this manner, higher production values indicate better productivity performance.

- Tender productivity is the number of tenders won to the number of submitted tenders.

$$\text{Market attractiveness} = \frac{\text{output}}{\text{input}} = \frac{\text{number of tendrs won}}{\text{actual umber of tenders submitted}} \quad (2)$$

- The plan utilisation efficiency is, for example, the ratio of the number of actual linear metres of double tee production to the plant's capacity.

$$\text{Plan utilisation efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{actual linear meter of cast}}{\text{Plant's capacity}} \quad (3)$$

In addition, Serdar (2011) has argued that a relationship exists amongst productivity measures. By consistently meeting the productivity measures at the project levels, an organisation can satisfy its customers or clients, achieve repeat purchases, and gain market share relative to its competitors. This will allow the organisation to meet productivity measures at the organisation level. If several organisations within the industry are doing well at the organisation level, this will ensure more satisfied clients; this, in turn, will attract more investment into the industry, thereby improving productivity at the industry level, which feeds into the national productivity stream (Durdyev & Mbachu, 2011).

This study focuses on measuring the current productivity and efficiency of the New Zealand precast concrete industry at the organisational level.

#### 2.7.2.4. Factors Affecting Productivity in the Construction Industry

Factors affecting productivity in the construction industry and their classifications vary, depending on the positions taken by researchers (Jarkas & Bitar, 2011; Yi & Chan, 2013). Some researchers have focused on labour productivity by directly surveying the workforce instead of the management because of the easily obtained labour information (Chan, 2002; Kaming, Olomolaiye, Holt, & Harris, 1997). Considering the significant contributions of other factors, a growing number of researchers have opted to measure total factor productivity instead (Crawford & Vogl, 2006; Hwang, Zhu, & Ming Jonathan Tan, 2017). Therefore, different factors affecting productivity need to be further examined.

The following factors have known to have significant effects on the productivity level.

Design change, poor work planning, inadequate sequencing, poor site layout, poor communications, frequent revision of drawings, low materials quality, material shortages, rework and inability to finance materials payment (Kaming et al., 1997; Makulsawatudom, Emsley, & Sinthawanarong, 2004). The structural design of a building, different construction methods, the use of a design-build method and just-in-time production, the procurement method (Dulaimi & Dalziel, 1994; Fox, Marsh, & Cockerham, 2002; Hwang et al., 2017; H. R. Thomas, Riley, & Sanvido, 1999).

Workers from different sites, with different experiences and skills have been shown to have different productivity outputs and perceptions of their supposed productivity (Olomolaiye* & Ogunlana*, 1989). This observation is supported by other studies that highlight the influence of individual skill levels, experience, and workplace environments on productivity outcomes (Seppänen et al., 2014; Loosemore & Andonakis, 2007). Seppänen et al. (2014) found that workers' experiences and skills contribute significantly to the variation in productivity levels across construction sites. They argued that construction companies need to focus on workforce development, training, and knowledge sharing to enhance overall productivity. Similarly, Loosemore & Andonakis (2007) examined the impact of worker motivation and satisfaction on construction productivity. Their study demonstrated that workers with higher levels of job satisfaction tend to be more productive and engaged in their tasks, emphasizing the importance of creating a positive work environment to maximize workforce efficiency.

A lack of organisational incentives for workers, difficulties in the recruitment of supervisors and workers, a high rate of labour turnover, absenteeism at the worksite and the communication problems with foreign workers all have an effect on productivity (El-Gohary & Aziz, 2013; Jarkas & Bitar, 2011). From the aspect of higher management, Chan (2002) has identified that the key differences between productive and non-productive projects were labour planning, the organisation of all aspects of work, workers feeling part of the team, job security for workers and site welfare (P. Chan, 2002). Project management, unskilled supervisors, poor communication, poor site layout, and inspection delay were among the top ten most significant factors affecting construction productivity (Makulsawatudom et al., 2004).

External factors are uncontrollable but will nonetheless affect a project. Weather effects on productivity are significant (Thomas et al., 1999). In Singapore, a heavy downpour during the monsoon season and interference from rainy weather can affect construction productivity (Lim & Alum, 1995). This observation is supported by other studies that have explored the impact of various weather conditions on construction productivity in different geographical locations (Koushki et al., 2005; Chua & Goh, 2015; Amusan et al., 2017).

Koushki et al. (2005) conducted a study in Kuwait, examining the effects of extreme temperatures on construction productivity. Their findings showed that high temperatures significantly reduced productivity levels, leading to delays in project schedules.

Chua & Goh (2015) explored the influence of weather conditions, including temperature, rainfall, and wind speed, on construction productivity in Malaysia. Their results indicated that adverse weather conditions, such as heavy rain and high temperatures, negatively impacted construction productivity by causing work interruptions and reducing the efficiency of construction workers.

Amusan et al. (2017) investigated the impact of rainfall on construction activities in Nigeria. The study found that the rainy season led to frequent work disruptions and delays, which in turn reduced overall productivity in the construction sector. Hot weather also affects labour productivity, and a thermal work limit has been recommended as an environmental determinant of heat stress for construction workers (Yi & Chan, 2013). Productivity may also be reduced by snow and cold temperatures. Industry-level factors, such as governmental interference, regulation, industry fragmentation, complex contractual agreements that often result in change orders or disputes, complicated building standards, and low levels of investment in technology, research, availability of materials and digitalisation are other types of external factors that may affect productivity (Barbosa, Woetzel, & Mischke, 2017; Johari & Jha, 2020; Le-Hoai, Dai Lee, & Lee, 2008; Mojahed & Aghazadeh, 2008; Smith, 2014).

Some factors have been studied regarding the productivity of construction industries. Table 2.2 categorises them according to five different existing departments from the case study company.

Table2. 2: Factors affecting productivity in the construction industry

| Category | Literature Review |
|---|---|
| Production | Lean principles (Peng & Pheng, 2011), procurement method (Dulaimi & Dalziel, 1994), reworks (Olomolaiye, Wahab, & Price, 1987), workers' skill level (Mojahed & Aghazadeh, 2008), labour turnover (Lim & Alum, 1995), supervision of labour (Jarkas & Bitar, 2011; Makulsawatudom et al., 2004), workers' experience (Mojahed & Aghazadeh, 2008), materials availability (Olomolaiye et al., 1987; Olomolaiye* & Ogunlana*, 1989), tools and equipment (Olomolaiye et al., 1987; Olomolaiye* & Ogunlana*, 1989), weather (A. P. Chan, Yi, Chan, & Wong, 2012; Lim & Alum, 1995; H. R. Thomas et al., 1999), poor instructions (Kaming et al., 1997; Makulsawatudom et al., 2004) |
| Design | Communication of information (Chen, Yan, Tai, & Chang, 2017; Jarkas & Bitar, 2011; Makulsawatudom et al., 2004), poor instructions (Kaming et al., 1997; Makulsawatudom et al., 2004), design changes (Kaming et al., 1997; Olomolaiye et al., 1987), incomplete design (Makulsawatudom et al., 2004), design and information process |
| Quality | Poor quality, incorrect quantity, and structural damage (Pheng & Chuan, 2001), waste (O'Brien et al., 2008), defects and rework (Ray, P. Ripley, & D. Neal, 2006a), handling space and adjusting of production resources (O'Brien et al., 2008), inspection delay (Makulsawatudom et al., 2004) |
| Management and planning | IT strategies (Henderson & Venkatraman, 1993), production delays (Pheng & Chuan, 2001), production scheduling (O'Brien et al., 2008) (Warszawski, 1984), poor management of the material supply chain (O'Brien et al., 2008), motivation of workers (Chan, 2002; El-Gohary & Aziz, 2013; Jarkas & Bitar, 2011; Mojahed & Aghazadeh, 2008), absenteeism (Kaming et al., 1997; Lim & Alum, 1995; Olomolaiye et al., 1987), planning and sequencing of work (Chan, 2002; Mojahed & Aghazadeh, 2008), competency of a project manager (El-Gohary & Aziz, 2013; Jarkas & Bitar, 2011; Makulsawatudom et al., 2004), project planning and resource allocation (Buckus, 2014) |
| Stock and delivery | Poor site layout (Kaming et al., 1997; Makulsawatudom et al., 2004), transportation |

### 2.7.3. Performance

Performance covers overall economic and operational aspects. Discussing and measuring performance has two main aims: first, to connect company goals and objectives to improvements, and second, to set targets for improvement activity. Goals are usually considered high-level, generally not expressed in numeric form. They are translated at 'the next level down' into measurable objectives (Mtotywa, 2007). Both should be demonstrably linked to the company's mission, which is the fundamental reason for a company's existence.

### 2.7.4. Quality

Quality is defined as the degree to which a company understands customers' perceptions of a variety of characteristics of the delivered products or services and is often expressed and managed using a range of technical quality factors such as percentage of defective goods (Dale & Plunkett, 2017; Rumane, 2016). Elassy (Elassy, 2015) has defined quality as fitness for purpose, and excellence. Sink et al.

(1984) argue that quality is a measure of performance on the input side, concerning the transformations of input, and also on the output side. According to (Elshennawy, 2004), quality is a form of perfection with intrinsic value.

## 2.8. Lean management methods

Scholars have continued to search for better ways to optimise the fabrication and management of precast components (Chen et al., 2017). Computer simulations and sharing of the construction information and the influences of these on the construction inventory have been studied to explore the impact of preliminary operations on subsequent operations (Tommelein, 1998). It has been demonstrated that variances in preliminary preparations and information sharing influenced subsequent operations (Chen et al., 2017). These authors showed that reducing variance in preliminary preparations and improving communication can reduce uncertainty in follow-up operations and high supply-chain inventories (Chen et al., 2017). A study by O'Brien and Fischer (2000) also found that production constraints affected supplier production output; the significant variances in site progress meant that suppliers must constantly adjust their production by moving production and construction resources between different projects.

Previous studies have also considered the overall production system model, to establish how precast concrete plants with limited resources approached the assignment of project production management personnel, and their production schedules, and production plans (Chan & Hu, 2001; Ko & Wang, 2010; Leu & Hwang, 2002; Patterson, 1984). Regarding storage and transportation, N. Dawood and Marasini (1999) studied the layout of handling yards for precast building products. A model was constructed, and simulations were carried out to find high-efficiency storage, loading and unloading, and allocation. Such a modelling approach would facilitate the precast production plan and give the yard administrator more detailed, complete, and timely information (Dawood & Marasini, 1999; Dean, Denzler, & Watkins, 1992; Marasini & Dawood, 2002).

Lean manufacturing has only recently been applied to the precast concrete industry despite its wide use in other industries. According to Ray’s research in 2006, on the one hand, it was estimated that about five percent of precast concrete industry members had undertaken a tough initiative in applying lean manufacturing, and about six percent of the precast concrete companies in the United States had active lean manufacturing programs. This author found that these companies were attaining a twenty percent or more improvement in labour productivity per year, up to a fifty percent increase in production (without significant capital spending), and up to a fifty percent reduction in defects and rework (Ray et al., 2006a).

The lean management system has been applied in manufacturing in the United States and other industrialised countries for more than a decade (Abdulmalek & Rajgopal, 2007). Lean manufacturing methods have been applied across entire firms, including engineering, administration, project management departments and manufacturing and construction (Peng & Pheng, 2011). The lean end-purpose is to find waste and reduce costs to transform a company into an efficient, smoothly running, competitive, and profitable organisation that continues to learn and improve (Ray et al., 2006a).

Minimising non-value-added activities: lean manufacturing focuses on cost reduction by eliminating non-value-added activities (Abdulmalek & Rajgopal, 2007). Value added is defined as any activity that transforms the product toward what the customer wants. Everything else is defined as 'waste'. Waste is any processing step that consumes resources without adding value (Abdulmalek & Rajgopal, 2007; Ray et al., 2006a). In 2006, the day-to-day activities of one hundred and twenty companies were tracked, and the results indicated that, on average, only five percent of activities were value-added while the remaining ninety-five percent were waste (Ray et al., 2006a). The lean manufacturing discipline has identified seven main categories of waste (Table2.3) (Chahal & Narwal, 2017; Henderson & Venkatraman, 1993).

Learning to identify waste is an important part of the lean manufacturing process because, often, businesses have become so accustomed to waste that it is not recognised. The lean manufacturing process adopts a value stream mapping method as the primary analytical starting point to break down the work process into detailed steps. The process steps are classified as either value-added or waste (Chahal & Narwal, 2017). Table 2.3 shows the sources of waste in each step across the work process in this study.

Table2. 3: Sources of wastage (Chahal & Narwal, 2017; Henderson & Venkatraman, 1993)

| Waste | Reasons / Explanation |
|---|---|
| Overproduction | From 'getting ahead' concerning production schedules. Here, the required number of products is disregarded, favouring efficient production capacity utilisation. |
| Inventory | Final, semi-finished products or parts kept in storage do not add value. Even worse, they usually add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities, and workforce. |
| Repair or reject | May end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints. |
| Motion | Any motion not related to adding value is unproductive. |
| Transport | An essential part of the production but moving unnecessarily will not increase the value. |
| Over-processing | Use of inadequate technology or poor design results in inefficient processing activities. |
| Waiting | When the hands of a worker are idle, such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job. |

Lean manufacturing techniques: many techniques are available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behaviour, sequence, proportion and variability of inspecting, waiting, processing and transporting activities. Many were invented in the early days of scientific management, such as time-lapse video recording, work sampling and flow charts (Scheer, Santos, Quevedo, & Mikaldo Jr, 2005). Lean manufacturing provides tools and methods that effectively reduce waste once it is recognised in the workflow. Below is a summary of some of the tools that producers have used successfully (Chahal & Narwal, 2017; Ray et al., 2006a):

The rapid improvement events (Kaizen) tool (Rusdiana, Soediantono, & Research, 2022) involves setting up a cross-functional waste reduction team to focus on a specific problem area. A standardised task is the method that is usually the way to perform a task most efficiently. Once standard tasks are established in the balanced flow (Takt time) method, process cycle time and standard staffing can be developed. Balancing staffing and materials flows to minimise walking, waiting, and repetitive materials handling is frequently a source of significant improvement in precast concrete plants (Ray, P. Ripley, & Neal, 2006b). Workplace organisation (5-S) is another tool (Gupta, 2022) – many producers are familiar with this workplace organisation and housekeeping system. Another tool is visual controls which can be as simple as painting lines on the floor to guide the placement and flow of materials. In the plant layout method, most producers find many opportunities to streamline material flow, minimise crane time, and reduce walking (Ray et al., 2006b). This tool includes an analysis of flow and how it relates to inventory. Carpenter and steel shops are often good places to start in the precast concrete plant. A mistake-proofing system will be designed to make it harder to conduct processes wrongly than to do them right. In the inventory reduction method (Ray et al., 2006b), inventory is a waste for the following reasons: it must be handled and stored. It is often subject to damage or obsolescence. Someone must keep track of inventory and find it when needed. It ties up capital that should be earning a return on investment. Work-in-process inventory beyond the needs of the immediate casting is a waste. Further methods and tools to reduce waste are correction at the source, bed setup reduction, total preventative maintenance, and team problem solving, (Ray et al., 2006b).

## 2.9. Automation and construction industry

Automation is not a new concept in construction; it has been around in its current form for decades now, but its application is limited to a few developed countries (Foundation, 2018). (Bock, 2007) notes that in the last three decades, the use of robotic automation has soared in both offsite and onsite construction. Japan is regarded as a world leader in the automation of construction. The shortage of construction workers and the ageing population in Japan have been the main drivers of automation in the Japanese construction sector (Jiang, Mao, Hou, Wu, & Tan, 2018; Tsuruta, Miura, & Miyaguchi, 2019) Japanese car manufacturer, Toyota, has been using automation to manufacture modular houses since the 1960s, and it is reported that. Japan's automated offsite construction (OSC) industry supplies about ten thousand houses each year (Matsumura, Gondo, Sato, Morita, & Eguchi, 2019). Some countries in Europe also have well-established OSC industries. In Sweden, the concept of automating prefabricated building components was triggered in 1965 by an agreement by the Swedish Parliament to build one million apartments in ten years (Mahapatra, Gustavsson, & Information, 2008). That initiative had full support of the Swedish government, and halfway through the ten years, the housing shortage in Sweden became a housing surplus (Bell, 2018).

Although automation has advanced in manufacturing, automation in construction has been slow (Khoshnevis, 2004). Later, Bock in 2017 mentioned that, although approaches to construction automation were still in an innovation or seed phase, it could be expected that with the continued effort put into research and development, these approaches might soon enter the growth phase and be adopted on a larger scale (Thomas, 2017).

Today's construction projects are characterised by a straightforward design and build period, increased quality demands, and low cost (Bock, 2008; Razkenari, Fenner, Shojaei, Hakim, & Kibert, 2020). Like many other industries, the construction industry has improved productivity and performance through automation due to technical developments that replace human labour with faster and more accurate mechanical processes (Chen et al., 2018 and Zavala, 2016). Automated systems in Japan are motivated by an expected shortage of skilled labour and will have economy and quality advantages over time. It is estimated that about ninety percent of current labour requirements will be replaced by automation (Bock, 1997). Those workers who remain will probably be highly skilled technicians who can program and maintain the robots (Bock, 1997). Automation in the precast concrete industry will, it is expected, integrate information management, a proper information flow and an intelligent production system.

## 2.10. **Automation and precast concrete industry**

The use of robotic technology in precast concrete element production for walls, floors, and roofs can result in more consistent quality of products and less waste in factories, because only the necessary amount of concrete is provided from the automated batch plant thanks to computer-assisted planning and programming (Bock, 2015). Computer-assisted planning and engineering provide the necessary data to produce elements such as reinforcing bars or mats originating from the architectural design of floor plans, elevation sections, HVAC plans, and structural calculations. Compared to conventional prefabrication, there are fewer mistakes in transferring data because of defined interfaces between planning, engineering, and production (Bock, 2015).

In New Zealand, there is a general lack of knowledge and information about precast and automated construction within the industry (Darlow, Rotimi, Shahzad, & Management, 2021). Engineers conduct the majority of their activities outdoors and usually record in notebooks, plant management and quality inspection information such as the production quantity, the inventory quantity, the materials quantity and the quality inspection information; data are not entered into the computer for control processing until after returning to the office. Therefore, time and spatial gaps exist between the plant and the office, which cause reduced efficiency in the data management by the engineering personnel and an increase in the number of data entry errors (Yin et al., 2009).

With the use of robotic handling devices, shutters can be freely positioned and allow casting free shaped and designed panels in concrete, and production of each kind of element as efficiently as required. The CAD data used for rapid precast concrete production by robotics is a strategic advantage for improving quality and staying competitive during uncertain market conditions. The physical environment of construction is often hostile to machines and people, so machine design must be sturdy and robust, accounting for extremes of weather, dust and unexpected forces (Joshi & Shah). According to a study that has been conducted regarding quality control of precast elements, the researcher could (1) illustrate systematically how dimensional and surface quality check for precast concrete elements can be implemented and how the inspection data can be stored and managed by combining building information modelling (BIM) and laser scanning technology, and (2) the identification of the applicability of the proposed approach through actual precast concrete element tests (Kim, Cheng, Sohn, & Chang, 2015).

The efficiency of precast production management can be improved using radio-frequency identification (RFID) technology (Yin et al., 2009). RFID technology can lead to high productivity gains: ninety-three percent for the operational activities (i.e., identification and locating). According to the simulation results, incorrect shipments and missing panels were eliminated by utilising RFID technology (Demiralp, Guven, & Ergen, 2012). Also, a significant reduction was observed by these authors in the accumulated duration of the activities related to the use of this technology, such as the identification of panel locations in the plant to avoid wasting time to search. Cost savings in the RFID cases were observed due to: (1) the reduced number of missing panels, and thus the reduced number of remanufactured panels; (2) the reduced number of incorrectly delivered or identified panels, and therefore, the decreased number of transfers; and (3) the reduced durations of some activities, resulting in decreased labour costs.

## 2.11. Importance of automation to the precast concrete plant, and its profitability improvement

Understanding the development of industrialisation and mechanisation of the concrete prefabrication industry could provide a useful lens on the history of development within this sector. The discussion will first focus on the CAD-CAM and building system requirements because they are essential for proper and successful automation. Beside forming tables, fixed forms, moulds and concrete mixing plants that have been widely used in most of Europe, significant advances in mechanisation were developed in the 1970s in Germany and Austria by inventing the first idea of pallet circulation plants (Neubauer, 2017b) – inventing one of the first flexible precast concrete construction systems to build housing (such as the Austrian company Mischek). It was necessary to produce concrete walls and floors efficiently 'just in time', against a background of higher construction demand and requirements for cheaper production. Flexible and mechanised shuttering systems and moving-table systems with curing chambers were developed for variant production of walls. There was almost no real automation until this moment, except that pallets were moved around by an electric control system connecting motors and sensors with concrete delivery, casting, demoulding and finishing work. The figure below shows a typical example of this type of work.

Figure2. 9: An early pallet circulation system for precast concrete wall panels

The early pallet circulation system for precast concrete wall panels is an innovative production method designed to increase efficiency in the manufacturing of precast concrete elements. This system was developed as a response to the growing demand for faster and more cost-effective construction methods, particularly in the context of large-scale building projects.

Figure2. 10: First shuttering machine within a pallet-rotation plant.

The first shuttering machine within a pallet-rotation plant is a significant technological advancement in the precast concrete industry, designed to automate and streamline the formwork process for precast elements. The integration of shuttering machines in pallet-rotation systems has greatly improved production efficiency, accuracy, and quality control in precast concrete manufacturing.

#### 2.11.1. **Automation Methods**

The following subchapters describe the possible automation methods in precast concrete factories. Some of these features have been in use for several decades, while others have been in use for only a short time. This automation might be combined according to the needs and possibility of respective prefabricated concrete products. The machines and automation cells based on the production of precast floors, and walls might also be applicable and meaningful for producing bar-shaped or volumetric concrete prefabricated elements.

Even at that time the first mechanisation steps were in use, such as a semi-automatic shuttering machine, to place the steel forms for up to two rectangular elements. This could be called the first shuttering robot. Uniform precast concrete elements used in eastern and central areas of Europe were growing more and more unpopular, partly because of low quality in terms of workmanship and durability. Several different companies from Austria and Germany and the Technical University of Vienna joined forces to develop the first flexible automatic concrete prefabrication plant in 1987. The concept was outstanding and was leading minds into the future. Several other methods were also being developing being in parallel. (Neubauer, 2017b)

Germany is a global machinery powerhouse; this technical ability, combined with Germany's housing needs after WWII, led to companies specialising in pre-casting machinery production. Most of the leading global suppliers of precast machinery – companies such as Vollert, Progress Group/EBAWE, or Weckenmann, come from Germany (Smicka, 2021).

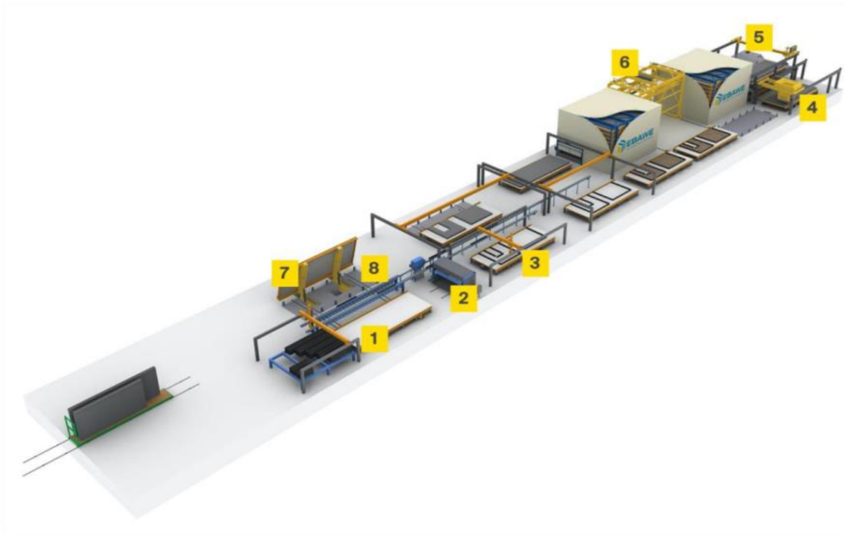



Figure2. 11: Automation system stages

The automation system for the production of wall panels, slabs, and other precast elements is relatively simple. As shown in fig 2.11, most of the work is done on a stainless-steel table (1) that moves through a carousel. The table (palette) is cleaned; shutters (Lego-like magnetic steel forms) are placed on the table and fixed to it with magnets either manually or by a robot arm (3). The form is then fitted with steel mesh to reinforce the concrete and other features such as pipes and various conduits. Concrete is then poured (manually or via a robot) into the forms. The prefinished panel is then compacted (by oscillation) and cured – depending on the climate – either in a curing chamber or in an open environment; smoothed for any imperfections (5 and 6) and tilted with a tilting table (7 and 8) so it can be manipulated. The finished panel is then transported into a storage yard or directly onto a truck and delivered to the site (Smicka, 2021).

Automated and robotic construction processes lead to a steady workflow throughout the year. Thus, the introduction of robotic technology should result in better working and health conditions, as well as advanced mechatronics know-how and skills (L Jaillon et al., 2009). The resulting reduction in construction time will improve the cost-benefit analysis of the projects, thanks to faster completion and better returns on investment.

#### 2.11.1.1. Flexible forms, tables, and formworks

The figure below shows stationary flexible forms and forming tables industrialising parts of the precast concrete prefabrication industry.

Figure2. 12: Old tilting table

The tilting tables and heatable steel tables, eventually equipped with a high-frequency compaction system and formwork mounted by magnets to produce high-quality solid walls and floors in a predictable daily output prefabrication plant. With use of the tilting system, the demoulding of walls becomes possible without damage to the edges and surfaces, and the ground steel surface offers a perfect surface on at least at one side of the concrete element.

#### 2.11.1.2. Long-bed production

Another form of automation is long-bed productions (Neubauer, mechanisation & structures, 2017). In this case, the automation machines must move over the long beds, the material and tools must be transported too, and workers must often change their workplaces. Some products more or less require this kind of production, such as pre-stressed precast products or hollow core floors, and for certain kinds of products, this system can be much more efficient than circulation plants. Suppose it is necessary and feasible to produce wall elements onto a kind of long bed structure, which could be practical, especially for small producers and in a start-up phase. In that case, a unique system can successfully be used. Tilting tables are aligned in lines, near each other, building a production line. A movable trolley (shuttle) runs under these tables, with the tilting device and a compaction device on board. When it is necessary to compact or tilt, the trolley moves up to a particular table and does the job. Thus, a lot of money is saved compared to tilting tables, by reusing the same device for all of the tables, and it is possible to use more or less all machines for plotting, cleaning, casting and trowelling, which are described later.

Usually, there would be four to fifteen steel-plated lines mounted on the floor in one production hall, with a length of 50 to 150 m. The ground long steel beds are usually equipped with two fixed side forms of the necessary height, between 60 and 125 mm, having a demoulding angle of 3–5 degrees. In the longways direction, the slabs are separated by steel or plastic cross shuttering, supporting bent or straight reinforcement bars, as shown in the figures below.

Figure2. 13: Floor production on the long bed with cross shuttering

Figure2. 14: pre-stressed floor production on the long bed with plotting device

To enable longer span or shallower elements, pre-stressing technology can be used instead of static reinforcement. This has been integrated quickly into long-bed production by simply having a suitable foundation, such as the stressing heads or anchorages and the pre-stressing equipment; for example, as shown in the figure below, Traditional cross shutters were slightly adapted or replaced by polystyrene shutters. It was also possible to mix pre-stressed and non-pre-stressed elements on different long bed lines within one production hall. Equipping these lines with automatic cleaning, plotting and cross shuttering machines, and automatic machines for pouring concrete and cutting the pre-stressing strands led this kind of precast concrete element production into the industrial and automatic production cycle stage.

Figure2. 15: Hollow core slab production (using extrusion method)

Lastly, it is necessary to mention the production of hollow-core slabs, the most widely known precast concrete element all over the world (Neubauer, mechanisation & structures, 2017). This is also produced on long beds, but due to the design requirement, the width of the production lines is usually 1.2 m, occasionally 2.4 m. Because of the use of dry-cast concrete, there is no need to have side forms, but pre-stressing equipment is an integral part of this production concept. Slip-formers were used in the early days of this technology, and extruders were invented in the 1980s to offer a more controlled casting process. Automatic cutting devices, plotters, and aspirator systems for voids and cut-outs automated this production system step by step. The following sections describe the automation tools for pallet and flooring production.

#### 2.11.1.3. Pallet circulation systems

Within a typical pallet circulation system (Neubauer, mechanisation & structures, 2017), the 'workpiece holders' bring the elements step-by-step to work places. The empty pallet usually starts with a cleaning process and continues to the formwork stations, followed by mounting parts, reinforcement, inspection, and casting stations. Curing will follow, and dependent on the complexity of the precast part, it might be re-sent into further production for the next steps. After the final curing step, the readymade element will be lifted off the form at a demoulding station and usually directly put into or onto a delivery cage or package. The steel-formwork will be removed, cleaned, and reused to produce the next element. In a plant like this, the work is automatically sent to the station where tools, work equipment and materials are available, and the workers do not have to move from station to station. If the plant is correctly designed, this method is the most efficient way to produce flexible wall and floor elements. Instead, this production method is seldom used for pre-stressed elements and volumetric pieces, but work reorganisation could still be advantageous.

Pallet circulation systems enable the optimum materials flow. Therefore, they play a central role in optimising production processes for cost-efficient precast concrete production. A pallet circulation system to produce diverse precast concrete parts is always planned individually as a flow production plant. The materials flow planning and the design of individual workstations depends on the precast concrete parts to be manufactured, for example, floor slabs, double walls, solid walls, sandwich walls, or façade elements. However, numerous particular components can also be manufactured efficiently in these circulation systems (Weckenmann, 2017).

An optimised manufacturing organisation is created by dividing the entire production process into individual work steps. Cost-efficiency is increased through production automation. This is done by mechanising individual workstations and equipping them with automation components. So, for example, pallet circulation systems are equipped with concrete spreaders, shuttering robots, and powerful reinforcement manufacturing facilities. As the formwork technology determines the quality of precast concrete parts, the shuttering profiles and shuttering pallets are treated continuously with pallet cleaners and pallet oilers. The shuttering profiles perfectly match the existing conditions and the system. In addition, the varied product range allows companies to equip their pallet circulation systems with the latest production and formwork technology and match these technologies with each other optimally. The pallet circulation system is moved to specially equipped buffer stations utilising a central transfer table to manufacture different production cycles. The central leading computer technologies allow the users to control and monitor the production process according to industry standards.

in order to industrialise and optimise the production of prefabricated concrete elements, the first precast concrete floor plant was designed in Germany. In this plant, the manual work stages could be done at certain fixed stations where all of the pallets were passed on one after another; that is, the work moves to the worker rather than vice versa. Tools, precast embedment (cast-in channels, sockets, boxes) and other necessary resources are located at the workstation where they are needed. In between the stations where some manual work takes place, a few automatic machines assure the quality and precision of the final product.

##### 2.11.1.4. Customisable production islands

A company that needs to produce a wide product range of precast concrete parts with different shuttering concepts can choose stationary production based on the principle of cell production. The individual types of formworks (stationary casting bed, tilting table, vibrating table, battery mould, mould for columns and beams, staircase formwork) are grouped. The materials flow of fresh concrete and reinforcement bars is planned accordingly. Although stationary production facilities have a lower output per hour than circulation systems, they allow more flexible production programmes (Weckenmann, 2017).

#### 2.11.2. **Current automated machinery in the precast concrete industry**

The primary task for industrialisation and a precondition for automation is the organisation of ‘workpieces’ into ‘workpiece holders’. The production of single elements will be grouped, and all primary and following tasks will be based on these working units. These could be tracked and supervised and lead to reliable just-in-time (JIT) production. This section briefly describes some of the automated machinery used in the precast concrete industry. The productive capacity of each piece of equipment is described.

##### 2.11.2.1. Concrete spreader

A concrete spreader provides significantly improved fully automated dosing of fresh concrete. The Gravimetric is a globally unique and patented concrete spreader that quickly and accurately fills various moulds with all kinds of concrete (Weckenmann, 2017). The concrete spreader can be operated on the crane and its integrated drive system. Depending on the requirements; gantry, half-gantry or bridge chassis systems are used. The working and travel speeds are infinitely adjustable to ensure quality and efficiency. The Gravimetric technology will also guarantee consistent flow control of all of the individual discharge elements of a concrete spreader. An automatically controlled concrete spreader will optimise production of prefabricated concrete parts. This allows the exact discharge of the concrete in the right amount, thus saving concrete (Weckenmann, 2017).

#### 2.11.2.2. Plotter and combination devices

The first machine to help the shuttering process on tables is a large plotting device. Depending on the size of the tables, the precision of the pallet-locking device and some other environmental factors, the precision of the plotting line is about ±2 mm. The plotter moves over the table and draws a picture of the following:

- element contour to be formed, including formwork marker, chamfer information and information about overlaying reinforcement.
- recesses within the element to be shuttered manually.
- position and symbols for precast mounting parts, to be mounted onto the pallet as well, if applicable elevated (solid walls)
- unique markers for reinforcement (position of lattice girders)
- other important information for the following manual work.

This device is used to transfer the outline of the concrete elements quickly and accurately to the formwork surface from the CAD data using a scale of 1:1. The outline data for precast concrete parts to position the shuttering profiles are created in the CAD system and transferred online or by using a data storage medium to the plotter or the combination device. To automate the production of precast concrete parts (in circulation systems, stationary casting beds or tables in different variants), companies will supply a range of accuracy systems that simultaneously eliminate any measurement errors (Weckenmann, 2017).

A shuttering robot can be used as an alternative for plants with diverse moulding requirements, such as solid walls or short cycle times. The shuttering robots are very versatile in their application and can, for example, automatically collect place and magazine bulkheads. Placing bulkheads with built-in magnets and fully automatic activation is also possible (Weckenmann, 2017).

#### 2.11.2.3. Shuttering cleaner and oiler

This equipment preserves clean mould faces, ensuring consistently good product quality. This is an essential prerequisite for all production programmes because soiling and dirt cause faulty products. Shuttering profiles and magnets must be constantly cleaned and sprayed with the correct concrete mould oils. This is the only way that permanent operational reliability and long service life are assured. The surface is cleaned with scrapers and electromotive brushes while a downstream spray oiler wets them with oil. A wide range of shuttering robots have been proving their worth since 1992 in more than a hundred precast concrete plants worldwide (Weckenmann, 2017). Precast concrete manufacturers worldwide have relied on accurate and versatile shuttering robots from industry in their automated production for many years.

Shuttering robot systems automatically carry out shuttering as per CAD specifications. Mounting parts of all kinds can be positioned at any time. The shuttering robots are integrated into the existing circulation control system. They can be retrofitted into existing precast concrete plants without difficulty (Weckenmann, 2017). Shuttering profiles are demoulded automatically from the formwork surface. The demoulding robot scans the formwork surface, disconnects the magnet connections of the shuttering profiles to be demoulded and places them on the formwork line that continues in the direction of the magazine or the shuttering robot.

Robots will soon be able to cut insert insulation material in wall production. Regarding exposed aggregate elements, a retarding lacquer robot system automatically applies the retarding lacquer by spraying it on.

#### 2.11.2.4. Positioning of mounting parts, support by laser projectors

Precisely placed and cast-in mounting parts are critical features of precast concrete elements. Mechanical connections between walls, floor, and an eventual necessary load-bearing structure; electrical connectors and mounting boxes with pipe works, plumbing and supporting sockets for transport and mounting are only a few of these. Mostly these specialised mounting parts are guided by position magnets, set by the robot, and the parts could be screwed on or snapped over. Of course, robots can set the mounting part directly, but the flexibility for different mounting parts will be limited by gripper and magazine and could be expensive if lots of pieces should be handled. High productivity requirements often lead to mounting part robots to enhance productivity.

#### 2.11.2.5. Reinforcement

Reinforcing the precast concrete elements is a critical task during the production process. It is necessary to meet many different requirements for reinforcement in different countries and their regulations. That is why many different machines and devices are needed to support this process.

It would be possible to buy reinforcement and reinforcement modules externally and include them in the supply chain management of production. Suppose a concrete prefabrication plant is optimised for Just in Time (JIT) production. In that case, this could be very difficult because the forecast will be challenging to control and might lead instead to inefficient production. Some plants still work with standard mesh, bent and cut into required forms within a local workshop. This is usually only the second choice for actual industrialisation of the prefabrication production.

#### 2.11.2.6. Batching concrete

Mixing concrete seems to be the most standard task for prefabricated concrete elements. It is usually not enough to work with standard concrete-like ready-mix plants to industrialise this process and receive high-quality concrete with the perfect surfaces.

Batching recipes for precast concrete often vary from those for ready-mix concrete. The available curing system usually depends on the required surface paired with the mould release agent, required fluid for automatic casting or extruding, and curing time, especially for semi-prefab and JIT delivery. Sometimes there are up to ten aggregates and chemicals to be combined to make a perfect precast concrete, and an experience operator is necessary to fulfil these requirements.

For this reason, automatic batching plants are used in all industrial precast concrete systems. Automatic weighing systems and the humidity measurement of aggregates is a 'must-have' within these plants. The mixing machine and the control system must be equipped differently, according to the needs of the different concretes to batch.

Again, these machines could be connected to a master computer system receiving the batching requests with the precise amount and order for a pallet or on a batch for a more considerable concrete lot. Usually, the flying bucket system transporting the concrete to the casting device will also be controlled by the batching control system and receive the required drop position from the master computer. In this way, the batching could be optimised according to JIT production, especially if a different type and strength of concrete is required.

#### 2.11.2.7. Concrete compaction

Two main leading technologies are used for the compaction of the concrete in the mould. High-frequency technology is used in the compaction of plasticised to stiff concrete and for larger slab and panel thicknesses or insulated elements. Use of this technology reduces the noise level to about 10 to 20 dB (A) – low-frequency technology produces high compaction energy at a reduced noise level for the user. So-called 'shaking technology' is used in low-frequency concrete compaction., The shuttering pallets are moved horizontally in a linear (X and Y) or circular motion with low frequency and high amplitude. The sound level remains below 70 dB (A), and the surfaces have very few pores. In addition, depending on which precast part is manufactured with which mass or dimensions, different compaction programs can be stored in and retrieved from the control system.

In addition to these two methods, the internal vibrator, if fixed high-frequency vibrators or low-frequency shaking technology is technically not possible, high-frequency internal vibrators are the method of choice. These are immersed mechanically or automatically into the concrete to compact it. This technology can also be used in combination with a concrete spreader.

#### 2.11.2.8. Pre-stressed products

In the manufacture of finished parts made from pre-stressed concrete, high-strength pre-stressing steel wires are introduced and pre-stressed. Precast concrete parts made from pre-stressed concrete are more rigid than reinforced concrete of the same structural height and, at the same time, need less steel at the same structural height.

The available equipment to produce top-quality pre-stressed concrete parts (Weckenmann, 2017):

- ‘rigidised’ formwork
- single and multi-stressing jacks
- machines for uncoiling and cutting the pre-stressing wire to length
- movable semi or fully automatic pre-stressing wire saws for cutting the finished concrete elements with electrically driven cut-off wheels
- stressing wire drums for transporting and laying out prefabricated pre-stressing wires
- abutment carriers and cross-perforated plates for pre-stressing beds
- strand placing manipulator cutting of pre-stressed wires and strands

To produce pre-stressed concrete elements, usually for pre-stressed floor slabs and beams, it is necessary to use metallic strands and pre-stressing bulkheads on either long beds or special pre-stressing pallets. The pre-stressing strands are inserted in specific, pre-calculated patterns into all elements on a long bed and tightened to a specific force before casting the concrete. After curing these elements, the pre-stressing strands must be cut at a particular position either precisely at the edge of a slab or with a precisely defined reinforcement overlap outside the slab to lift off the elements from the table. Because there are many steps in this process, the cutting has been automated with a system working on the base of long-bed production.

Before cutting, at least the cross shutters must be removed – in such plants, this is done automatically by another run of the cleaning plotting shuttering machine – before the strand-cutting device can do its job. Every time the strands are cut at any side of an element, all of the elements will move slightly in the lengthwise direction on the table because of the rest of the strengthening force in the wires. The cutting position must therefore be automatically scanned by suitable devices and recalculated every time. Following this calculation, the cutting is done, for example, by a CNC-4-axis circular sawing system. A perfect distance measuring system for long-range and optimised scanning technology for uneven concrete edges is crucial to this process.

Because this machine is able to operate self-controlled over the long bed with a high cutting speed, it will save a lot of manual work and lifting off the slabs can immediately follow the machine. This cutting is used only for pre-stressed semi-prefabricated floors and solid prefabricated floors up to 100mm depth but could be implemented in all shuttered production systems.

Another slab-cutting system has long been in use in hollow-core products, but this system is entirely different. There are no cross shutters with this product, and the whole extruded or formed slab with a fixed cross-section is cut by sawing machines according to the length requested by the production planning. There are only straight cuts; the rest must be done manually. At the cutting of pre-stressed floors, the slab's edges are formed by shutters, which may have different forms, including curved, and smaller cutters cut only the pre-stressing wires.

#### 2.11.2.9. Automation machinery and regular maintenance requirements

Regular inspections and maintenance create operating safety, save money, and contribute significantly to maintaining the operational readiness and efficiency of a precast concrete plant, keeping powerful machinery and equipment in good condition to produce top-quality products consistently over a long service life. The service technicians must be expertly trained in the technology of the equipment and machines. They must be able to perform all of the necessary inspection and maintenance tasks, instructions and repairs quickly and efficiently. In some cases, control and central computer systems can be maintained remotely. If necessary, some technicians will service a plant outside of the production times so that production schedules will not be interrupted (Weckenmann, 2017).

### 2.11.3. To what extent automation is possible/limited for different products

The possibilities for automation vary today, but it seems there is nothing that cannot be automated (Neubauer, 2017a; Smicka, 2021). Automation brings predictability to an industrial production process, although staff working in between automation cells can introduce some unpredictability (Neubauer, 2017a). As well as labour policy and industrial psychology arguments, some other issues sometimes limit automation in the precast concrete industry (Neubauer, 2017a).

The New Zealand construction sector comprises many micro, small and medium enterprises. In the past two years, twenty-eight percent of businesses have introduced automation to their business processes. The top three reasons for automating were to increase productivity (twenty percent of businesses), to reduce human error (seventeen percent), and to improve the quality of products and services (fourteen percent) (StatsNZ, 2020).

Researchers suggest some significant lists of systems that can be used for automation in precast concrete plants. This is helpful to this study, to show the availability of automation systems' (Neubauer, 2017b).

#### 2.11.3.1. Flat Slab

Flat slabs are easily mechanised in different factory types. They are made on long beds and pallet rotation plants according to productivity needs. Reinforcement is possible with automatic systems; reinforcement overlap must meet the shuttering system for automation, bridged girders are usual. But, if the floor slab is curved or too complex, manual work in the factory will be needed. Flat slab products are produced mainly on long bed plants because of the necessary pre-stressing equipment, but some can be made in pallet rotation plants. Formwork in the crosswise direction to the pre-stressing strands is difficult for automation, and it is necessary to limit the pre-stressing patterns, typically to between four and eight per unit depth. There are several automation methods for pre-stressed systems available.

#### 2.11.3.2. Hollowcore by slip-forming and extrusion techniques

Hollowcore is now the most widely used type of precast flooring; annual production in Europe is in the order of 30 million m2. representing 40 to 60% of the precast flooring market (Elliott & Jolly, 2013). This success is mainly due to efficient design and automated production methods, unit depth and capacity, surface finish, and structural efficiency (Elliott, 2017).

The production of floor slabs covers the full range of almost fully automated to entirely manual, depending on the type of units (Elliott, 2017). Slip-formed and extruded pre-stressed units (hollowcore), using a semi-dry mix, are eighty to ninety-five percent automated depending on investment and the preferences of manufacturers regarding manual production of specific tasks. It is equally possible for hollowcore to be wet cast into moulds, casting SCC around rectangular or circular polystyrene void formers (Elliott, 2017). There are two main proprietary types of production.

- Type A

As a case study, oval or non-circular voids are produced by the slip-forming technique shown in figure 2.16. Compaction is by vibration, often in two or three layers, and an external cable and winch pull the machine.

Figure2. 16: Oval voids hollow core machine with slip-forming technique

- Type B

Mainly circular or near-circular voids are produced by the extrusion technique shown in the picture below. Compaction is by pressing and vibrating the concrete behind the point of delivery, and the machine pushes itself forward from the rear thrust. The positions of the tendons, for both vertical cover and side cover to cores, is controlled by a set of guides.

Figure2. 17: Circular voids hollow core machine with extrusion technique

**Comparisons of slip-forming and extrusion techniques:**

In comparing the two techniques, slip-forming machines tend to be noisy (>85 dB) but have lower maintenance costs. One problem is that the slip-forming machine may move forward in jerks, leaving a rippled surface on the sides (and sometimes the tops) of the units, with the result is that the unit's width is 2 to 3 mm too large, causing problems in tight-fitting spaces. However, this profile may improve the horizontal diaphragm capacity of the floor slab. New investors in hollowcore machinery prefer the slip-forming process, although the extrusion process gives a better finish and is more dimensionally accurate. Problems occur with the wear of the augers due to contact with the coarse nature of dry mix concrete, particularly crushed gravel, resulting in changes in the cross-section. Logistical problems such as time-consuming bed changes from one height to another and the extent of maintenance and cost of replacement parts have led to the development of the new hydraulic extruders and electronically controlled extruders that have lowered operational costs through parts replacement and minimised downtime between end changes (Elliott, 2017).

#### 2.11.3.3. Solid precast walls

If the thickness requires multi-reinforcement layers, reinforcement preparation will not be completely automatic, or automation machinery will be cost-intensive. The shuttering system could be complex depending on the connection systems between the elements. Thus, the system and the different wall thicknesses must be standardised to enable efficient automation. In production, precast embedment will be challenging to mount, and if produced on tables, one side of the element must be smoothed.

Solid floors are more or less the same as solid walls; in comparison with pre-floor systems, all necessary pipe and electric installation must be done entirely in the prefabrication factory and is usually manual work within automatic machines.

#### 2.11.3.4. Stairs

No real automation is possible for these products, except that industrialisation with particular, flexible (adjustable waist, rise and going) forms are possible; and straight stair flights are sometimes produced on pallet rotation systems. The reinforcement cages can be pre-produced in automatic mesh welding plants.

#### 2.11.3.5. Beams and columns

Beams and columns are produced mainly in fixed forms, usually with pre-stressing equipment for most beams and columns. There have been some trials of mechanisation and automation, but they were not successful (Neubauer, 2017a).

#### 2.11.3.6. Volumetric elements

Complex prefabricated elements (3D-prefabrication) out of concrete are usually challenging to automate. Industrialisation can prepare reinforcement and the production in fixed forms, moving around a circulation plant. The fixed forms must be prepared manually from timber or metal and are usually reused several times with minor adaptations. If automation is requested, perfect prefabrication CAD data, including detailed reinforcement and layered information for concrete volume, is required.

#### 2.11.3.7. Double Tees

Factory-cast double tee units are primary components in buildings and car parks and have also been used as transverse slabs in some types of bridges. The top flange, typically 50 to 75 mm in thickness and reinforced with one sheet of steel mesh, distribute uniform structurally line and point loads to the structural webs that are typically 1.2 m apart (for a 2.4-m wide unit) and the mesh reinforcement is designed accordingly (Elliott, 2017).

#### 2.11.4. Design requirements to support automation

A professional design of a concrete building structure is essential for the industrialisation and automation of prefabricated concrete elements. First, it is necessary to use a professional CAD system equipped with precast concrete extensions. If the prefabrication engineer were to consider all requirements manually when drawing the elements in standard CAD software, the process would be very complex and subject to the likelihood of data errors which would hinder or stop the production later on. Thus, exceptional support for all necessary design requirements from the CAD software is essential. However, these design requirements sometimes conflict with the usual or certified construction methods in the target market. To be cost-effective, it is sometimes necessary to change some construction paradigms or adapt the forms and methods used, appropriate to efficient precast structures. Professional consultants could support the necessary steps, having experience in different markets (Neubauer, 2017b)**.**

#### 2.11.5. Resource requirements to support automation

Flexible automation in the concrete prefabrication industry is well developed in Europe because of the high labour costs, particularly in Scandinavia. Quality and precision demands for prefabricated concrete elements are sometimes very high, and professional staffs for concrete prefabrication are becoming rarer, which is why automation continues to develop to cover as many of the processes as possible. However, it is considered that full automation will never be possible, anywhere in the world (Neubauer, 2017b).

Given this situation, the employees continuing to be necessary can be grouped into two sectors. One includes a few highly skilled people to design, manage, maintain and supervise the industrial production, and to support the other group of staff who fulfil standard tasks with high speed, reliability, and using quality machines and processes. Manual production tasks support the quality and precision of the end-product. Industrial and automated plants must also have a skilled maintenance staff able to perform or organise all necessary mechanical and electrical maintenance work and support the elimination of faults and 'standstills' in the plant. This person must know how to communicate with the hotlines of a range of suppliers, search out mechanical and electrical errors, find reasons and perform remedies. All professional machinery and control systems provide hotline service, including remote access to the device to support the local staff. The ability to communicate in English by telephone, mail, or any other media will be a precondition for this role in the plant.

- Technical employees and their necessary skills

Industrial and automated factories must have a certain number of highly skilled employees, and their skills are sometimes exceptional. The plant management should consider experienced staff to work along other staff to teach them their knowledge. Drafters for industrial prefabrication construction: CAD technicians are not architects, but they must be construction engineers or draftsmen with the knowledge to consider many construction topics. The digital model of the building, constructed out of prefabricated concrete, will be generated in a CAD system, and this model must be error-free, or the factory will produce components with errors, resulting in costly repairs on site.

Even if a plant is very new, an industrial factory must have continual preventive maintenance. Automation is sometimes very technical and relies on this technique, and mechanical and electrical staff are vital to keep it running successfully for decades. Even in the hopefully rare cases of 'standstills', these staff members must be able to analyse the problem fast (supported by the MES system) and obtain remote assistance to resolve it.

A concrete prefabrication plant is only efficient and successful if the delivery transport and the erection logistics are perfect. Skilled staff members are required for the logistics office, to organise the information from the integrated IT solution. Ideally, these staff members coordinate the unpredictability of the construction site with the high IT predictability of prefabrication production.

- Integrated and automated prefabricated production process

It is not enough to have automatic machines and transport systems to support an optimised production process. Today's successful automated prefabricated production processes must be highly integrated into the planning, production and delivery of products, and the worker's information in the factory must be carefully considered. The more the objective is prefabricated production using just-in-time (JIT) production and delivery, the more it becomes necessary to have a coordinated flow of information and data in all directions. Every part of the plant must be provided with the just the necessary data to enable automatic production by machines or through manual decisions needing to be made by staff.

- Labour cost and automation

One factor that requires consideration at any automation project is the comparison of costs for automation with the cost of manual working staff. In Europe, the cost of manual work and all associated taxes are very high, so automation is in demand to reduce low skilled labour in prefabrication factories. In some other countries however, labour costs are so low that automation is not economical. Even in countries with low labour costs, however, some form of automation or mechanisation may be required because prefabricated concrete elements must meet specific quality requirements to be successfully placed on the market. Flat slabs are manufactured throughout Southeast Asia, but if they are manually produced with poor precision this highly effective, fast, and durable construction system could get a bad market reputation, leading to much more cast-in-situ construction, wasting all of the advantages of prefabricated construction. The labour cost of mounting the prefabricated elements on site must also be considered, considering cost savings due to faster preparation, better quality, independence from weather, and the possibility of using the production line earlier to start producing for the next project.

- Limits of automation

The possibilities of automation are various today, and it seems there is nothing that cannot be automated. Automation brings predictability to an industrial production process where staff working in between automation cells can introduce unpredictability. However, in addition to labour policy and industrial psychology arguments, some other issues limit automation in the precast concrete industry.

Permissions and authorisations – regulation may place limits on automation. Precast concrete plants, in the same way as construction systems, are usually regulated by the government or an organisation delegated by the government. If the construction regulations make automation difficult, the time needed to obtain the certification of the prefabricated variation to enable automated production in a particular plant must be considered. If it is slow and difficult to develop local construction rules, a 'back door' must be considered to produce the actual certified elements for the first period and change to more efficient methods after the certification is done.

### 2.11.6. Stepwise automation

It is not easy to modernise, industrialise and automate a precast concrete plant and a safe return on investment is needed. Consideration must be given to environmental conditions in the market. The following matters should be considered.

Depending upon the planned factory output, intelligent automation may be the best place to start, especially in countries where concrete prefabrication technology is not well known, and where – unlike in Europe and North America – labour costs are low.

Use of a plant layout, which could be easily extended and prepared, could ease the start-up phase if the necessary production volume is not too high. More uncomplicated automation to ensure high quality – plotting devices, high-quality pallets, concrete spreaders, batching plants, and minimum of MES – could be used. If after some years, the market share has grown, an extension would be possible.

If required productivity is high initially, however, the starting point could be to build a smaller plant and extend to a second separate plant, rather than to build one huge prefabrication factory. Huge plants are sometimes complex to operate because broad experience, professionalism and IT equipment are needed in order to manage all of the issues, including supply chain management, delivery transport and mounting. Sometimes very large prefabrication plants fail to gain the designed output capacity quickly, and the return on investment is delayed because of the environmental conditions of the local construction market. Such factories may also reach technical and output acceptance but the return on investment (ROI) is delayed because of over-dimensioning or over-automation.

### 2.11.7. Optimised automation

According to (Elliott, 2017), automation optimisation depends on a range of factors, including the balance between labour costs and machinery, the availability of skilled labour to operate computerised equipment or to perform skilled tasks manually, the availability of space in four dimensions of volume and time, and the means to install automated plant with good access for the supply of materials; quality control of components and the production methods, planned sales forecasts for the mass production of critical components in large volume projects, the changing ethos for off-site fabrication and the balance between time-cost-quality ratios; and a set of functions that can be developed for any or all of the previous points.

#### 2.11.8. **Summary and outlook**

Worldwide, the costs of and the demand for labour are increasing, and the market will move inevitably towards automation – in some places very slowly, but in others very fast.

Automation in the construction industry can improve market attractiveness, plant utilisation, production processes, labour cost, profitability, and gross profit margins. Existing factories with mainly manual operations can adapt to automation and its changing parameters. Automation can be readily installed in stages to enhance or complement existing operations, without relying on complete automation. Mechanisation, industrialisation, and automation are vital features of the precast concrete industry. For the automation of this industry, it is not enough simply to have many automatic machines. A suitable IT solution is needed, to run an industrialised high technology production plant with highly motivated and skilled staff, in order to achieve industrialised production and delivery. Moreover, innovative management and sales skills are needed to identify the market, so as to make optimal use of such a plant. Software for integration will be developing rapidly, considering the production process, and integrating real estate planning, construction, planning, BIM, production and delivery. Machinery will develop to incorporate new prefabricated construction methods.

## 2.12. Profitability improvement (method and selection)

### 2.12.1. Introduction

As discussed earlier, profitability is the overriding goal for the success and growth of any business, and it can be defined as the ratio between revenue and cost (Tangen, 2005). Earning a profit is considered essential for the survival of the business. Profitability analysis measures how well a firm will perform, in order to generate profits. The firm's profitability is highly influenced by internal and external variables, such as the size and growth of the organisation, liquidity management, and a component of the costs and inflation rate (Pradhan & Das, 2016).

At the company level, improving productivity is fundamental to the survival of firms because it means that they can meet their obligations to workers, shareholders, and governments while remaining viable in the market (Tran & Tookey, 2011). Companies must produce more for each dollar spent on the plant to remain profitable. Productivity growth is strongly correlated to economic growth and increases in welfare (Tran & Tookey, 2011). Productivity is one of the most crucial and frequently cited resource performance indicators that can be used to assess the success of a plant.

The sections below demonstrate several improvement methods and discuss the reasons why the researcher selected them for this study.

### 2.12.2. Profitability improvement methods

Using cost as the denominator in the efficiency measure of profitability, both dimensions of effectiveness and efficiency can be combined to represent profitability. Profitability is an indicator of productivity, which targets maximising the extent of achievement of the set objectives while minimising the unique resources employed in the process (Durdyev & Mbachu, 2011). This perspective has given rise to several buzzwords such as 'lean production' (which targets waste reduction as a means of optimising the use of resources), 'Total Quality Management' (TQM – which targets achieving value through a total re-engineering of the production process rather than ad-hoc quality assurance measures), 'Automation Adoption' (which targets reducing labour costs and non-profitable processes, removing human errors, increasing market attractiveness and improving resource utilisation), and value management (which targets maximising utility output, while minimising the resources expended in the process).

#### 2.12.3. Investment assessment and method selection

Adoption of automation requires considerable capital investment and at the same time the value of the firm must be increased for the benefit of the shareholders. It is essential to determine whether an organisation's long-term investments such as new machinery, replacement of machinery, new plants, new products, and research development projects are worth the funding of cash through the firm's capitalisation structure (debt, equity or retained earnings) (Mona, 2016; Sheffrin, 2003). Research toward a successful automation system is essential to identify and understand the nature of uncertainty surrounding the critical project variables and, on the other hand, having the tools and methodology to process the risk implications of the project.

## 2.13. Multi-Criteria Decision Methods

The Multi-Criteria Decision-making Method (MCDM) was introduced in the early 1970s and has become the fastest-growing method in many different applications to structure information and evaluate everyday problems with multiple, conflicting, and non-commensurable goals (Malik, Yusof, & Na'im Ku Khalif, 2021). The technique is a well-known tool for solving complex real-life problems due to its intrinsic ability to judge diverse alternatives regarding various decision criteria.

The MCDM method helps with the choice among various criteria by analysing the scope of the criteria, weighting them, and choosing the optimal results using multi-criteria decision-making techniques (Dalalah, Al-Oqla, Hayajneh, & Engineering, 2010; Darko et al., 2019).

The literature review has examined scholarly literature pertaining to decision analysis. To identify those articles that would provide the most valuable information, a search was conducted for standard MCDM methods in the title, abstract, and keywords utilising the following databases: Elsevier, Springer, ScienceDirect, and IEEExplore. These included journal articles and conference proceedings concentrating mainly on operations research and management science. These were narrowed down to articles that focused on applying popular MCDM approaches. Each paper was grouped by its MCDM technique and reviewed thoroughly. The following six MCDM methods were identified throughout the review: 1) WSM, 2) MAUT, 3) AHP, 4) Fuzzy Set Theory, 5) PROMETHEE, and 6) TOPSIS. These MCDM methods are frequently used to facilitate the resolution of real-world decision-making problems.

The following table addresses the different MCDM methods with their advantages and disadvantages and situations where they may be best applied.

Table2. 4: Different MCDM methods with their advantages and disadvantages

| Method | Proposed By / Date | Advantages | Disadvantages | Areas of Application | Ref |
|---|---|---|---|---|---|
| WSM | L. A. Zadeh: 1963 | - Very simple computation process<br>- Suitable for managing single-dimension problems | - There is no possibility of integrating multiple preferences<br>- Evaluates only one dimension | - Selection of Sustainable Energy Source | (Marler & Arora, 2010; Misra & Ray, 2012; Saraswat, Digalwar, & Yadav, 2021; R. Wang, Zhou, Ishibuchi, Liao, & Zhang, 2016; Wimmler, Hejazi, Fernandes, Moreira, & Connors, 2015) |
| TOPSIS | S. Opricovic: 1990 | - Works with a fundamental ranking<br>- The method ultimately uses allocated information<br>- The information need not be independent<br>- The method has a rational and understandable logic, and the concept is in a relatively simple mathematical form<br>- The computation process is quite simple compared with other methods<br>- Results are obtained quite quickly compared to other methods | - In principle, the method works based on Euclidean distance, and negative and positive values do not influence calculations<br>- A substantial deviation of one indicator from the ideal solution strongly influences the results<br>- The method is suitable when the indicators of alternatives do not vary very strongly | Selection of Sustainable Energy Source | (Boran, Genç, Kurt, & Akay, 2009; Jato-Espino, Castillo-Lopez, Rodriguez-Hernandez, & Canteras-Jordana, 2014; Parveen & Kamble, 2021; Saraswat et al., 2021; Siksnelyte, Zavadskas, Streimikiene, & Sharma, 2018) |
| PROMETHEE | J. P. Brans and P. Vicke: 1982 | - The method is beneficial when there are alternatives that are difficult to harmonise<br>- The method works with qualitative and quantitative information<br>- Uncertain and fuzzy information can be incorporated into calculations | - The computation process is quite long compared with other methods<br>- Calculations are very complicated; therefore, the method is only suitable for experts | - Selection of Sustainable Energy Source<br>- | (Alinezhad & Khalili, 2019; Amaral & Costa, 2014; A. Kumar et al., 2017; Meyer, 2009; Saraswat et al., 2021; Siksnelyte et al., 2018; M. Wang, Lin, & Lo, 2010) |

| | | | | | |
|---|---|---|---|---|---|
| MAUT | - P.C. Fishburn: 1965, R.L.<br>- Keeney: 1969<br>- H.R. Raiffa: 1969 | - Takes uncertainty into account<br>- Can incorporate preferences | - Needs a lot of input<br>- Preferences need to be precise (subjective) | - Economics<br>- Finance<br>- Actuarial<br>- Water management,<br>- Energy management<br>- Agriculture | (Saraswat et al., 2021) |
| AHP | Thomas Saaty: 1970 | - Easy to use;<br>- Hierarchy structure can easily adjust to fit many sized problems<br>- not data-intensive<br>- The computation process is quite simple compared with other methods<br>- The method has a comprehensible logic<br>- The method is based on a hierarchical structure; therefore, it has a strong focus on each criterion used in the calculations<br>- Flexible, Easy to use, Stand Alone Method, | - Problems due to the interdependence between criteria and alternatives; can lead to inconsistencies between judgement and ranking criteria; rank reversal.<br>- The more decision-makers that are involved, the more complex the assigning weights are<br>- Requires data collected based on experience | - Performance-type problems<br>- Resource management<br>- Corporate policy and strategy<br>- Public policy<br>- Political strategy<br>- Planning<br>- Selection of Sustainable Energy Source<br>- Construction Management | (Darko et al., 2019; Ishizaka & Labib, 2009; Kaya, Çolak, & Terzi, 2018; A. Kumar et al., 2017; T. L. J. J. o. s. s. Saaty & engineering, 2004; Saraswat et al., 2021; Shahroodi, Keramatpanah, Amini, & Sayyad Haghighi, 2012; Siksnelyte et al., 2018) |
| Fuzzy Set Theory | - | - Qualitative analysis can be expressed in a quantitative form; systematic analysis method; require less quantitative data information. | - Evaluation result is based mainly on expert judgement;<br>- determining eigenvalues and eigenvectors accurately is complicated;<br>- heavy workload of data statistics with numerous indicators,<br>- hard to process weight calculation. | - Risk assessment of deep excavation | (Atanassov, 1999; Bao & Huang, 2008; Cho, Choi, Kim, & Safety, 2002; Lin, Shen, Zhou, & Xu, 2021) |

The WSM method could be used for managing simple, single-dimension problems. Usually, there are many contradictory aspects when determining which precast concrete plant's production line could be suitable for adoption of automation. Therefore, the WSM method is not recommended for this type of research. The TOPSIS method has a rational and understandable logic, the concept is in a relatively simple mathematical form, the computation process is straightforward, and results are obtained quickly. However, the method is only suitable when indicators of alternatives do not vary enormously because a substantial deviation of one indicator from the ideal solution strongly influences the final results. The success of the PROMETHEE method comes from its mathematical features and usefulness in solving uncertain and fuzzy information problems. The method is very complicated, and the computation process is very long. The analytic hierarchy process (AHP) has increased tension in the construction management (CM) domain to analyse complex situations and make sound decisions. It was also revealed that AHP is flexible and can be used as a stand-alone tool or in conjunction with other tools to resolve construction decision-making problems. In addition, the most prominent justifications for using AHP were found to be small sample size, high level of consistency, simplicity, and availability of user-friendly software.

The (Saaty, 1988) AHP represents a popular MCDM method that has attracted considerable attention throughout industry, including construction, over the past two decades. Construction decision-making problems, in particular, have been characterised as being complex, ill-defined and uncertain (Chan, Chan, Yeung, & management, 2009). Al-Harbi (Al-Harbi, 2001) further suggests that the elements of construction-related decision-making problems are numerous and that the interrelationships between these elements are complicated and often nonlinear. Consequently, the ability to make sound decisions is crucial to the success of construction activities and operations. AHP provides a powerful means of making strategic and sound construction decisions (Jato-Espino et al., 2014); it breaks the problem in the hierarchical network tree and then solves it (Haddad, Liazid, & Ferreira, 2017; Saraswat et al., 2021); it allows decision-makers to employ multiple criteria quantitatively to evaluate potential alternatives and then select the optimal option. Because of AHP's inherent ability to deal with various types of decisions, it has been applied widely in construction management (CM) research over the past two decades (Akadiri, Olomolaiye, & Chinyio, 2013; E. H. Chan, Suen, Chan, & management, 2006; Nassar & AbouRizk, 2014; Ruiz, Romero, Pérez, & Fernández, 2012; Zou, Li, & Economics, 2010).

AHP was created by T. Saaty (Saaty, 1980) to deal with decision-making problems in complex and multi-criteria situations (Dyer & Forman, 1992; Saaty, 1990). The decision-maker assigns relative weights to each criterion and evaluates alternatives based on these weights (Saaty, 1980). This research is not, however, concerned with explaining specific details about the method, but rather with its basic concepts. AHP assists in decision-making characterised by several interrelated and often competing criteria. It establishes priorities amongst decision criteria when set within the context of the decision goal (Shapira, Goldenberg, & management, 2005). By applying these MCDM techniques, organisations can systematically assess and prioritize different automation options, considering various factors such as cost, potential benefits, risks, and implementation complexity.

### 2.14. **Benchmarking studies**

Benchmarking is a systematic process of comparing an organisation's performance with industry standards, best practices, or the performance of similar organisations, specifically targeting profitability attributes (Dattakumar & Jagadeesh, 2003; Talib et al., 2011). By conducting benchmarking studies focused on profitability factors, companies can gain insights into the potential financial benefits and challenges associated with their business strategies, identify areas for improvement, and learn from the experiences of others in the industry (Elmuti & Kathawala, 1997; Maire et al., 2012). This can help precast concrete plant operators develop more informed strategies to enhance profitability, set realistic targets, and avoid potential pitfalls related to cost management, pricing, and operational efficiency. Benchmarking can be performed through various methods, including internal benchmarking, competitive benchmarking, functional benchmarking, and generic benchmarking (Kumar & Chandra, 2006; Singh et al., 2016; Watson, 2007).

## 2.15. Research Gap

The literature review has revealed several research gaps in the field of precast concrete industry, particularly in the New Zealand context. Firstly, there is a lack of decision support tools specifically tailored to the precast concrete industry in New Zealand. This is crucial for guiding the effective adoption and optimisation of automation systems in the industry, given the numerous challenges such as increasing building consents, construction output, wages, labor costs, and housing index.

Another identified research gap is the limited empirical studies on the impact of automation adoption on profitability in precast concrete plants, both nationally and globally. Although automation adoption has been investigated in other industries, such as manufacturing and healthcare, further research is needed to focus specifically on the precast concrete industry.

Additionally, there is a research gap concerning pre-screening attributes that should be considered before adopting automation technologies in precast concrete plants. While some literature is available on pre-screening attributes in other industries, research specifically focused on the precast concrete industry is required to identify the most relevant and essential attributes to consider.

Moreover, the relationship between productivity factors and the profitability of precast concrete plants has not been thoroughly explored in the existing literature. This gap signifies the need for a comprehensive investigation into factors influencing the profitability of precast concrete plants.

Overall, the identified research gaps emphasize the necessity for further research in the precast concrete industry, particularly within the New Zealand context. Addressing these gaps will contribute to the body of knowledge in the field, provide valuable insights for precast concrete organisations seeking to enhance their competitiveness and profitability through automation, and offer relevant and practical guidance for industry stakeholders.

## 2.16. Summary

Based on the literature review, building consents, construction output, minimum wages, average hourly wages in manufacturing, labour cost and the housing index trends in New Zealand are all increasing. As a result, a modern and sustainable construction technology, the prefabricated method, is required to replace the conventional cast-in-situ concrete construction. However, this industry has some other challenges too, such as low profitability, high level of company closures and bankruptcies and a shortage of skilled workers.

There is a general lack of information and knowledge within the New Zealand construction industry about prefabricated and automated construction. Automation adoption in this industry has the potential to increase productivity, labour efficiency, reduce non-profitable processes and to improve the quality of the precast concrete elements. Furthermore, 'just-in-time' (JIT) production, which improves the market attractiveness, will be possible with some automation and industrialisation. A step-by-step automation adoption approach is often a better idea and will finally lead to greater acceptance, satisfaction, and better further development for the end products.

Although the literature review shows that much attention has been paid to identifying factors affecting the productivity of the construction industry, there was no factor measuring their relation to the profitability of precast concrete plants. There is currently no study or guide for automation adoption and optimisation systems in the precast concrete plant organisations in New Zealand or worldwide.

# 3. Research Methodology

## 3.1. Introduction

This chapter discusses the various research methods utilized in the current study, the reasons for selecting these methods, and their various stages. The study adopts an applied, exploratory, and explanatory approach, combining qualitative and quantitative methods to address the research problem of optimizing automation adoption processes in the precast concrete industry. This chapter presents an overview of the research methods, the main research problem, the steps used to frame this problem, and the framework for the study's methodology. The following chapter will present a real-life case study to better illustrate the methodology used in the study.

## 3.2. Research Methods

According to Creswell (2013), there are three main categories of research methods used in observational studies: qualitative or exploratory, quantitative, and mixed methods (a hybrid of qualitative and quantitative methods). Mixed-methods research combines the strengths of qualitative and quantitative approaches to provide robust findings to answer the selected research questions and objectives (Aramo-Immonen, 2013; O'Cathain et al., 2007; Schoonenboom & Johnson, 2017; Wisdom et al., 2013).

The current study employs a mixed-method approach, incorporating a case study supported by empirical data-gathering, interviews, and a literature review. The qualitative phase includes a literature review, interviews with ten SMEs from the case study organisation, and direct observations within the precast plant to understand the actual process and operations flow of production lines. The quantitative phase consists of close-ended questionnaires, such as pairwise comparison and direct rating questionnaires, administered to forty-six SMEs from the Auckland precast concrete industry to validate the decision support tool (Framework) and rate the importance of the attributes on automation decision selection.

### 3.2.1. Qualitative Data Collection and Analysis

The qualitative data collection in this study includes interviews, and direct observations. Interviews with SMEs from the case study organisation aim to identify profitability challenges. Direct observations within the precast plant are structured to understand the actual process and operations flow of production lines. The qualitative analysis addresses research objectives RO1, RO2, and RO3.

Qualitative data analysis involves transcribing interviews, coding the data, and identifying emerging themes. Thematic analysis is conducted to interpret the data and draw conclusions based on the research objectives.

### 3.2.2. Quantitative Data Collection and Analysis

The quantitative data collection in this study includes close-ended questionnaires, such as pairwise comparison and direct rating questionnaires, administered to forty-six SMEs from the Auckland precast concrete industry. This data collection aims to validate the decision support tool and rate the importance of the attributes on automation decision selection. The quantitative research method addresses research objectives RO4 and RO5.

Quantitative data analysis involves descriptive and inferential statistics. Descriptive statistics summarize the main features of the collected data, while inferential statistics allow for generalisations to be made about the population based on the sample data.

### 3.2.3. Reliability and Validity

To ensure the reliability and validity of the study, several strategies are employed, including triangulation of data sources, pilot study, and the use of multiple data collection methods. Triangulation of data sources involves cross-validating findings by comparing results from different data sources (Creswell & Miller, 2000). Pilot study involves providing participants with the opportunity to review and confirm the accuracy of the data collection (Creswell & Poth, 2018). The use of multiple data collection methods enhances the robustness of the study and ensures the findings are reliable and valid (Morse, 2015 & Creswell, 2018).

### 3.2.4. Summary

This chapter has presented an overview of the research methods and the rationale behind their selection for the current study. The mixed-method approach, incorporating qualitative and quantitative methods, is employed to address the research problem of optimizing automation adoption processes in the precast concrete industry. The qualitative data collection involves interviews, direct observations, and a literature review, while the quantitative data collection includes close-ended questionnaires. Data analysis procedures are outlined for both qualitative and quantitative data. Strategies to ensure the reliability and validity of the study are also discussed, such as triangulation of data sources, participant checking, and the use of multiple data collection methods. This comprehensive research design aims to provide a solid foundation for the study and generate robust findings to address the research objectives. The interrelationship between all the research questions, objectives and methods is summarised in chapter 1, table 1.1.

## 3.3. Data collection method

This thesis used six different data collection methods to answer all of the research questions and objectives, as demonstrated in Table 1:1. The use of multiple source data collection techniques is essential to ensure data reliability, to strengthen the credibility of results findings and provide a meaningful interpretation of data in data analysis (Flick, 2013; Merriam, 1998; Shanks & Bekmamedova, 2018). These data collection techniques were selected to match the practical research questions in this thesis (Ferguson & Kazdin, 2016). All of the data collection methods are discussed as follows.

### 3.3.1. Literature Review method

The literature review involves identifying the problem, searching the existing literature, evaluating the data extracted, analysing the data, and presenting the data in a unique format that contributes to a new understanding of the topic under consideration (Cooper, 1998; Oxman, 1994; Torraco, 2005; Whittemore & Knafl, 2005). The literature review was conducted in this thesis to address RO1 and RO2. RO1 used the literature review to establish the current challenges associated with the profitability of precast construction plants with an operational base in NZ. Accordingly, RO2 adopted a literature review as a method of data collection to identify the potential for automated systems (automation) within precast construction plants. The existing literature data were extracted by searching keywords through educational databases such as

Scopus, Google Scholar and Web of Science. The findings from the literature review were used to present the current challenges of the precast concrete plants, the required information to measure profitability attributes and to illustrate the available automation systems in the industry.

### 3.3.2. Interview technique for data collection

The rationale behind using the interview technique was to collate information about the case study organisation. A selective and purposive sampling method (H. R. Bernard, 2011) was used to select a group of staff willing to grant approximately one hour of their time for a semi-structured interview. Table 3.3 summarises the participants from ten SMEs within the case study organisation. All of the interviewees were asked the question, What are the challenges of New Zealand's precast concrete plants generally, and your current company's challenges?

A subject matter expert (SME) is an individual who has sufficient skills, knowledge, and experience for a particular field (Hopkins & Unger, 2017; Kelly, 1995). The SMEs are utilised to provide unique and insightful details on a subject matter under consideration based on their qualities such as technical expertise within the area of investigation, recognised competence, availability to contribute, independence, and level of confidence that they have a genuine understanding of the subject under investigation (Lavin, Dreyfus, Slepski, & Kasper, 2007; Marshall, 1996). The SME's contributions could be centred on years of industrial experience or formal education gained over several years (Lavin et al., 2007). One of the primary criteria for selecting the SMEs was that each must have worked at least ten years in the precast construction industry and actively participated in the precast concrete plant's work. The willingness of the intended participants and their confidence level in responding to interview questions were fully considered (Marshall, 1996). The SMEs were approached individually, and a convenient date and time for interview were scheduled upon their acceptance.

According to Creswell and Poth (2018), the ideal number of interview participants varies between five and thirty participants for these two main reasons, (i) their level of knowledge of the research problem under investigation and (ii) the semantic saturation points of the interview emerging themes. Umar and Egbu (2018) consider that six interview participants are adequate for a qualitative study, provided the participants provide useful information about the subject area. The SME was selected as the most appropriate data collection method as it provides unrestricted opportunities for the participants to make contributions based on their experience. The subject matter experts were selected using purposeful sampling techniques, as these allow the selection of individuals with extensive knowledge of the subject matter to offer meaningful and insightful details (Babbie, 2013; J. A. Maxwell, 2013; Neuman, 2014). All of the SMEs who participated are in top positions in the case study organisation. The selected SMEs are the most suitable individuals to contribute toward establishing the current challenges associated with the profitability of precast construction plants.

Table3. 3: Interviews with the subject matter experts (SMEs) from the case study

| # | Years of Experience | # | Years of Experience |
|---|---|---|---|
| Interviewee 1 | 30 | Interviewee 6 | 20 |
| Interviewee 2 | 20 | Interviewee 7 | 10 |
| Interviewee 3 | 15 | Interviewee 8 | 11 |
| Interviewee 4 | 15 | Interviewee 9 | 10 |
| Interviewee 5 | 20 | Interviewee 10 | 30 |
| Average years of experience | | | **18.1** |

Based on the precast concrete plant principles, the interviewees provided detailed discussions to address RO1 under research question one in this thesis.

### 3.3.3. Direct Observation technique for data collection

Based on table 2.4 and section 3.4.5 of this study,  identifying and measuring waste and value-added activities are integral to the manufacturing process. This is because often, businesses have become so accustomed to waste that it is not recognised. The value stream mapping method (VSM) is the primary analytical starting point to break down the work process into detailed steps. Therefore, seven on-site direct observations were conducted along with the mould leaders of all seven products, to identify and measure each production line's waste and value-added activities. As a result of the VSM analysis, a better understanding of the whole process was achieved.

The observations also aimed to address 'art of RO1 (Factors affecting profitability) and RO4 (The percentage of wasted time for each production line). For this thesis. Visualising non-visible works, such as information exchanges, is essential in understanding how work is accomplished (Li, 2015). Therefore, VSM helped to discover any potential information problems not easily identified within the production system.

### 3.3.4. Closed-ended questionnaire technique for data collection

A closed-ended question is a pre-determined quantitative data collection method that allows the questionnaire participants to select an answer from a defined number of response options (Colosi, 2006; Lavrakas, 2008). This structured data collection technique promotes consistency among the questionnaire respondents, since it allows the selection of answers from only a pre-selected set of options (Colosi, 2006). Closed-ended questionnaire techniques are mostly used where there is a need to quantify data, categorise respondents, and conduct large-scale data collection and analysis (Dillman, Smyth, & Christian, 2014). The pre-defined options presented to the questionnaire respondents must be carefully selected to address the primary purpose of the research question; options must not be similar in conceptual meaning and should be easy to understand (Gouldthorpe & Israel, 2014). The data collected through a closed-ended questionnaire are usually analysed using a range of different statistical techniques (Wang, Hong, & Hsu, 2006). The closed-ended questions are carefully designed and specifically constructed, and each question is worded such that the questionnaire is self-explanatory, including all of the specific response options (Boynton & Greenhalgh, 2004; Wang et al., 2006).

The rationale behind using the questionnaire technique Is that it is a cost-effective approach to gathering a large amount of data, and the data obtained can be quantified (Bird, 2009; Bulmer, 2004; Krause, 2002; McGuirk & ''Neill, 2016). A pairwise questionnaire was presented to the participants to rank the pre-screening attributes based on the decision support tool. A yes/no questionnaire was administered to the same group of participants to validate the decision support tool. The closed-ended questionnaires were constructed to give clarity for easy participation. A purposeful sampling technique was adopted in selecting participants for this study, based on their knowledge of precast concrete plants. This method allows participants with the greatest knowledge of the research focus to be selected (Maxwell, 2013).

A total of forty-six participants were chosen across Auckland, comprising production managers (7%), operational managers (7%), quantity surveyors (13%), contract managers (7%), project managers (24%), senior draftsmen (7%), general manager (3%), estimator (11%), production engineers (20%), and project coordinators (4%). The electronic version of the open-ended questionnaires was distributed and answered during the COVID-19 pandemic, to maintain appropriate physical distance.

For this thesis, the closed-ended questionnaire validated the validation questions for the decision support tool (by using the direct rating method of analysis), rated the importance of attributes on the automation decision support tool (by using the AHP method of analysis), and addressed the minimum requirement for attributes in the NZ market to maximise profitability (by using the direct rating method of analysis) in RO3.

#### 3.3.4.1. Pilot Study on Closed- ended Questionnaires

Before administering the main survey, a pilot study was conducted to assess the clarity, reliability, and validity of the questionnaire (Van Teijlingen & Hundley, 2001). The pilot study also aimed to identify any potential issues or improvements that could be made to the survey before distribution to the target population (Creswell & Creswell, 2017).

- Participants

A total of seven participants were chosen from a precast concrete plant in Auckland. These participants represented a diverse range of professionals within the precast concrete plants, ensuring that the pilot study participants were representative of the population of interest (Teddlie & Yu, 2007).

- Procedure

Participants were asked to complete the questionnaire and provide feedback on any unclear or confusing questions, as well as any technical difficulties they encountered during the completion process (Litwin, 2013). The pilot study was conducted over a period of one week.

- Data Modifications

Following the completion of the pilot study, the participant'' responses and feedback were thoroughly analysed. Based on the participant'' feedback and the reliability analysis, several modifications were made to the questionnaire (Dörnyei, 2003):

Ambiguous or unclear questions were rephrased for better clarity and understanding. For example, in Question 1, participants found the term "too low”" vague, so the question was revised to include specific thresholds or percentages to define “"too low”" more clearly (Sarantakos, 2012).

The order of some questions was rearranged to improve the logical flow and coherence of the questionnaire. For instance, Question 2, which asked participants to rate the importance of various criteria, was moved to follow Question 1, which addressed the implementation of automation systems in a precast concrete plant. This reordering allowed participants to consider the criteria in the context of automation adoption more coherently (Sarantakos, 2012).

The response options for some questions were refined to provide more appropriate choices and reduce the likelihood of response bias. In Question 3, participants were asked to provide percentage values for various factors influencing profitability. Based on the pilot study feedback, an additional option, “Not applicable” or “Don’t know”" was included to accommodate participants who might not have specific percentage values in mind (Dillman, Smyth, & Christian, 2014).

These modifications aimed to improve the quality, reliability, and validity of the questionnaire, ensuring that the survey would effectively capture the desired information from the main target population (Creswell & Creswell, 2017).

- Conclusion

The pilot study was an essential step in the development and refinement of the closed-ended questionnaire, enabling the identification and resolution of potential issues before the main survey distribution (Van Teijlingen & Hundley, 2001). By conducting the pilot study, the questionnaire was optimized, providing a solid foundation for collecting accurate, reliable, and valid data from the target population in the subsequent main study (Creswell & Creswell, 2017).

### 3.3.5. **Archival data collection method**

Archival analysis is a quantitative research method that collects data from files, documents, records and other sources relating to organisations' activities to give insightful output within assessed databases (Ventresca & Mohr, 2017). According to (Moers, 2006), archival data is data for which the original purpose for gathering it was not academic research. In addition, (Lewis-Beck, Bryman, & Liao, 2003) describe archival research as a method to collect, evaluate, interpret and analyse sources found in archives, for purposes other than those for which they were initially collected. This analysis technique is time-consuming but cost-efficient and reliable while providing a useful source of data collection that is manageable practically (Bowen Glenn, 2009; Caulley, 1983; Wesley, 2010). Motubatse and Chauke (Motubatse & Chauke, 2020) state that the advantage of archival research is its low sampling requirement and potential for easy replication. This study used the daily reports published by the case study organisation. The 'production statement data' and 'financial statement data' from the organisation were identified as archival data, and historical data from 2010 to 2017 were extracted from the production and financial departments.

The researchers collected all raw data into a secure database, password-protected for privacy reasons. Microsoft Excel was used to examine and measure the relationship between variables and raw data, with the aim of filtering redundant data and irrelevant attributes. The extracted data were carefully analysed to elicit meaning and explanatory constructs. Accordingly, the archival data collection method was chosen to address RO4 by collecting the data and analysing the profitability of the products in the case study.

### 3.3.6. **Why the case study?**

There are several reasons why case study research was applied in this research. First, several authors (Creswell & Poth, 2016; Yin, 2018) argue that the choice of research approach depends largely on the defined research questions. 'How' and 'what', particularly, make case study research a relevant approach due to their explanatory nature. This approach coincided with the research questions defined in this study, focusing on studying the pilot project for generalisable results. Second, the automation adoption project could be considered the defined 'case' of the organisational process to be studied. Third, Thorne (Thorne, 2021) also states that a case study methodology is preferable when current events are studied. This is because it enables researchers to use extensive sources of evidence, introducing direct observations and interviews of involved personnel for data triangulation.

The case study in the thesis is the main contractor operating in both New Zealand's North and South Island construction markets, which makes them suitable for this study to be observed. Further, the unique scope of their projects, which cover most of the range of precast and prestressed products, justifies the case-study company to the construction sector in New Zealand. Thus, the conditions for a critical case (Yin, 2018) selection are met since the company realise the importance of information to improve the profitability of precast plants. As the thesis study is bounded by a single organisation, the case study type is determined as a single case.

Data collection shifts to the embedded level (Yin, 2018), where a group of professionals from different departments participated in the study. This way, it became possible to hold different levels of information from varying experiences and expertise. The current case study was selected to test the theory of automation adoption in precast concrete plants in New Zealand. Therefore, a case study approach was required in order to understand the process and operations flow.

Finally, case study research requires preparation, and the pre-study conducted for this project would fulfil this requirement, making a case study a natural continuation of the research approach. Using the literature review results to sharpen the research questions would contribute to a more insightful case study to address the identified research gap (Yin, 2015). In this study, the case study and related direct observation addressed RO1, RO4 and RO5. RO1 used the interview with the case study staff to investigate the factors affecting the organisation's profitability. RO4 used direct observation in the case study to measure the waiting time on the production lines. RO5 was focused on providing recommendations and pathways towards implementing the optimised automation system in the case study. The case study chapter provides more details about the case study organisation used in this study (4).

### 3.3.7. Sample Size Justification

In this research, researcher used a mixed-methods approach, which involved both quantitative and qualitative data collection methods. For the close-ended questionnaire, they collected quantitative data, while for the structured interviews, they collected qualitative data.

Regarding the sample size, researcher carefully selected the participants based on the inclusion criteria that were aligned with the population of precast concrete plants in New Zealand. For the close-ended questionnaire, they obtained responses from 46 participants from 19 precast concrete companies in Auckland, which provided a representative sample of the population of precast concrete plants in New Zealand. The sample size was determined based on the feasibility and practicality of obtaining responses from the target population. Furthermore, the responses were analysed using statistical software, and the sample size was found to be sufficient for the analysis.

For the structured interviews, researcher conducted in-depth interviews with 10 participants, which were purposively selected based on their knowledge and expertise in the field of precast concrete manufacturing and/or automation. The data collected from the structured interviews were transcribed and analysed using qualitative data analysis, and the sample size was found to be adequate for the analysis.

In conclusion, the sample sizes used in my study were carefully selected and justified based on the research design, feasibility, and practicality of obtaining responses from the target population, as well as the theoretical saturation of data for the structured interviews.

## 3.4. Data analysis

In this section, the researcher explains how all the different analyses or tools have been used in this thesis.

### 3.4.1. AHP method

By changing the problem into a hierarchy of subproblems, the AHP helps the decision-makers to evaluate the decision elements by comparing them with one another using pairwise comparison. Subsequently, the relative weights of attributes were determined based on the AHP method. The method was developed by Saaty (1980) and has been extensively studied and refined since (Zhang & Zou, 2007). Adopting the AHP method in this step led to generating the matrices for comparing different attributes. Table 3.4 shows the actual relative weights for pairwise comparisons.

Table3. 4: Fundamental scales for pairwise comparison

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two factors contribute equally to the objective |
| 3 | Moderate importance | Experience and judgement slightly favour one factor over another |
| 5 | Strong importance | Experience and judgement strongly favour one factor over another |
| 7 | Very strong importance | One factor is favoured very strongly over another. Its dominance is demonstrated in practice |
| 9 | Extreme importance | The evidence favouring one factor over another is of the highest possible order of affirmation |

In this study, attributes are compared to determine how important they are to the decision-makers concerning the goal. Assume that n is the number of attributes for a given product; hence, the number of comparisons is n(n-1)/2. Pair comparison scores for n factors can be presented as a matrix, D:

$$D = \begin{bmatrix} W11 & \dots & W1n \\ . & Wij & . \\ Wn1 & \dots & Wnn \end{bmatrix}$$

In this pairwise comparison matrix, the number in the *i*th row and *j*th column gives the relative importance of factor *i* as compared with factor *j*, where both are a pair of attributes, and w*ij* = w*i*/w*j*; such that w*i* and wj are the relative weighted value judgements by decision-makers for alternative *i* and *j*, respectively. The final weights are obtained by normalising any column *j* of D, such that:

$$W_i = \frac{1}{n}\sum_{j=1}^{n} \frac{w_{ij}}{\left(\sum_i^n w_{ij}\right)}; \quad \text{for } i, j = 1, 2, \dots .$$

The eigenvector is obtained by dividing the weight vector (W) with the consistency vector (V), where V is given by A*W (Sharma, Al-Hussein, Safouhi, & Bouferguene, 2008). In other words, the relative weights of factors are estimated by applying the average of all eigenvector elements. According to Saaty (1980), the results of the pairwise comparisons should be checked for consistency using the indices consistency index (CI) and consistency ratio (CR) with the following equation.

$$CR = \frac{CI}{RI},$$

Where CI represents the deviation from consistency and is calculated as

$$CI = \frac{\lambda_{max} - m}{m - 1},$$

Table3. 5: Random Index value

| M (Number of factors) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Source: Zhang & Zou, 2007.

where m is the number of elements in the matrix row, and RI is the random index values determined from Table 3.5.

### 3.4.2. Direct rating method to determine a score

In the direct rating method, the decision-maker directly assigns numerical values to an alternative (NCHRP, 2007). This method includes having survey respondents assign numerical values directly to an individual attribute on a predefined scale, such as 0-10 (Li & Sinha, 2009). Experts allocate 10 points among attributes in proportion to their importance in this study. The 10-point scale is adopted in rating data, as table 3.6 illustrates. MS represents the mean score in this table, a common way to generalise the data (Guo, 2010; Islam, Sakakibara, Karim, & Sekine, 2011). It is applicable when the response levels are measured at an ordinal scale. MS is defined as follows.

$$Mean\ Score\ (MS) = \frac{\sum_{i=0}^{10} aixi}{10\ \sum_{i=0}^{10} ai}$$

where $ai$ is a constant expressing the weight given to $i$, and $xi$ are variables expressing the frequency of the response for $i = 0,1,2,3, \ldots ,10$

Table3. 6: Attribute levels based on mean scores appointed by experts

| Score points by SMEs | Level of importance | Mean score range |
|---|---|---|
| 0 | Absolute low | 0.0 ≤MS < 1.0 |
| 1 | Extremely low | 1.0 ≤MS < 1.5 |
| 2 | Very low | 1.5 ≤MS < 2.5 |
| 3 | Low | 2.5 ≤MS < 3.5 |
| 4 | Rather low | 3.5 ≤MS < 4.5 |
| 5 | Medium | 4.5 ≤MS < 5.5 |
| 6 | Rather high | 5.5 ≤MS < 6.5 |
| 7 | High | 6.5 ≤MS < 7.5 |
| 8 | Very high | 7.5 ≤MS < 8.5 |
| 9 | Extremely heigh | 8.5 ≤MS < 9.5 |
| 10 | Absolute | 9.5 ≤MS < 10 |

### 3.4.3. Pareto Analysis Method

Pareto analysis is a statistical technique in decision-making used to select a limited number of tasks that produce a significant overall effect. To define this concentration, we followed the lead of Vilfredo Pareto, who, over 100 years ago, observed that 80% of ‘effects’ derive from 20% of ‘sources’ (Caspi et al., 2017; D Haughey, 2015). Through Pareto analysis, 80% of improvement is achieved by focusing on the most crucial 20% of causes. As a formal technique, it is useful where many choices compete for attention. It consists of estimating the benefit delivered by each action with subsequent selection of a number of the most effective actions that deliver a total benefit reasonably close to the maximal. (Karuppusami & Gandhinathan, 2006).

To conduct the analysis, draw the line at 80% on the y-axis, parallel to the x-axis. Then drop the line at the point of intersection with the curve on the x-axis. This point on the x-axis separates the important causes on the left (vital few) from the less critical causes on the right (trivial many). The value of the Pareto Principle for a project manager is that it is a reminder to focus on the 20% of things that matter. Of the things that need to be done for a project, only 20% are crucial. That 20% produces 80% of the results. Identify, and focus on those things first, but do not entirely ignore the remaining 80% of the causes (Duncan Haughey, 2010). Below an example

| Man Hrs/Profit | Count | Cumulative Count | Cumulative % |
|---|---|---|---|
| Product1 | 349 | 349 | 43.7 |
| Product2 | 169 | 518 | 64.8 |
| Product3 | 79 | 597 | 74.7 |
| Product4 | 77 | 674 | 84.4 |
| Product5 | 60 | 734 | 90.0 |
| Product6 | 50 | 784 | 93.7 |
| Product7 | 32 | 816 | 95.6 |
| Product8 | 18 | 834 | 97.4 |
| Product9 | 10 | 844 | 98.9 |
| Product10 | 2 | 846 | 100.0 |

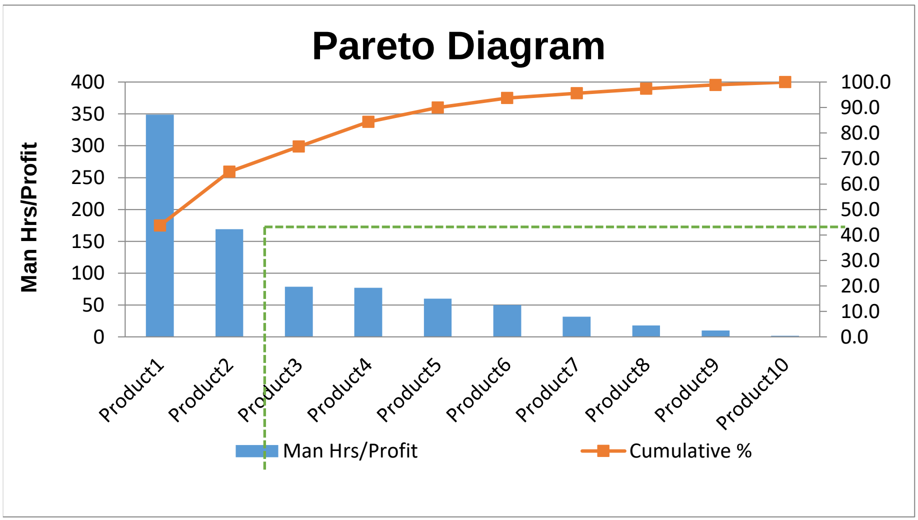



Figure3. 1: Pareto diagram sample

### 3.4.4. Thematic analysis (TA)

Thematic analysis (TA) is a widely used qualitative research method for identifying, analysing and reporting the patterns of themes in a dataset (Braun & Clarke, 2006). TA is a flexible method that can be applied across various epistemological and theoretical perspectives (Braun & Clarke, 2012).

The result of a thematic analysis should highlight the most salient constellations of meanings present in the dataset (Joffe, students, & practitioners, 2012). In this study, TA was employed to systematically examine the challenges associated with the profitability of precast construction plants, drawing on data from interviews, literature reviews, and direct observation. This section outlines the process of thematic analysis and its application in the current research.

The thematic analysis process general consists of six phases (Braun & Clarke, 2006):

- Familiarisation with the data: This involves reading and re-reading the collected data, such as interview transcripts, literature review findings, and direct observation notes, to become familiar with the depth and breadth of the content. Researchers may also make initial notes or observations during this phase (Braun & Clarke, 2006).

- Generating initial codes: In this phase, the researcher systematically codes the data by identifying and labelling meaningful features or segments related to the research questions. Codes are then organized into potential themes or subthemes (Saldaña, 2015).

- Searching for themes: The researcher reviews the initial codes and begins to group them into broader themes or categories. This process may involve merging, splitting, or refining themes to ensure they are coherent and distinctive (Braun & Clarke, 2006).

- Reviewing themes: During this phase, the researcher reviews the themes to ensure they are consistent with the coded data and the overall dataset. This may involve further refining or discarding themes that do not have enough supporting evidence or that do not fit the research questions (Braun & Clarke, 2006).

- Defining and naming themes: Once the themes have been reviewed and refined, the researcher defines and names them, providing a clear and concise description of the meaning and scope of each theme. This process helps ensure the themes are meaningful and relevant to the research questions (Braun & Clarke, 2006).

- Writing the report: Finally, the researcher writes a report that integrates the identified themes, providing a coherent and logical narrative that answers the research questions. The report should include examples from the data to support the identified themes and demonstrate the validity of the analysis (Braun & Clarke, 2006).

In the current study, the thematic analysis method was applied to identify the main challenges associated with the profitability of precast construction plants. The analysis revealed six major themes, as discussed in the Case study section: market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin, and non-profitable processes. These themes were derived from the systematic coding and categorisation of the data and provided a comprehensive understanding of the factors affecting the profitability of precast construction plants.

In summary, thematic analysis is a valuable method for analysing qualitative data, offering flexibility and rigor in examining complex research questions. By using thematic analysis, this study has generated a rich and nuanced understanding of the challenges associated with the profitability of precast construction plants, which can inform future research and practice in the construction industry.

### 3.4.5. **Value Stream Mapping (VSM)**

Considering the importance of analysing non-profitable processes in production lines for the aim of this study, the current study employs a lean tool, specifically Value Stream Mapping (VSM), as the foundation for this analysis. In production, 'the value-added' is defined as any activity transforming the product toward what the customer wants (Abdulmalek & Rajgopal, 2007). Everything else is defined as 'waste' – which is any processing step that consumes resources without adding value (Abdulmalek & Rajgopal, 2007; Ray et al., 2006a). In 2006, the day-to-day activities of 120 companies were tracked, and the results indicated that, on average, only 5% of activities were value-added while the remaining 95% were waste (Ray et al., 2006a). Learning to identify waste is an integral part of the lean manufacturing process – businesses have become so accustomed to waste that it is not recognised. The value stream mapping method (VSM) is the primary analytical starting point in lean manufacturing to break down the work process into detailed steps. The steps in the process are either value-added or waste (Chahal & Narwal, 2017). Table 3.6 shows seven different waste categories and breaks down the work process into detailed steps.

For the past few years, almost every manufacturing and service industry sector has applied some form of lean methodology. Likewise, lean-based tools have been applied to both simple and complex construction projects. As a lean tool for manufacturing, value stream mapping is an essential graphical tool that aims to describe production processes and identify and reduce waste (Y. Li, 2015). Since 1993, the philosophy of lean production and the principles of VSM have been applied to construction (Pasqualini & Zawislak, 2005). Value stream mapping (VSM) originated in the Toyota Production System. VSM's functions are to analyse and design the flow of material and information required to bring a product or service to the end consumer (Rother & Shook, 2003). VSM has been used in manufactures that use visual work processes to find waste created during their operations. VSM improves work strategies by developing a deeper understanding of the workflows through entire systems, establishing a strategic direction for improvements, and delivering value to end-users (Martin & Osterling, 2014).

According to Li (Li, 2015), there are five basic steps for applying VSM. The first step is to define the product family and then draw a current state map of the product; after identifying the non-value-added and value-added processes, the project team brainstorms and combines lean concepts with the value added to construct a future state map. The final step is to design and implement an action plan with a detailed process map (Li, 2015).

The use of VSM in construction has some benefits with the prominent ones as follows.

- Provides a holistic view of the entire flow

A better understanding of the whole process can be achieved by mapping the value stream. Connecting separate parts into a more holistic system helps the team identify the necessary and the unnecessary functions, allowing some to be removed or changed for better process flow. VSM also helps to uncover any potential information problems not easily identified within the production system. Visualising non-visible works, such as information exchanges, are essential in understanding how work is accomplished (Li, 2015).

- Identifies Waste

Applying VSM to map the current state of the product or service shows value-added and non-value-added processes and waste during the production process.

- Generates improvement plans

Once wastes are identified in the production process, the team can build an improvement plan using lean concepts to eliminate waste and add value.

Table3. 7: Sources of wastage (Chahal & Narwal, 2017; Henderson & Venkatraman, 1993; Y. Li, 2015)

| Waste | Reasons / Explanation |
|---|---|
| Over-production | From 'getting ahead' concerning production schedules. The required number of products is disregarded in production capacity utilisation. |
| Inventory | Final, semi-finished, or parts kept in storage do not add value. Even worse, they usually add cost to the production system by occupying space and financial resources and requiring additional equipment, facilities, and workforce. |
| Repair or reject | May end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints. |
| Motion | Any motion not related to adding value is unproductive. |
| Transport | Having to move unnecessarily will not increase the value. |
| Over-processing | Use of inadequate technology or poor design results in inefficient processing activities. |
| Waiting | A worker's hands are idle, such as when there are imbalances in the schedule, lack of parts, machine downtime, or when the worker is simply monitoring a machine performing a value-adding job. |

### 3.4.6. Archival Data analysis used in this study

Archival analysis was used as a data collection method for a quantitative research study on a precast concrete plant in New Zealand. The archival data included historical information from the organisation's daily reports, production statement data, and financial statement data. The data was extracted from the production and financial departments, covering the years 2010 to 2017.

Archival analysis involves collecting, evaluating, interpreting, and analysing sources found in archives for purposes other than those for which they were initially collected. This method is time-consuming but cost-efficient, reliable, and provides a practical data source. In this study, archival analysis was chosen to address the research objective of analysing the profitability of the products in the case study.

The researchers collected raw data into a secure, password-protected database. Microsoft Excel was used to examine and measure the relationship between variables and raw data, filtering redundant data and irrelevant attributes. The extracted data were carefully analysed to elicit meaning and explanatory constructs.

The findings section presents an analysis of the labour efficiency, market attractiveness, sales forecasting, plant utilisation, gross profit margin, profit efficiency, and non-profitable processes of all production lines for the different products (A to G). The data provides insights into the performance of each product and how factors such as labour costs, market attractiveness, and plant utilisation affect their profitability.

In conclusion, archival analysis was used in this study to collect and analyse historical data from the case study organisation, allowing the researchers to assess the profitability performance of the precast concrete plant in New Zealand. The analysis of the extracted data provided valuable insights into the factors affecting the plan’s performance and suggested areas for improvement.

# 4. Case study (a New Zealand Case Study)

## 4.1. Introduction

This study is based on data collection and analysis related to a precast concrete plant that has its operational base in Auckland, New Zealand. As explained in the methodology chapter (see chapter 3), this plant was selected because of access to data and operational information. A precast concrete firm was selected because its product line lends itself to the study aim: to automate precast production within similar organisations in New Zealand. The selected plant has product lines that are currently being produced manually and for which automation may be an option. The plant has a nominal capacity of 125 cubic meters per day for seven different products. From the company's records, the plant's total production from 2010 to 2017 was 33,180m3, giving an average production of 4,147m3/yr. There are two main activities in each production line: (1) preparing a mould and the required steel, and (2) casting the concrete for the elements. The precast items are known as 'element'. Each precast element remains in its place until the elements reach the required strength. This phase usually lasts around one day, and then the elements will be transported to a storage area. Next, a subcontracted company will transport the elements to a construction site on the due date. As in other countries, there is no standard for element dimensions, and each company produces their products with varied basic dimensions. An increasingly competitive construction market asks for new flexible production in any size and shape they require. It is a challenging task during the production process to integrate the supply chain and the various departments within the company to maximise profitability while increasing safety.

During the period of preliminary discussions with a project manager who was working in the case study organisation, it experienced some challenges which affected its profitability. By researching the company's infrastructure and through interviews with ten key staff, the researcher identified the challenges that had affected the company's profitability. Permission was then granted to the researcher to extract specific data from the production and financial departments to achieve RO1, RO4 and RO5.

## 4.2. Current production lines in the case study

### 4.2.1. Double Hollowcore

The company has one 30m long bed for this production line; this product has regularly been used as a standard bridge section for spans of up to 18m since standard plans were produced in 1964 by the then New Zealand Ministry of Works (MoW, 1970). These bridges are the most common pre-tensioned concrete bridge and account for 32% of pre-tensioned concrete bridges on the New Zealand state highway network, with a total of 264 bridges in service when data was extracted from the NZTA Bridge data system (BDS) in 2008 and 2011.

The design of this product has evolved considerably over time, particularly after the development of economical cast-in steel and polystyrene void formers which allowed the voids to be enclosed in the precast unit. The 1964 standard drawings provided designs for spans ranging from 6m to 12m. Figure 1 shows standard cross-sections for a 6m and a 12m span.

The current New Zealand Transport Agency (NZTA) document published in 2008 contains standard plans for pre-tensioned concrete double hollow core bridges with spans of 12m and 14m, with the new type of single hollow-core beam with one large void preferred for longer spans. The beams are 576mm deep and contain 12.7mm ‘super’ strands as pre-tensioned reinforcement. Specified 28-day compressive strength is 50mPa, and minimum clear cover depth to pre-tensioned reinforcement is 40mm, while the actual specified clear cover depth of the strands is 50mm in the shear key and 54mm in the soffit. Stirrups enclose the pre-tensioned reinforcement for the length of the beams. Cross-sections for the 2008 NZTA standard double hollow core beams are given in Figure 4-1.

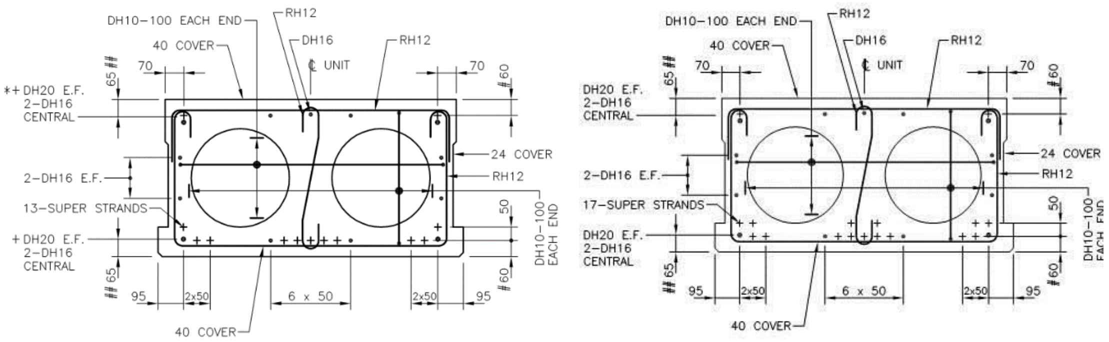



Figure4. 1: a and b–- 2008 NZTA Standard plans (12m and 14m span)

### 4.2.2. **Double tee**

The company has 2 double tee production lines which they are 65m long and 2.4m wide, and each one can produce different depths of this product from 200mm to 550mm. The stop ends and spacers between the products are used, and thus only 55 linear meters of bed is usable per cast. Therefore, the average production capacity of this product is calculated as formula 4-1.

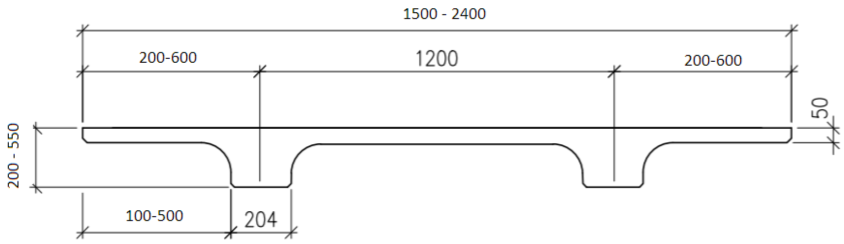



Figure4. 2: Double Tee typical section

$$A1 = N(204 * 150 + 1200 * 50) * 2L$$

$$A2 = N\,(204 * 500 + 1200 * 50) * 2L$$

$$M = \frac{(A1+A2)}{2}$$

- M: The average capacity of daily production
- A1: The maximum capacity of daily production for 200d product
- A2: The maximum capacity of daily production for 550d Product
- N: QTYs of available bed
- L: The maximum length of each cast

$M = \frac{2(30600+6000)*2*55000+2(102000+6000)*2*55000}{2}$ = 27m3/day ➔ 27 * 244 = 6,588m3/Yr

OR 2(Qty)*55(Lm)*244(Day)= 26,840 Lm / Yr

If the company works 244 days per year, the plant's maximum capacity will be 6,5588m3/year, or 26,840 Lm/year.

Where:

- 2: number of casts per day
- 55: the maximum length of each cast
- 244: Annual working days

If the company works 244 days per year, the plant's maximum capacity will be 6,5588m3/year or 26,840 Lm/year.

### 4.2.3. Flat slab

The company had four production lines that could be used for flat slabs. The table below summarises their dimensions and capacity.

Table 4. 1: Flat slab dimensions and capacities

| | |
|---|---|
| 2010 to Apr 2017 | Production Line 5: $Maximum\ capacity\ per\ day = 60 * 1.2 * \frac{(0.150+.075)}{2}$ = 8.1 $\frac{\text{m3}}{\text{day}}$ *244 = 1976m3/Yr.<br>Production Line 2: $Maximum\ capacity\ per\ day = 160 * 1.2 * 0.075 = 14.4 \frac{m3}{\text{day}} * 244$ = 3513m3/Yr. |
| Apr 2017 onward | Production Line 3: $Maximum\ capacity\ per\ day = 160 * 1.2 * 0.075 = 14.4\ \frac{m3}{\text{day}}$ = 3515m3/Yr.<br>Production Line 4: $Maximum\ capacity\ per\ day = 160 * 1.2 * 0.075 = 14.4 \frac{m3}{\text{day}}$ = 3513m3/Yr. |

From 2010 to April 2017, only two production lines were available to cast this product, but after April 2017, the company decided to utilise all four production lines to mass-produce them. The production capacity has thus been increased to 12500m3/Yr.

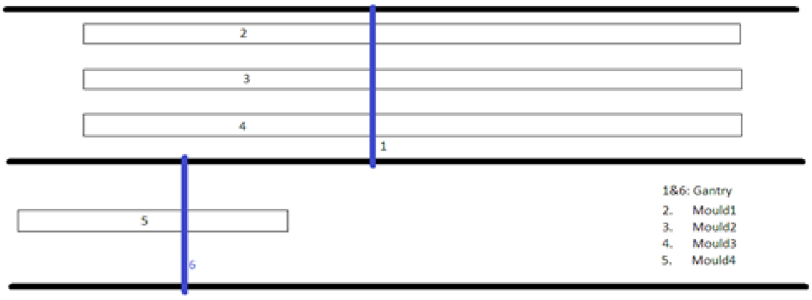



Figure4. 4: The case study layout of flat slab

### 4.2.4. **Hollowcore**

The company had a semi-automated machine and three production lines for this product. The figure below shows the typical section of hollowcore, and the table below shows the dimensions and capacity of its production line.

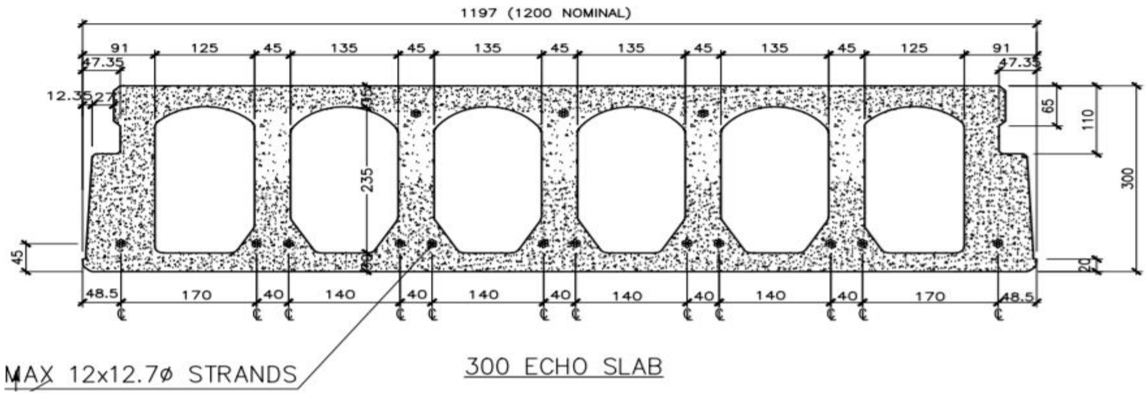



Figure4. 5: A typical section of hollowcore

The company had three production lines 160m long and 1.2 wide, and each one could produce different sizes from 150 to 400 depths as below.

Table 4.2: Hollowcore dimensions and capacities

| | |
|---|---|
| Jul 2010 – Nov 2017 | 150d -> $Maximum\ capacity\ per\ day = 160 * (0.15 * 1.2 - 6 * (0.090 * 0.140)$ = 16.704 m3/day<br>200d ->$Maximum\ capacity\ per\ day = 160 * (0.20 * 1.2 - 6 * (0.140 * 0.140)$ = 19.584 m3/day<br>300d ->$Maximum\ capacity\ per\ day = 160 * (0.30 * 1.2 - 6 * (0.135 * 0.235)$ = 27.144 m3/day<br>400d ->$Maximum\ capacity\ per\ day = 160 * (0.40 * 1.2 - 6 * (0.135 * 0.330)$ = 34.03 m3/day<br>Average= 24.365 m3/day -> 5,945m3/Yr. |

### 4.2.5. **Super tee**

The case study has one production line of 60m long and adjustable for up to 1500 deep. The plant can produce different sizes from 1025 to 1500 depths. This product is a recently developed section that is increasing in usage in both New Zealand and Australia for long-span precast pre-tensioned concrete bridges. This product is significantly larger than a traditional T-beam and contains one large void. Its cross-section is similar to the U-beams, except that they have flange outstands on either side at the top of the section, providing permanent formwork for the deck slab. The popularity of this product has been steadily increasing, and the 2008 standard bridge plans issued by the NZTA contain drawings for 1025mm and 1225mm deep for spans of 20m to 30m (Beca & Opus 2008). Cross-sections taken from the 2008 NZTA standard plans are shown in Figure 4.6. The standard designs specify 15.2mm diameter 'low relaxation stress relieved super' strands and 50mPa concrete. The minimum required clear cover depth for all reinforcement is 40mm.

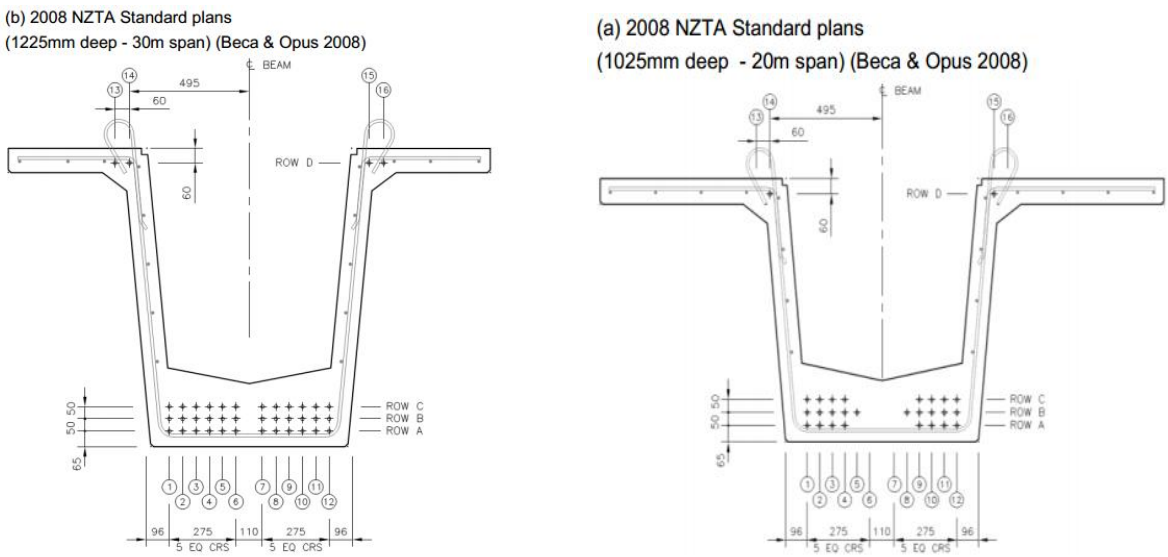
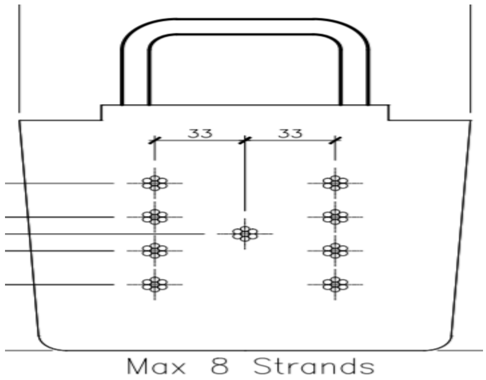



Figure4. 6: Typical cross-sections for super tee: 2011

### 4.2.6. Ribs




The case study company had eight production lines of 60m long, and different depths. It can produce different sizes according to the shop drawings and client requirements. Only 40 linear meters of each production line is usable per cast because stop ends and spacers are used between the products.

The average capacity of ribs production is calculated in the table below.

Table4. 3: Ribs dimensions and capacities

| | | |
|---|---|---|
| From 2010 to Nov 2017 | 100d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.100)$<br>120d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.120)$<br>150d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.150)$<br>175d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.175)$<br>200d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.200)$<br>225d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.225)$<br>250d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.250)$<br>275d $Maximum\ capacity\ per\ day = 160 * (0.150 * 0.275)$<br>Average= 4.48 m3/day → 1093 m3 /Yr. | |
| Nov 2017 onward | 4.48 m3/day → 1,093 m3 /Yr.<br>Plus<br>5.98 m3/day → 1,460 m3/Yr. | = 2553m3/Yr. (Total capacity from Nov 2017) |

### 4.2.7. Shell beam

The company had two production lines of 30 meters long, 400mm and 600mm wide, Figure 4.7.

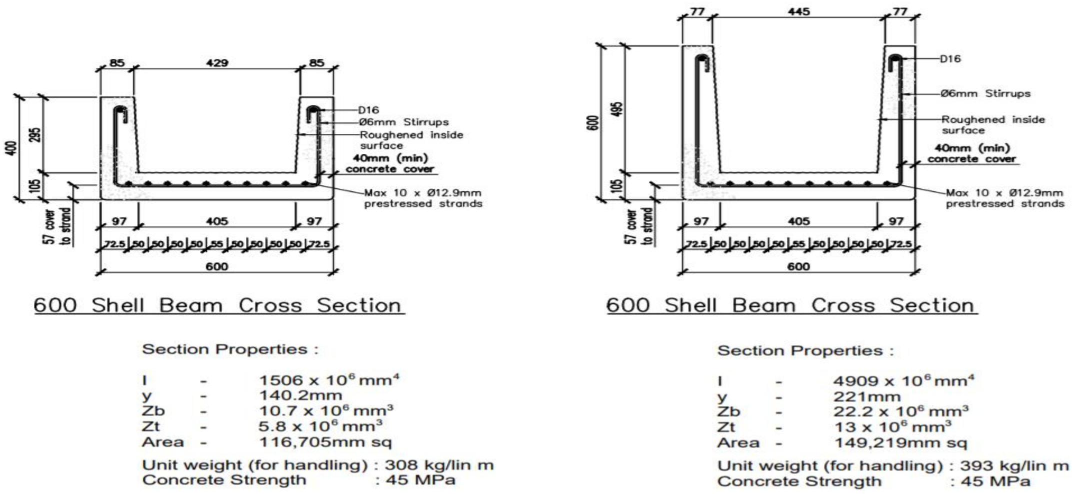



Figure4. 7: A typical section of shell beam

The table below shows the dimensions and production capacity of this product.

Table4. 4: shell beam dimensions and capacities

| | |
|---|---|
| 2010 –2017 | Type 400w -> $Maximum\ capacity\ per\ day = 30 * [((0.4 * 0.4) - (0.23 * 0.3)) + ((0.4 * 0.6) - (0.244 * 0.5)]/2$ = 3.14 m3/day<br>Type 600w -> $Maximum\ capacity\ per\ day = 30 * [((0.4 * 0.6) - (0.43 * 0.3)) + ((0.6 * 0.6) - (0.445 * 0.495)]/2$ = 3.81 m3/day<br>Average= 3.475 m3/day -> 848m3/Yr. |

## 4.3. Direct Observations

As discussed earlier, in section 3.3.3, identifying and measuring the value-added and non-value-added activities are an integral part of the lean manufacturing process. VSM was used in this study with the intention of capturing the percentage of waste generated in each of the activities through mapping the current state of the processes. The product names are coded to avoid revealing confidential company statistics to the market. Products A to G are the names used in this study – the actual products will be known only by the researcher and the company's management team.

The VSM implementation in this study included the following steps: (1) data collection and mapping the activities of each production lines; (2) identifying the value- and non-value-added activities on each production lines, and finally (3) calculating the total percentage of the time on each production line which was not of value to the company. The period of site observation was seven weeks, with a full day visit to the production line each week. It included on-site observation and process mapping using a VSM approach. For example, the researcher observed on site that the workers who were working on a long line casting bed walked many kilometres per day to work or collect their tools. Time and motion studies have previously shown that precast concrete plant personnel typically are paid one to two hours a day simply for walking (Ray et al., 2006b). Walking does not add value and does not transform the product into what the customer wants. Thus, unnecessary walking is wasted time. The researcher also observed that one forklift was operating one hour each day to lift and shuffle the special steel material from the other side of the site to prepare the production bed to be poured which was wasting the time. However, the customers are only interested in receiving a good quality product on time, and they are not willing to pay for any of these valueless operations. Table 4.5 and figure 4.8 show the result from VSM analyses of the product lines and broken down them into detailed steps.

Table4. 5: Value-added and type of waste – Product B

| Activities (group of 6 people) (Should finish in 9.73 Hrs) | Value Added | Time/ Mins | Type of waste | Time / mins |
|---|---|---|---|---|
| Mould cleaning and oiling | Yes | 240 | -- | -- |
| Mould changing (If necessary) | No | -- | Processing – old technique | 1440 / 10 = 144 |
| Cages and mesh preparing | Yes | 270 | -- | -- |

| Activities (group of 6 people) (Should finish in 9.73 Hrs) | Value Added | Time/ Mins | Type of waste | Time / mins |
|---|---|---|---|---|
| Stop ends and setup. | Yes | 180 | -- | -- |
| Detailing | No | -- | Process | 240 |
| Placing the cages and strands | Yes | 720 | -- | -- |
| Stressing the stands | Yes | 60 | -- | -- |
| Stressing the strand (waiting) | No | -- | Waiting | 120 / 2 = 60 |
| QC checking | No | -- | Waiting | 30 |
| Waiting for truck | No | -- | Waiting | 540 |
| Pouring concrete | Yes | 420 | -- | -- |
| Lifting, cleaning and storage/despatch | Yes | 300 | -- | -- |
| Remedial – If necessary | No | -- | Repair | 120 |
| Walking –to access tools | No | -- | Motion | 180 |
| Total of all activities | 62% | 2190 | 38% | 1314 |

Thus, the key insight from the table above is that about 38% of the effort expended in product B does not add value to the product, at least not from the customer's viewpoint. The unnecessary efforts identified will incur extra costs to the case study organisation and reduce its productivity and profitability.

The study identified the value-adding and non-value-adding activities in the production of seven other products and their effects on the profitability of the precast concrete plant. For confidentiality reasons, only a summary is shown in figure 4.8. As a result, product C at 63% has the maximum time wastage, and product B has the minimum time wastage at 38%.

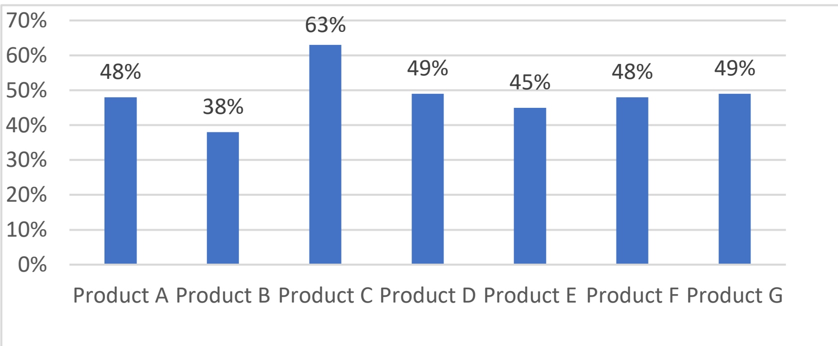



Figure4. 8: Wasting time of products A to G

Despite the high level of offsite production systems in New Zealand, housing prices are increasing, and a labour shortage remains the main issue. Offsite production is a technology to reduce the number of workers on construction sites with the goal of reducing overall labour costs. But – as described above – the case study organisation itself is labour-intensive. This situation led to the researcher's investigation to identify its profitability challenges and to seek improvements.

#### 4.3.1. Direct observation approach and its analytical steps and key findings

The researcher used direct observation and the value stream mapping (VSM) technique to gather data on the production processes and identify areas for improvement in the precast concrete industry.

The observation approach involved physically observing the production processes and taking detailed notes on the activities, materials, and people involved. The researcher observed the production processes at a precast concrete plant and recorded the data on a standard template developed for the study. The observations were conducted over several days at plant to capture a comprehensive picture of the processes and identify any variations in the production flow.

The analytical steps for the observation approach included categorizing the observed activities into process steps, identifying any bottlenecks or inefficiencies in the production flow, and mapping the overall process flow. The researcher used the value stream mapping technique to create a visual representation of the production flow, including all the process steps, materials used, and time required for each step. The VSM allowed the researcher to identify areas for improvement in the production flow and potential solutions for addressing any inefficiencies or bottlenecks.

Overall, the combination of direct observation and the VSM technique provided a comprehensive understanding of the production processes and identified areas for improvement in the precast concrete industry. The analytical steps taken helped to identify and address any inefficiencies and bottlenecks in the production flow, ultimately contributing to the overall goal of optimizing automation in the industry.

- **The key findings derived from the direct observation and VSM**

1. Identification of non-value adding activities: The direct observation method and VSM approach allowed for the identification of non-value adding

activities, such as waiting times and transportation, which were causing delays and inefficiencies in the precast concrete production process.

2. Inefficient layout: The direct observation and VSM approach also revealed that the layout of the production facility was not optimal, causing excessive movements of materials and workers, leading to delays and inefficiencies.

3. Bottlenecks in the production process: The VSM approach identified bottlenecks in the production process, such as the casting and curing stages, which were causing delays and impacting the overall efficiency of the precast concrete production process.

4. Opportunities for improvement: The direct observation and VSM approach identified opportunities for improvement in the precast concrete production process, such as reorganizing the production layout, improving communication and coordination, and implementing new technologies to streamline processes and reduce waste.

## 4.4. Interview with SMEs (case study company staff)

This section investigates the challenges associated with the profitability of the case study company through interviews with ten key staff members (refer to section 3.3.2). Proposals based on six different categories (refer to 2.11.8) such as market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin, and non-profitable processes are listed below.

### 4.4.1. Plant utilisation, gross profit margin and quality issues:

Some of the interviewees were concerned about quality issues that caused the low profitability of the plant . Interviewees 7 and 8: *Overproduction will result in a number of quality issues, including: (a) casted products remaining on site for an extended period of time, causing deformation and other chemical and physical changes; (b) late [in the day] concreting of the product, resulting in low strength and a longer time to de-mould the next day. (c) late concreting resulting in overtime work for the workers, which is costly to the company. (d) late concreting requires more product movement if storage space is limited which results in product defects and additional costs .*

Interviewees 7 and 8 also argued that *A comprehensive design checklist would limit the likelihood of delays and errors during the manufacturing phase. Confirmation of engineering drawings, component classification, production resources, and site needs are among the other preparations required during production planning* .

### 4.4.2. **Plant utilisation and market demand:**

Depending on the job, different sorts of casting elements are required. For each kind, many elements may be required by clients and on different deadlines. *The production schedules are strongly tied to market attractiveness, plant utilisation, labour efficiency and construction site (or client, in this study) requirements. Precast concrete plant cannot provide more elements than indicated in the delivery schedule since most of the sites do not have enough space to store large and bulky elements. If elements are manufactured ahead of schedule, they must be stored in the factory and incur inventory costs. There is also a limitation of inventory space in the plants. If the inventory elements in stock on a given day are insufficient to meet client demand, the delivery will be postponed till the demand for the product is met, As a result, contractual penalty charges are incurred with a missed delivery date* . In the same vein, Interviewees 2, 6 and 9 added that; *Sufficient inventory stock levels must be maintained to compensate for the variations in site progress or as a possibility due to delays in the [company's] production process* .

### 4.4.3. **Market attractiveness:**

Any precast company is divided into different departments which need to have a certain level of communication. Interviewee 5 argued that *The jobs undertaken by precast production companies can be roughly divided into structural design, production planning, component manufacturing, and handling operations. The time from production planning to the completion of storage and transportation may run for weeks or even months, therefore a proper communication is very critical.* This interviewee also addressed the lack of communication between those departments as a reason for low productivity and duplication and extra cost in the process. Interviewee 4 stated that: *[We] require an integrated database for the storage and retrieval of information related to the planning, design, and manufacturing of the whole precast concrete components* . As the production schedule must be adjusted weekly based on the actual production and installation changes of products at the client's site (J.-H. Chen et al., 2017), effective communication between the designers and their clients will increase the quality and productivity of shop drawings. Interviewee 3*: Proper communication between draftsman and structural designer will increase productivity and reduce the chance of delay and mistakes in production. Also, preparations needed during project production planning include confirmation of the engineering drawings, component classification, production resources, and site requirements to mitigate mistakes and reworking during the construction phases.*

### 4.4.4. Plant utilisation, labour efficiency, market demand

Recent developments in computational methods have led to novel ways of constructing better production schedules, and it is time to see what benefits these methods hold for precast scheduling (W. Chan & Hu, 2002). Interviewees 1, 2 and 3 discussed the importance of production planning and scheduling. They pointed out that *the mould production space is significant to the plant's overall production allocation. Proper mould production scheduling will greatly affect total plant production and mould costs. Mould production scheduling starts by verifying the component specifications based on the project's structural design. Precast components with similar specifications should be assigned to the same mould group for production. This prevents excessively complex mould setup during production that increases mould production time and takes up production space*.

### 4.4.5. Gross profit margin, plant utilisation, labour efficiency and market demand, non-profitable processes, market attractiveness

Planners need to balance multiple project objectives, including meeting the due dates, improving mould utilisation rates, reducing production line change overs, and maintaining inventory levels (W. Chan & Hu, 2002). Interviewee 5 explained that *Plant operators should make full use of their production lines and minimise the number of changeovers. Long runs of a particular element type on a single mould are preferable if this does not compromise due dates and exceed desired inventory levels*. Interviewee 2 added that *Planning in response to due dates alone may result in many changeovers and may drive up mould adaptation costs, which can be considerable if the cost of lost production time is included .* Having no proper planning will incur extra costs for the company and reduce its reputation in a competitive market. Interviewee 2 stated that *due to the large variances in project size and difficulty, the decision-maker at the precast plant must assign appropriate planning personnel based on the project characteristics* .

### 4.4.6. Gross profit margin, labour efficiency, plant utilisation and market demand

Flexible/interactive planning is needed, including weekly team meetings required for all 'in progress' jobs to reduce unnecessary expenses. Interviewee 2 also suggested that *Current scheduling practices in precast plants are basic and depend greatly on experience. This may lead to inefficient resource utilisation, over-inventory, and missing delivery dates. Computer-assisted scheduling may, therefore, be useful in producing better production schedules* . He also added: *the precast plant must be relatively flexible in terms of production scheduling and storage space due to (1) build-to-order makes economies of scale difficult to achieve; (2) multiple projects may be running concurrently; (3) installation requirements and design changes at project sites are always variables; and (4) production, storage, transportation, and installation must be dynamically balanced*. Moreover, *during the construction process at precast concrete plants, the distribution of production resources, design, and progress management are all dependent on communication and coordination between experienced engineers with strong project skills. One person does not always know all of the technical capabilities and productivity of the project personnel or all the plant resources of different projects. This would, however, be necessary for optimal planning* .

### 4.4.7. Plant utilisation, market demand, market attractiveness, gross profit margin and labour efficiency

To meet required deadlines, the planning team should consider all of the current resources, such as the precast concrete plant's production area, mould production capability, concrete production, and storage area. As interviewee 10 explained: *When considering the different workloads and deadlines of each project as well as the different combinations of projects under contract, along with the installation requirements and production and supply characteristics for each project site, project* *planners must then take into account all of the subsequent production schedules, production lines, and handling plans* .

Precast productions are dealing with a variety of restrictions, including production schedule, handling space, and responding to requirements by adjusting production resources to minimise the project completion time. The schedules are compressed using a production line technique or by doing a full-team review of the optimisation strategy to satisfy these constraints. However, only very little research into precast production planning and optimal decision-making has been conducted to date for storage, transportation, and increasing the company's profits – which are the critical factors for decision-makers (Chen et al., 2017). Interviewee 2 explained that *In practice, we often find that the internal resources are not being used most efficiently and logically. Sometimes, we even find poor decisions during the project production and handling*.

### 4.4.8. Market demand, plant utilisation, labour efficiency, gross profit margin and non-profitable processes.

The precast concrete components in the company's facility will usually have standard shapes or configurations, and the moulds are theoretically used for manufacture multiple times (Chen et al., 2017). Interviewee 9 stated that *the precast concrete plant delivers the components to the [project] site for installation, based on the site's request and the progress of each project* . A well-designed yard management system will help the company store, find, and deliver the units needed with the highest productivity and quality rate.

Interviewee 4 mentioned that *the inventory of completed precast components is an important constraint for precast concrete plants. Some precast components are quite large, so the inventory takes up storage space and represents a cost to the company. Faced with limited production space and pressure from clients on product delivery, precast concrete plants need to plan their production to build up inventory in advance. This inevitably leads to a shortage of storage space at precast concrete plants as well as difficulties in the component handling* . Interviewee 9 argued that *each project site usually needs different types of casting elements. There may be several elements needed for each type at different due dates. Plant production schedules are strongly* *tied to site progress and site delivery schedules. Most construction sites do not have much space to stockpile large and bulky elements, so plant operators cannot deliver more elements than specified in the delivery schedule. If elements are produced before their delivery date, they must be stockpiled at the plant itself and incur inventory costs. Inventory space in the plants is also severely limited. Suppose the inventory elements in stock cannot meet site demand on a given day. In that case, delivery is delayed until production meets the demand, thereby incurring contractual penalty costs associated with a missed delivery* . In a similar vein, Interviewees 2, 6 and 9 added that *Sufficient inventory stock levels must be maintained to compensate for the variations in site progress or as a possibility due to delays in the production process.*

### 4.5. Results (current challenges associated with the profitability of precast construction plants)

By using the Thematic Analysis (TA) method, as discussed in section 3.4.4, all the transcribed interviews, the literature review and the direct observation dataset were reviewed and coded to identify common themes – topics, ideas, and patterns of meaning that come up repeatedly. The result of a this analysis should highlight the most salient constellations of meanings present in the dataset (Joffe et al., 2012). The thematic analysis revealed several challenges that precast construction plants face in maintaining their profitability. These challenges were grouped into six themes: market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin, and non-profitable processes (see Table 4.6).

These themes encompass a wide range of factors affecting the profitability of precast construction plants, such as Procurement, planning, communication, production line utilisation, production line changeovers, design change, late casting, overproduction, concrete truck standing, quality, crack, incorrect cast, resource utilisation, site delays, loading delays, missing deliveries, quality issues, storage issues, production delay, loss of product, loss of reputation, wasted labour time, overtime, unnecessary product movement, waiting time, limited storage space which influences the future job, production line allocation, production rate, labour utilisation, multiple project objectives, low profitability, production line change over, inventory, plant utilisation, low margin, competitive market, unnecessary expenses, inefficient resource utilisation, multiple jobs running, design changes, inexperienced staffs, project completion time, company's profit, resource utilisation, production planning, storage issues and additional costs to the company caused by limiting production space, contractual delay costs.

Table 4.6 presents a summary of the challenges associated with each theme, along with the relevant factors. For example, market attractiveness is affected by factors such as quality, crack, incorrect cast, resource utilisation, storage issues, production delay, loss of product, loss of reputation, wasted labour time, overtime, unnecessary product movement, waiting time, limited storage space influencing future jobs, labour utilisation, competitive market, unnecessary expenses, inefficient resource utilisation, and contractual delay costs. Market attractiveness can be quantified as the rate of winning jobs divided by the market demand. Likewise, other themes can be quantified using specific ratios or measures, as shown in Table 4.6.

Table4. 6: challenges that are associated with the profitability of precast construction plants

| Categories | Factors |
|---|---|
| Market Attractiveness | Quality, crack, incorrect cast, resource utilisation, storage issues, production delay, loss of product, loss of reputation, wasted labour time, overtime, unnecessary product movement, waiting time, limited storage space which influences future jobs, labour utilisation, competitive market, unnecessary expenses, inefficient resource utilisation, contractual delay costs. $\text{Market attractiveness} = \frac{\text{Rate of winning jobs}}{\text{Market Demand}}$ |
| Plant Utilisation | Procurement, planning, production line utilisation, production line changeovers, late casting, incorrect cast, resource utilisation, missing deliveries, loss of product, limited storage space which influences the future job, production line allocation, production rate, labour utilisation, multiple project objectives, production line changeover, inventory, plant utilisation, competitive market, inefficient resource utilisation, multiple jobs running, resource utilisation, production planning, storage issues and additional cost to the company caused by limiting production space. $\text{Plant Utilisation} = \frac{\text{Production Rate}}{\text{Production Line Capacity}}$ |
| Labour cost | Procurement, planning, communication, production line changeovers, design change, late casting, overproduction, concrete truck standing, quality, crack, incorrect cast, resource utilisation, loading delays, wasted labour time, overtime, unnecessary product movement, waiting time, labour utilisation, production line changeover, plant utilisation, inefficient resource utilisation, inexperienced staffs, production planning. $\text{Labour efficiency} = \frac{\text{Labour cost (NZD)}}{\text{Total Sales (NZD)}}$ |
| Gross profit margin | Procurement, planning, communication, production line utilisation, production line changeovers, design change, late casting, overproduction, concrete truck standing, quality, cracks, incorrect cast, resource utilisation, site delays, loading delays, missing deliveries, quality issues, storage issues, production delay, loss of product, loss of reputation, wasted labour time, overtime, unnecessary product movement, waiting time, |

| Categories | Factors |
|---|---|
| | limited storage space which influences future jobs, production line allocation, production rate, labour utilisation, multiple project objectives, low profitability, plant utilisation, low margins, competitive market, unnecessary expenses, inefficient resource utilisation, multiple jobs running, inexperienced staffs, company's profit, resource utilisation, production planning, storage issues and additional costs to the company caused by limiting production space, contractual delay costs. Gross profit margin = $\frac{\text{sales––cost of goods sold}}{\text{Sales}}$ OR $\frac{\text{Gross profit}}{\text{Sales}}$ |
| Market demand | Affordable housing, housing supply and demand, site and market demand, construction methods, labour cost, labour shortage, quality, reputation, JIT, site delay Market Demand = $\frac{Quantity\ of\ the\ \ incoming\ tenders}{Total\ Plant\ capacity}$ |
| Non-profitable processes | production line utilisation, production line changeovers, resource utilisation, production delay, wasted labour time, unnecessary product movement, waiting time, labour utilisation, inefficient resource utilisation, inexperienced staffs, production planning. $\text{Non} - \text{profitable processes} = \frac{\text{Unproductive times (minutes)}}{\text{Production line time (minutes)}}$ |

In conclusion, understanding the challenges associated with the profitability of precast construction plants is crucial for improving their overall performance and sustainability. The systematic analysis of the current challenges using the thematic analysis method offers valuable insights into the factors that need to be addressed to enhance the profitability of precast concrete plants. By addressing these challenges, precast plants can improve their market position, increase their efficiency, and contribute to the overall growth of the construction industry. Future research can focus on developing strategies and solutions to overcome these challenges and enhance the profitability of precast construction plants.

# 5. Case study profitability measurement

By referring to the research methodology chapter and section 4.5, the profitability of the precast concrete plant that is the subject of the case study can be measured, based on its market attractiveness, plant utilisation, labour efficiency, non-profitable processes, market demand and gross profit margin. As discussed in the literature review, profitability is an essential measure of a company's performance. Unlike productivity, which a company achieves by maximising the number of units produced in a given time frame, profitability requires minimising costs and maximising profits for a given output level. It relates to the quality of a company's management, including creating output with less waste, using fewer resources, or spending less money than standard market practice (Morris, 2009). Profitability enables a business to make the best possible use of its own resources. For example, a profitable company will produce more quality products, with less waste, and use less energy and other resources during a given period than an inefficient company (Prokopenko, 1987; Shaaban, 2010; shmula, 2007).

As discussed in section 3.3.5 and 3.4.6 of this research, the archival data collection and analysis were the key components of the case study profitability measurement of this research. The archival data method was used to gather data on the historical context of offsite manufacturing in the New Zealand construction industry, and to identify trends and patterns over time. In the following section, the researcher will use above method to analyse the case study profitability aspects.

## 5.1. Deciding which products are to be included in the case study.

As discussed in the literature review section, financial goals are becoming more important indices of a company's success. Moreover, the gross margin is significant because it reflects a company's core profitability before overhead costs, and it illustrates the financial success of a product or service.

Pareto Analysis (refer to 3.4.3) is used as a statistical technique in decision-making to select a limited number of tasks that produce significant overall effects. As shown in figure 5.1, about 85% of the total revenue has been allocated to only seven products out of fourteen. Products A, B, C, D, E, F and G contributed more than 80% of the company's revenue, labour cost, gross margin, and gross profit margin during 2010-2016. Therefore, products A to G were selected in this case study for further analysis.

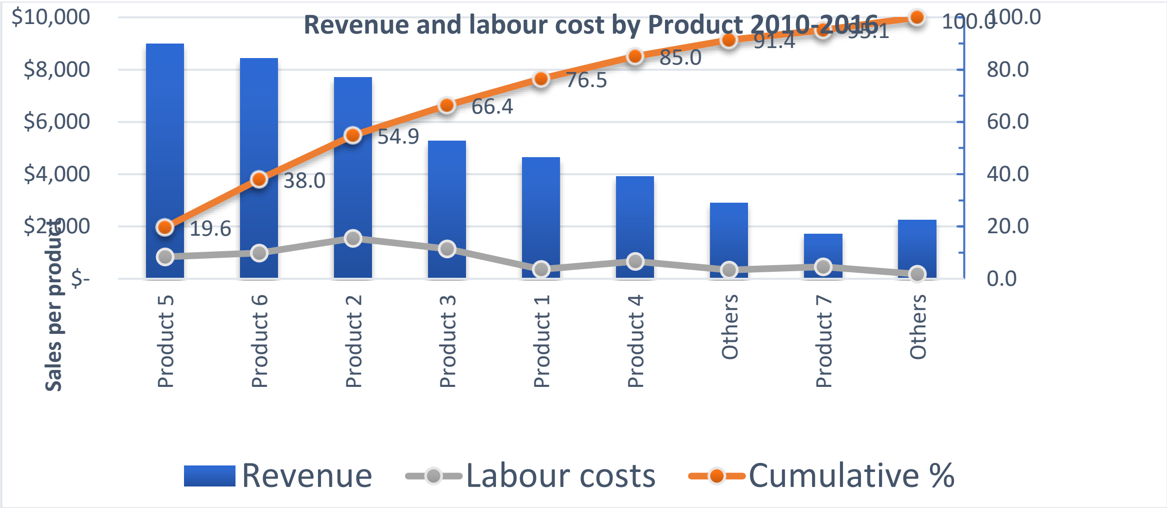



Figure5. 1: Revenue and labour cost by-product 2010-2016

The gross profit margin was measured as an indicator of the efficiency of the case study company's sales operations concerning the cost of goods sold, figure 5.2.

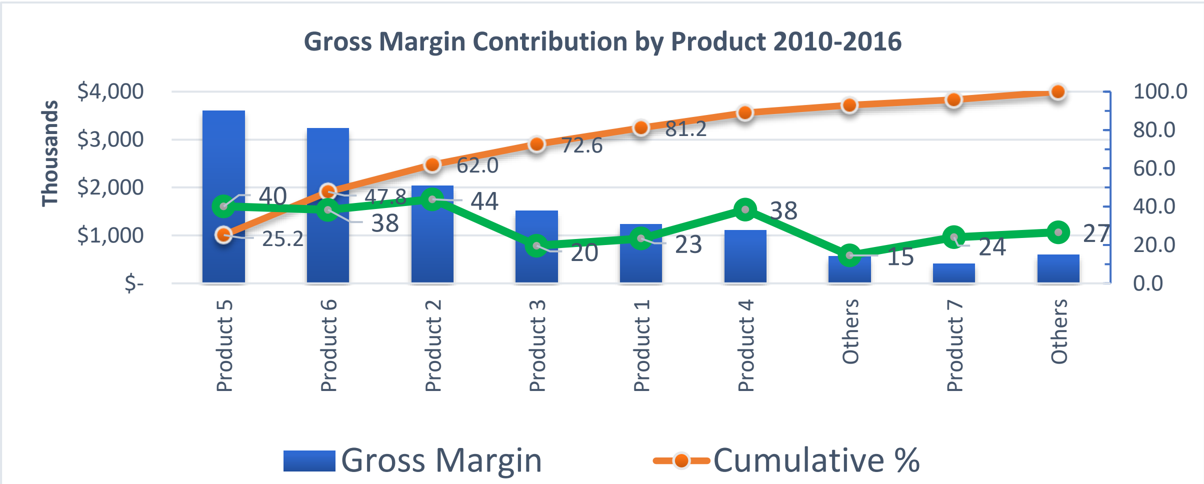



Figure5. 2: Gross margin & Gross profit margin by product 2010-2016

This ratio is based on the company's net sales because the company's sales are the most important aspect of its operation. Sales make a profit, and there can be no profit without sales.

## 5.2. Labour Efficiency Analysis

As explained, efficiency is measured by dividing an actual output rate by the standard output rate and multiplying the outcome by 100 per cent. The standard output rate in precast concrete companies is the volume of work produced per unit of time (Prokopenko, 1987; Shaaban, 2010; shmula, 2007).

For this case study, the researcher investigated every product's labour efficiency from 2010 to 2016. To measure labour efficiency, the researcher extracted the recorded costs of every product produced during that period. Using the labour cost and actual production for each year, this study was able to calculate the actual labour efficiency of all products, as shown using the equation below.

$$\text{Labour efficiency} = \frac{\text{Labour cost (NZD)}}{\text{Production (Lm)}}$$

The lower the labour cost, the more efficient the operation

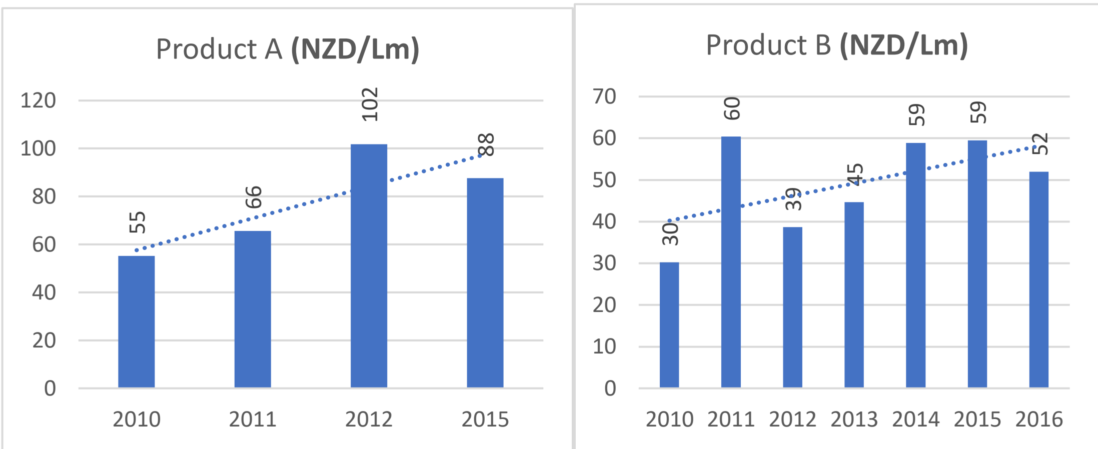



Figure5. 3: Product A & B Labour $/metres

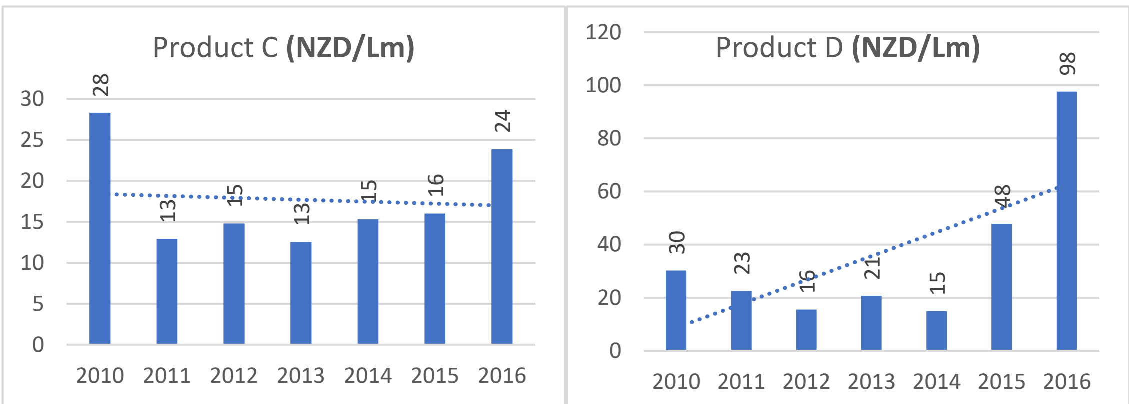


Figure5. 4: Product C & D Labour $/metres

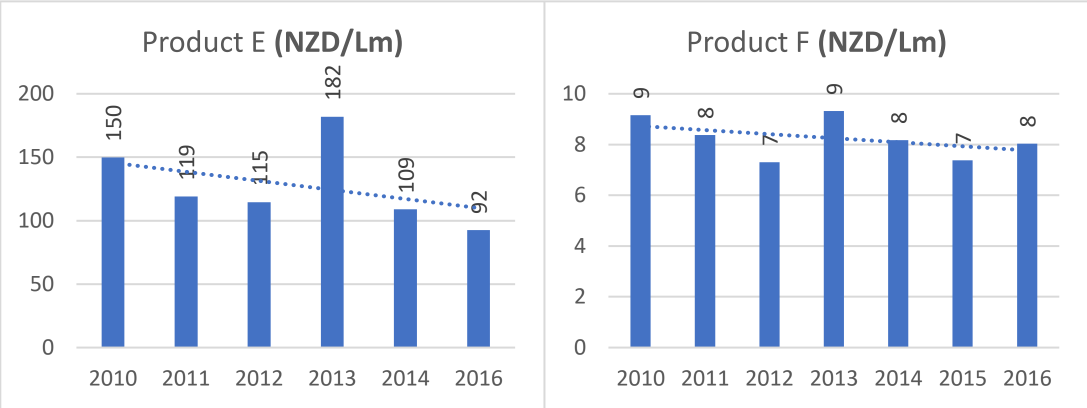



Figure5. 5: Product E & F Labour $/metres

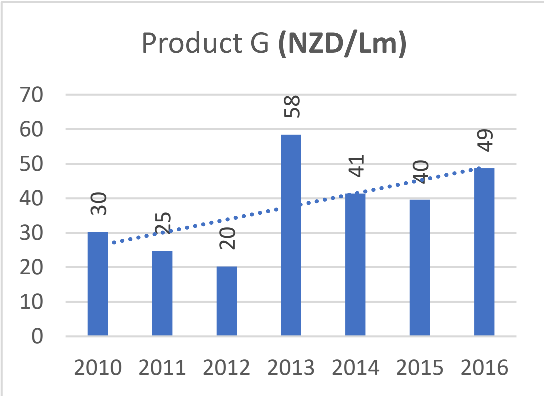



Figure5. 6: Product G Labour $/metres

Figure 5.3 shows that Product A achieved its greatest labour efficiency in 2010 by spending $55/metre and the lowest efficiency in 2012 by spending $102/metre of product. For the last seven years, the trendline shows the increasing labour cost per metre of product. Product B achieved its highest labour efficiency in 2010 and the lowest efficiencies in 2011, 2014, and 2015.

Figure 5.4 shows that Product C achieved its highest labour efficiency at $13/metre in 2011/2013 and the lowest efficiency, at $28/metre, in 2010. The low labour efficiency of this product in 2010 will be investigated in further studies. Product D achieved the highest labour efficiency in 2012/2014 and the lowest in 2016, with $98/metre of production.

Figure 5. shows that Product E achieved the highest labour efficiency in 2016 and the lowest in 2013. Also, Product F achieved the highest labour efficiency in 2012/2015 and the lowest in 2010/2013 with $9 /metre of production.

Figure 5.6 shows that Product G achieved the highest labour efficiency of $20/metre in 2012 and the lowest efficiency, at $58/metre, in 2013.

In conclusion, the labour efficiencies of all of the products had changed over the years. Although the labour cost of products A, B, D and G has an increasing trend, this cost shows a decreasing trend for products C, E and F. According to the table below, product F has the lowest labour cost, and product E has the maximum.

Table5. 1: Labour Efficiency Summaries

| Products | Most labour-efficient year | Least labour-efficient year |
|---|---|---|
| A | 2010 (55$) | 2012 (102$) |
| B | 2010 (30$) | 2011 (60$) |
| C | 2011,2013 (13$) | 2010 (28$) |
| D | 2014 (15$) | 2016 (98$) |
| E | 2016(92$) | 2013 (182$) |
| F | 2012,2015 (7$) | 2010,2013 (9$) |
| G | 2012 (20$) | 2013 (58$) |

## 5.3. Market demand and sales

The higher the market demand and product revenue, the better the investment. It has been forecast that market demand for product B will gradually increase for the next five years to reach the maximum of 153,231m2 demand in 2023. Also, the market demand for product F steadily moves to 231,744 metres in 2023. Product E is one of the most profitable products of the case study, and through its future demand, the profitability will be increased. This study shows that the market demand will gradually increase to more than 10,000 metres in 2023. There will be increasing market demand, forecast to reach 153,000 metres, for Product C in 2023. The trend line of market demand for Product G is gradually decreasing, which means the market may not be interested in this product in future. In summary, the market demand for all products except Product G is increasing. Market attractiveness analysis of the products is therefore required to be measured.

Figure 5.7 compares the market demand for all seven products in the case study versus their maximum capacity.

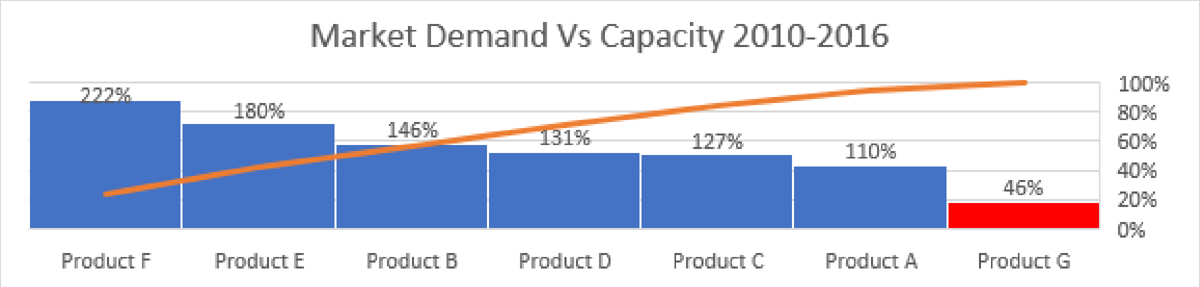



Figure5. 7: Product Market Demand vs their Capacity during 2010 and 2016

Figure 5.7 shows that the market demand for six products (A, B, C, D, E and F) was more than 100% of their maximum capacity, meaning that there was enough opportunity in the market to fill in the full capacity of the entire product lines. Market demand was forecast to be high enough to fill the plant's total capacity for all the products except product G.

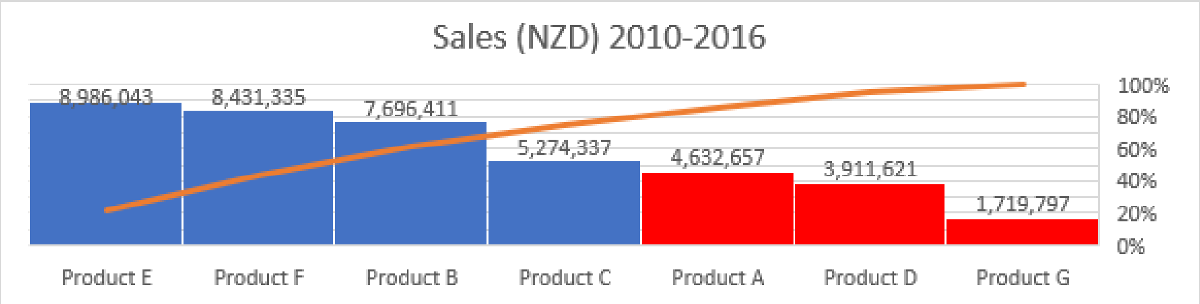



Figure5. 8: Product Sales during 2010 and 2016

## 5.4. Labour cost contribution

As in the table below, the labour cost contribution was measured by dividing the actual labour cost of each product versus their total generated sales value.

Table5. 2: Labour cost contribution

| | Products | Total Labour Cost $ | Total Sales $ | Labour Cost contribution |
|---|---|---|---|---|
| DHC | Product A | $364,583 | $4,632,658 | 8% |
| TEE | Product B | $1,550,124 | $7,696,411 | 20% |
| FS | Product C | $1,145,691 | $5,274,337 | 22% |
| HC | Product D | $667,037 | $3,911,623 | 17% |
| SUP | Product E | $834,583 | $8,986,044 | 9% |
| RIB | Product F | $991,557 | $8,431,336 | 12% |
| SHB | Product G | $463,710 | $1,719,798 | 27% |

Product G had the highest labour cost contribution in this case study, and product A the lowest.

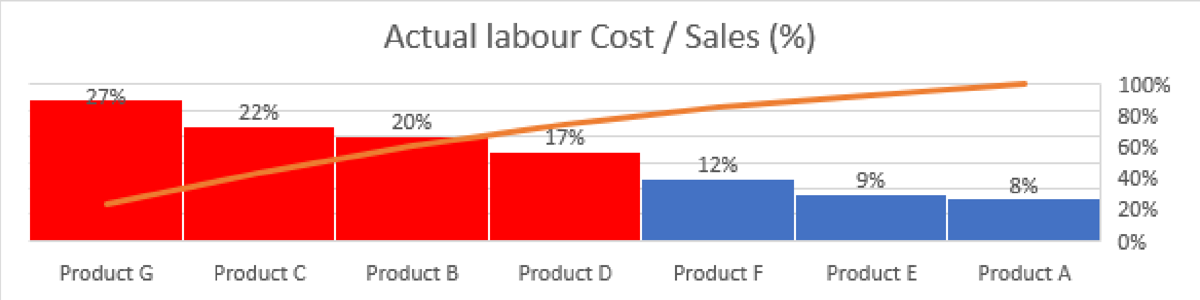



Figure5. 9: Actual labour cost of products divided by their sales (%) during 2010 and 2016

## 5.5. Market Attractiveness

The market attractiveness of each product relies on different parameters, such as a change in design, sale price, planning, competitors, client's requirements, contractual wordings, and in some cases, reputation in the precast market. This study gathered all of the required historical data to measure the market attractiveness of products in the current precast concrete plant from January 2009 to December 2017.

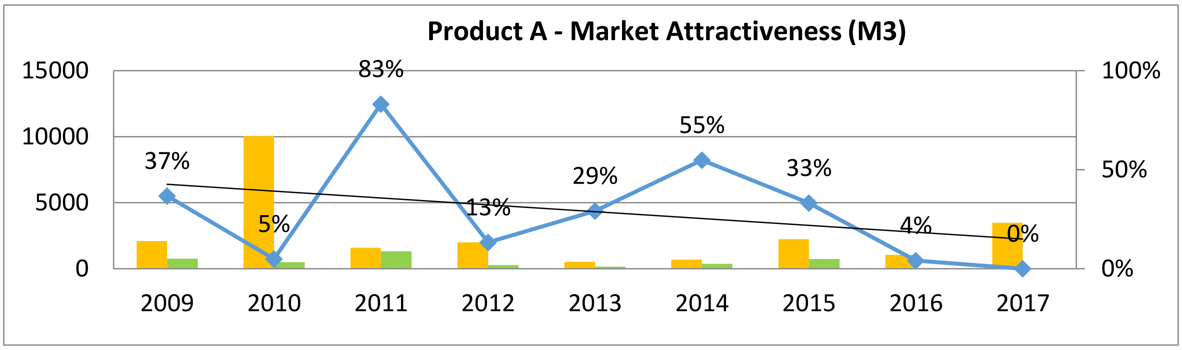



Figure5. 10: Product A–- Market Attractiveness

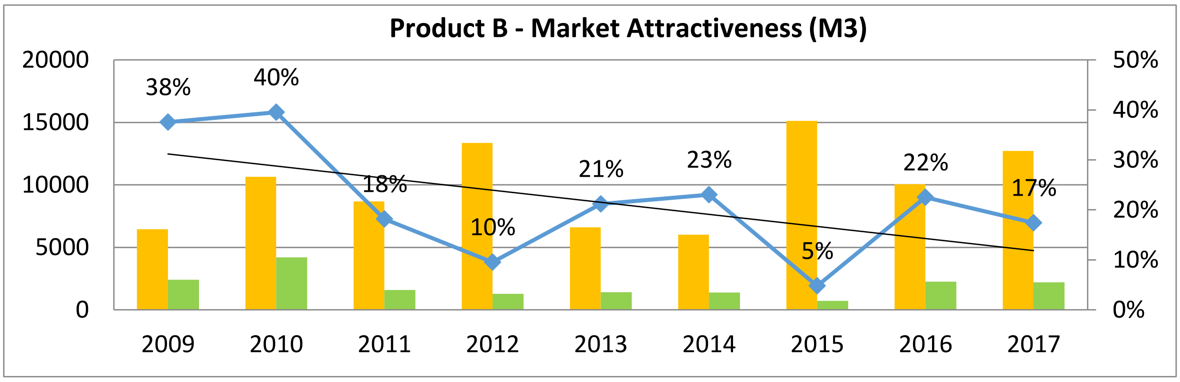



Figure5. 11: Product B–- Market Attractiveness

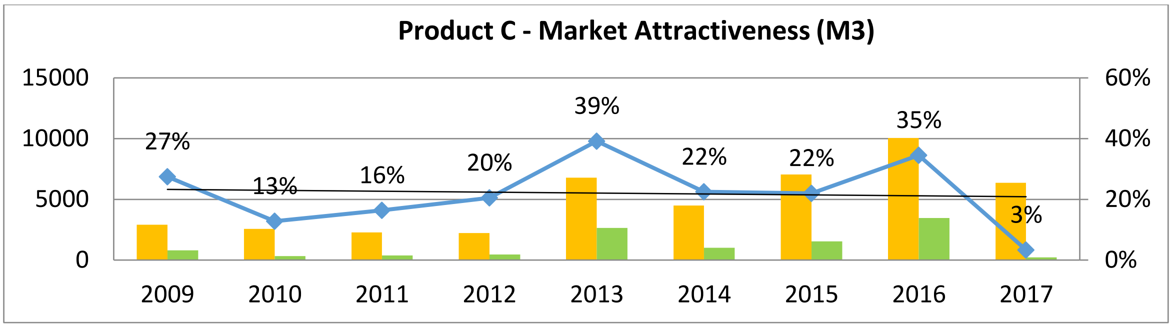



Figure5. 12: Product C–- Market Attractiveness

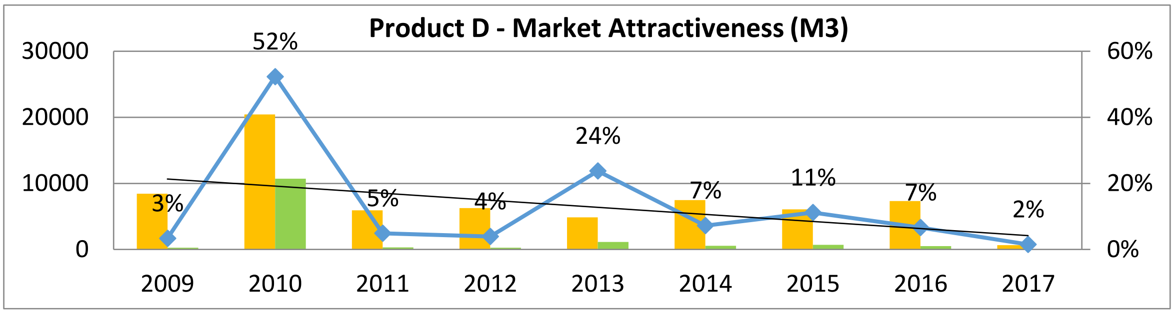



Figure5. 13: Product D–- Market Attractiveness

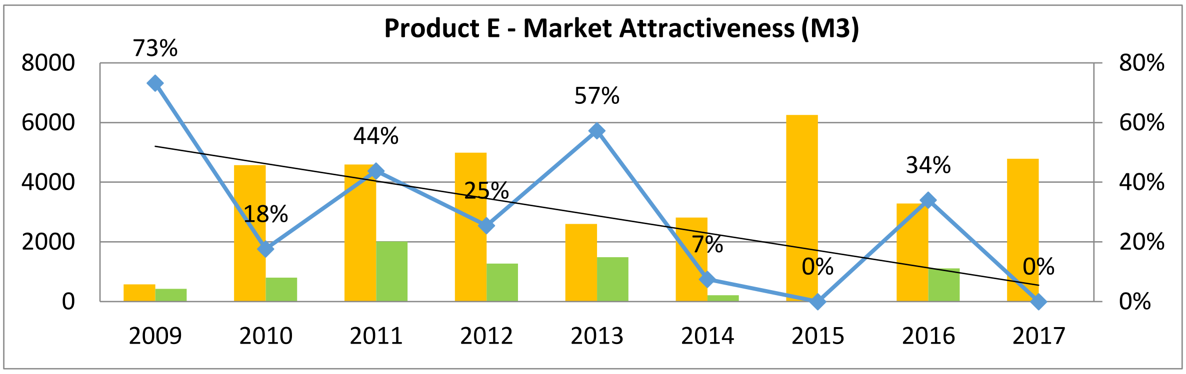



Figure5. 14: Product E–- Market Attractiveness

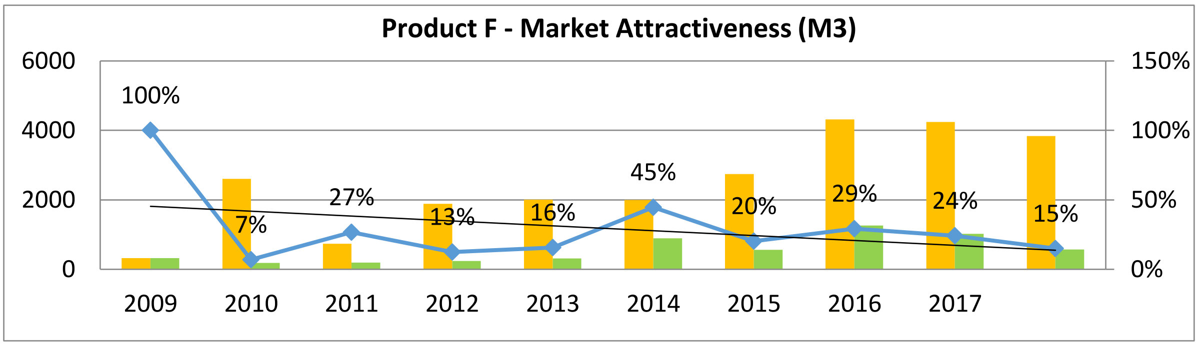



Figure5. 15: Product F–- Market Attractiveness

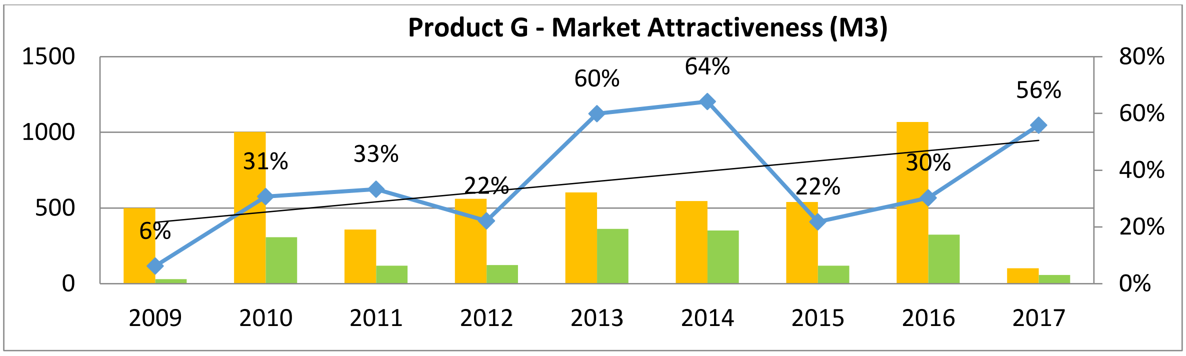



Figure5. 16: Product G–- Market Attractiveness

Product A was at its maximum market attractiveness of 83% in 2011 and zero in 2017. The trendline shows that the attractiveness rate was gradually decreasing from 2009 to 2017. Product B was at its maximum market attractiveness of 40% in 2010 and 5% in 2015. The trendline also shows the attractiveness rate gradually decreasing from 2009 to 2017. Product C was at a maximum market attractiveness of 39% in 2013 and a minimum of 3% in 2017. The trendline shows that the attractiveness rate was steadily flat from 2009 to 2017. Product D was at a maximum market attractiveness of 52% in 2010 and a minimum of 2% in 2017. The trendline shows that the attractiveness rate gradually decreased from 2009 to 2017. Product E was at its maximum market attractiveness of 57% in 2013 and a minimum of zero in 2015 and 2017. The trendline shows the attractiveness rate gradually decreasing from 2009 to 2017. Product F was at its maximum market attractiveness of 45% in 2013 and a minimum of 7% in 2009. The trendline shows the attractiveness rate gradually increasing from 2009 to 2017. Product G was at its maximum market attractiveness of 64% in 2014 and a minimum of 6% in 2009. The trendline shows the attractiveness rate gradually increasing from 2009 to 2017.

Figure 5.17 summarises the overall market attractiveness of the seven products in the case study. As can be observed, product E overall showed the best attractiveness of 34% and product A had the lowest attractiveness of 18% from 2009 to 2017.

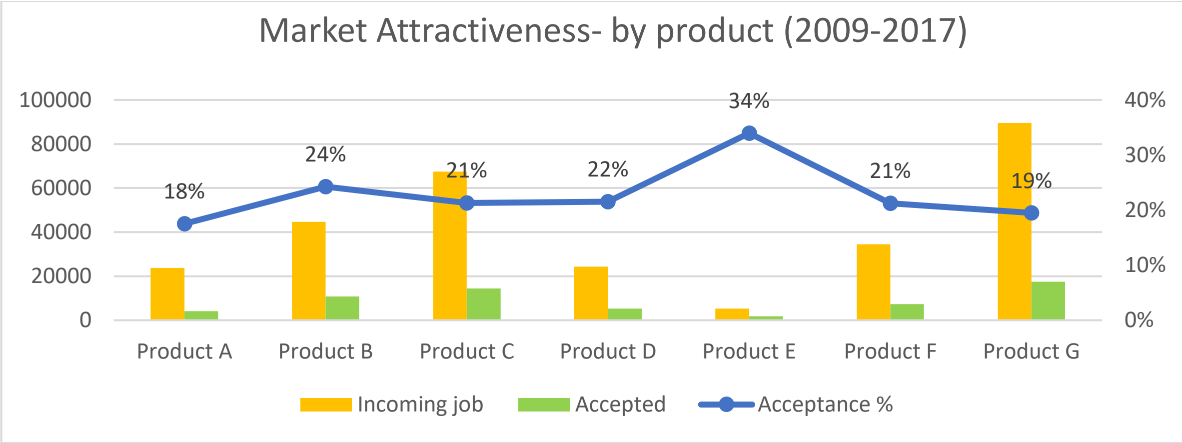



Figure5. 17: Market Attractiveness of 7 products from 2009 to 2017

Product A has a minimum attractiveness rate of 18% between 2009 and 2017, and product E has 34%. The overall market attractiveness is acceptable compared to the average market practice, which is 20-25%. The researcher will investigate some products with the lowest and highest attractiveness rates in future studies to determine the causes and their influences on the company's profit.

## 5.6. Sales forecasting

Forecasting is the process of estimating or predicting the future. Forecasting aims to provide reliable estimates of future business that will assist management in making accurate decisions and producing sound plans for the future. Forecasting deals with the future, so the range of errors in forecasting can be broad, no matter how efficient the forecasting system is. Nevertheless, better quality information ensures greater accuracy in the forecasting process. A company must decide whether and how to forecast most accurately and economically, because long-term plans, production plans and master schedules are based on sales forecasting. Materials are ordered, and personnel are employed for the expected sales pattern for the next period. The general demand for construction influences sales of precast concrete building products. This demand is subject to substantial fluctuations caused by such diverse factors as capital spending by government, the general strength of the economy, the demand for housing – which reflects mortgage interest rates – and seasonal factors and weather. This list conveys the difficulties associated with sales forecasting in the precast concrete industry. Sales forecasting is nonetheless an essential and crucial managerial practice, and its accuracy is vital for any company and business's survival (N. N. Dawood & Neale, 1993).

The table below shows the products quoted and cast by the case study company from 2008 to 2017.

Table5. 3: Case study's tendered and accepted jobs (2008-2017)

| Year | Product B (m) | | Product C (m2) | | Product D (m2) | | Product E (m) | | Product F (m) | | Product G (m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quoted | Accepted | | | | | | | | | | |
| 2008 | 36,653 | 100% | 13,280 | 100% | 9,506 | 100% | 1,971 | 100% | 14,573 | 100% | 8,304 | 100% |
| 2009 | 55,192 | 30% | 35,193 | 27% | 69,578 | 32% | 906 | 72% | 87,886 | 10% | 4,907 | 7% |
| 2010 | 87,131 | 34% | 25,078 | 14% | 141,562 | 44% | 7,297 | 19% | 28,991 | 27% | 9,823 | 26% |
| 2011 | 84,652 | 16% | 28,656 | 16% | 43,950 | 11% | 7,246 | 43% | 58,679 | 17% | 3,664 | 36% |
| 2012 | 35,732 | 35% | 27,745 | 21% | 49,582 | 8% | 7,702 | 25% | 67,134 | 18% | 5,751 | 22% |
| 2013 | 64,898 | 20% | 80,261 | 39% | 35,625 | 22% | 3,997 | 57% | 68,138 | 42% | 6,203 | 57% |
| 2014 | 51,313 | 26% | 50,440 | 26% | 55,530 | 18% | 4,504 | 7% | 95,585 | 19% | 5,098 | 61% |
| 2015 | 141,545 | 5% | 82,217 | 23% | 48,151 | 9% | 9,716 | 0% | 43,514 | 101% | 5,665 | 24% |
| 2016 | 94,068 | 24% | 122,796 | 36% | 54,761 | 8% | 5,599 | 34% | 144,313 | 24% | 11,138 | 29% |
| 2017 | 118,447 | 19% | 71,376 | 4% | 5,902 | 2% | 7,353 | 0% | 125,689 | 13% | 990 | 51% |
| **Total** | **769,631** | **24%** | **537,042** | **27%** | **514,147** | **25%** | **56,291** | **24%** | **734,502** | **27%** | **61,543** | **41%** |

A forecasting model has been developed to analyse historical data and forecast demand for another five years. Some forecasting methods were applied to historical data for six groups of products of a major manufacturer (the case study). A significant difficulty is the period of the forecast. It should be at least five years ahead because of the plant automation strategy, which relies on accurate forecasting.

As mentioned, this study uses historical data to build models based on mathematics and mathematical statistics methods, consisting of fitting a mathematical trend line or curve to time series data, which are then extrapolated into the future. In calculating or predicting a future value using a current value, the predicted value is a y-value for a given x-value. The known values are existing x-values and y-values, and the new value is predicted using linear regression. This function can be used to predict future sales or inventory requirements. This study uses all of the collected data from table 5.3 and the Microsoft Excel Forecast Linear formula to create figures 5.18(a-f), the forecast demand for six groups of products.

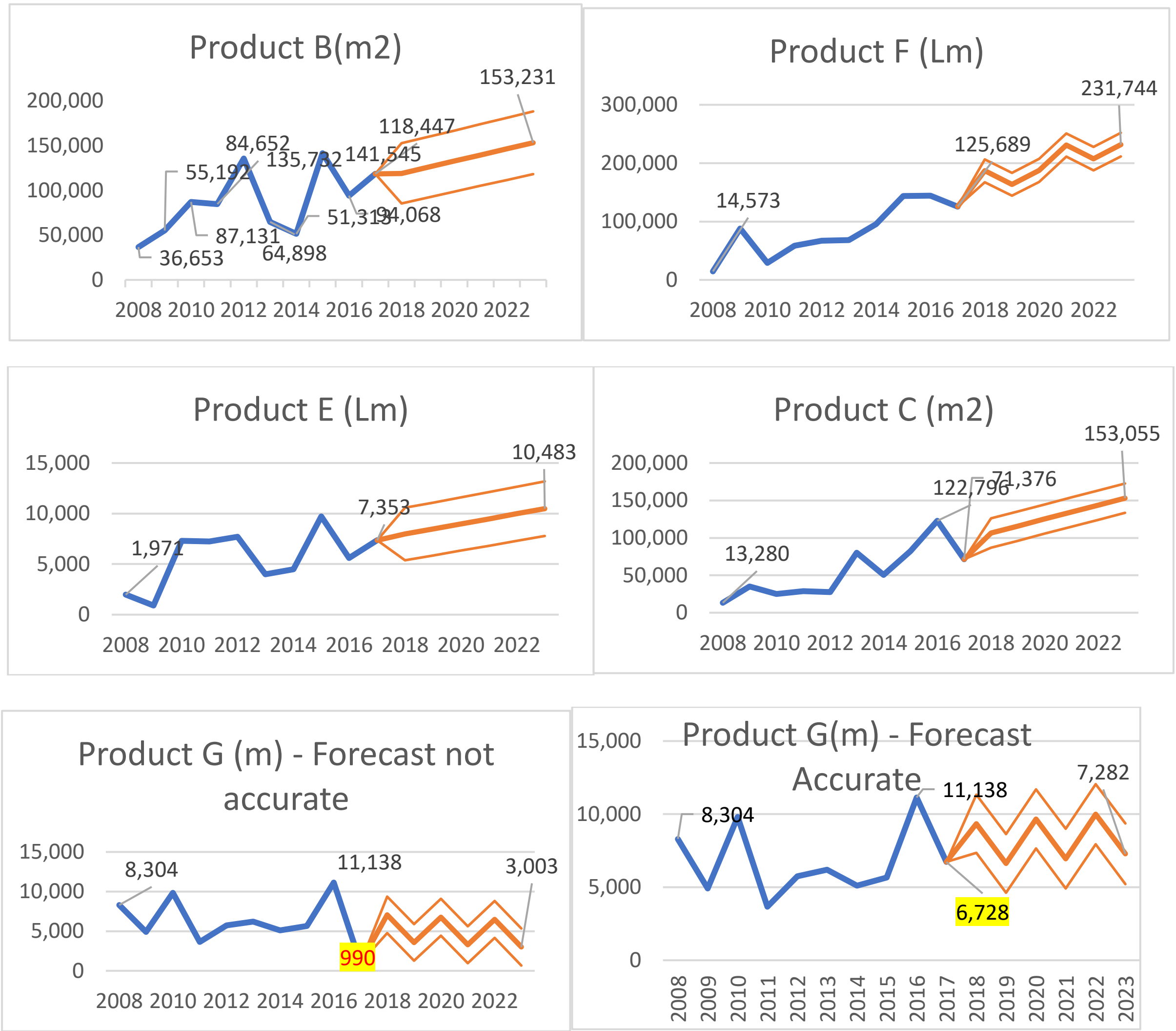



Figure5. 18 (a-f): Demand 2008-2017 & forecast for the next five years

Product B showed a minimum demand of 36,653m2 in 2008 and a maximum demand of 141,545m2 in 2015. It has been forecast that the trend will gradually increase for the next five years to reach the maximum of 153,231m2 demand in 2023.

Demand for Product F has been increasing since 2008. Figure 5.18(b) shows the minimum demand of 14,573Lm in 2008 and the maximum 125,689Lm in 2017. The trend steadily moves the demands to 231,744Lm in 2023.

Product E is one of the most profitable products of the case study, and by achieving sufficient future demand, the profitability will be increased. Figure 5.1l) shows that the trend will gradually increase to more than 10,000Lm in 2023.

Product C showed a minimum demand of 13,280m2 in 2008 and a maximum of 122,796m2 in 2016. Figure 5.18(d) shows the increasing trend from 2008 to 2023. It has been forecast that this demand will reach 153,000m2 in 2023.

Product G becomes one of the questionable products in this case study. According to the branch manager's information, the management had decided that because of the low profitability, no new orders were accepted for this product from 2017. Therefore, 5.18(e) is not accurate. To find accurate data, the researcher decided to remove the biased data and forecast a new data set, as shown in figure 5.18(f). This figure shows the new forecast by the new data set used in 2017 to solve the bias data. As can be observed, the trend is slowly increasing to reach 7,282m in 2023.

The chart below shows the summary of sales forecasting 5 years ahead for all seven products.

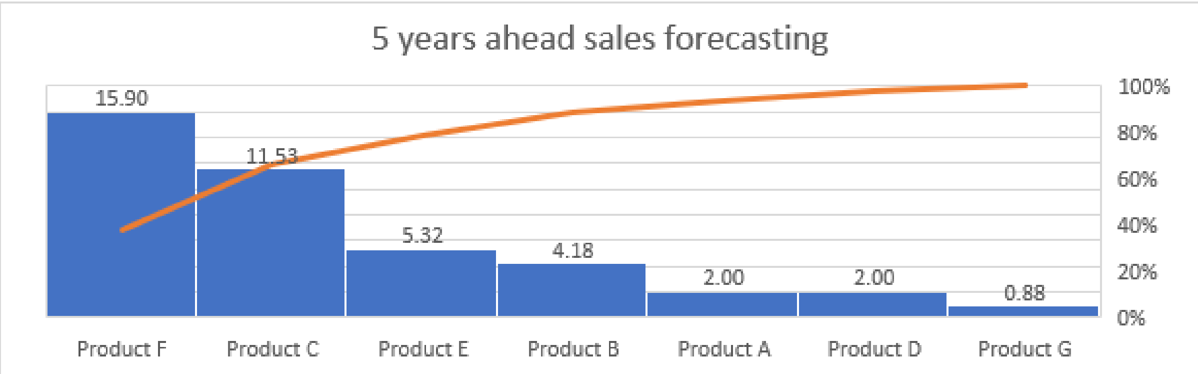



Figure5. 19: sales forecasting 5 years ahead

As can be observed, the future demand for all products except product G increases. This five-year projection gives researchers confidence that this industry will have sufficient market demand in the future.

## 5.7. Plant Utilisation

Pareto Analysis is a statistical technique used in decision-making to select a limited number of tasks that produce a significant overall effect. To define this concentration, we followed the lead of Vilfredo Pareto, who, over 100 years ago, observed that 80%‘of 'effects' derive from 20%‘of 'sources' (Caspi et al., 2017).

The researcher collected the required historical data to analyse profitability within the case study company. The annual production data was extracted from the daily casting sheets for each product. The most effective years, which showed 80% utilisation of the whole plant, have been identified using the Pareto analysing method during the last seven years.

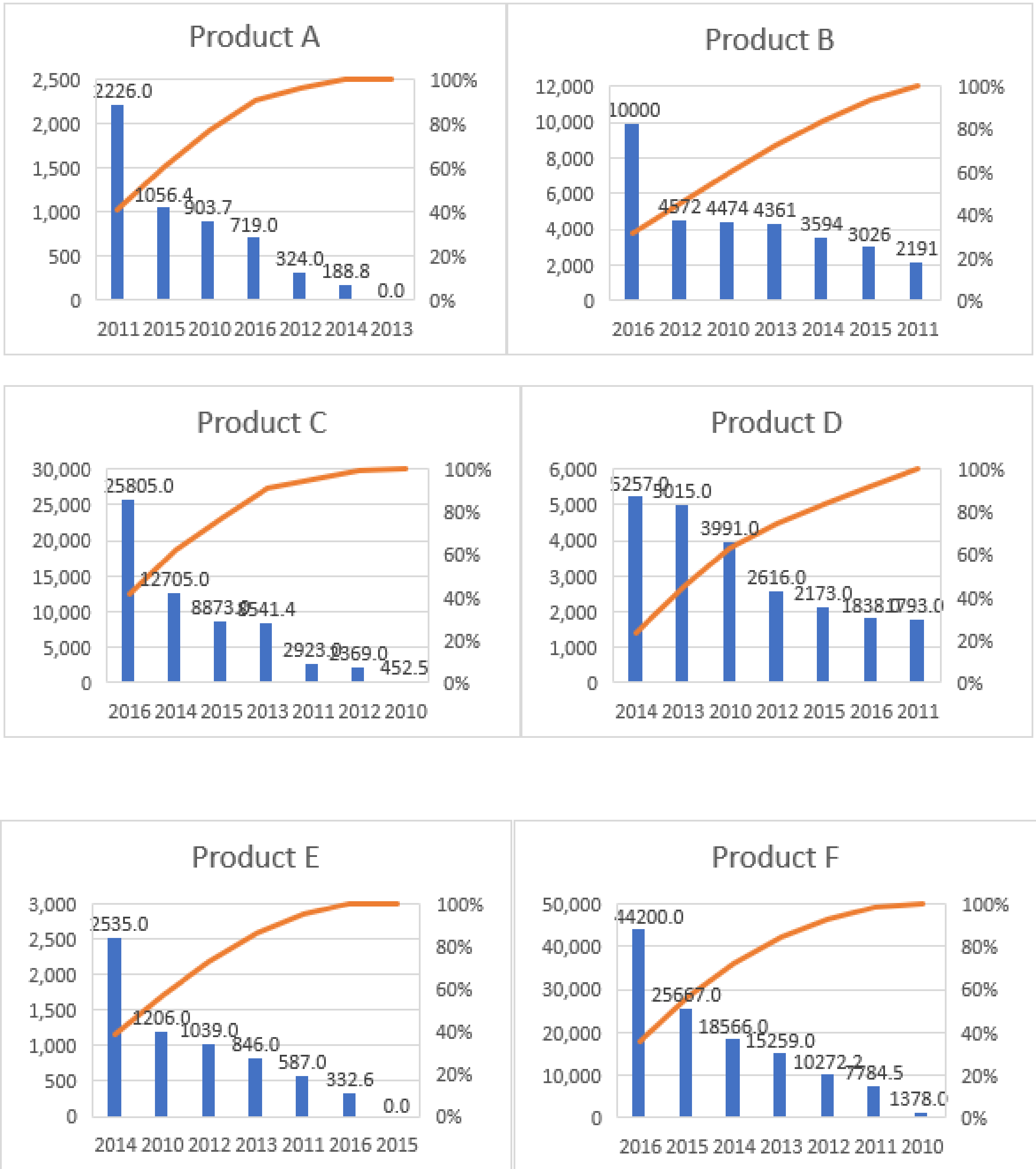



Figure5. 20: Linear Metres Production

### 5.7.1. **Product A**

Product A shows a maximum capacity of 3,660 linear metres per year. Capacity: (30 Lm per day *244 casting days per year) * 0.5 = 3,660 Lm/Yr.

Figure 5-20(a) shows the production of Product A. It had the lowest production in 2013, with zero casts, and maximum production in 2011, with 2,226 Lm of products. According to the Pareto analysis, this product had 80% of its production in 2010, 2011 and 2015. As the maximum capacity of the company is 3,660 Lm/Yr, statistically, the lowest utilisation of Product A was in 2014, and it is $\frac{188.8}{3660}$ =5.16%, which is extremely low. Additionally, the average utilisation of this product over the last seven years was 21.15%, which is also very low.

$$\text{Average utilisation } = \frac{\frac{(2226+1054+903+719+324+189+0)}{7} = 774}{3660} = 21.15\%$$

### 5.7.2. **Product B**

Product B has a maximum capacity of 26,860 linear metres per year. Capacity: 2 Number of Moulds * (55 Lm per day *244 casting days per year) = 26,860 Lm/Yr.

Figure 5-2 (b) shows Product B production. It had the lowest production in 2011, with 2191 Lm produced, and maximum production in 2016, with 10,000 Lm of products. According to the Pareto analysis, this product had about 80% of its utilisation in 2010, 2012, 2013 and 2016. As the maximum capacity of the company is 26860 Lm/Yr, statistically, the minimum utilisation of Product B is $\frac{2191}{26860}$ =8.16%, which is extremely low. The average utilisation of this product, according to the formula below, was 17% over the last seven years which is very low.

$$\text{Average utilisation} = \frac{\frac{(10000+4572+4474+4361+3594+3026+2191)}{7} = 4602}{26860} = 17\%$$

### 5.7.3. **Product C**

Product C has a maximum capacity of 78,080 linear metres per year. Capacity: 2 Number of Moulds * (160 Lm per day *244 casting days per year) = 78,080 Lm/Yr

Figure 5-2 (c) shows Product C production. It had the lowest production in 2010, with 452 Lm produced, and maximum production in 2016, with 25,805 Lm of products. According to the Pareto analysis, this product had about 80% of its utilisation in 2016, 2014 and 2015. As the maximum capacity of the company is 78,080 Lm/Yr, statistically, the minimum utilisation of Product C is $\frac{452}{78080}$ =0.58%, which is extremely low. The average utilisation of this product, according to the formula below, was 11.3% during the last seven years which is very low.

$$\text{Average utilisation} = \frac{\frac{(25805+12705+8873+8541+2923+2369+452)}{7}=8810}{78080} = 11.3\%$$

### 5.7.4. **Product D**

Product D has a maximum capacity of 39,040 linear metres per year. Capacity: 2 Number of Moulds * (160 Lm per day *244 casting days per year) * 0.5 = 39,040 Lm/Yr

Figure 5-2 (d) shows Product D production. It had the lowest production in 2011, with 1793 Lm produced, and maximum production in 2014, with 5257 Lm of products. According to the Pareto analysis, this product had about 80% of its utilisation in 2014, 2013, 2010 and 2012. As the maximum capacity of the company is 39,040 Lm/Yr, statistically, the minimum utilisation of 'Product D' is $\frac{1793}{39040}$ =4.6 %, which is low. The average utilisation of this product, according to the formula below, was 8.3%, during the last seven years which is also low.

$$\text{Average utilisation} = \text{is } \frac{\frac{(5257+5015+3991+2616+2173+1838+1793)}{7}=3240}{39040} = 8.3\%$$

### 5.7.5. **Product E**

Product E has a maximum capacity of 3,660 linear metres per year. Capacity: (30 Lm per day *244 casting days per year) * 0.5 = 3,660 Lm/Yr.

Figure 5-2 (e) shows Product E production. It had the lowest production in 2015, with zero production, and maximum production in 2014, with 2535 Lm of products. According to the Pareto analysis, this product had about 80% of its utilisation in 2014, 2010, 2012 and 2013. As the maximum capacity of the company is 3,660 Lm/Yr, statistically the minimum utilisation of Product E is $\frac{332}{3660}$ =9.1%, which is extremely low. The average utilisation of this product, according to the formula below is 25.5% during the last seven years, which is very low.

$$\text{Average utilisation} = \frac{\frac{(2535+1206+1039+846+587+332+0)}{7}=935}{3660} = 25.5\%$$

### 5.7.6. **Product F**

Product F has a maximum capacity of 43,920 linear metres per year. Capacity: (180 Lm per day *244 casting days per year) = 43,920 Lm/Yr

Figure 5-2 (f) shows Product F production. It had the lowest production in 2010, 1378 Lm, and the maximum production in 2016, 44200 Lm. According to the Pareto analysis, this product had about 80% of its utilisation in 2016, 2015 and 2014. As the maximum capacity of the company is 43,920 Lm/Yr, statistically, the minimum utilisation of Product F is $\frac{1378}{43920}$ =3.13%, which is extremely low. The average utilisation of this product, according to the formula below, is 40% during the last seven years which is low.

$$\text{Average utilisation} = \frac{\frac{(44200+25667+18566+15259+10272+7784+1378)}{7}=17589}{44200} = 40\%$$

### 5.7.7. **Summary**

In summary, product D had the lowest utilisation level of 8.3% during those seven years, and product F had the highest level of 40%. The highest utilisation level of product D is lower than all other products. That means product D had the lowest plant utilisation. All six products had a utilisation level of less than 41%. Thus, the case study company's plant utilisation was less than 41% during the last seven years.

Table5. 4: Plant utilisation summaries

| Products | Maximum Capacity | Lowest utilisation year | Highest utilisation year | Average utilisation | 80% of utilisation |
|---|---|---|---|---|---|
| A | 3,660 | 2014 (189) 5.16% | 2011 (2,226) 61% | 21.15% | 2010, 2011, 2015 |
| B | 26,860 | 2011 (2191) 8.16% | 2016 (10,000) 37% | 17% | 2010,2012,2013,2016 |
| C | 78,080 | 2010 (452) 0.6% | 2016 (25,805) 33% | 11.3% | 2014,2015,2016 |
| D | 3,9040 | 2011 (1793) 4.6% | 2014 (5,257) 13.5% | 8.3% | 2010,2012,2013,2014 |

| | | | | | |
|---|---|---|---|---|---|
| E | 3,660 | 2016 (332) 9.1% | 2014 (2,535) 69 | 25.5% | 2010,2012,2013,2014 |
| F | 43,920 | 2010 (1378) 3.13% | 2016 (4,4200) 100% | 40% | 2014,2015,2016 |

## 5.8. Gross Profit Margin Analysis

The primary objective of a business undertaking is to earn profits, as profit-making is essential for its survival. Profitability analysis measures how a firm is performing to generate profits. Firm profitability is strongly influenced by internal and external variables such as the size of the organisation, liquidity management, growth of the organisation, component of costs and inflation rate (Pradhan & Das, 2016). Financial goals are becoming more important indices of a company's success. Gross margin is essential because it reflects a company's core profit before overhead costs, and it illustrates the financial success of a product or service.

There are currently many indicators proposed for assessing the financial performance of companies. Wagner (Lucato et al., 2017) has said that for a company to assess and manage its business, it must first define its performance indicators with the organisation's goal and its employees (Pradhan & Das, 2016). To meet this need, these authors recommended using the following financial performance indicators: gross margin, gross profit margin, net income, ROS (Return on Sales) and ROI (Return on Investment). Given these considerations, this research proposes to use the following financial performance indicators: gross margin, gross profit margin, and labour costs.

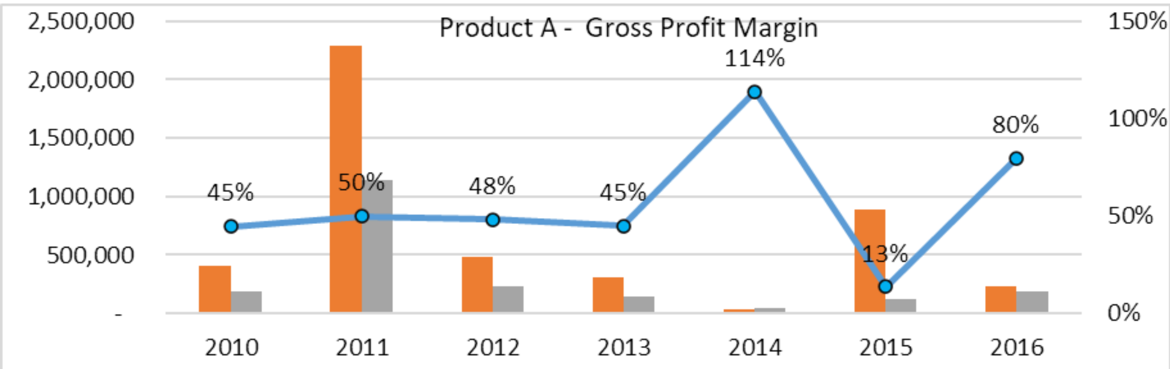
According to the literature, the gross profit margin is the gross margin of each product divided by its sales. In 1996, Osisioma defined gross profit margin as a measure of the efficiency of a 'firm's sales operations concerning the cost of goods sold. Using the gross profit figure avoids the distortion caused by non-operating costs and revenue and thus limits itself to evaluating the trading and manufacturing operations. This ratio is based on the 'firm's net sales because a 'firm's sales are its most important feature. A low gross profit margin indicates that the cost of goods is relatively too high.

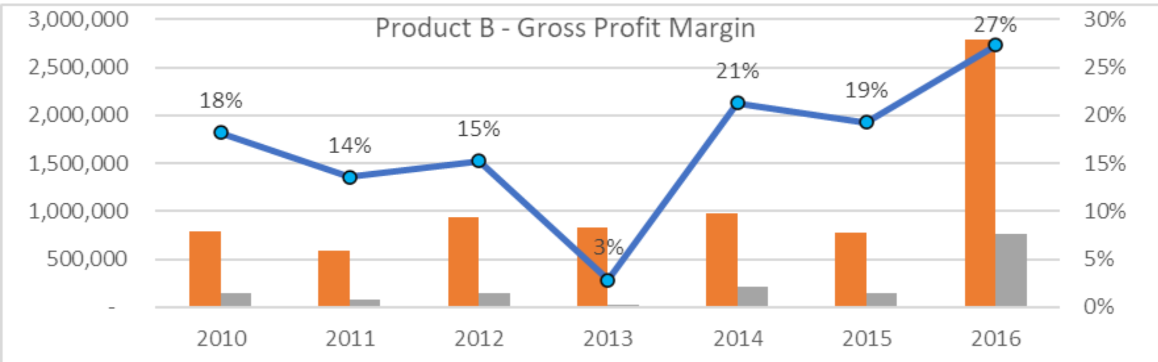
Gross profit margin = $\frac{\text{sa–es} - \text{cost of goods sold}}{\text{Sales}}$ Or $\frac{\text{Gross profit}}{\text{Sales}}$

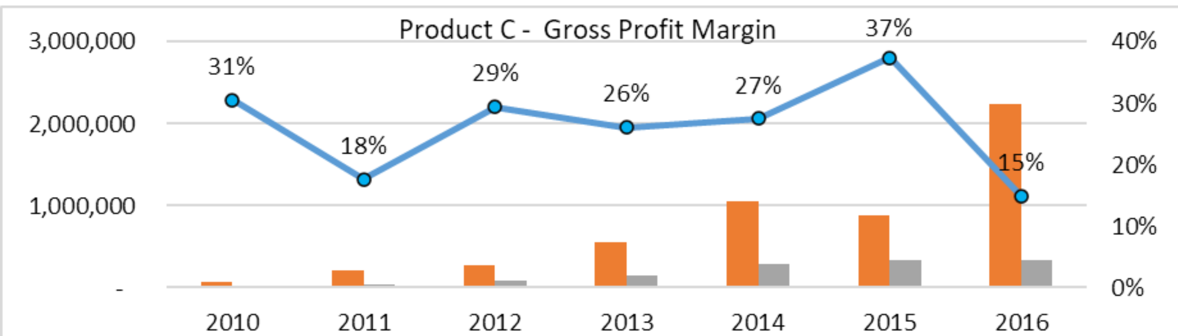
Gross profit margin measures the relative profitability of a 'firm's sales after the cost of sales has been deducted. The higher the gross profit margin the better, or the lower the relative cost of the merchandise sold (Pradhan & Das, 2016).

The researcher did not know the company's policy for the 'GPM's benchmark, so the Branch Manager and Quantity Surveyor were interviewed to discuss this. It was established that the company has different goals for gross profit margins each year according to the top management's inputs. However, 27% to 30% is the average target to achieve.

For products A to G, the gross profit margin charts for the period of 2010-2016 have been drawn as below:



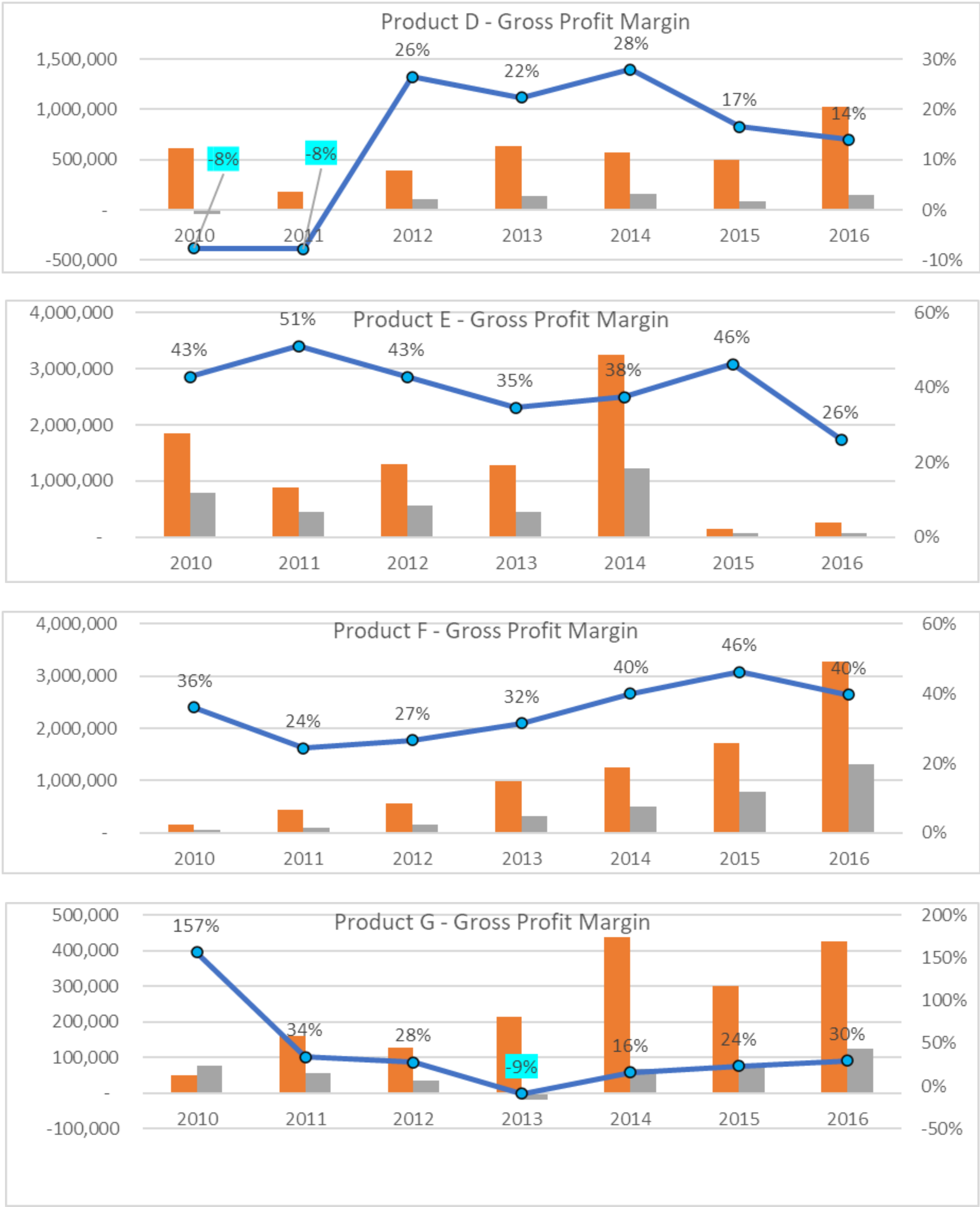



Figure5. 21: Gross profit margin (GPM)

The maximum gross profit margin (GPM) of Product A in 2014 and 2016 was 114% and 80% respectively, but the minimum was 0% and 13% in 2017 and 2015. This figure showed that in 2015, the company did not reach the minimum GPM of 27-30% for product A. The reasons will require to be investigated in future studies.

Product B had a maximum GPM of 27% in 2016 and a minimum of 3% in 2013. As can be observed, the GPM trendline is increasing. However, the company could only reach the GPM target in 2016. Therefore, this product was not profitable enough from 2010 to 2015.

Product C showed the highest GPM of 37% in 2015 and the minimum GPM of 15% in 2016. It showed that in 2011 and 2016, the company did not reach the minimum GPM of 27-30% in product C. The reasons will be investigated in their further studies.

Product D showed a maximum GPM of 28% in 2014 and a minimum of -8% in 2010 and 2011. During 2010 and 2016 did not reach the minimum GPM of 27 to 30%, except in the year 2014. In sum, this product was not profitable enough for the company.

Over the last seven years, product E's GPM has been consistently above target, reaching 51% in 2011 and 26% in 2016.

Product F had a maximum GPM of 46% in 2015 and a minimum of 24% in 2011. During the last seven years, the GPM was always above the target, which means it was always profitable. The GPM trendline of this product is increasing.

Although Product G showed its maximum profit in 2016, with the maximum GPM of 157% in 2010 and a minimum of -9% in 2013. This product was not profitable enough from 2013 to 2015.

In conclusion, each product’s overall gross profit margin during 2010-2016 is summarised in this figure. On the one hand, Product A had a maximum GPM rate of 44%, and Product D had a minimum GPM rate of 15%, which represents how healthy they are in terms of profitability. Regarding value, Products F and E were the most profitable, and Products D and G were the least profitable products during that period.

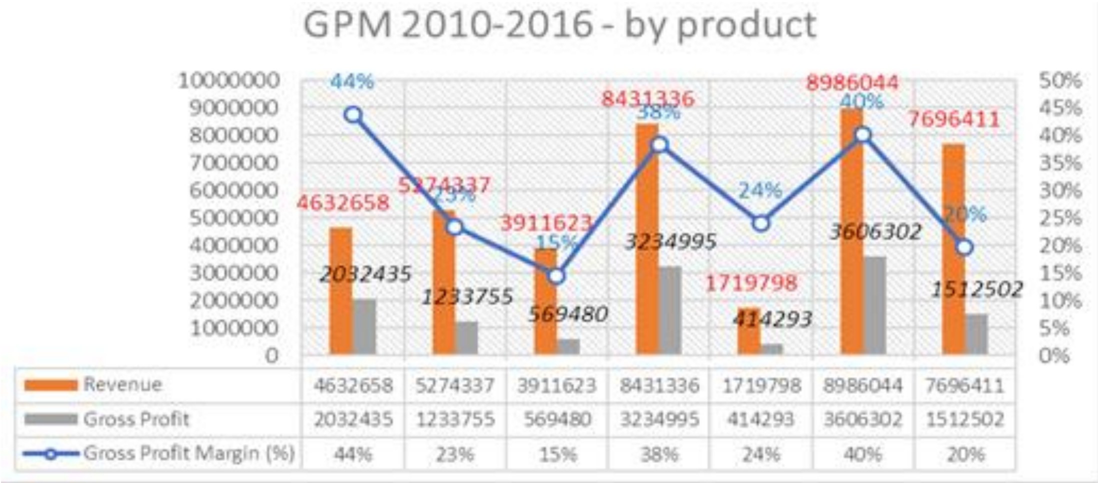



Figure5. 22: Overall Gross Profit Margin of the plant by-product during 2010-2016

Figure 5.23 shows the whole plant's investments and profits from 2010 to 2016. The table shows that revenue was highest in 2016 and there was a gross profit value of 2,951,747 NZD and 29% GPM, while 2010 had the minimum gross profit value of 1,197,84 NZD and 31% GPM.


Figure5. 23: Total GPM of the plant from 2010 to 2016

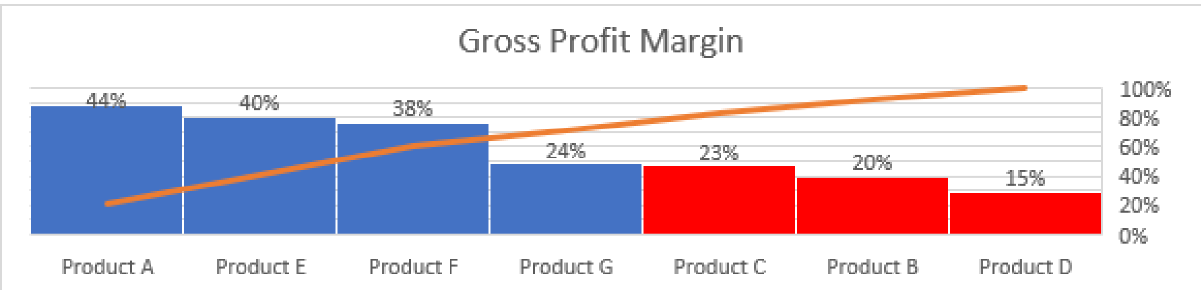



Figure5. 24: Product Gross Profit Margin during 2010 and 2016

## 5.9. Gross Margin Analysis

Pareto Analysis is used as a statistical technique in decision-making for selecting limited products that produce a significant gross margin in the case study. An analysis of the historical data in the case study has resulted in figure 5.16 (d). As shown, products A, E, F and G have 80% of the total gross from 2010 to 2016.

The core profitability gross margin is important because it reflects a company's core profit before overhead costs, and it illustrates the financial success of a product or service. Therefore, this study used the Pareto principle to illustrate the gross margin of the different products, as shown in figure 5.25. This figure shows that 80% of the gross margin of the case study company during 2010-2017 is related to four different products (E, F, A and B)

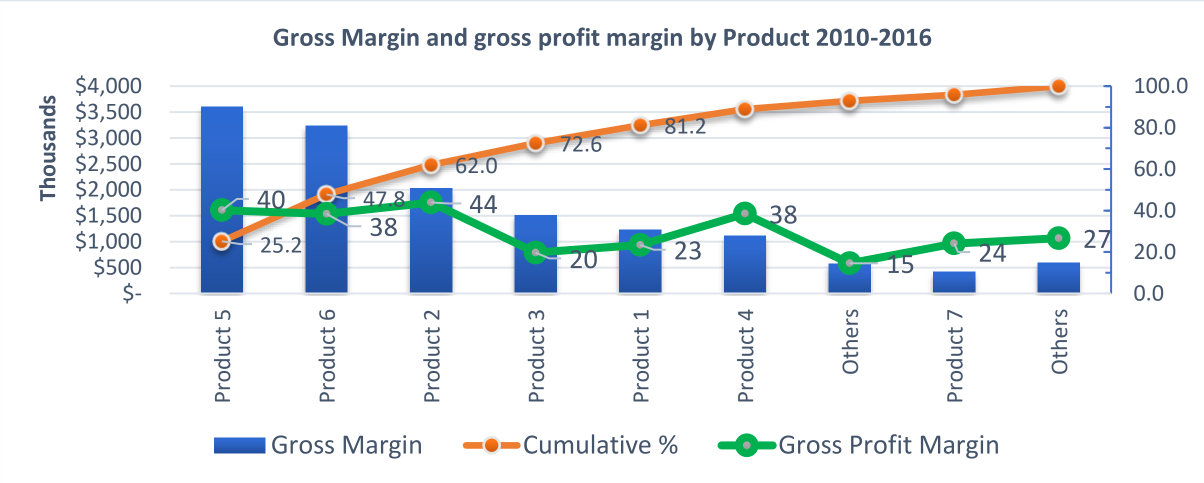



Figure5. 25: Gross margin & Gross profit margin by product 2010-2016

## 5.10. Profit Efficiency Analysis

Profit efficiency requires costs to be minimised while profits are maximised for a given level of output (Prokopenko, 1987; Shaaban, 2010; shmula, 2007). The equation below shows the profit efficiency, the gross margin divided by linear metres of production.

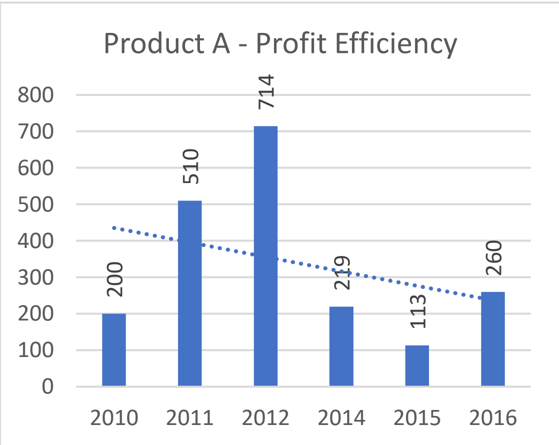
$$Profit\ efficiency\ (\frac{NZD}{LM}) = \frac{Gross\ margin}{Linear\ Meter\ production}$$

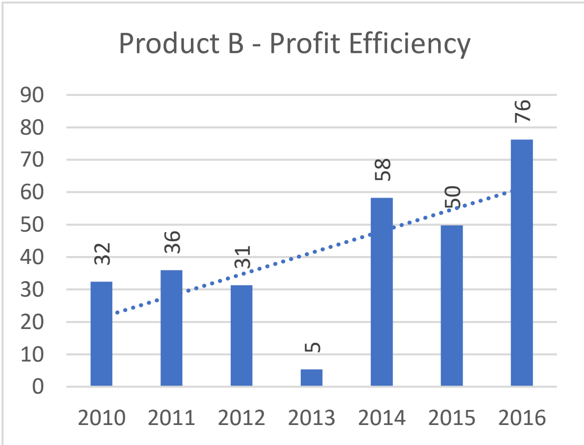
The researcher collected and calculated the required data from the financial department. The gross margin of each product was calculated and then divided by the linear metre/s of production to measure the profit efficiency of the product. The table below summarises the annual profit efficiency of each product from 2010 to 2016.

Table5. 5: Profit efficiency - by product

| Year/Product | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 2010 | 200 | 32 | 44 | -12 | 657 | 42 | 304 |
| 2011 | 510 | 36 | 13 | -8 | 771 | 14 | 48 |
| 2012 | 714 | 31 | 33 | 40 | 539 | 15 | 34 |
| 2013 | - | 5 | 17 | 28 | 530 | 20 | -13 |
| 2014 | 219 | 58 | 23 | 30 | 480 | 27 | 20 |
| 2015 | 113 | 50 | 37 | 38 | - | 31 | 40 |
| 2016 | 260 | 76 | 13 | 78 | 209 | 30 | 56 |

The profit efficiency of seven different products was investigated. According to figure 5.26, during the period 2010-2016 the profit efficiency gradually decreased for most products. The falling trends could be caused by parameters such as labour cost, wages, reducing sales price in tendering because of competition; quality issues, fluctuation, or extra expenses such as penalties due to delays or defects.



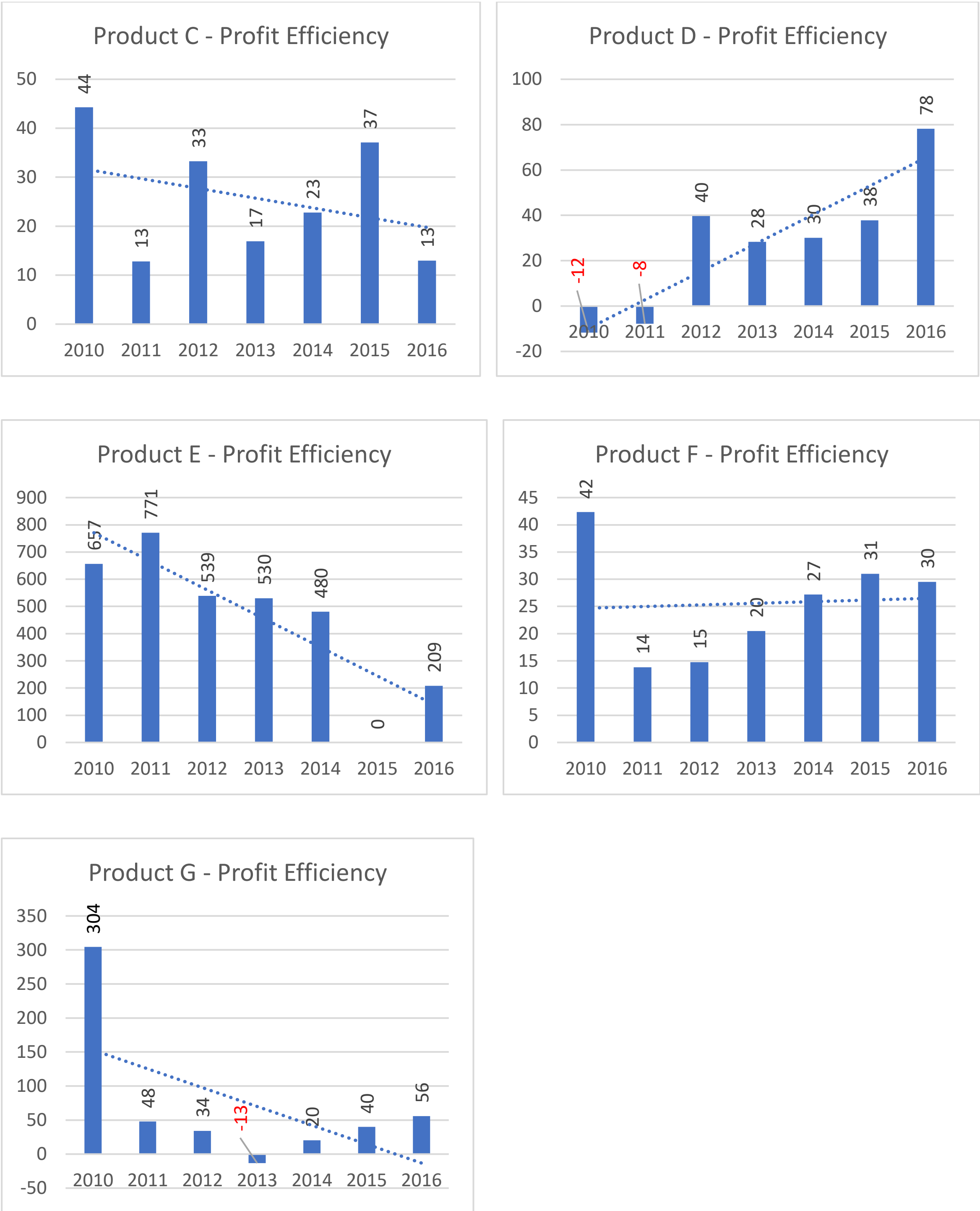



Figure5. 26: Profit Efficiency (NZD/Lm)

Product A showed maximum profit efficiency in 2012 and minimum efficiency in 2015, by 113 dollars in profit per metre of production. Product B had a maximum profit efficiency in 2016 and minimum efficiency in 2013, with $5 per metre, which is very low and will require investigation in future studies.

Product C showed a maximum profit efficiency in 2010 and minimum efficiency in 2011/2016. Product D had a maximum profit efficiency in 2016 and negative efficiencies of -12, -8 $ per metre in 2010 and 2011, which will require investigation in future studies.

Although Product E had zero production in 2015, it had a maximum profit efficiency of $771 per metre in 2011 and minimum efficiency of $209 per metre in 2016. Product F had a maximum profit efficiency of $42 per metre in 2010 and minimum efficiency of $14 per metre in 2011.

Product G had a maximum profit efficiency in 2010 and minimum efficiency in 2013, which will require investigation in future studies.

## 5.11. **Findings**

This chapter illustrates the labour efficiency, market attractiveness, sales forecasting, plant utilisation, gross profit margin, profit efficiency, and non-profitable processes of all production lines.

### 5.11.1. **Product A**

According to the Pareto analysis, Product A had 80% of its plant utilisation in 2010, 2011 and 2015. The average utilisation of this product was 21.15%, which is very low. Product A had its highest labour efficiency in 2010 and lowest efficiency in 2012. During the last seven years, the trendline shows this product's increasing labour cost per metre of production. Financially, this product had maximum profit efficiency in 2012 and minimum efficiency in 2015. This product had a maximum market attractiveness of 83% in 2011 and zero in 2017. The trendline shows that the attractiveness rate gradually decreased from 2009 to 2017, which means market attractiveness was becoming much more difficult than in previous years. Although Product A had the maximum GPM of 44% from 2010 to 2016, It could not reach the minimum GPM target in 2015.

### 5.11.2. **Product B**

Product B had the lowest plant utilisation in 2011 and the maximum in 2016. According to the Pareto analysis, this product had about 80% of its utilisation in 2010, 2012, 2013 and 2016. The average production of this product over the last seven years was 17% which is very low. This product had its highest labour efficiency in 2010 and the lowest in 2011, 2014, and 2015. Financially, this product had a maximum profit efficiency in 2016 and minimum efficiency in 2013. This product had a maximum market attractiveness of 40% in 2010 and 5% in 2015. The trendline shows the attractiveness rate gradually decreasing from 2009 to 2017, which means market attractiveness was becoming more difficult than in previous years. The GPM of product B was less than required from 2010 to 2015; therefore, this product was not profitable for the case study company during those six years.

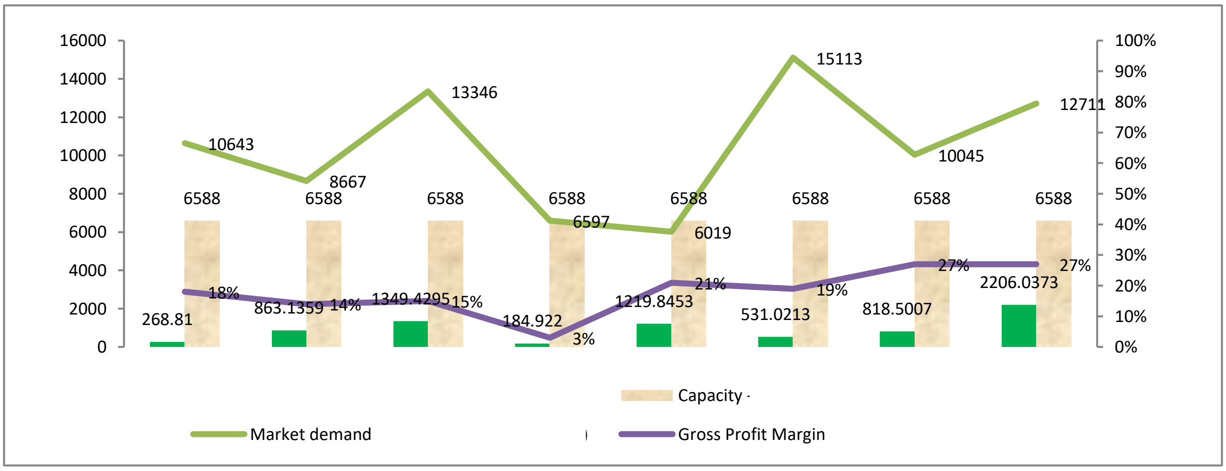



Figure5. 27: Product B productivity, capacity, market demand and gross profit margin

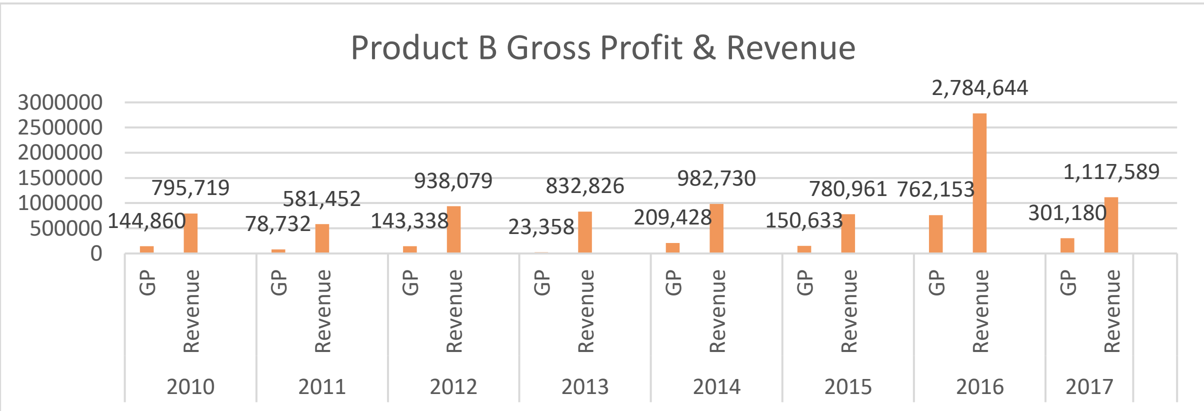



Figure5. 28: Product B Gross Profit & Revenue

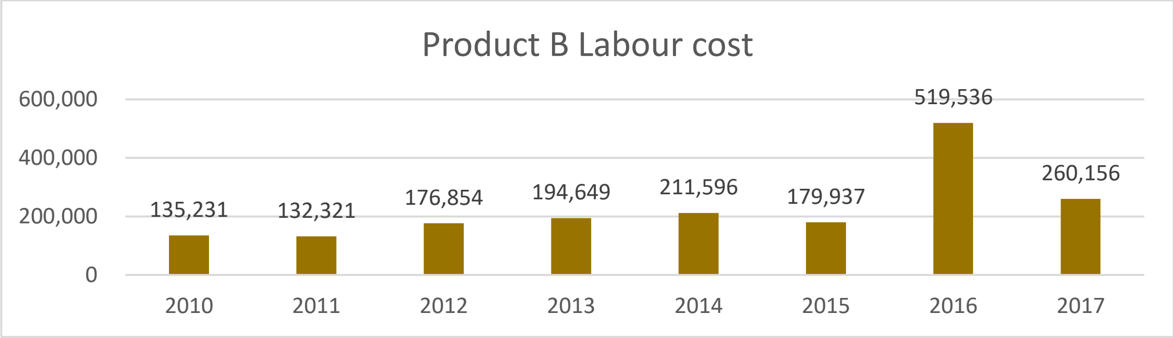



Figure5. 29: Product B Labour cost

During the previous eight years, 2010-2017, the company could not produce product B at full capacity, although the market demand was much more than the capacity. The researcher went through more detailed data to determine the most probable reasons.

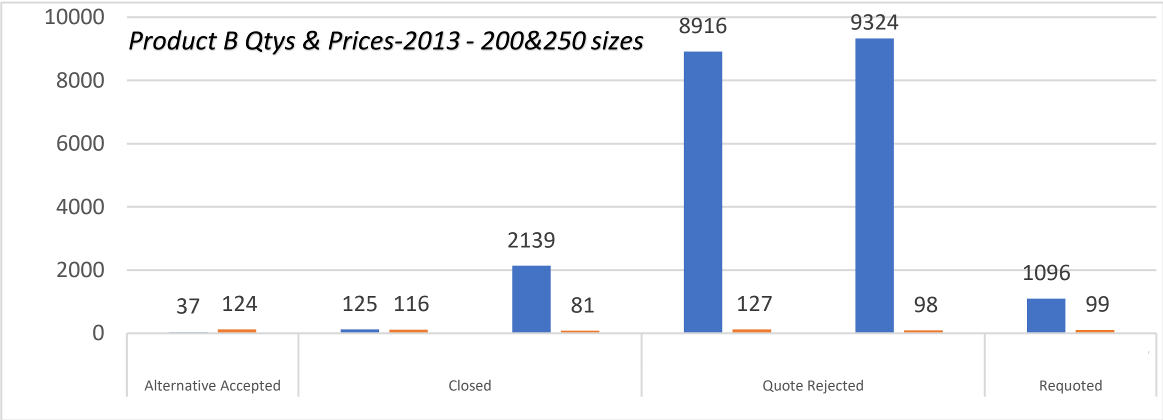



Figure5. 30: Product B pricing jobs – (The year 2013 & Size 200 & 250)

Figure 5.30 shows the detailed status of product B. The job status is divided into four categories; Alternative accepted, Closed, Quote rejected and Requoted. The closed status means approved and finished jobs. The balance of the status figures represents rejected jobs. For example, the company won 2,139m2 of 250d with $NZ81 per m2 and lost 9,324m2 of 250d with an average price of $NZ98 per m2.

According to the financial performance section, the labour cost of Product B during 2010-2016 was $1,550,124, which is more than the gross margin of this product in the same duration. This product has a very high labour cost in this company.

In conclusion, by reducing the labour costs for this product, the company could fulfil its capacity, increase its chance of winning tenders, and increase its profitability.

### 5.11.3. **Product C**

Product C had the lowest plant utilisation in 2010 and the highest in 2016. According to the Pareto analysis, this product had about 80% of its utilisation from 2014 to 2016. The average utilisation of this product during the last seven years was 11.3%, which is very low. This product had its highest labour efficiency in 2011 and 2013 and the lowest efficiency in 2010. Financially, this product had a maximum profit efficiency in 2010 and minimum efficiency in 2011 and 2016. This product had a maximum market attractiveness of 39% in 2013 and a minimum of 3% in 2017. The trendline shows that the attractiveness rate was steadily flat from 2009 to 2017, which means the ratio of winning jobs was almost the same during the last nine years. Product C had a low GPM in 2011 and 2016, which could not reach the minimum profit target.

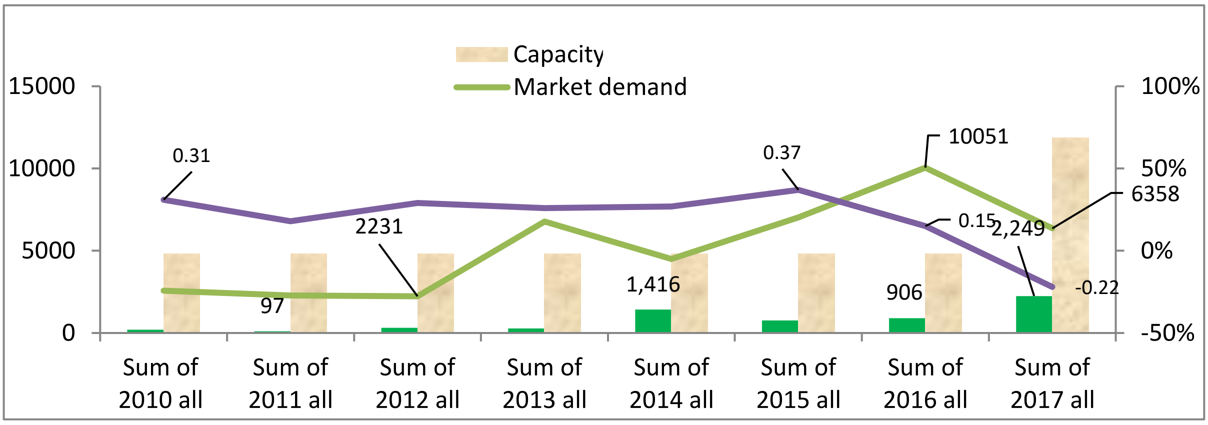



Figure5. 31: Product C productivity, capacity, market demand and gross profit margin

Product C is the second most concrete usage in 2010-2017, Figure 8. Product C had its minimum GPM of 15% in 2016 and 37% in 2015.

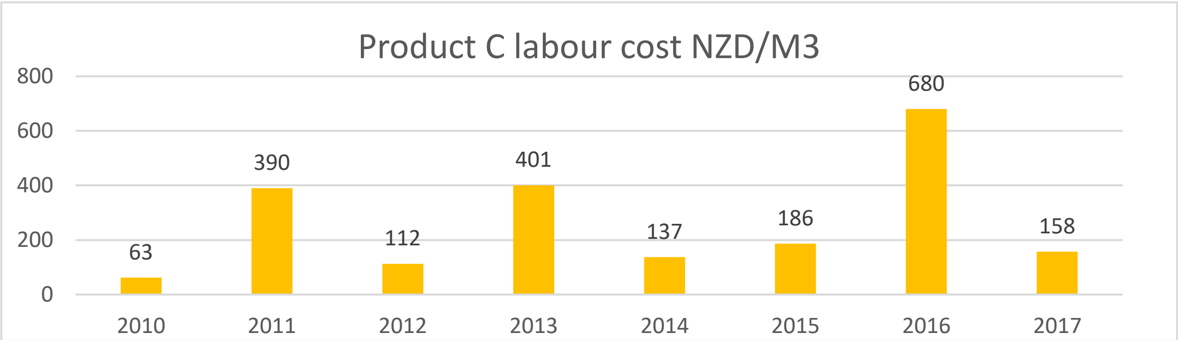



Figure5. 32: Product C Labour Cost per Cubic Metre/s

The researcher went through the deep data to determine the low gross profit margin in 2016. As observed in the figure above, the labour cost per cubic metre in 2016 was very high compared to other years. That could be the likely reason for the low gross profit margin.

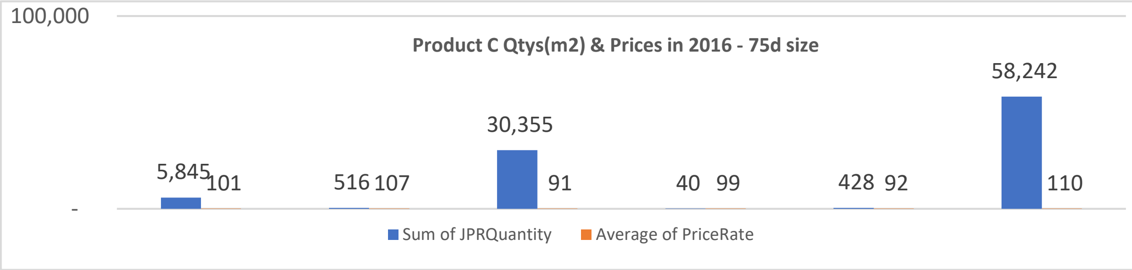



Figure5. 33: Flat Slab QTYs & Prices (The year 2016 & 75mm thickness)

Figure 5.33 shows the tendering status, quantity, and average prices in 2016 for only one size of flat slab. The job status is divided into six categories: quoted, quote rejected, quote accepted, in progress, completed, and closed. The quoted job means the company has not had a response from clients, quote rejected means rejected jobs, and the rest are approved status. For example, the company won 37,184m2 of product C at the size of 75mm with an average price of $NZ91.75 per m2 and lost 58,670m2 of the same product with an average price of $NZ109.86 per M2.

$$Average\ Price\ (Approved) = \frac{5845 * 101 + 516 * 107 + 30355 * 91 + 40 * 99}{5845 + 516 + 30355 + 40}$$
$$= NZD\ 91.75$$

$$Average\ Price\ (Rejected) = \frac{428 * 92 + 58242 * 110}{428 + 58242} = NZD\ 109.86$$

According to the financial performance section, the labour cost of Product C during 2010-2016 is $NZ1,145,691 which is almost the same as the gross margin of this product in the same duration, $NZ1,233,755.

In conclusion, by reducing the labour costs for this product, company could fulfil its capacity and increase its chance of winning tenders and profitability.

### 5.11.4. Product D

Product D had the lowest plant utilisation in 2011 and the maximum utilisation in 2014. According to the Pareto analysis, this product had about 80% of its utilisation from 2010 and 2012 to 2014. The average utilisation of this product during the last seven years was 8.3%, which is extremely low. This product had the highest labour efficiency in 2012 and 2014 and the lowest in 2016. Financially, it had a maximum profit efficiency in 2016 and negative efficiencies of -12, -8 NZD/Lm in 2010 and 2011. This product had a maximum market attractiveness of 52% in 2010 and a minimum of 2% in 2017. The trendline shows that the attractiveness rate gradually decreased from 2009 to 2017, which means getting jobs accepted was becoming more difficult than in previous years. Product D could not reach the minimum GPM target in 2010, 2011, 2012, 2013, 2015 or 2016. Therefore, this product had a minimum GPM rate of 15 amongst products A to G, and it was not profitable.

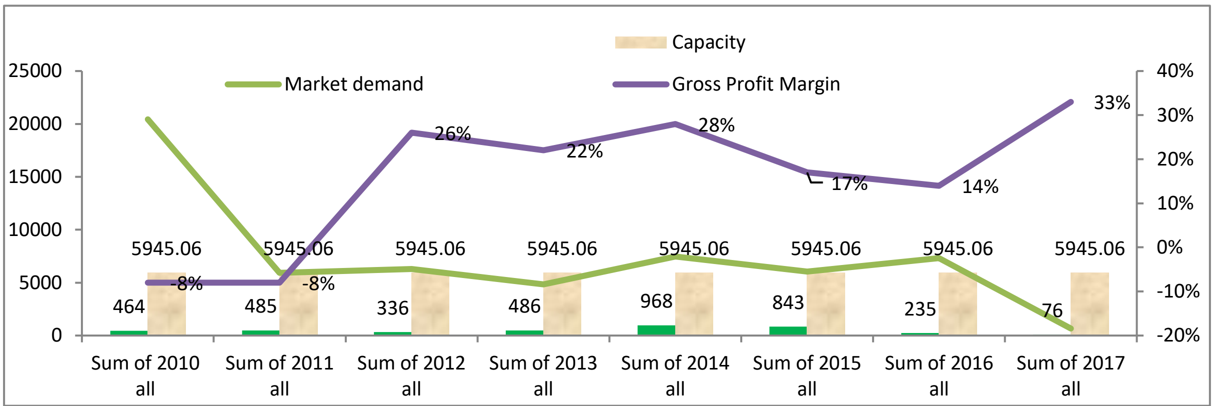



Figure5. 34: Product D productivity, capacity, market demand and gross profit margin

### 5.11.5. Product E

Product E showed the lowest productivity in 2015 and the maximum plant utilisation in 2014. According to the Pareto analysis, this product had about 80% of its utilisation from 2010 and 2012 to 2014. The average utilisation of the product during the last seven years was 25.5%, which is very low. This product had the highest labour efficiency in 2011 and the lowest efficiency in 2010. This product had a maximum profit efficiency in 2011 and minimum efficiency in 2016. This product had a maximum market attractiveness of 57% in 2013 and a minimum of zero in 2015 and 2017. Its trendline shows the attractiveness rate gradually decreasing from 2009 to 2017, which means that it was becoming more challenging to get jobs accepted. The GPM was always above the target, which means that it was always profitable.

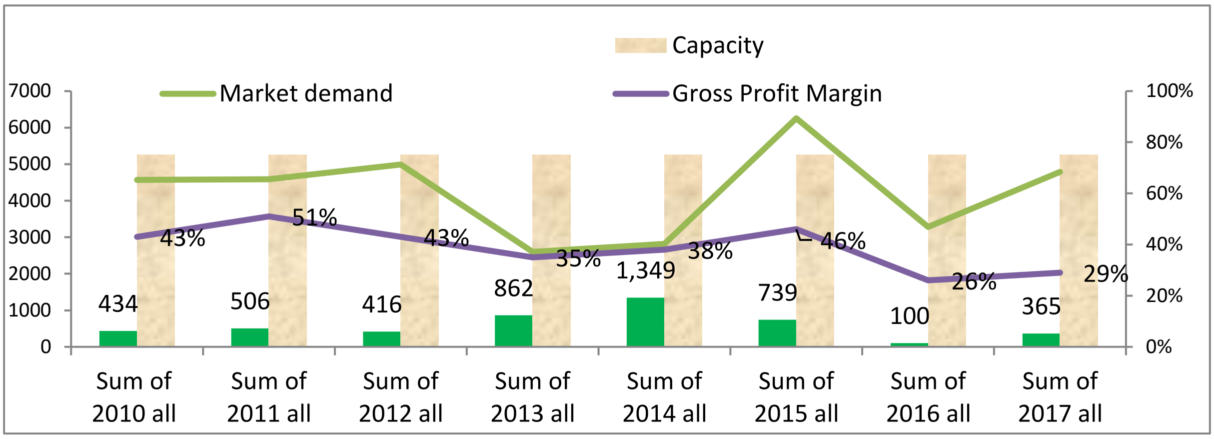



Figure5. 35: Product E productivity, capacity, market demand and gross profit margin

### 5.11.6. **Product F**

The gross profit margin for Product F in 2011 was 24%, which means that this product's most inefficient sales operations were during 2010-2016, concerning the cost of goods sold, shown in Figure 5.36. Product F had its maximum GPM in 2015, which means efficient sales operations concerning the cost of goods sold. This product has minimum production of 114m3 in 2010 due to its low market attractiveness and maximum production of 1149m3 in 2016 due to high attractiveness. This means that its market attractiveness is one of the main reasons for profitability.

Possible biases

Although the gross profit margin in 2013 was above the target, figure 5.15 (a), the labour cost per cubic metre is too high – shown in figure 5.15 (b). The researcher will need to conduct an additional investigation and discussion with the department in charge to determine any possible bias.

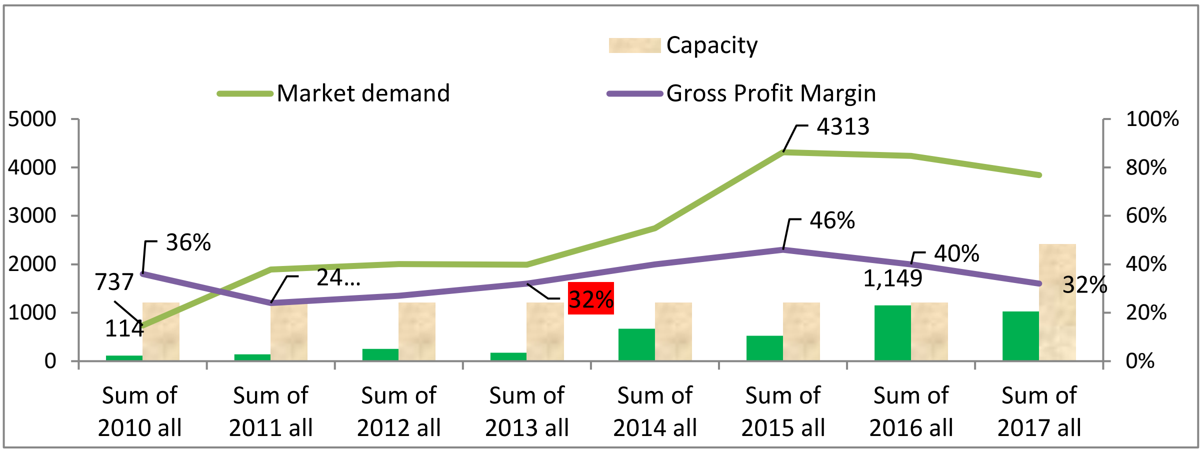



Figure5. 36: Product F productivity, capacity, market demand and gross profit margin

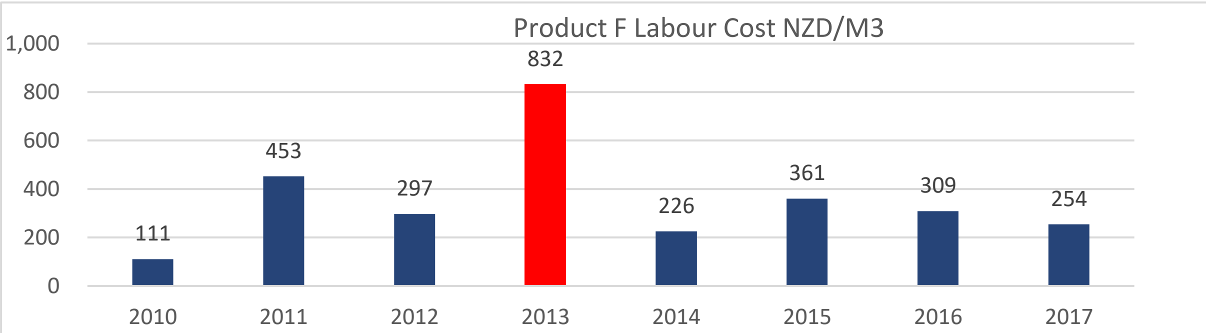



Figure5. 37: Product F Labour Cost per Cubic Metre/s

As can be observed from figures 5.36 and 5.37, from 2010 to 2012, the labour costs directly impacted the GPM. In addition, from 2014 to 2017 the labour costs had an inverse impact on the GPM. A further investigation is required to determine the reasons for the high labour cost ratio and the high gross profit margin.

After requesting access and drilling down to the specific records, figure 5.38 shows the acceptance rate of 2015 in detail. As observed from the trendline, the smaller the size of the products, the more successful the winning percentages, which means the same labour cost but less concrete usage.

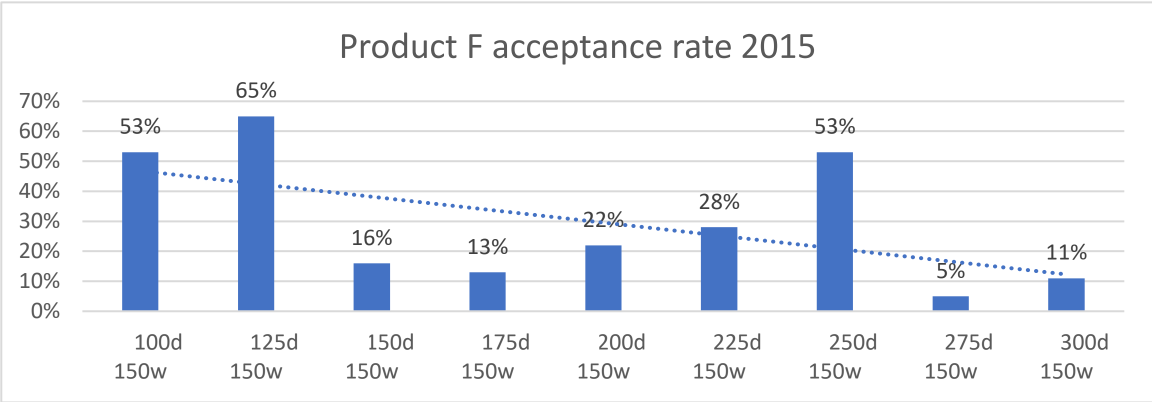
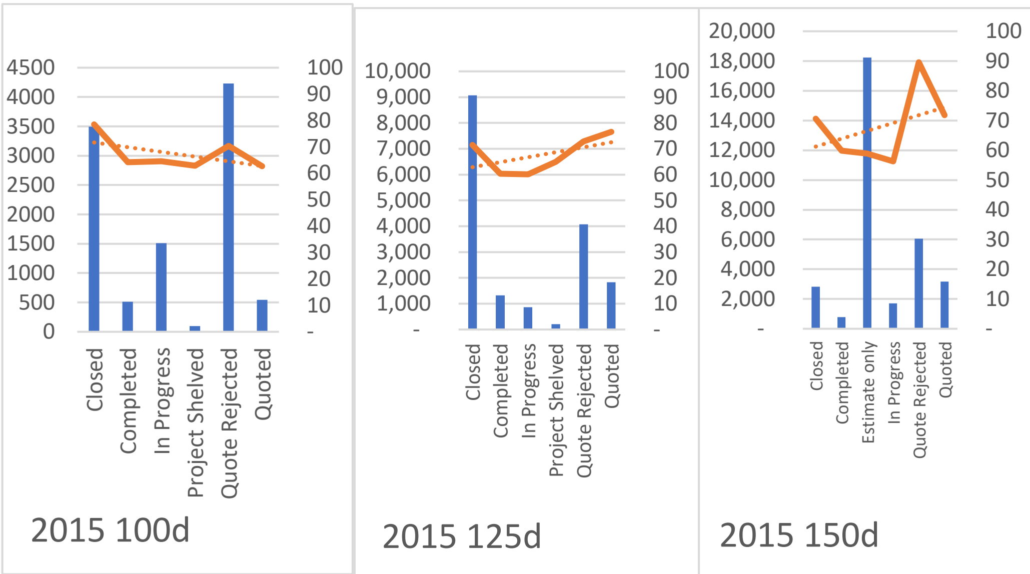
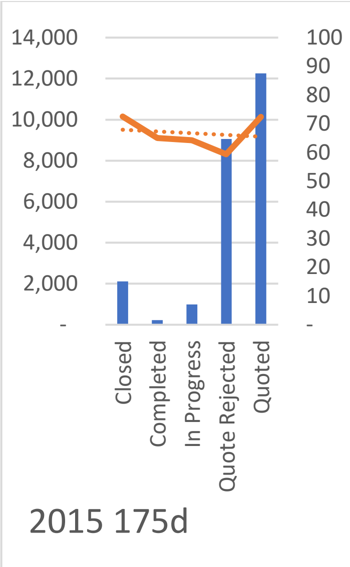
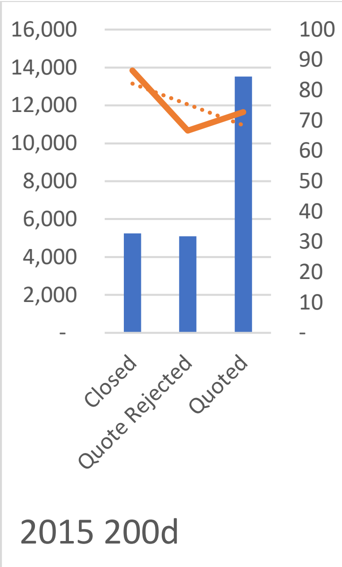


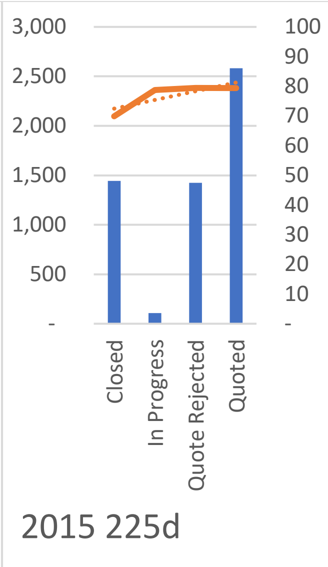

Figure5. 38: Product F acceptance rate (The year 2015 & different sizes)

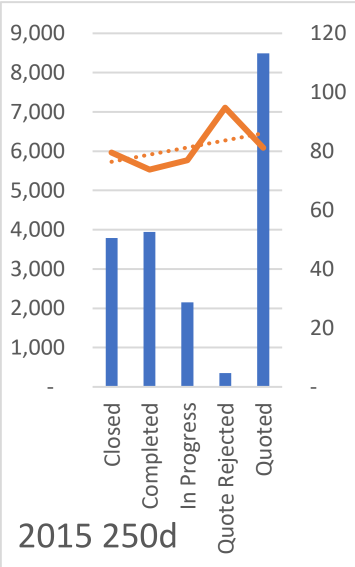
To observe why some jobs were rejected, we have listed all tender statuses for product B in 2015 and the average price rates for each size in Figure 5.39. Most were rejected due to the high sale prices.

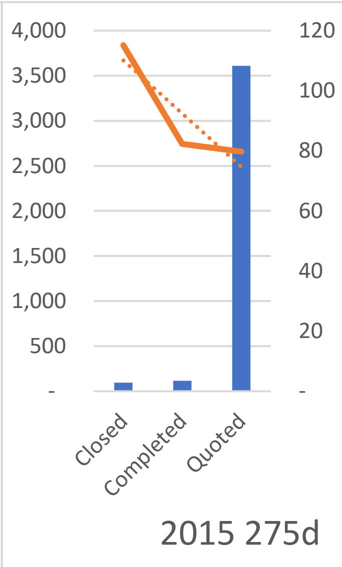


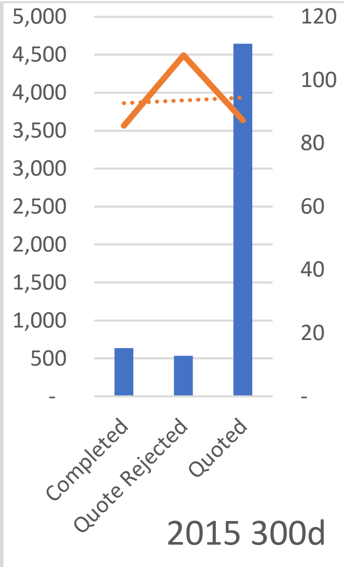

14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
100
90
80
70
60
50
40
30
20
10
-
Closed
Completed
In Progress
Quote Rejected
Quoted
2015 175d


16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
100
90
80
70
60
50
40
30
20
10
-
Closed
Quote Rejected
Quoted
2015 200d


3,000
2,500
2,000
1,500
1,000
500
-
100
90
80
70
60
50
40
30
20
10
-
Closed
In Progress
Quote Rejected
Quoted
2015 225d


9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
-
120
100
80
60
40
20
-
Closed
Completed
In Progress
Quote Rejected
Quoted
2015 250d


4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
120
100
80
60
40
20
-
Closed
Completed
Quoted
2015 275d


5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
120
100
80
60
40
20
-
Completed
Quote Rejected
Quoted
2015 300d

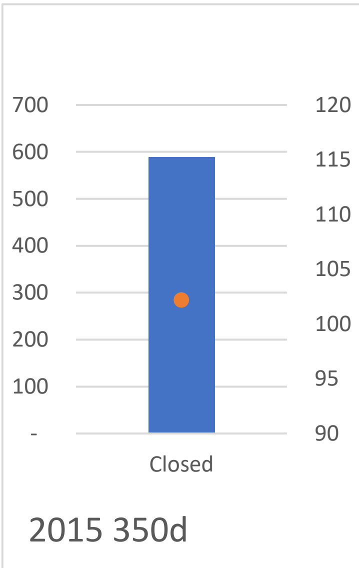

700
600
500
400
300
200
100
-
120
115
110
105
100
95
90
Closed
2015 350d

Figure5. 39: Product F – Tender prices and status in 2015 and different sizes

Product F showed the lowest plant utilisation in 2010 and the maximum in 2016. According to the Pareto analysis, this product had about 80% of its utilisation from 2014 to 2016. The average utilisation of this product during the last seven years was 40%, which is very low. This product had the highest labour efficiency in 2012 and 2015 and the lowest in 2010 and 2013. This product had a maximum profit efficiency in 2010 and minimum efficiency in 2011. This product had a maximum market attractiveness of 45% in 2013 and 7% in 2009. The trendline shows the attractiveness rate gradually increasing from 2009 to 2017, which means that job acceptance was becoming much easier than in previous years. The GPM was always above the target, which means that it was always profitable.

### 5.11.7. **Product G**

Product G had the lowest labour efficiency of 58 NZD/Lm in 2013 and the highest efficiency, at 20 NZD/Lm, in 2012. Product G had a maximum profit efficiency in 2010 and minimum efficiency in 2013, which will be investigated further. Product G had its maximum market attractiveness rate of 64% in 2014 and a minimum of 6% in 2009. The trendline shows the attractiveness rate gradually increasing from 2009 to 2017, which means getting jobs accepted was becoming easier. This product was not profitable enough from 2013 to 2015.

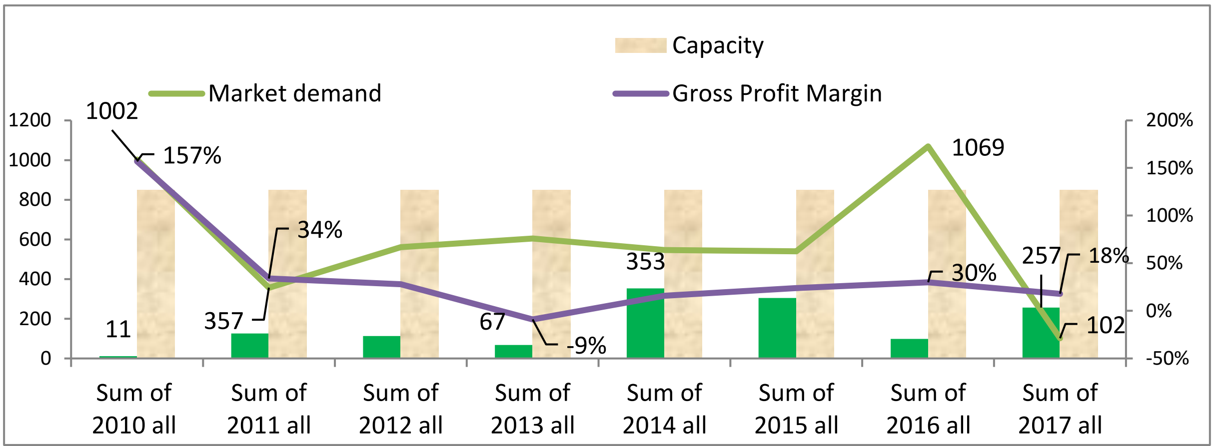



Figure5. 40: Product G productivity, capacity, market demand and gross profit margin

Figure 5.40 shows the labour cost per cubic metre of producing this product. In 2013, the labour cost was too high, which caused a negative GPM.

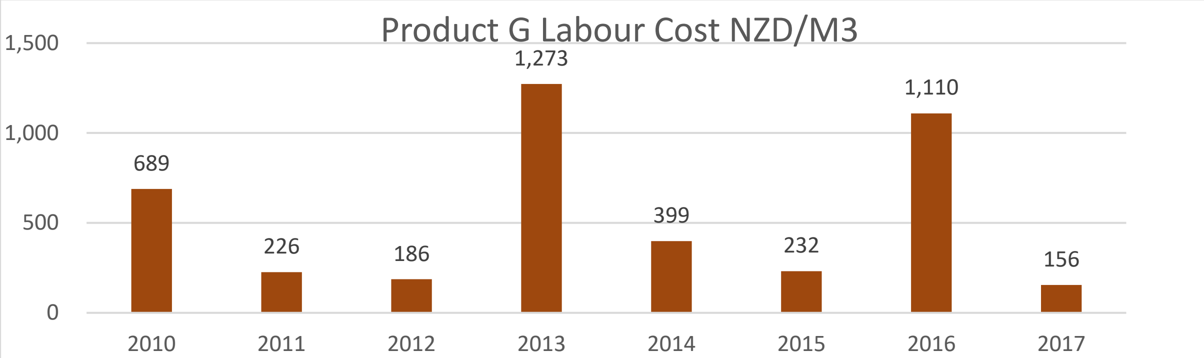



Figure5. 41: Product G Labour Cost per Cubic Metre/s

Product G showed the lowest labour cost efficiency of 58 NZD/Lm in 2013 and the highest efficiency of 20 NZD/Lm in 2012. Product G had a maximum profit efficiency in 2010 and minimum efficiency in 2013. The market attractiveness of Product G reached a maximum of 64% in 2014 and a minimum of 6% in 2009. The trendline indicates that the attractiveness rate gradually increased from 2009 to 2017, which indicates that getting a job was becoming easier. This product could not be profitable enough from 2013 to 2015.

## 5.12. Validity of Analyses Derived from Historical Data

The use of historical data for the assessment of profitability, market attractiveness, plant utilisation, labour efficiency, and other performance measures has been demonstrated in the preceding sections. However, the validity of the analyses derived from the historical data is crucial for the reliability of the conclusions and recommendations made in this study. In this section, we will discuss the validity of the analyses based on the most recent citations and academic literature.

- **Validity of Historical Data Analyses**

The use of historical data for decision-making in business and management is well-established in academic literature (Armstrong, 2001; Gardner, 2006). Historical data can provide valuable insights into past trends and patterns, which can help inform future strategies and decisions. However, the validity of the analyses derived from historical data depends on several factors, including the quality and relevance of the data, the accuracy of the analytical methods, and the ability to account for changing circumstances and external factors (Armstrong, 2001; Elliott & Timmermann, 2016).

Recent literature has highlighted the importance of ensuring the quality and relevance of the historical data used for analysis. This includes selecting data that accurately reflects the company's performance, considering the context in which the data was generated, and accounting for any limitations or biases in the data (Elliott & Timmermann, 2016; Sargan, 2018). In the present study, the historical data used for the analyses was gathered from reliable sources within the company, ensuring a high level of data quality and relevance.

The accuracy of the analytical methods used in this study, such as thematic analysis, linear regression, and Pareto analysis, is supported by their widespread use in academic literature and their established validity in various research contexts (Braun & Clarke, 2006; Saldaña, 2015; Triantaphyllou & Mann, 1995). The use of multiple methods to assess the different aspects of company performance also enhances the validity of the overall analysis, as it reduces the likelihood of drawing incorrect conclusions based on a single method (Denzin, 1978).

However, one potential limitation of relying on historical data for analysis is the need to account for changing circumstances and external factors that may affect company performance. For example, changes in the market, competitors, regulations, or customer preferences can impact a company's profitability, market attractiveness, and other performance measures (Elliott & Timmermann, 2016; Fildes & Ord, 2002). In the present study, the use of sales forecasting and market demand analysis helps to account for these changing factors, providing a more accurate and reliable assessment of future performance.

- **Implications for Future Research**

The validity of the analyses derived from historical data in this study has several implications for future research. First, it demonstrates the potential value of using historical data to inform strategic decision-making in precast concrete plants and other industries. By carefully selecting and analysing relevant data, researchers and practitioners can gain valuable insights into past performance and use these insights to inform future strategies and decisions.

Second, the study highlights the importance of using multiple analytical methods to assess different aspects of company performance. By employing a range of techniques, researchers can gain a more comprehensive and accurate understanding of the factors affecting a company's profitability, market attractiveness, and other performance measures.

Finally, the study underscores the need for future research to continue examining the validity of historical data analyses in various contexts and industries. As the business environment continues to evolve, it is crucial for researchers and practitioners to stay informed about the latest developments in data analysis techniques and their applications in decision-making.

## 5.13. Statistical Conclusion

In conclusion, this study used historical data to measure the profitability performance of the case study precast concrete plant in New Zealand. By analysing the attributes above from the precast concrete plant studied, this study found that the plant did not win enough jobs to feed the production up to its maximum capacity because of its high sale prices and did not meet the target GPM most of the time, due to increasing competition and New Zealand's high labour costs.

Product F had the highest plant utilisation rate, good GPM, and an increasing attractiveness rate trend. At the same time, Products B and D had a low plant utilisation rate (17% and 8%) and low profitability from 2010 to 2016. The trendlines for most of the products show that the attractiveness rate gradually decreased from 2009 to 2017, which means it was becoming more challenging for this company to win jobs in the New Zealand precast concrete market.

Table5. 6: Summary of case study's data extraction

| | Labour Cost $/m | Market Demand vs Capacity | Total Sales Value $ | Labour cost contribution | Market Attractiveness | Plant Utilisation | GPM | Profit Efficiency $/m | Wasted Time |
|---|---|---|---|---|---|---|---|---|---|
| A | 77.75 | 110% | $4,632,658 | 8% | 18% | 21.15% | 44% | 336 | 48% |
| B | 49.14 | 146% | $7,696,411 | 20% | 24% | 17% | 20% | 41.1 | 38% |
| C | 17.71 | 127% | $5,274,337 | 22% | 21% | 11.3% | 23% | 25.7 | 63% |
| D | 35.86 | 131% | $3,911,623 | 17% | 22% | 8.3% | 15% | 27.7 | 49% |
| E | 127.83 | 180% | $8,986,044 | 9% | 34% | 25.5% | 40% | 531 | 45% |
| F | 6.86 | 222% | $8,431,336 | 12% | 21% | 40% | 38% | 25.6 | 48% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| G | 37.85 | 46% | $1,719,798 | 27% | 19% | 20.5% | 24% | 69.9 | 49% |
| **Ave** | **50.43** | **137%** | **$5,807,458** | **16%** | **23%** | **21%** | **29%** | **151** | **49%** |

## 5.14. Conclusion

In conclusion, the case study on the precast concrete p’ant's profitability provided a comprehensive analysis of the business by examining various factors that contribute to its success. The study began with a thorough investigation of the market attractiveness, which helped to identify the competitive landscape and the potential growth areas within the industry. It was observed that the precast concrete market demonstrated a robust growth path, driven by increasing construction activities and the inherent advantages of precast concrete, such as durability, sustainability, and time efficiency.

The Pareto Analysis served as a fundamental tool in determining the most significant products within the plant’s portfolio, enabling management to focus on high-impact areas for improvement. Upon further examination of the labour efficiency, it was discovered that there were opportunities to enhance productivity and reduce costs through process optimisation and staff training. Additionally, market demand analysis revealed the need to realign the product mix, prioritising products with higher demand and profitability.

Sales forecasting played an essential role in providing insight into future market trends, which allowed the plant to allocate resources and plan production more effectively. The study found that while some products remained strong in the market, others displayed declining trends, requiring proactive measures to maintain a competitive edge. By examining plant utilisation, the study highlighted areas where efficiency could be improved, such as optimising production schedules, investing in automation, and reducing downtime. This would lead to increased capacity and output, contributing to the overall profitability of the plant.

Gross margin analysis further illuminated the financial performance of the products, unveiling the areas where the plant could improve its pricing strategy, reduce production costs, and streamline its supply chain. By addressing these factors, the plant would be able to bolster its profitability and secure a stronger position in the market.

This comprehensive study has provided valuable insights into the precast concrete plant's performance, empowering management to make informed decisions about future investments, resource allocation, and strategic planning. It is, however, crucial to bear in mind that the industry is dynamic and subject to change. Continuously monitoring the market conditions, updating the analyses, and reviewing the latest academic literature and case studies are vital to ensure the long-term success and sustainability of the precast concrete plant.

# 6. Findings

This study contributes to the existing body of knowledge by developing a decision support tool, PPAST, that enables precast concrete plants in New Zealand to select the best possible automation path for their plants, thereby improving their profitability. In practice, this tool will help decision-makers to articulate their objectives and attitudes towards risk when exploring the feasibility of automation and guide them in formulating an optimal strategy for its application.

## 6.1. Introduction

Despite a high level of offsite production systems in New Zealand, housing prices are increasing, and a shortage of labour is the main issue. Offsite production is a technology intended to reduce the number of workers on construction sites, with the expectation of reducing labour costs. However, the offsite industry itself, which requires a range of skilled labourers during the manufacturing process. is also labour-intensive. This research has shown a high level of bankruptcies among precast concrete production companies. This study attempts to establish the profitability challenges for these companies, and to seek ways to improve the situation. There are many different approaches to improving profitability, such as lean management, total quality management, and adoption of automation. This study has used the automation adoption method as a lens through which to study the New Zealand market, and has conducted a case study. Through this case study a framework has been developed, enabling NZ precast concrete companies to select the best possible automation path for their plants, to improve their profitability. The study has shown that is valuable to develop a tool that helps decision-makers to articulate their objectives and attitudes towards risk when exploring the feasibility of automation, and while formulating an optimal strategy for its application.

## 6.2. Decision support tool (PPAST)

Development of the decision support tool (PPAST) for precast concrete plants in New Zealand was based on a comprehensive literature review, interviews, and direct observation (VSM method). This section describes the process undertaken to develop a framework to select the best possible automation path for the case study company, to improve its profitability. The significant advantages of automation in precast concrete plants are commonly cited when arguing for its benefits. Yet, the decision to employ automation is still largely based on familiarity and personal preferences rather than on rigorous data. The process for adopting automation, and especially the sequencing analysis for a given precast concrete plant, is not a simple decision-making problem based on a single attribute but a multi-attribute decision-making process involving multiple decision makers. It is also a decision-making problem with a high degree of inherent uncertainty and risk. The framework that has been established for the PPAST tool is based on the relationship between the possibility of automation and factors affecting profitability. Hence, it is useful to develop a tool that helps decision-makers to articulate their objectives and attitudes towards risk when exploring automation feasibility and guides them to formulate an optimal strategy to apply automation. PPAST (Precast Plant Automation Selection Tools), a product of this research, makes these tasks possible (Figure 6.1).

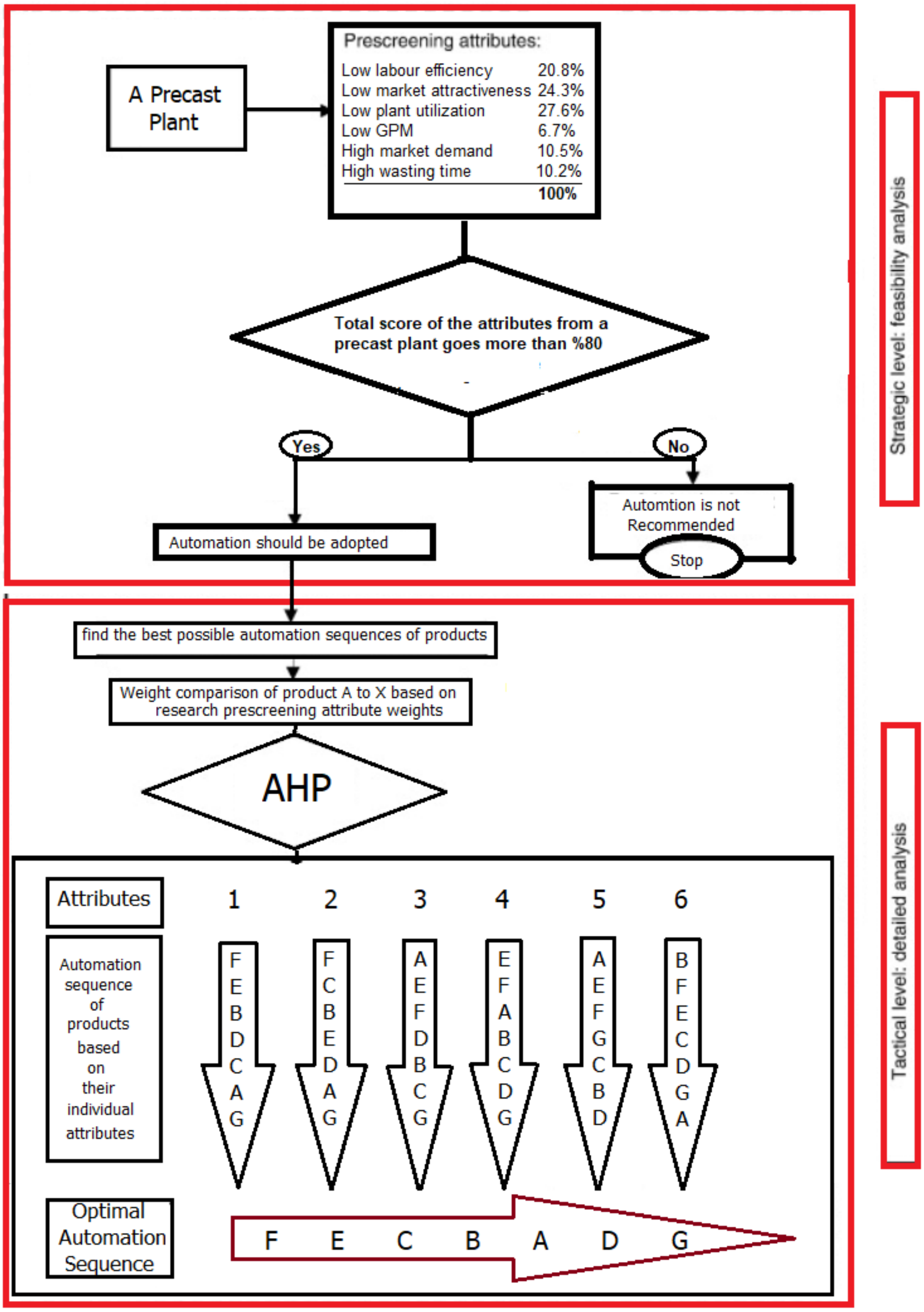



Figure6. 1: Decision support tool (Framework)

PPAST, the decision support tool that has been developed, is divided into two sequential levels: the strategic and the tactical level.

The strategic phase is used to evaluate the feasibility of automation by employing a list of pre-screening attributes (the TA method was selected: refer to 3.4.4 to identify its attributes) such as market attractiveness, plant utilisation, labour efficiency, waiting time, market demand and gross profit margin. Information on these chosen attributes is usually available at the early stages. The AHP method was selected (refer to section 2.13 and table 2.4) to measure the weight and importance of all attributes from the experts in the field.

If the outcome of the prior strategic investigation is a decision to proceed with automation, the following tactical phase involves evaluation of the automation sequences of components for a particular plant, based on their performance attributes.

- Validation questions for the framework (VQ)

Based on the objectives established by the PPAST, the importance of automation, and the factors which this research has shown to be affecting the profitability of precast concrete plants, the following questions were raised to facilitate the development of a purposeful framework:

VQ 1: will implementing automation improve the profitability of a precast concrete plant if the current market attractiveness of their products is low?

VQ 2: will implementing automation improve the profitability of a precast concrete plant if the current plant utilisation of their products is low?

VQ 3: will implementing automation improve the profitability of a precast concrete plant if the current labour cost of their product is high?

VQ 4: will implementing automation improve the profitability of a precast concrete plant if the current 'wasting time' rate of their product is high?

VQ 5: will implementing automation improve the profitability of a precast concrete plant if the current GPM of their product is low?

VQ 6: will implementing automation improve the profitability of a precast concrete plant if the current market demand for their product is high?

The PPAST has the potential to assist decision-makers through the process of automation and optimisation in precast concrete plants in New Zealand. The application of AHP is new in the context of precast plant automation method selection. Responses from the participants demonstrates the effectiveness and practicability of the decision-making tool. However, the proposed model would be more powerful if it were developed further into a computer program, through which expected utilities for specified alternatives could be evaluated easily. A computer-based or web-based program version of the proposed tool will be considered for future research.

## 6.3. Validate decision support tool (PPAST)

The use of closed-ended questionnaires among small and medium-sized enterprises (SMEs) as a method of data collection is known to validate frameworks as it seeks to acquire evidence to measure the construct of the subject matter under consideration, and it evaluates the framework validity (Angell, 2017; Clark & Catts, 2007). The use of SMEs as a basis for investigations is a reasonable and cost-effective means of gathering sufficient data for quantitative research within a specific timeframe (de Soto et al., 2018). To validate the decision support tools, all of the six validation questions listed in the previous section needed to be discussed and evaluated with the subject matter experts in the industry. This study targeted experts working in the precast concrete plants in New Zealand.

### 6.3.1. Direct rating to validate the VQs

By referring to 3.4.2, the direct rating method, and the first question of the survey (Appendix 2), forty-six SMEs in the NZ precast concrete industry agreed on implementation of an automation system in the NZ precast concrete plants, based on the validation questions. As a result, 87% of the participants confirmed that all of the VQs used in this this study were valid. Table 6.1 shows the results.

Table 6. 1: Result of Question 1 on the VQs (refer to 9.4.3 for calculation)

| Do you agree with the implementation of automation systems in the NZ precast concrete plants to improve profitability if; | | Yes | No | Agree % |
|---|---|---|---|---|
| 1 | the plant labour efficiency is low? | 41 | 5 | 89% |
| 2 | the plant market attractiveness is low? | 41 | 5 | 89% |
| 3 | the plant utilisation is low? | 44 | 2 | 96% |
| 4 | the plant GPM is low? | 37 | 9 | 80% |
| 5 | the plant market demand efficiency is high? | 41 | 5 | 89% |
| 6 | the plant ‘wasting time’ rate is high? | 37 | 9 | 80% |
| | **Average** | **40** | **6** | **87%** |

## 6.4. AHP analysis to rate the importance of the attributes on the automation adoption decision

Based on section 3.3.6 of this thesis, the AHP method as a multi-criteria decision-making tool has been chosen to rate the validation questions. The purposive sampling method was used based on the AHP recommendation because of the availability of only a limited number of experts in the area (Kucukaltan & Topcu, 2019). By changing the problem into a hierarchy of sub-problems, the AHP method (refer to section 3.4.1) helps decision-makers to evaluate the decision elements by comparing them with one another using pairwise comparison. Subsequently, relative weights of attributes were determined based on the AHP method.

Based on the formulation of the AHP method for weight assignment of attributes, a questionnaire survey (Appendix 2) was conducted, to collect data from selected experts, in order to analyse the significance of one attribute in comparison with another with respect to the goal of adoption of automation. For this purpose, forty-six SMEs participated in this research to compare and assign relative weights to indicate the significance of pairs of attributes by using the nine-point Likert scale. Finally, the weights of attributes were determined based on the SMEs' inputs and using the AHP method as shown below table in 6.2:

Table 6. 2: Rate of attributes affecting an automation adoption decision (Refer to 9.4.2 for calculation)

| Attributes affecting an automation adoption decision | Weight - based on pairwise comparison of each attribute by SMEs |
|---|---|
| Labour efficiency of their products is low | 0.21 or 21% |
| Market attractiveness of their products is low | 0.24 or 24% |
| Plant utilisation of their products is low | 0.27 or 27% |
| Gross profit margin of their product is low | 0.07 or 7% |
| Market demand efficiency of their product is high | 0.11 or 11% |
| 'Wasting time' rate of their product is high | 0.10 or 10% |
| Total | **1.00 or 100%** |

As a result of this analysis, plant utilisation was shown to be the most important attribute for an automation adoption decision in the precast concrete plants in New Zealand.

## 6.5. Pareto analysis method to decide on automation adoption

Pareto Analysis (refer to section 3.4.3) was employed as a statistical technique in decision-making because it can be used to select a limited number of tasks that produce a significant overall effect. This study has shown that if any precast concrete plant in New Zealand has a minimum of 80% of its total weight on the attributes mentioned above, then adoption of an automation system is a suitable course of action. Otherwise, automation is not recommended.

By working through the PPAST's two level process (strategic and tactical), an optimal automation strategy considering the precast plant's characteristics and the decision makers' risk attitudes could be established, making the evaluation of automation adoption more objective and transparent.

## 6.6. Strategic Level (Feasibility study)

The pre-screening attributes of the case study company were extracted from the company data set and a calculation was conducted to establish whether automation implementation would be recommended for the company to improve its profitability.

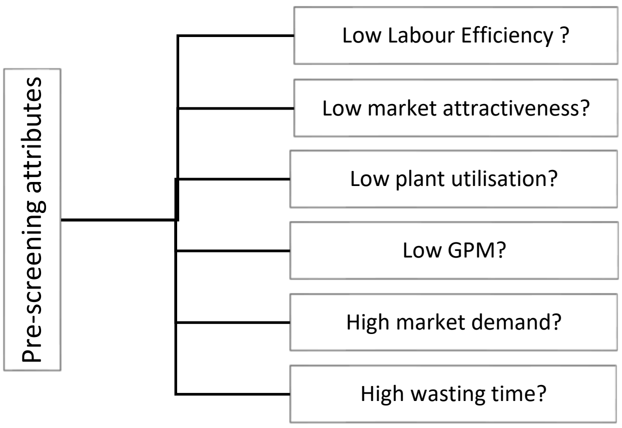



Figure6. 2: Pre-screening attributes

Therefore, by referring to the pre-screening attributes, table 5.6 (summary of data extracted relating to the case study company), and table 6.2 (rate of attributes affecting automation adoption decision), table 6.3 was generated as below:

Table6. 3: Summary of the case study attributes value and their total eligible scores for automation adoption

| Products | Pre-screening attributes | | | | | |
|---|---|---|---|---|---|---|
| | Market demand | Labour cost contribution | Market attractiveness | Plant utilisation | GPM | Wasting time |
| A | 110% | 8% | 18% | 21.15% | 44% | 48% |
| B | 146% | 20% | 24% | 17% | 20% | 38% |
| C | 127% | 22% | 21% | 11.3% | 23% | 63% |
| D | 131% | 17% | 22% | 8.3% | 15% | 49% |
| E | 180% | 9% | 34% | 25.5% | 40% | 45% |
| F | 222% | 12% | 21% | 40% | 38% | 48% |
| G | 46% | 27% | 19% | 20.5% | 24% | 49% |
| Case study company Ave. | 137% | 16% | 23% | 21% | 29% | 49% |
| Minimum of market | 100% | 11% | 35% | 30% | 33% | 10% |
| Eligible? Based on VQs | Yes | Yes | Yes | Yes | Yes | Yes |
| Automation adoption score | 10.5% | 20.8% | 24.3% | 27.6% | 6.7% | 10.2% |
| Result | 100% Automation is recommended | | | | | |

Table 6.3 suggests the automation adoption requirement of the case study company. In this table all of the pre-screening attributes of the products from the case study company were measured (Table 5.1). The average was calculated and compared to the minimum requirement of the market. If the average was better than the market, then the related weight (score) of the pre-screening attributes could be added to the result.

As shown above, the case study company scored 100% for the requirement for adoption of automation. An automation system will improve the profitability of the case study company. In the following section, the tactical level, researcher used the AHP method to provide recommendations and pathways towards the implementation of the optimised automation system in the case study company.

## 6.7. Tactical Level (Detailed Analysis)

Based on the results of the feasibility study, shown in section 6.6, automation is recommended to be implemented in the case study company, to improve its profitability. This section will evaluate automation sequences for the products made by the company, based on the results of the pre-screening attributes. The AHP technique was used in this level to measure the weight and importance of all of the attributes from the case study.

### 6.7.1. Weight comparison of pre-screening attributes on each product

Weight comparison of products from the case study based on their research pre-screening attributes were calculated by using the direct rating method (by dividing the value of each pre-screening attribute into the total sum of pre-screening values). All calculations were conducted for all six attributes on seven products, and table 6.4 shows the summary of the output. The higher the percentage from the pre-screening attributes columns, the stronger the suggestion for adoption of automation for the related product.

Table6. 4: Weight comparison based on all six attributes

| Product | Pre-screening attributes | | | | | |
|---|---|---|---|---|---|---|
| | Market attractiveness | Labour cost contribution | Plant utilisation | GPM | Market demand | Wasting time |
| A | 11.30% | 7.00% | 14.70% | 21.60% | 11.40% | 14.10% |
| B | 15.10% | 17.40% | 11.80% | 9.80% | 15.20% | 11.00% |
| C | 13.20% | 19.10% | 7.90% | 11.30% | 13.20% | 18.60% |
| D | 13.80% | 14.80% | 5.80% | 7.40% | 13.60% | 14.40% |
| E | 21.40% | 7.80% | 17.70% | 19.60% | 18.70% | 13.20% |
| F | 13.20% | 10.40% | 27.80% | 18.60% | 23.10% | 14.10% |
| G | 11.90% | 23.50% | 14.30% | 11.80% | 4.80% | 14.40% |
| Total | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.00%** |

As shown in table 6.4, market attractiveness and GPM are higher for product E, labour cost for product G, plant utilisation and market demand for product F, and wasting time for product C.

### 6.7.2. Automation adoption sequence of products on the case study based on their attributes

As shown in figure 6.3, the researcher measured the importance and sequence of each product for automation in relation to the pre-screening attributes, by using the AHP method.

| | | | | | |
|---|---|---|---|---|---|
| n= | 7 | Number of products (2 to 10) | Scale: | 1 | AHP 1-9 |
| N= | 6 | Number of attribute (1 to 20) | α: | 0.1 | Consensus: 88.4% |
| p= | 0 | Selected attribute (0=consol.) | 2 | 7 | Consolidated |

**Objective** multi-criteria decision-making tool for the decision support system on to determine which products to be automated in precast concrete plant

**Author** Reza

**Date**

Thresh: 1E-08 Iterations: 5 EVM check: 2.2E-10

**Table**

| | Products | Comment | Weights | +/- |
|---|---|---|---|---|
| 1 | Product A | | 12.5% | 0.0% |
| 2 | Product B | | 14.5% | 0.0% |
| 3 | Product C | | 13.5% | 0.0% |
| 4 | Product D | | 11.3% | 0.0% |
| 5 | Product E | | 16.3% | 0.0% |
| 6 | Product F | | 17.9% | 0.0% |
| 7 | Product G | | 14.1% | 0.0% |

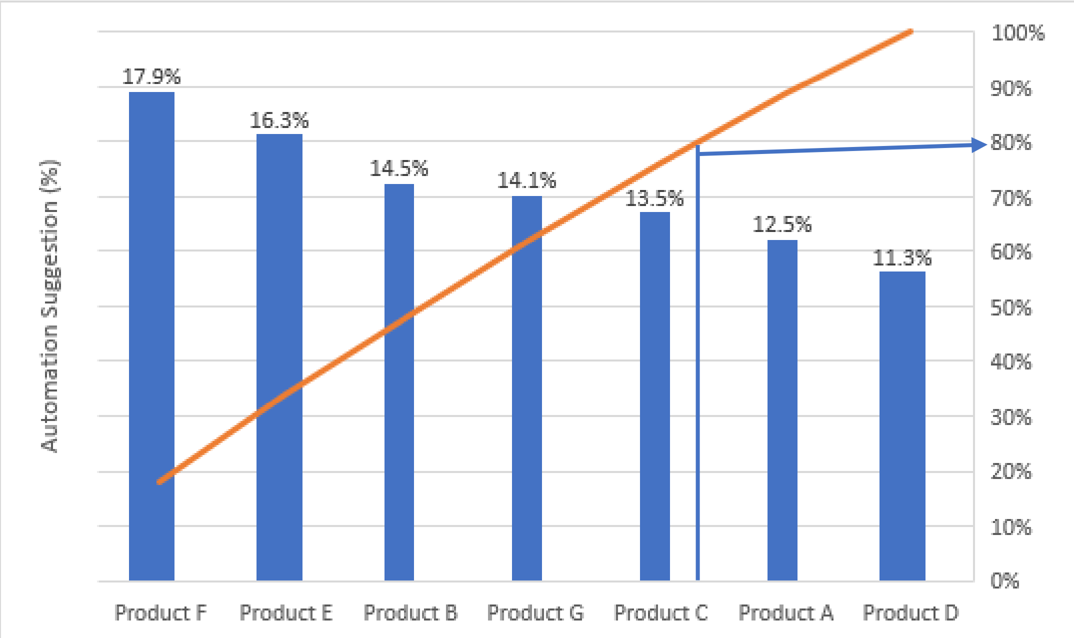
**Result**

| | | | | | |
|---|---|---|---|---|---|
| **Eigenvalue** | | Lambda: 7.000 | | MRE: | 0.0% |
| **Consistency Ratio** | 0.37 | GCI: 0.00 | Psi: 0.0% | CR: 0.0% | 0.0% |

Figure6. 3: AHP method to measure the importance/sequence of product for automation

All seven products and their six related attributes were analysed using AHP and as a result, product F is shown to have the highest weighting for automation with 17.9%, then product E, B, G, C, A and lastly D with 11.3%. For a better visualisation for presentation to the company's board, all of the automation adoption sequence has been shown in table 6.5 as a histogram chart. By using this result, the decision-makers from the case study company can consider the automation system.

Table6. 5: Automation adoption sequence of products on the case study based on their attributes (for calculation refer to 9.4.1)




## 6.8. Conclusion

The findings of this study provide valuable insights into the challenges faced by precast concrete production companies in New Zealand and offer practical solutions for improving profitability through the adoption of automation. By developing and validating the PPAST decision support tool, this research contributes to both theory and practice.

- Contribution to Theory

This study adds to the body of knowledge surrounding the offsite construction industry, particularly in the context of precast concrete production. The research identifies the profitability challenges faced by companies in this industry and explores the potential benefits of automation as a solution. By developing a robust decision support tool (PPAST), the study provides a theoretical framework that enables precast concrete companies to assess the feasibility of adopting automation and to formulate an optimal strategy for its implementation.

The use of AHP as a multi-criteria decision-making tool in the context of precast plant automation method selection is a novel contribution to the existing literature.

Additionally, the study showcases the application of the PPAST tool in a real-world case study, demonstrating its practical relevance and effectiveness in the industry.

- Contribution to Practice

The practical implications of this research are significant for precast concrete production companies in New Zealand. The PPAST tool provides a structured and systematic approach to evaluating the potential benefits of automation adoption. By guiding decision-makers through the process of considering multiple factors that influence profitability, the tool enables a more informed and objective assessment of automation opportunities.

In conclusion, this study demonstrates the successful application of the PPAST tool in a real-world setting, highlighting its practical relevance for the industry. By developing a practical decision support tool that can help precast concrete plants in New Zealand make informed decisions on automation adoption, this research contributes to the existing body of knowledge on automation in the construction industry and offers valuable insights for industry practitioners. The findings from this study can be used as a benchmark for other precast concrete production companies, both in New Zealand and globally, seeking to improve profitability through automation adoption. The main contribution of this chapter is its novel approach to systematically evaluating alternative automation scenarios in precast concrete production plants, providing a systematic approach to assess the feasibility of automation and the factors affecting its profitability.

### 6.8.1. The key findings of this research are as follows:

- **Challenges and Solutions:** This study highlights the challenges faced by precast concrete production companies in New Zealand and offers practical solutions to improve profitability through the adoption of automation.

- **Theoretical Contributions:** The research contributes to the body of knowledge on offsite construction, specifically precast concrete production, by developing and validating the PPAST decision support tool. It also presents the novel use of AHP as a multi-criteria decision-making tool in the context of precast plant automation method selection.

- **Practical Contributions:** The PPAST tool provides a structured and systematic approach to evaluating the potential benefits of automation adoption for precast concrete production companies in New Zealand. It guides decision-makers in considering multiple factors affecting profitability, leading to more informed and objective assessments of automation opportunities.

- **Real-World Application**: The study showcases the successful application of the PPAST tool in a real-world case study, demonstrating its practical relevance and effectiveness in the industry.

- **Global Benchmark:** The findings from this study can be used as a benchmark for other precast concrete production companies, both in New Zealand and globally, seeking to improve profitability through automation adoption.

- **Systematic Evaluation:** The main contribution of this chapter is its novel approach to systematically evaluating alternative automation scenarios in precast concrete production plants, providing a systematic way to assess the feasibility of automation and the factors affecting its profitability.

# 7. Conclusion

## 7.1. Introduction

New Zealand has been experiencing an increasing level of bankruptcies among offsite manufacturers, despite an increase in the number of building consents and demand. This thesis has explored the potential for automation in the New Zealand precast concrete plants, and has made several contributions to the literature. The first is in establishing a framework for managing cost-efficient automation systems within precast construction plants. An initial analysis was conducted to identify key factors that affect profitability within precast construction companies. This led to an examination of how these factors can be managed with automated systems, resulting in the development of a decision support tool that optimises system efficiency.

Second, by developing and validating a decision support tool that optimises system efficiency through automated methods; this research has identified how automated systems can improve profitability within precast construction plants. The results from the research indicate that there would be significant increases in both profit margin and return on investment when automated processes were implemented, as compared with manual processes across all levels and categories of plant operation. The original contributions of this research to the body of knowledge and a summary of the research objectives are outlined The recommendations for further research are also presented below.

## 7.2. Review of research objectives

The focus of this study has been to address the challenges affecting the profitability of precast concrete plants; developing a decision support tool for optimised implementation of automation to improve profitability and employing the decision support tool developed in the case study company. This study developed five research questions and objectives, and a summary of how it has achieved each research objective is outlined below.

**Objective one:** to establish the current challenges associated with the profitability of precast concrete construction plants.

The background to the challenges was established through a literature review, interviews with the subject matter experts (SMEs) from the case study company, and direct observation of its production lines. The finding of the first objective categorised under six themes: market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin, and non-profitable processes.

*Market attractiveness* is calculated by dividing the 'rate of winning jobs' into the 'market demand', and includes several factors, including quality, number of cracks, incorrect cast, resource utilisation, storage issues, production delay, loss of product, loss of reputation, wasted labour time (unnecessary overtime), unnecessary product movement (wasted time), waiting time (waiting for raw materials), limited storage space which influences future jobs (limited stock levels), labour utilisation (under- or overstaffed), competitive market (competitors undercutting on price), unnecessary expenses (productivity issues), inefficient resource utilisation (not using resources efficiently). The Market Attractiveness Factor is used to determine how well a production firm will perform in a specific market. This can be used by prefabrication factories to determine whether they should enter into a new market, and also aids in determining the effectiveness of their current business strategy.

*Plant utilisation* is a term used to describe the efficiency of a plant in terms of how many parts it is producing per hour. This is calculated by dividing the 'production rate' into the 'capacity' and includes a number of factors including procurement, planning, production line utilisation, production line changeovers, late casting, incorrect casting, resource utilisation, missing deliveries, loss of product, limited storage space which influences a future job, production line allocation. Production rate is calculated by dividing "number of parts produced" by "total working hours". Labour utilisation is determined by dividing 'hours worked' by 'hours available for work'. The competitive market and inefficient resource utilisation are both factors that impact plant utilisation. A competitive market means that there are other companies producing similar products, which drives down prices and causes companies to reduce prices in order to compete. Inefficient resource utilisation can be caused when there are not enough resources such as storage space available, which may cause bottlenecks in production and result in reduced plant utilisation rates.

*The labour efficiency factor* is a metric that measures the effectiveness and efficiency of a company's labour force. It is calculated by dividing the total cost of labour by total sales, and includes many factors, including: procurement, planning, communication, production line changeovers, design change, late casting, overproduction, concrete truck standing time (the amount of time trucks spend waiting to unload), quality issues (cracks or incorrect castings), resource utilisation (unused staffs), loading delays, wasted labour time (time spent on unnecessary product movement), waiting time (waiting for someone else to finish their task so you can start yours), labour utilisation (too many people doing one thing at once), production line changeover (when the line has to be changed to produce another product because demand for the original product has decreased or increased), inefficient resource utilisation (inexperienced staff).

*Gross profit margin* is the percentage of total sales that a company makes after subtracting the cost of goods sold from the total revenue. It is calculated by dividing the ‘sales minus cost of goods sold’ by the ‘total sales’ and includes factors including procurement, planning, communication, production line utilisation, production line changeovers, design change, late casting, overproduction, concrete truck standing, quality, cracks, incorrect cast, resource utilisation, site delays, loading delays, missing deliveries, quality issues and more. Gross profit margin is important because it indicates how much money a company earns from its raw materials. Gross profit margin can be used to determine whether a company has sufficient capital to cover its expenses. A high gross profit margin means that a company's products are profitable enough to cover operating costs and provide some extra revenue for future investments or expansion plans. These issues are addressed in chapters two and three.

**Objective two:** to identify the potential for automated systems to improve profitability within precast construction plants.

The potential for automated systems to improve profitability within precast construction plants was identified by conducting an exhaustive literature review in Chapter 2. The literature review found that automated techniques can provide improvement opportunities for offsite production in terms of market attractiveness, plant utilisation, labour cost efficiency and reduction of non-profitable processes.

The chapter also provided an overview of precast concrete production systems and the key performance indicators (KPIs) that are commonly used to evaluate these systems. Chapter 2 also identified four categories of obstacles surrounding the use of automation systems in the offsite construction industry in New Zealand: high capital costs, a lack of education about automation, and a lack of regulations to support offsite production manufacturing.

*The level of capital investment* needed for adoption of automation is considerable. It is essential to determine whether an organisation's long-term investments such as new machinery, replacement of machinery, new plants, new products, and research development projects are worth the funding of cash through the firm's capitalisation structure. Even if a plant is very new, an industrial factory must have continual preventive maintenance. Automation is sometimes very technical and costly and , and both mechanical and electrical staff are vital to keep it running successfully for decades.

*The lack of automation knowledge* in the New Zealand construction industry has a huge impact on automation adoption. An automated industry requires a certain number of highly skilled employees, and their skills are sometimes exceptional. For example, CAD technicians are not architects, but they must be construction engineers or draftsmen with the knowledge to consider many construction topics. The digital model of a building, to be constructed from prefabricated concrete, will be generated in a CAD system, and this model must be error-free, or the automated factory will produce components with errors, resulting in costly repairs on site.

*Permissions and authorisations – regulation* may place limits on automation. Precast concrete plants, in the same way as construction systems, are usually regulated by the governments or an organisation delegated by the government. If the construction regulations make automation difficult, the time needed to obtain certification of a prefabricated variation to enable automated production in a particular plant must be considered.

**Objective three:** to measure the profitability of products in precast construction plants

This study used historical data to measure the profitability performance of a precast concrete plant in New Zealand. The results in Chapter 5 show that the plant did not win enough jobs to feed the production up to its maximum capacity, and the attractiveness rate gradually decreased from 2009 to 2017.

Profitability is an essential measure of a company's performance because it allows a company to make the best possible use of its own resources, including producing more quality products, with less waste, using fewer resources, or spending less money than standard market practice.

Pareto Analysis was used to select six products that contributed more than 80% of the company's revenue, labour cost, gross margin, and gross profit margin during 2010-2016.

**Objective four:** to develop a decision support tool (PPAST) to optimise the implementation of automation in precast construction plants in New Zealand.

In Chapter six, objective four develops the response to the fourth research question in this thesis by providing a framework for selection and optimisation of automation in the precast concrete plants in New Zealand. In addition – based on the objectives of the PPAST, the importance of automation, and the factors which are affecting the profitability of precast concrete plants – six VQs were formulated to facilitate the purposeful framework. This framework is based on the relationship between the potential for automation and the factors affecting profitability. Hence, it was useful to develop this tool that helps decision-makers to explore automation adoption and to formulate an optimal strategy to apply automation.

The validation of the developed decision support tool took place in two stages with questionnaires answered (Appendix 2) by forty-six SMEs. The direct rating method was used for the first question to rate all six VQs to validate them, and the AHP method was used for the second question to rate all six VQs by comparing their importance for automation adoption. As a result of the first stage, 87% of participants confirmed that all of the VQs are valid and can be used as a baseline for automation adoption decision-making. The results of the second stage revealed the importance of pre-screening attributes that can used for decisions regarding automation adoption.

**Objective five:** to provide recommendations and pathways towards the implementation of an optimised automation system in the case study company by utilising the outcome of research objective 3 into the developed decision support tool, research objective 4.

The decision support tool developed (PPAST) and the data calculated from objective three were used to provide recommendations and pathways towards implementation of automation in this company. During the feasibility study phase of the PPAST, the calculated attributes were compared to the minimum requirements in the New Zealand market. Any attributes that could not meet the minimum requirement were given a score (i.e. weight of attributes which were extracted by AHP in objective five). As the total score of the case study was equal to 100% (refer to table 6.3), the adoption of automation was recommended.

A detailed analysis phase was then undertaken to find the optimal sequencing of automation for the company. In this section, the attribute values of each product were used as the AHP input data. Calculations were conducted on all seven products and six attributes.

By implementing the validated decision support tool into the case study company, the results shown below were extracted.

Table 7. 1: Best automation adoption sequence of products on the case study based on their attributes

| Automation Sequence | Products |
|---|---|
| 1 | Product F |
| 2 | Product E |
| 3 | Product B |
| 4 | Product G |
| 5 | Product C |
| 6 | Product A |
| 7 | Product D |

Among the products with the highest rank for automation adoption, Products F, E, and B have the highest weight for considering automation in this company. Product F has the highest market demand and plant utilisation rate. Product E had the second highest market demand and plant utilisation. Product C had the highest non-value-added production process among all other products. Of the products with the lowest rank for automation adoption, Products D, A, and C to follow have the lowest weight for considering automation system in this company. Product D had the lowest plant utilisation and GPM among all other products. Product G had the lowest market demand and highest labour cost. Although product A had the lowest labour cost, it had the lowest market attractiveness and higher GPM.

Below is a summary of the findings of this study:

1) Based on comprehensive literature reviews, interviews, and direct observation, it was found that there are six key factors that affect profitability: market attractiveness, plant utilisation, labour efficiency, market demand, gross profit margin and non-profitable processes (unnecessary wasted time).

2) A decision support system has been developed and validated to aid decision-makers in identifying their objectives and attitudes toward risk when exploring the feasibility of automation and formulating their optimal automation strategy. Essentially, it serves as a framework for evaluating whether an automation strategy will be effective at achieving its objectives.

3) It was determined that the decision support tool was able to determine whether a precast concrete company should adopt an automated management system through a series of measurements of the profitability factors in the company.

### 7.2.1. **Original research contribution**

This thesis contributes to the existing body of knowledge regarding the profitability of the offsite manufacturing industries. This study focuses on improving the identified factors affecting the profitability of the precast concrete plants in New Zealand. The study has also addressed the adoption of optimised automation systems in these plants. Finally, this study provides recommendations and pathways towards the implementation of an optimal automation system in the case study company (one of the largest precast concrete plants in New Zealand) by utilising their attribute values into the decision support tool developed. The contributions of this study are outlined and discussed below.

### 7.2.2. Theoretical contribution

The significant theoretical contribution of this thesis is the development of a decision support framework for adoption of automation in the manufacture of precast concrete. The framework offers a valuable theoretical contribution to the body of knowledge by presenting the profitability challenges and automation adoption in New Zealand precast concrete plants. The study's findings establish the optimal automation adoption system in precast concrete plants in New Zealand, which is a country with high labour costs and skill shortages. This study has demonstrated with empirical evidence that there are significant financial impacts on the offsite manufacturing companies in New Zealand at the present time. Most of these are as a result of low profitability, GPM, cash flow, and a highly competitive market industry. The outcomes from this study align with the existing literature on automation and factors affecting profitability, as the thesis used literature review, archival data analysis, closed-ended questionnaire, and interviews with subject matter experts in its analysis.

## 7.3. Research delimitations and limitations

While the findings of this study have provided solutions, guidance, and recommendations for automation adoption in New Zealand precast concrete plants to improve their profitability, there are some clear delimitations and limitations surrounding the research.

Delimitations of the study include its focus on the adoption of automation in precast concrete plants in New Zealand and the collection of research data within a specific period (historical data for the case study company's pre-screening attributes ranging from 2010 to 2017).

And the study's limitation to financial knowledge and construction management aspects without considering the engineering aspects of the automation systems. The limitations also involve the potential for change in the identified attributes related to profitability challenges over time, the possibility of bias in respondent's' perceptions due to the use of a Likert scale, and the dependency of the decision support tool's validation on the judgment of SMEs, which could be biased and suggest the possibility of uncertainty. However, measures were taken to minimize bias in the study, by conducting triangulation analysis and using mix-method research.

### 7.4. Recommendations and required actions to Stakeholders of the Case Study:

The adoption of automation in precast concrete plants should be approached with a critical eye towards the potential benefits and challenges it poses, to ensure that it leads to profitability (Mokhlesian & Ramezanianpour, 2020; Won & Kim, 2021).

The precast construction industry is constantly evolving, and stakeholders need to adapt to stay competitive. One of the most promising ways to do this is through the adoption of automation technologies. Studies indicate that the adoption of automated processes can result in enhanced efficiency; however, profitability remains uncertain due to various internal and external influences (Daugherty & Wilson, 2021; Brynjolfsson & McAfee, 2020). Automation adoption does not guarantee profitability in this case study; however, this research required optimal allocations (determining the optimal mix of automation and conventional production). Therefore, simply investing in automation is not enough. Stakeholders must take a comprehensive approach that prioritizes high-ranking products, improves low-ranking products, develops workforce skills, enhances market attractiveness, and optimizes plant utilisation and profitability. By doing so, stakeholders can create a more efficient and profitable precast construction business. In this section, we will outline specific recommendations and actions that stakeholders can take to achieve these goals.

✓ **Invest in automation:**

Stakeholders should consider adopting automation technologies in their precast construction plants, as the research indicates an increase in profitability when automated processes are implemented by:

- Conducting a thorough decision support analysis to identify if automation is suitable for the company.
- Prioritising the most appropriate automation plan.

- Developing a comprehensive implementation plan, including timelines and milestones for the integration of automation into existing processes.

✓ **Prioritize automation adoption for high-ranking products:**

Stakeholders should prioritize the implementation of automation for Products F, E, and B, as they have the highest weight for considering automation in the company. These products have high market demand and plant utilisation rates, making them ideal production lines for automation investments by:

- Identifying the most suitable automation technologies for the specific production processes of Products F, E, and B.
- Developing a phased implementation plan for integrating automation into the production lines of these products, considering the financial and operational implications.
- Allocating resources, including budget and personnel, to achieve the automation projects for these high-ranking products.
- Monitoring the performance of automated processes and adjust as needed to ensure optimum efficiency and return on investment.

✓ **Address and improve low-ranking products' attributes:**

For Products D, A, and C, which have the lowest weight for considering automation, stakeholders should identify the underlying issues affecting their market attractiveness, plant utilisation, and gross profit margins by:

- Conducting a comprehensive analysis to identify the factors contributing to the low ranking of Products D, A, and C in terms of market attractiveness, plant utilisation, and gross profit margins.
- Developing targeted strategies to address the identified issues, which may include improving product quality, adjusting pricing strategies, or streamlining production processes.
- Implementing the improvement strategies and monitor their impact on the performance of the low-ranking products, adjusting as needed to achieve desired results.

Once the performance of the low-ranking products has improved, reassess the potential for automation and prioritize investments accordingly.

- ✓ **Develop workforce skills:**

To successfully implement automation, stakeholders should invest in upskilling their workforce, particularly in technical skills related to automation and the use of CAD systems for error-free production by:

- Identifying skill gaps within the workforce and develop targeted training programs.
- Collaborating with local educational institutions to develop relevant training courses.
- Offering incentives for employees to participate in ongoing professional development.

- ✓ **Improve market attractiveness:**

Stakeholders should focus on enhancing the quality of their products, reducing errors, and optimizing resource utilisation to increase their market share and competitiveness in the industry by:

- Investing in quality control measures to reduce product defects and errors.
- Optimizing resource utilisation through better planning and management.
- Developing a strong marketing strategy to showcase the company's strengths and value.

- ✓ **Enhance plant utilisation:**

To improve efficiency, stakeholders should invest in better procurement, planning, and production line management. They should also address bottlenecks in resource utilisation and storage capacity to increase overall plant utilisation rates by:

- Implementing effective procurement strategies to ensure timely delivery of raw materials.
- Developing efficient production schedules to minimize downtime and changeovers.
- Investing in facility upgrades to increase storage capacity and address production bottlenecks.

- ✓ **Monitor and optimize profitability:**

Stakeholders should continuously track their profitability and key performance indicators (KPIs), adjusting their strategies and operations accordingly to maximize their profit margins and return on investment by:

- Establishing a robust system for tracking profitability and key performance indicators (KPIs).
- Conducting regular reviews of financial performance and operational efficiency.
- Using data-driven insights to adjust strategies and operations to maximize profitability and return on investment.

In conclusion, stakeholders can create a more competitive, efficient, and profitable precast construction business by taking a comprehensive approach. This approach should include implementing automation technologies to boost profitability and efficiency. Stakeholders should prioritize automation adoption for high-ranking products and address the underlying issues of low-ranking products to optimize resource allocation and maximize returns. Additionally, investing in workforce skill development, improving market attractiveness, enhancing plant utilisation, and continuously monitoring and optimizing profitability are crucial steps in this process.

## 7.5. Future research

The findings in this research have contributed significantly to the body of knowledge both in theory and practice within the precast concrete plant system in New Zealand, especially decisions regarding automation and its implementation. The research findings opened many opportunities for future research suggestions and improvement.

Further research should consider investigating how the adoption of automation in the precast concrete plants will affect labour shortages, with an emphasis on the construction industry. The impacts of automation technique on profitability improvement were examined, research on the other techniques to determine profitability is recommended. Future research could examine the long-term effects of automation implementation on various aspects of precast concrete plant operations, including productivity, product quality, plant utilisation, workforce skills, and overall profitability. This would help stakeholders better understand the sustainability and resilience of automation investments in the industry.

Another possible direction for future research is to assess the environmental and social implications of adopting automation technologies in precast concrete plants. This could involve investigating the potential reduction of greenhouse gas emissions, energy consumption, waste generation, as well as the effects on worker well-being, job satisfaction, and community relations. Comparative studies across different countries and industries: Comparative research can be conducted to analyse the implementation of automation technologies in precast concrete plants in different countries and industries, offering a broader perspective on the factors influencing the success of automation adoption and the potential for transferring best practices across industries and regions.

# 8. Appendices

## 8.1. Semi-Structured Interview Questions

This interview is adopted with the objective of knowing and understanding this precast concrete plant's actual process and operation flow. Please state your views on the problems and solutions related to information flows supporting production. Your input will help the researcher explore the key factors constraining profitability performance in precast concrete plants in New Zealand.

**Section A: Background information**

- ☐ Working in the precast concrete plant (the case study of this research)
- ☐ Have 5 years of work experience in the NZ construction and precast concrete industry
- ☐ At least mid-senior management level to be able to make decisions about product mix

**Section B: Feasibility study examining the challenges associated with the current case study and precast concrete plants in NZ**

i. What are your organisation's challenges related to the productivity of production lines?

ii. What are the challenges of New Zealand's precast concrete plants?

iii. How do you think an automation system can be used to improve precast concrete plants?

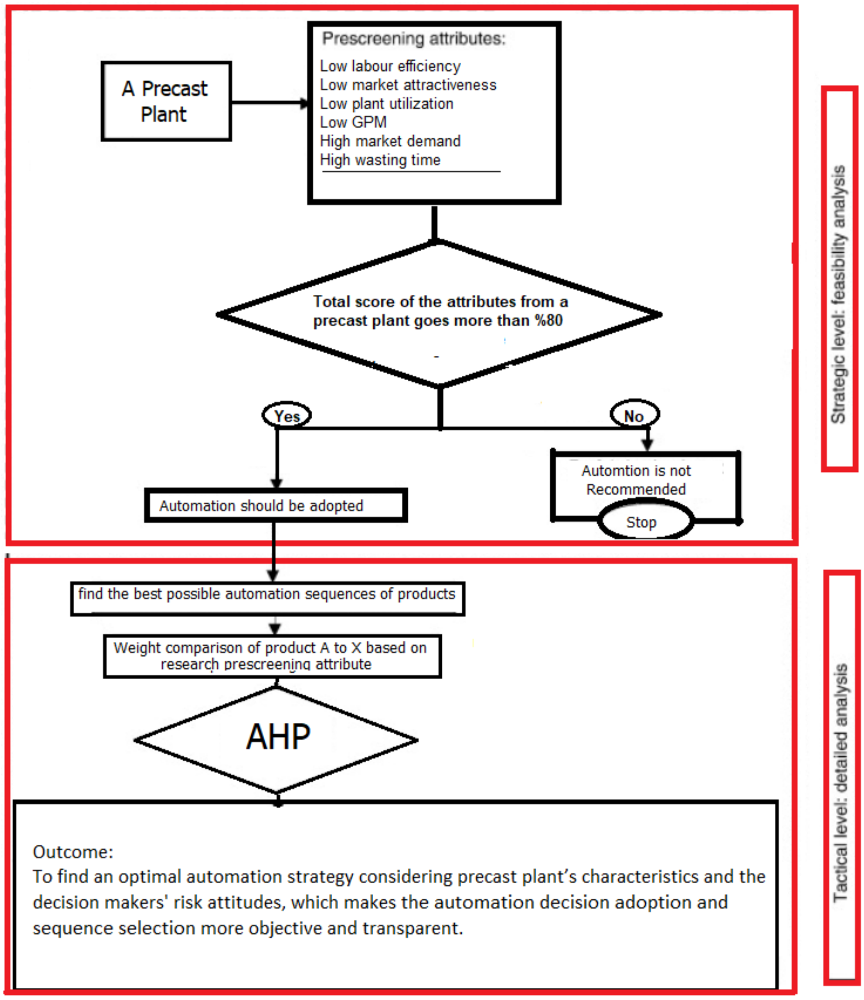
## 8.2. Questionnaire Survey

**Section A: Background information**

- ☐ Working in the precast concrete plant (the case study of this research)
- ☐ Have 5 years of work experience in the NZ construction and precast concrete industry
- ☐ At least mid-senior management level to be able to make decisions about product mix

**Section B: Research Questionnaire Background**

I have done research on implementation of automation in precast concrete plants in New Zealand. Based on comprehensive literature reviews, interviews, and direct observation (VSM method), six main factors (categories) affecting the profitability of the precast concrete industry have been identified as: 1-Market attractiveness, 2-Plant Utilisation, 3-Labour efficiency, 4-Market demand, 5-Gross profit margin, 6-non-profitable processes (unnecessary wasted time).




PPAST, the decision support tool developed, is divided into two sequential levels: the strategic level and the tactical level. The strategic level is conducted to evaluate the feasibility of automation employing a short list of pre-screening attributes, such as market attractiveness, plant utilisation, labour efficiency, wasted time, profit efficiency and gross profit margin. Information on these chosen attributes is usually available at the early stages. The AHP (Analytic Hierarchy Process Technique) is used in this level. The tactical level is conducted to evaluate automation sequences of components for a particular plant based on performance attributes, if the result of the prior strategic level is to proceed with automation. The evaluation attribute concerns will be identified by the AHP method and your (participant) answers to the questionnaires below.

PPAST has the potential to assist decision-makers to make an appropriate automation decision and sequence selection in the precast concrete industry. The application of AHP is new in the context of precast plant automation method selection. Response from you (participant) will be used to validate my decision-making tool.

I need your contribution by responding to a few questions (relating to my findings) based on your experiences in the construction industry and precast concrete plants. I have prepared a set of questionnaires which allow me to evaluate my decision-making tools and extend my knowledge. Your input/response would be appreciated.

**Section C: Research Questionnaires (3 Questions)**

Question 1:

| | Do you agree with the statements below in relation to the implementation of automation systems in a NZ precast concrete plant? | Yes (1-10) | No (0) |
|---|---|---|---|
| 1 | Automation adoption will improve profitability of a precast concrete plant if the current labour efficiency of their product is too low | | |
| 2 | Automation adoption will improve profitability of a precast concrete plant if the current market attractiveness of their products is too low | | |
| 3 | Automation adoption will improve profitability of a precast concrete plant if the current plant utilisation of their products is too low | | |
| 4 | Automation adoption will improve profitability of a precast concrete plant if the current GPM of their product is too low | | |
| 5 | Automation adoption will improve profitability of a precast concrete plant if the current market demand efficiency of their product is too high | | |
| 6 | Automation adoption will improve profitability of a precast concrete plant if the current wasting time rate of their product is too high | | |

Question 2:

| | | Please rate the importance of the criteria below (Between 1 and 9) by comparing their need for automation adoption | | more important? | Scale |
|---|---|---|---|---|---|
| i | j | A | B | A or B | (1-9) |
| 1 | 2 | Lower labour efficiency | Lower market attractiveness | | |
| 1 | 3 | | Lower plant utilisation | | |
| 1 | 4 | | Lower GPM | | |
| 1 | 5 | | Higher market demand | | |
| 1 | 6 | | Higher level of wasting time | | |
| 2 | 3 | Lower market attractiveness | The lower plant utilisation | | |
| 2 | 4 | | The lower GPM | | |
| 2 | 5 | | Higher market demand | | |
| 2 | 6 | | Higher level of wasted time | | |
| 3 | 4 | Lower plant utilisation | Lower GPM | | |

| | | | | | |
|---|---|---|---|---|---|
| 3 | 5 | | Higher market demand | | |
| 3 | 6 | | Higher level of wasted time | | |
| 4 | 5 | Lower GPM | Higher market demand | | |
| 4 | 6 | | Higher level of wasted time | | |
| 5 | 6 | Higher market demand | The higher wasting time | | |

## Question 3:

| | Based on your experiences of the NZ construction market,<br>Provide percentage values for various factors influencing profitability | % | N/A |
|---|---|---|---|
| 1 | What is the minimum market demand vs production capacity of a precast concrete plant to keep up with profitability? | | |
| 2 | What is the maximum labour cost vs total sale value of a precast concrete plant to keep up with profitability? | | |
| 3 | What is the minimum market attractiveness vs production capacity of a precast concrete plant to keep up with profitability? | | |
| 4 | What is the minimum plant utilisation of a precast concrete plant to keep up with profitability? | | |
| 5 | What is the minimum gross profit margin of a precast concrete plant to keep up with profitability? | | |
| 6 | What is the maximum wasting time of a precast concrete plant to keep up with profitability | | |

## 8.3. Questionnaire survey participants

Participants in interviews:

| # | Role | Years of Experience | # | Role | Years of Experience |
|---|---|---|---|---|---|
| 1 | Estimation manager | 30 | 6 | Production supervisor | 20 |
| 2 | Project manager | 20 | 7 | Quality control manager | 10 |
| 3 | Senior draftsmen | 15 | 8 | Quality control supervisor | 11 |
| 4 | Branch manager | 15 | 9 | Despatch manager | 10 |
| 5 | Operational manager | 20 | 10 | Consultant | 30 |

Participants for questionnaires:

| | Qty | Role | Companies |
|---|---|---|---|
| 7% | 3 | Production managers | 3 |
| 2% | 1 | Operational manager | 1 |
| 13% | 6 | Quantity surveyors | 5 |
| 7% | 3 | Contract managers | 3 |
| 24% | 11 | Project managers | 11 |
| 7% | 3 | Senior Draftsmen | 2 |
| 7% | 3 | General Managers | 3 |
| 11% | 5 | Estimators | 3 |
| 20% | 9 | Production engineers | 7 |
| 4% | 2 | Project Coordinators | 2 |
| Total | **46** | | |

## 8.4. AHP Calculation

### 8.4.1. Automation adoption sequence of products in the case study, based on their attributes

| | | | | | | |
|---|---|---|---|---|---|---|
| **n=** | 7 | Number of products (2 to 10) | Scale: | 1 | | AHP 1-9 |
| **N=** | 6 | Number of attribute (1 to 20) | α: | 0.1 | Consensus: | 88.4% |
| **p=** | 0 | Selected attribute (0=consol.) | 2 | 7 | Consolidated | |

**Objective** multi-criteria decision-making tool for the decision support system on to determine which products to be automated in precast concrete plant

**Author** Reza

**Date**

Thresh: 1E-08 Iterations: 5 EVM check: 2.2E-10

**Table**

| | Products | Comment | Weights | +/- |
|---|---|---|---|---|
| 1 | Product A | | 12.5% | 0.0% |
| 2 | Product B | | 14.5% | 0.0% |
| 3 | Product C | | 13.5% | 0.0% |
| 4 | Product D | | 11.3% | 0.0% |
| 5 | Product E | | 16.3% | 0.0% |
| 6 | Product F | | 17.9% | 0.0% |
| 7 | Product G | | 14.1% | 0.0% |

**Result**

| | | | | | |
|---|---|---|---|---|---|
| **Eigenvalue** | | | Lambda: 7.000 | MRE: | 0.0% |
| **Consistency Ratio** | 0.37 | GCI: 0.00 | Psi: 0.0% | CR: 0.0% | 0.0% |

**Matrix**

| | | Product A 1 | Product B 2 | Product C 3 | Product D 4 | Product E 5 | Product F 6 | Product G 7 | | | | normalized principal Eigenvector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product A | 1 | 1 | 6/7 | 1 | 1 1/9 | 3/4 | 2/3 | 8/9 | | | | 12.46% |
| Product B | 2 | 1 1/6 | 1 | 1 | 1 2/7 | 8/9 | 4/5 | 1 | | | | 14.53% |
| Product C | 3 | 1 | 1 | 1 | 1 1/5 | 5/6 | 3/4 | 1 | | | | 13.47% |
| Product D | 4 | 1 | 7/9 | 5/6 | 1 | 2/3 | 5/8 | 4/5 | | | | 11.27% |
| Product E | 5 | 1 1/3 | 1 1/8 | 1 1/5 | 1 4/9 | 1 | 1 | 1 1/6 | | | | 16.30% |
| Product F | 6 | 1 3/7 | 1 2/9 | 1 1/3 | 1 3/5 | 1 | 1 | 1 1/4 | | | | 17.88% |
| Product G | 7 | 1 1/8 | 1 | 1 | 1 1/4 | 6/7 | 4/5 | 1 | | | | 14.10% |

### 8.4.2. Rate of attributes affecting automation adoption decision (refer to 9.4.2 for calculation)

| | | | | | |
|---|---|---|---|---|---|
| **n=** | 6 | Number of products (2 to 10) | Scale: 1 | | **AHP 1-9** |
| **N=** | 10 | Number of criteria (1 to 20) | α: 0.1 | Consensus: | **99.2%** |
| **p=** | 10 | selected Participant (0=consol.) | 2 72 | **Criteria 10** | |

**Objective** multi-criteria decision-making tool for the decision support system on to determine which products to be automated in precast concrete plant

**Author** Reza

**Date**

Thresh: 1E-08 Iterations: 6 EVM check: 4.2E-09

**Table**

| | **Products** | **Comment** | **Weights** | **+/-** |
|---|---|---|---|---|
| 1 | The lower labour efficiency | | 20.8% | 7.6% |
| 2 | The lower market attractiveness | | 24.3% | 7.4% |
| 3 | The lower plant utilization | | 27.6% | 8.4% |
| 4 | The lower GPM | | 6.7% | 6.4% |
| 5 | The higher market demand | | 10.5% | 3.2% |
| 6 | The higher wasting time | | 10.2% | 3.1% |
| 7 | | | 0.0% | 0.0% |

**Result**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Eigenvalue** | | | Lambda: | 6.499 | MRE: | 48.8% |
| **Consistency Ratio** | 0.37 | GCI: 0.28 | Psi: 0.0% | CR: 8.0% | | |

**Matrix**

| | | 1 The lower labour efficiency | 2 The lower market attractiveness | 3 The lower plant utilization | 4 The lower GPM | 5 The higher market demand | 6 The higher wasting time | normalized principal Eigenvector |
|---|---|---|---|---|---|---|---|---|
| The lower labour efficiency | 1 | 1 | 1 1/9 | 1 | 1 | 2 4/7 | 2 2/3 | 20.76% |
| The lower market attractiveness | 2 | 1 | 1 | 7/8 | 6 2/7 | 2 1/3 | 2 2/5 | 24.32% |
| The lower plant utilization | 3 | 1 | 1 1/7 | 1 | 7 1/7 | 2 5/8 | 2 5/7 | 27.59% |
| The lower GPM | 4 | 1 | 1/6 | 1/7 | 1 | 3/8 | 3/8 | 6.68% |
| The higher market demand | 5 | 2/5 | 3/7 | 3/8 | 2 5/7 | 1 | 1 | 10.48% |
| The higher wasting time | 6 | 3/8 | 3/7 | 3/8 | 2 5/8 | 1 | 1 | 10.17% |

### 8.4.3. Direct rating to the validation questions

| | Do you agree with the below statements in relation to the implementation of automation systems in NZ precast concrete plant? | Yes (1-10) | No (0) |
|---|---|---|---|
| 1 | Automation adoption will improve profitability of a precast concrete plant if the current labour efficiency of their product is too low | 41 | 5 |
| 2 | Automation adoption will improve profitability of a precast concrete plant if the current market attractiveness of their products is too low | 41 | 5 |
| 3 | Automation adoption will improve profitability of a precast concrete plant if the current plant utilisation of their products is too low | 44 | 2 |
| 4 | Automation adoption will improve profitability of a precast concrete plant if the current GPM of their product is too low | 37 | 9 |
| 5 | Automation adoption will improve profitability of a precast concrete plant if the current market demand efficiency of their product is too high | 41 | 5 |
| 6 | Automation adoption will improve profitability of a precast concrete plant if the current wasting time rate of their product is too high | 37 | 9 |

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