A Method to Assess the Application of Additive Manufacturing to Inventory Replenishment

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Acronyms

3DP – Three-Dimensional Printing

AM – Additive Manufacturing

CAD – Computer Aided Design

CG1 – Complexity Group 1

COGS – Cost of Goods Sold

CSL – Cycle Service Level

DC – Distribution Centre

DDM – Direct Digital Manufacturing

EOQ – Economic Order Quantity

ERP – Enterprise Resource Planning

FOB – Free On Board

MOQ – Minimum Order Quantity

MRO – Maintenance, Repair and Operations

NZD – New Zealand Dollars

QRC – Quick Release Coupling

SCOR – Supply Chain Operation Reference

SKU – Stock Keeping Unit

TM – Traditional Manufacturing

VBA – Visual Basic for Applications

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Abstract

Companies have historically struggled to deal with their stock, especially the long inventory tail. As most of the inventory management techniques that deal with slow-moving stock have proved to be rather inefficient, this research investigates the use of additive manufacturing to 3D print items on demand and therefore mitigate the inventory carrying and associated costs. This research has been applied to a Hydraulic Equipment Business in New Zealand, which was tested through an inequation that models the traditional manufacturing and 3D printing costs, yielding the 'tipping point' for the use of the 3D printing technology. Even though the results obtained herein were negative for this particular case regarding the use of additive manufacturing, this research has developed a methodology to assess the trade-off between traditional manufacturing and 3D printing and also provides insights into the characteristics of the inventory of the businesses that are most likely to benefit from the use of the technology.

Keywords: additive manufacturing, 3D printing, inventory tail, slow-moving inventory.

1. Introduction

The importance for a company to keep the right stock levels of products is historically well known. Nonetheless, relatively recent catastrophic cases involving giant retailers such as Target, Walmart and Kmart have shown that underestimation of inventory related aspects have led to significantly more than simply not having the adequate inventory amounts (Trujillo, 2016). As it is highlighted later in this research, there is the need to explore further techniques of inventory management that go beyond what is currently applied, and newly developed technologies could be a solution for such improvement.

Pareto's Law, which states that 80% of the effects come from 20% of the causes (Godfrey & Kenett, 2007) and its implications are commonly applied within industry (Jamshidi & Jain, 2016) – for instance a small percentage of a company Stock Keeping Units (SKUs) account for the vast majority of sales (Ramanathan, 2004), with percentages varying across different types of industries, businesses and scales. Ramanathan also argues that, similarly, there will be a large percentage (70%:80%:90%) of SKUs that generate only a small percentage of sales. There is therefore typically a long tail of inventory that companies must carry in order to deliver a high cycle service level (CSL) to customers.

This research proposes that additive manufacturing (AM) and its characteristics can be employed in favour of companies that have historically struggled to deal with slow-moving inventory. Therefore, as well as investigating inventory management techniques, this review has assessed whether three-dimensional printing (3DP) is suitable for manufacturing slow-moving inventory and aimed to identify if there is value in moving towards wider use of it, i.e., whether businesses could somehow take advantage of the technology for the specific purpose of reducing the carrying cost and potential redundancy of inventory tails.

The literature comprises several different inventory management techniques, namely ABC analysis (Ramanathan, 2004), economic order quantity (Blackstone & Cox, 1985), cross-docking (Ladier & Alpan, 2016) and multi-echelon optimisation (GmbH, 2013), among others. These techniques however tend to focus on the fast-moving items, which are those that contribute to the largest percentage of sales. While other research has also been conducted on slow-moving items, simplified scenarios that potentially undermine the findings have been considered (Whitin & Young, 1955). Authors such as Pannet (as cited in Wagner & Walton, 2016) have already demonstrated that 3DP has several potential benefits, including reduced manufacturing lead-times (Berman, 2012) and reduced inventory carrying costs (Wagner & Walton, 2016). The researcher however, has not found articles within the literature that explore the trade-offs of the adoption of AM by business that are willing to take advantage of the technology. While the advantages and disadvantages of utilising 3DP are well known, the direct costs involved in TM and AM have not yet been extensively compared and there is still uncertainty around the relevance of the costs involved. The lack of an assessment methodology to explore the trade-offs between additive and traditional manufacturing from a logistics perspective is therefore the gap that this research was intended to bridge.

Thus, the primary research objective was to create a methodology that enables the assessment of the trade-offs between TM and 3DP, taking into account the costs involved on both sides, for businesses willing to adopt an in-house 3DP solution. With this tool on hand, it will be possible to answer the following question, “Which items of a company’s stock should be 3D printed as opposed to being purchased via TM suppliers?” on a SKU by SKU basis. While these individual responses still do not give a definitive ‘yes’ or ‘no’ to the question regarding whether the technology should be adopted, as there are other factors involved such as the ability of the machine to cope with the order sizes which is specific to each case, it gives a strong indication as to whether 3DP should be considered as an alternative manufacturing method. The results herein obtained, which are aligned with the literature, indicated which case studies are likely to yield positive results regarding the adoption of 3DP.

This assessment tool that explores the trade-off has been developed in the form of an inequation that takes into account the TM and 3DP costs, yielding the tipping point for the use of 3DP. In order for the inequation to be tested, a case study was conducted post-selection of the data provider. Due to the subjectivity of the case in question (and the infeasibility to take a quantitative approach), this research has been conducted under a qualitative approach and any subjectivity related to the business analysed has been interpreted and filtered. The approach was initiated with the pre-stated research question and was followed by an initial data collection that allowed the researcher to test the business in question against three criteria. With the criteria met and the researcher having access to the business, he then collected the remaining necessary data to fill the gaps existing in the company's database.

Five complexity groups were created to categorise the SKUs in accordance to their manufacturing complexities. The analysis consisted of populating the nine variables of the inequation on an item by item basis, allowing the relevance of each cost to be evaluated. The trends for each complexity group were then compared against each other, in order to reveal what pattern occurs as more complex items are to be 3D printed.

In parallel to the analysis, one of the items of the portfolio was selected and 3D printed at Massey's University's metal printer (Albany campus). This allowed the researcher to understand further the 3D printing process and the costs involved. This has been referred to as the Validation Process, which supported the idea that the items analysed can in fact be 3D printed (although no strength tests have been conducted to test the material properties).

With the result of the inequation obtained on an item by item basis, it was possible to infer directly in this particular case whether or not a 3D printer should be adopted as a new manufacturing method. Areas of potential further research were described in the light of the results.

2. Literature Review

2.1 Introduction

The first part of this review of literature identifies some of the main inventory management techniques employed over the years in industry, describing their methodologies and capabilities when applied to stock groups with different characteristics and requirements. Particularly, this review is interested in identifying management techniques that could to some extent minimise the problematic aspects of slow-moving inventory.

The second part of this review briefly introduces AM, its advantages and applications, and then presents pieces of the literature that relate AM to its impacts in the supply chain, extracting information that could contribute to the development of a basis to this research. In particular, this review highlights studies that analyse or raise questions about the feasibility of 3D printing slow-moving inventory or products of a similar nature, such as spare parts, which would also be of interest. In addition, this section exposes the resources and limitations of the current 3DP equipment in terms of materials, dimensions and complexity of its products. Given the difficulty in answering these questions, the review looks into what is being currently developed within industry by the leading companies, universities and other entities that have heavily invested in 3DP technologies.

Finally, this review will explore the trade-offs between utilising TM means and AM, identifying the different variables that interact with one another and define the best method to move forward with. This trade-off will be illustrated in the form of an inequation, which enables the calculation of the 'tipping point' from TM to 3DP.

2.2 Inventory Management Techniques

From a supply chain perspective, inventory can be seen as one of the stages of the material flow from production to the end-user (Averkamp, n.d.). Inventory represents a trade-off between the costs of replenishment, transport, batch sizes and, on the other hand, the necessity for carrying that stock. As it represents part of a company's asset investment, it is therefore expected that there will be an appropriate level of return from it within a reasonable period of time. If there is an overestimation of the appropriate investment, i.e., stock overage, part of the company's money will be 'locked up' in the form of inventory, possibly resulting in lower returns or even stock obsolescence, as well as incurring extra costs such as storage and insurance costs as pointed out by Golas and Bieniasz (2016). The authors also argue that, similarly, if there is an underestimation of the appropriate investment, i.e., stock shortage, the company may lose sales opportunities, decreasing customer satisfaction. Hence inventory management can be seen as an attempt to maximise a company's return on assets as well as keep a high CSL to customers.

Authors such as Blackstone Jr. and Cox (1985) classify the inventory control techniques in two different groups: those suitable to be applied in SKUs with no dependence to demand and those suitable to be applied in demand dependent SKUs. Some of the main inventory management techniques are briefly described in the next section.

2.2.1 ABC analysis.

ABC analysis is regarded as one of the most used inventory management techniques and can be easily employed by managers due to its simplicity and streamlined approach to classification (Ramanathan, 2004). It is a technique based on the Pareto's Principle that classifies inventory SKUs into three distinct groups namely A, B and C (Hatefi, Torabi, & Bagheri, 2014), enabling better inventory management of large portfolios. In this context, Pareto's Principle states that a small portion of a company's portfolio will account for most of the sales. This portion is regarded as A Class, and its importance indicates that SKUs within this group should be constantly reviewed and observed (Ramanathan, 2004), having for instance its demand frequently forecasted and its stock-on-hand periodically checked. The level of importance decreases towards the C Class, which should not be reviewed so often, meaning that the low importance of this group demands less effort from the management team. Companies with a high number of SKUs might use more than three groups to categorise items appropriately (Teunter, Babai, & Syntetos, 2010). A typical ABC Classification can be seen on Figure 2.1:

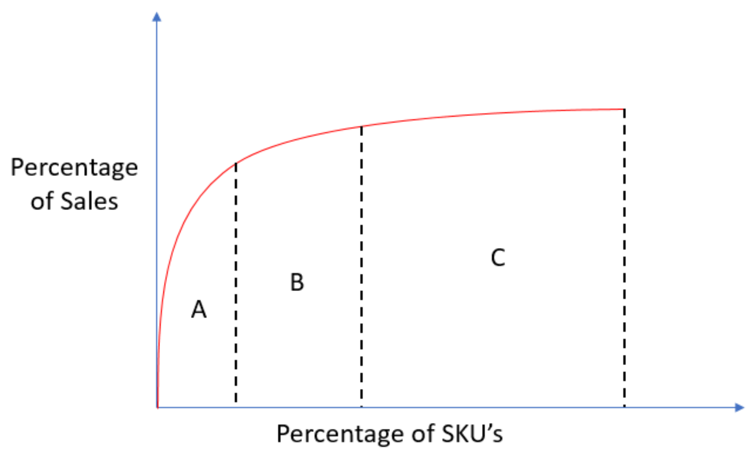


Figure 2.1. Typical ABC Classification Pattern

The historical method used for classification was a single criterion known as the dollar usage, i.e., unit price multiplied by annual demand (Jamshidi & Jain, 2016). However, the use of other, or multiple criteria has been suggested, such as: "obsolescence; lead times; substitutability; repairability; criticality; and, commonality" (Flores & Whybark, 1986, p. 40) as can be seen on the work done by Jamshidi and Jain (2016). The authors employed criticality as their most important criterion, measuring items cruciality to a company's operation according to one of the company's employees. They argue that the traditional criterion alone is not altogether appropriate. However, other authors such as Rezaei and Salimi (2015), criticise the use of subjective criteria, citing specifically criticality as an example. Building a model from shortage and overage costs of SKUs, the authors measured items criticality with a more scientific approach that is not biased by professional's opinions.

2.2.2 Economic order quantity.

While some authors argue that the Economic Order Quantity (EOQ) was introduced by F. W. Harris in 1913 (Taleizadeh & Pentico, 2014; Jawad, Jaber, & Bonney, 2015), others attribute credit to R. H. Wilson (Choi & Noble, 2000). EOQ, also known as Continuous Review Model, is a replenishment technique applied to independent demand items that determines the replenishment pair (s,Q), i.e., when to order (s) and how much to order (Q) at that instant (Blackstone & Cox, 1985). The techniques approach to replenishment aims to keep at a low level both ordering and inventory carrying costs (Rezaei, 2014), as the name suggests. The formulas for Q and s and the necessary parameters are as follows (Blackstone & Cox, 1985, p.28):

$$Q = \sqrt{\frac{2.d.r}{h}}$$

d = item's annual ordered quantity

r = order cost

h = item's annual holding cost

$$s = D + k.v$$

D = average demand during lead time

v = standard deviation of demand during lead time

k = management determined variable

The use of EOQ has a limited range of applications as the model is developed under some specific assumptions, such as items have a constant and continuous average demand, and also a constant known replenishment lead-time (Blackstone & Cox, 1985). Some practical scenarios are also not taken into account, for instance variable prices or discounts offered by suppliers depending on the quantity of items ordered (Taleizadeh & Pentico, 2014). Further researches have been developed gearing EOQ towards specific items, such as perishable products (Nahmias, 1982) and “growing items”, i.e., livestock (Rezaei, 2014, p.109).

2.2.3 Cross-docking.

Cross-docking is a technique that consists of maintaining direct flow of goods between transport systems, reducing warehousing to a minimum (Ladier & Alpan, 2016). In this system, goods are transported into a smaller facility, unloaded and thereafter loaded into another vehicle, not necessarily of the same sort. This facility, known as the ‘cross-dock’, represents an alternative to direct shipping, allowing for instance the consolidation of consignments coming from multiple suppliers as mentioned by Nikolopoulou, Repoussis, Tarantilis, and Zachariadis (2017). The authors also highlight the existence of two separate sub-systems of routing: the first links suppliers to the cross-dock and the second links the cross-dock to customers. To some extent, cross-docking can be utilised to reduce storage and therefore inventory, as products are not meant to remain stored in the facility. However, it is not useful for SKUs with for instance medium or long lead times and where instant delivery required.

2.2.4 Multi-echelon optimisation.

Multi-echelon inventory optimisation is a technique that takes advantage of the integration of the different stages in the supply chain to optimise inventory levels. In a supply chain with two or more levels, i.e., multi-echelon, the technique evaluates what is the ideal quantity to be stored in each level for each product (GmbH, 2013).

Important work in the field has been developed by Clark and Scarf (1960, p. 475) and later on expanded by Goh and Porteus (2016). The former developed a mathematical model based on the costs of each configuration in the multi-echelon, attempting to determine "the optimal purchasing quantity". This technique is similar to the EOQ model as it is initiated from similar parameters, but it considers multiple stages in the supply chain. Basically, it aims to minimise the overall costs in the whole multi-echelon. The theory was developed to a supply chain of the type: [N] -> [ ] -> [ ] -> [2] -> [1], i.e., each level has only one supplier. According to the authors, the results for the multiple supplier's problem is not as good as for the simpler case.

2.3 Slow-Moving Inventory Management

Slow-moving products are items within inventory with a low frequency of ordering and according to Pareto's Law, they represent a disproportionately large portion of a company's stocked products relative to sales of the same products (Ramanathan, 2004). Even though these SKUs are not commonly sold, they are frequently produced in large lots due to the advantages of scale production which leads to the increase of inventory levels. Furthermore, some of these items are only kept to maintain a high cycle service level and often are not even a source of profit. The resulting consequences for businesses in this situation will be reduced profits/lower bottom line, since money is tied up/consumed in the form of funding inventory and the consequential costs of storage, handling, and product redundancy/obsolescence risk, ultimately also leading to a loss in business competitiveness.

Inventory management of slow-moving items is usually an inconvenience for companies, specifically for those organisations with a large assortment of products and materials in their portfolios. An example of this is the fastener industry with their extensive range of bolts, nuts, and screws with different lengths, diameters, and materials. The situation where companies commit to their customers to carry spare parts for the reasonably expected life of a capital asset such as an automobile have to deal with added complexity of items that are not commercialised anymore or that exist in excess are recurrent demand within their industry (Pinçe & Dekker, 2011).

Industry has historically struggled to apply modelling and forecasting techniques to items with such a sporadic demand. Research of note in the field was done by Whitin and Youngs (Heyvaert & Hurt, 1956) in which they developed a method to determine ideal stock levels for low demand items. The authors, who considered the demand to be normally distributed, assumed that it can actually be random, and this assumption was taken only for the sake of simplification (Whitin & Young, 1955). Heyvaert and Hurt (1956) studied the same problem and presented, in their opinions, a more practical result. However, as well as Whitin and Young, they have also assumed the demand to be normally distributed. Ward (1978) argues that in an analysis conducted with past stock logs, around 87.5% of stock items were either not sold within a year or had such an irregular demand that the commonly applied Gaussian distribution was not suitable to model it.

In relation to the problematic aspects of the inventory tail, the following sub-section “Additive Manufacturing” explores the 3DP capabilities attempting to match these with the characteristics of slow-moving items.

2.4 Additive Manufacturing

AM, also known as 3DP, or Direct Digital Manufacturing (DDM), is the manufacturing process of creating a physical object from its digital 3D model, which is designed using Computer

Aided Design (CAD) software and thereafter 3D printed through depositions of very thin layers of its cross-sections (Berman, 2012). The additive nature of 3DP contrasts with TM, which is best described as a subtractive process. A classical comparison can be illustrated with wood carving (subtractive) vs. Lego assembling (additive) as exemplified by Kietzmann, Pitt, and Berthon (2015), who consider it to be a disruptive invention of the modern era. 3DP has been claimed by the Financial Times to be greater than the internet (Morton-Clark, & Garrahan, 2012) and has been the focus of thousands of studies worldwide.

The technology, which can be traced back to topography, photo-sculpture (Bourell, Beaman, Leu, & Rosen, 2009) and material deposition (Bourell, 2016) in the 19th century, was conceived in the middle 1980's, when Charles Hull invented and patented the stereolithography machine, which hardens a photopolymer liquid resin in the desired shape ("The Free Beginner's", n.d.). Since then, there have been further developments of other techniques, including Digital Light Processing, Selective Laser Sintering, Fused Deposition Modelling, Selective Laser Melting, and Electro-Beam Melting (Petrovic, Gonzalez, Ferrando, Gordillo, Puchades, & Griñan, 2011), which use raw materials such as "polymers, epoxy resins, nylon, wax, powders, oils and nutrients, as well as titanium, sterling silver, stainless steel, leather, sandstone, and materials that mimic human cells" (Kietzmann et al., 2015, pp. 210-211), and outputs differentiating by accuracy, waste, endurance, among others. ("The Free Beginner's", n.d.).

While some link the invention to a revolution or disruption of TM means, others sceptically limit it to specific applications. With its rapid development over recent times (Grynol, 2013; Bourell, 2016), supported by recent heavy investment in countries such as Singapore, USA, UK, New Zealand, Australia, China and Korea (Rylands, Böhme, Fan, Gorkin, & Birtchnell, 2016), and the expiry of some patents, which has allowed a more widespread use of the technology

(Bourell, 2016), scientists are now discovering what some of the true impacts of 3DP are, even though it is still in relative infancy in the history of manufacturing, therefore leaving room for various hypothesis.

2.4.1 Advantages.

Apart from other advantages that will be described ahead, there are two main aspects that drive the use of 3DP in the industry: initial manufacturing speed and cost-effectiveness (Berman, 2012). Figure 2.2, which has merely symbolic values, exposes the difference in production rate between 3DP and two TM methods:

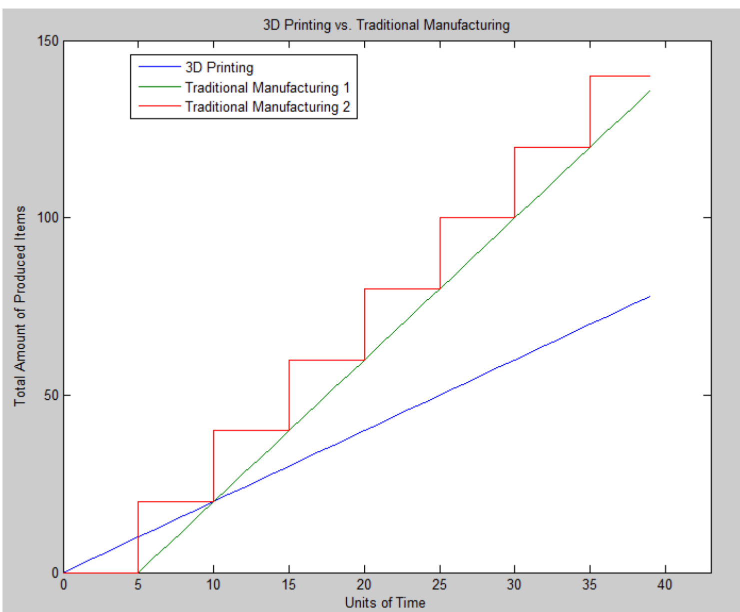


Figure 2.2. Production Rate: 3DP vs. TM

- 3DP – production runs at a constant pace, slower than TM, but without significant setup (Berman, 2012) or changeover (Liu, Huang, Mokasdar, Zhou, & Hou, 2014) time.
- TM 1 – start delayed by setup time and production running at a constant pace, but faster than AM. The curve could illustrate, for example, screws being produced one after

another in a manufacturing line.

- TM 2 – start delayed by setup time and production happening in steps. This pattern represents, for instance, an industry that runs batches on furnaces with fixed capacity.

Note that it is not the average speed in the whole process that makes 3DP attractive, but rather the initial speed, given that it requires a short setup time to function, which is typically not true for TM methods. Even though a technical CAD model has to be designed for every SKU, this process happens only at the creation phase of that item, and not every time it has to be printed. In Figure 2.2, it is also possible to see that after some units of time, traditional means overtake AM, producing items at a higher rate, therefore more suitable for subtractive manufacturing.

In addition to initial time, cost effectiveness is also drawing manufacturers attention to 3DP (Grynol, 2013). Figure 2.3 below illustrates the cost per output unit for both methods:

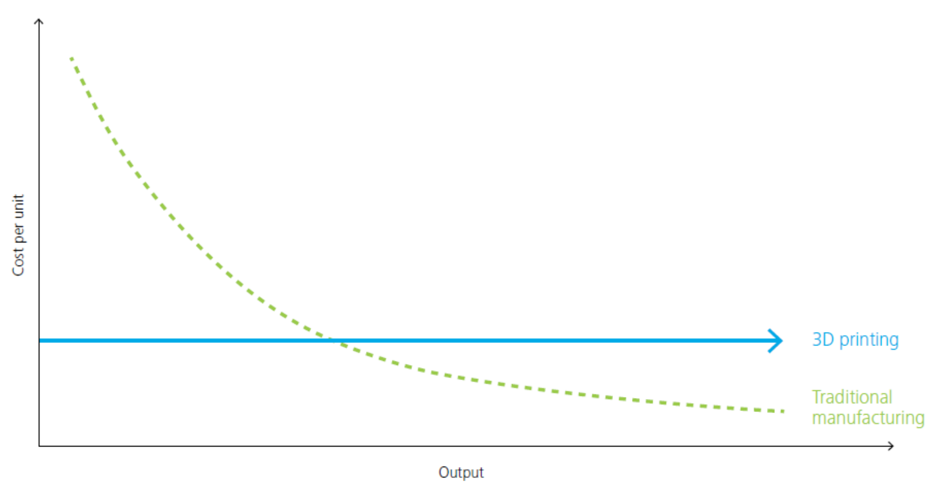


Figure 2.3. Production volumes versus costs: TM versus 3DP (Grynol, 2013)

When a small production run is considered, AM is preferred given its lower (and constant) cost per unit. As output units increase, TM expenses dilute over the number of items, making it more appealing (Grynol, 2013). Note that the ‘3D printing’ curve could move downwards or upwards in respect to the ‘Traditional Manufacturing’ curve depending for instance on the costs of materials employed, making it more or less appealing.

Now suppose that a company requires a customised item to meet a specific purpose. Using TM means, a new mould would have to be created. In cases where the mould has no other use, the company would not benefit from scalability, therefore incurring all the tooling expenses to that single piece. Furthermore, if that item was composed by two or more subassemblies, they would have to be manufactured separately and joined at the end (Petrick & Simpson, 2013). Finally, in situations where the desired output has not met expectations, even a small correction would generally require the process to be commenced from the starting point again. The issues mentioned can be solved by three other advantages 3DP delivers to the market: firstly the ability to create highly customised items and refine their designs via software with negligible extra costs; secondly the purposelessness of moulds or tools ("The Free Beginner's", n.d.), given that the 3D digital model is the only factor that determines the output's shape and design; and finally, manufacture of items with pre-joined subassemblies, which is created through the layer-by-layer deposition.

Relatively low and constant expenses for short production runs have allowed manufacturers to employ AM in the production of batches with a reduced quantity of items (Matias & Rao, 2015). That avoids not only high and unnecessary stock levels (since excesses would be made to take advantage of scalability), but also avoids production line interruptions, which incur extra costs on production (Sasson, & Johnson, 2016). AM advantages could be even better exploited in situations where the small batch was composed of customised (Petrovic et al., 2011) or complex (Bourell, 2016; Bourell et al., 2009) items, which are usually costly to produce via TM; or with a variable (Knofius, van der Heijden, & Zijm, 2016) or random (Sasson & Johnson, 2016) demand.

2.4.2 Applications.

Due to its numerous advantages, AM has been used in a wide range of applications including for instance prototyping - fast modifications or refinements in models design without incurring extra costs and the ability to iterate from one complex shape to another have allowed a perfect fit between application and technology (“The Free Beginner’s”, n.d.). Table 2.1 illustrates some of the 3DP applications, such as the healthcare industry, which benefit from the production of customised items.

Table 2.1 - *3DP Applications*

Industry	**Application**	**Reference**
Healthcare	Deaf aid devices	(Sandström, 2016)
	Dental crowns	(Berman, 2012)
	Prosthesis	(Venekamp & Le Fever, 2015)
	Implants	(Petrovic et al., 2011)
Construction	Concrete structures	(Lim, Buswell, Le, Austin, Gibb, & Thorpe, 2012)
Others	Filters	(Rylands et al., 2016)
	Roller sleeves	

3DP applications are even more widespread, as can be seen on Table 2.2, which contains examples of specific applications of highly regarded organisations employing AM in their manufacturing processes:

Table 2.2 - *Organisations employing 3DP*

Company	**3D Printed Items**	**Reference**
Bentley	Metal front grilles, components of the exhaust system, and door-knobs for personalised cars	(Pinter, 2015)
Boeing	20,000+ aircraft parts	(Krassenstein, 2015)
General Electric	Jet engine fuel nozzles	
Ford	Engine cover, the 500,000th printed part	(Gilpin, 2014)
Nike	Cleats	
NASA	"flame-retardant vents and housings, camera mounts, large pod doors, a large part that functions as a front bumper, and many custom fixtures"	("3D printing", n.d., p. 1)

As shown on Table 2.2, examples of high profile organisations taking advantage of 3DP technologies are not scarce. Boeing for instance is not only printing aircraft parts, but also has just broken the Guinness World Record, in conjunction with the Oak Ridge National Laboratory, for the largest solid 3D printed piece, a trim tool used to manufacture one of their jet's wings (Koslow, 2016). In addition, General Electric is obtaining better results with printed nozzles in comparison with previous methods, and already owns more than 300 3D printers in an attempt to bypass printer speed constraints, as mentioned by Gilpin (2014).

Bioengineering is also benefiting from the development of 3DP, which has enabled the production of structure shapes to frame bio-tissues, assisting on the reconstruction of human parts as complex as organs. In addition, there are also tests being undertaken in respect to drug production (Venekamp & Le Fever, 2015). Another application that has come into play with the development of AM is spare parts management. Since companies tend to avoid keeping a safety stock for all parts that could break or be found to be faulty in a product within the warranty period, CEO's now place their hopes in the technology that offers the possibility to deal with sporadic demands, complex items, long lead times and provides cost-effective production of small quantities as mentioned by Cohen, Agrawal, N., and Agrawal, V. (as cited in Knofius et al., 2016).

An illustration and a further approach of the use of 3D printers can be seen in the article written by Liu et al., (2014), in which an analysis using the supply chain operation reference (SCOR) model was conducted comparing the introduction of AM in various levels of the aircraft spare parts supply chain. They not only suggested the use of AM in aircraft spare parts, but also raised the question of whether AM should be introduced at the distribution centre (DC) level (centralized approach) or at the next level, service locations (distributed approach). This idea could also be considered a previous exercise to the thesis developed in this research, i.e., before a business considers moving to 3DP, it would first evaluate in which stage of the supply chain should a product be printed.

2.4.3 Limitations & future trends.

Even though the use of 3DP is increasing, the technology still presents some obstacles that prevent further widespread use. As highlighted in Figure 2.3, costs of TM methods are still lower than those incurred for 3D printing large quantity of items, making AM not suitable for mass production (Berman, 2012; Grynol, 2013). In this context, 3D printers' manufacturing speed is also an issue that hinders its use for scalability.

Powerful 3D printers have been developed, but the capabilities of 3D printers available for the general public are still not so appealing (Grynol, 2013). Also, there are challenges around the final product finishing and endurance, as well as limited materials available (Berman, 2012). However, there seems to exist an optimistic forecast all over the industry towards the development of AM. As well as past factors such as patent expiries which will continue to occur, Bourell (2016) also highlights that with the competition for market share, printed parts demand rise and research in the field will yield price reductions in both 3D printers and raw materials, leading to improved performances. Increasingly favourable scenarios are being found where the use of this technology is creating benefits, and this is expected to subsequently lead to more widespread use of AM.

Bourell (2016) also reviews the basics of 3DP operation – the construction of layers through infinitesimal additions of material. He argues that the speed constraint could be sorted out by the introduction of an areal addition of material, i.e., all points of a cross-section would be added to the item instantly.

Despite the current limitations and considering its characteristics, 3DP shows a potential to replace part of the supply approach for the inventory tail and therefore turns out to be an alternative for business to reduce inventory carrying costs, transport costs and reduce lead-times. The applicability of AM and the trade-offs between TM and AM are further explored in the Conceptual Model.

2.5 Conceptual Model

As seen in sub-chapter 2.2, existing inventory management techniques do not specifically focus on the long-tail, but rather prioritize the A class items. Research into management of slow-moving inventory has also been conducted, but the real characteristics of these items forced the authors to assume simpler scenarios. In this context, 3DP and its characteristics such as short lead-time can be utilised to deal with slow-moving stock.

As cited in earlier sections, there are clear advantages and disadvantages related to the use of 3DP. Table 2.3 illustrates a brief comparison between key advantages and disadvantages of TM and AM:

Table 2.3 - *TM vs. AM: Advantages and Disadvantages*

Feature	**Traditional Manufacturing**	**3D Printing**	**Reference**
Unit Cost	Low/Medium (benefits from scalability)	High	(Grynol, 2013)
Lead-time	Medium/High	Very low	(Berman, 2012)
Transport Cost	Medium/High	Low (raw material)	(Wagner & Walton, 2016)
Inventory Carrying Cost	Medium/High	Low	(Wagner & Walton, 2016)

Despite the uniqueness within each business, an overall conceptual model can be drawn from the above table, enabling the identification of the subtle ‘tipping point’ in which TM is not an advantage anymore and, in its place, products should be manufactured using AM methodologies. This ‘tipping point’ will vary between individual products and can be, at a first stage, illustrated by the inequation below, in which the left-hand side contains costs related to AM and the right-hand side contains costs related to TM:

$$C_{RAW} + T_{RAW} + C_{FIN} < U_{TM} + T_{TM} + I_{CC} \qquad (1)$$

As stated in Inequation (1), for each item, AM costs are related to:

- the cost of raw material C_{RAW} necessary to 3D print that particular item;
- the raw material's shipping cost T_{RAW} (proportional to the item's weight);
- the finishing cost C_{FIN}, which corresponds to the time spent to post process (e.g. smooth or polish) the item after it is 3D printed.

From the buyer's point of view, for each item, costs related to TM are the following:

- the item's unit price U_{TM};
- the shipment cost from the supplier to the buyer T_{TM};
- the inventory carrying cost I_{CC} which relates to the missed opportunity of investing the money locked in the form of inventory.

In addition, regarding the right-hand side of the inequation, one must also consider that when stock is carried as opposed to 3D printed on demand, there is the need for extra warehouse storage space. Each item of the stock accounts for a portion of the warehouse space, and this cost will be incorporated into the equation as C_{WH}. Furthermore, it is not uncommon for a company to write off every year part of the stock that became obsolete before the items were used or sold. This may happen due to a change in customer demand, to a product having exceeded its shelf life or due to a change in industry safety standards. This cost will be incorporated into the inequation as C_{OB}, the cost of obsolescence.

Even though the use of 3DP neglects the need for extra storage space and there is little or null risk of item's obsolescence, one cannot neglect the on-going investment in the 3DP technology, which corresponds to the 3DP machine, the software licence and other requirements.

In order to take this into account, this research will look at the on-going cost of leasing an industrial 3DP machine, incorporated into the inequation as C_{3DP}. The final form of the inequation, referred to as Inequation (2), is then yielded and is as follows:

$$\mathbf{C_{RAW} + T_{RAW} + C_{FIN} + C_{3DP} < U_{TM} + T_{TM} + I_{CC} + C_{WH} + C_{OB}} \quad (2)$$

It is important to note that in Inequation (2) there are one-off costs such as C_{RAW}, T_{RAW}, C_{FIN}, U_{TM}, T_{TM} and C_{OB}, and on-going periodical costs such as C_{3DP}, I_{CC} and C_{WH}. In order for this research to compare both sides of the inequation, a common time window must be established for the on-going costs. For convenience, a monthly time span is chosen.

A primary researcher estimation would place the 'tipping point' of Inequation (2) in the threshold between the B and C Class SKUs, due to the usual relatively medium turnover of the B Class (subject to the business and industry to be analysed, and the criteria used for the ABC Classification). It is however anticipated that there could be some products, likely to be within the B Class, that given their peculiarities, would also qualify to be 3D printed (this topic is further described in the next chapter). The researcher believes that the A Class is totally outside the scope of application, but this will also be later confirmed. Regarding the C Class, it is expected that the longer the tail (i.e., the percentage of the whole portfolio), larger is the potential for the use of 3D printing within that business.

2.6 Research Gap

The suggestion for 3D printing slow-moving inventory is not new and has been pointed out, for example, by Pannet (as cited in Wagner & Walton, 2016), as a way of: benefiting from instant production therefore avoiding long lead-times, dealing with uncertain demand therefore avoiding high stock levels, and finally taking advantage from the cost-effectiveness of small production runs. However, as also identified by Sandström (2016), there is scarce research that provides solid parameters for companies to support decisions around whether to move towards the adoption of AM, and that is therefore the gap this research will attempt to investigate and provide further insights on the topic. The exploration of the variables that model the contrast between TM and 3DP will enable a better understanding of the matter and will provide another point of view on this new manufacturing method that will tend to spread over the industry as it is improved.

As developed in the conceptual model, Inequation (2), which is a function of nine variables, provides the critical point for the use of AM. This research will further explore the role of each variable in the inequation, their importance in the overall result, and their impacts over one another. While some of the parameters may be crucial and may affect directly the inequation's result, others may potentially be neglected without any loss. Furthermore, the variable values may sit within a pre-determined range, which could be defined by the kind of business, the type of products, materials, or any other aspects yet to be investigated.

A second topic that will also be explored is the applicability of the above inequation in the company's portfolio. It is anticipated that there will be some range of products within the company assortment of items that will not be relevant to be analysed for example due to their high turnover frequency, whereas others may be more appealing than the rest given for instance their higher contribution to the inventory carrying cost. Figure 2.4 illustrates the likely range of SKUs to which the analysis will be applicable:

- Region 1: the bottom of the tail, i.e., the SKUs with the lowest turnover. The threshold point is yet to be investigated.
- Region 2: SKUs that are not comprised in Region 1 due to their high turnover, but would qualify to be 3D printed due to a peculiarity, such as item value or any other

factor yet to be discovered.

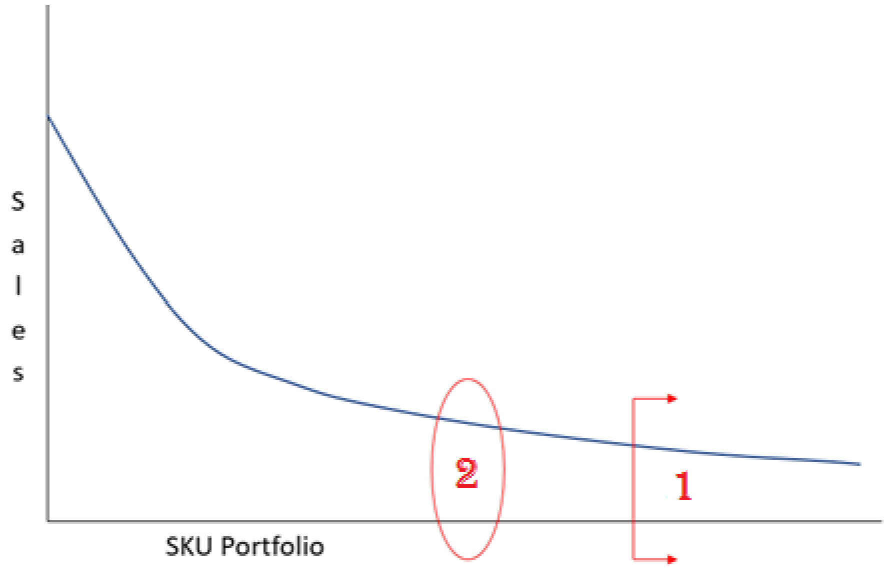


Figure 2.4. Applicable regions within the company portfolio.

Finally, it is expected that the application of the inequation with further exploration of its variables relevance and importance will contribute to shed a light on the research's main question: "Which items of a company's stock should be 3D printed as opposed to being purchased via TM suppliers?" and consequently support or reject the hypothesis that 3DP could minimise the problematic aspect of slow-moving inventory.

2.7 Summary

The research aims to investigate the use of 3D printers to manufacture items of companies' inventory and the consequent benefits. The literature review firstly explored some of the main inventory management techniques known, highlighting that they mainly focus on the high velocity SKUs and provide low or nil contribution to relieve the problematic aspects of the long tail. The review thereafter investigated 3DP characteristics, capabilities and applications, unveiling its potential and fit with the slow-moving items as its increasingly widespread use over time despite its current limitations.

Based on the trade-offs between TM and AM, a conceptual model was developed in the form of an inequation and its potential applicability over companies' products assortment was questioned, with a further suggestion (yet to be proved) on the real application range. With the lack of historical in-depth knowledge in the field and the potentials already described matching slow-moving items and 3D printers, a research gap was identified, and it is what this research proposes to scrutinise to provide further insights on the topic. The inequation will be tested in a business in New Zealand that would qualify to be a data provider for this research.

The subsequent chapter, Research Methodology, contains details of the approach to be taken towards testing the conceptual model, i.e., what view the researcher will apply to be led to a conclusion.

3. Research Methodology

3.1 Introduction

The scientific thinking in the academy of sciences utilises two main different types of research to describe the surrounding world: quantitative and qualitative (Bryman & Bell, 2011). Quantitative research tends to follow a deductive path when research is linked to theory. It means that the research usually begins with a hypothesis being drawn from the theory. This process progresses with data collection and analysis of outcomes and findings, which will finally either support or reject the initial hypothesis (Bryman & Bell, 2011). On the other hand, qualitative research is commonly developed under an induction process, in which observations of the nature lead to creation of theory (Bryman & Bell, 2011).

The next two sections introduce the ontological and epistemological perspectives of conducting research and the following section positions this research within those perspectives. It is important to situate this research within these two points of view since the data that populates the core of the research is directly influenced by the researcher's choice of methodology, therefore yielding a likely distinct result regarding the use of 3DP over different SKU profiles. In this context, the pre-stated question: "Which items of a company's stock should be 3D printed as opposed to being purchased via TM suppliers?" is likely to have a different answer in each situation.

3.2 Epistemology

According to Grix (2002), epistemology "focuses on the knowledge-gathering process" and from an epistemological perspective, two approaches can be taken: a positivist or an interpretivist. The first one tends to be more suitable for quantitative research, as it analyses the world from an objective point of view and removes the subjectivity of for instance, human interpretation. The knowledge is therefore built and validated when there is no bias incurred by social aspects (Bryman & Bell, 2011). The latter, however, states that the world can be analysed not from a cold point of view but from different perspectives. In this case, everyone provides a contribution in the interpretation, based for instance on his/her life experience, which is the so called Interpretivism (Bryman & Bell, 2011).

Considering the epistemological perspective, an interpretivist approach would suit better the content of this research. Inequation (2) deducted above will be applied and tested in a specific business that is heavily subject to the choices of its stakeholders. The current reality of the business, for instance its market position, and all the aspects that relate to this particular company are a result of the contributions of those that have been involved with it, hence there is a large component of human interaction (Bryman & Bell, 2011). Thus, it must be acknowledged that the results to be yielded at the end of this research will have been impacted by human subjectivity.

It is therefore clear that this research could not be conducted under a positivist approach, which would assume that the data to be collected is free from any human interpretation or contribution. That it would be observed, codified and measured, rather than interpreted and comprehended under the human perspective (Bryman & Bell, 2011).

3.3 Ontology

Ontology is “what we believe constitutes social reality” (Blaikie, 2000, p.8). From an ontological perspective, and aligned with the positivist approach, the Objectivism looks to the world from a tangible and palpable view. It defines the world as independent of the human perception, i.e., the world is what it is, regardless of how it is interpreted by human eyes (Bryman

& Bell, 2011). On the contrary, the constructionist approach sees the world as a big puzzle in which every piece is a result of the people's views and their contributions. Bryman and Bell (2011) illustrates this contrast using a company as an example: while objectivists argue that rules and regulations mould individuals within a company shaping them to fit the company's pre-established culture, the constructionists argue that the company culture is a result of the individual's contributions, their beliefs and behaviours.

As outlined above, and aligned with the Interpretivism, Constructionism sees the world as a result of people's contributions. People receive information from the nature, process it, and provide inputs according to their experiences and values in life. Thus, the Constructionism (as opposed to Positivism) is the most appropriate approach to be utilised given that the company to be used as a data provider to this research is heavily influenced by people – its suppliers, managers, employees and even its customers have an influence and contribution on it. The results of this research, whatever they might be, cannot be analysed from a cold point of view, and the subjectivity imposed by the humans involved cannot be neglected.

3.4 Research Strategy

In an ideal world, the researcher would like this research to be quantitative – the results herein obtained could be then extended to distinct business and industries with little loss of significance. In addition, the researcher's electrical engineering background which comprised years of formula deduction and theory leading to practice have made the researcher believe that science, whenever possible, should not be accompanied by human interpretivism, but rather be fairly direct and yield the same result regardless of who the scientist is. However, certain aspects of the quantitative research undermine this approach in this particular case: limited time, financial resources, and especially the need to access a reasonable amount of businesses for the data to be collected quantitatively. The latter being a limiting factor for this research to be conducted under a quantitative approach, the researcher has decided to conduct this research under a qualitative approach with a view that the results will still be useful (despite the limited generalisation) and will provide insights into the main question of this research.

According to Bryman (2012), a qualitative approach usually starts with a general research question as a starting point for the research to be developed. Answering partially or thoroughly this question is what drives the researcher to investigate the surrounding world. The question is followed by the selection of appropriate sites and subjects (provided that they meet certain criteria), those that will serve as a guinea pig for the research to be conducted. Here, it must be acknowledged that different sites and subjects are likely to yield different results, hence the subjective and interpretivist nature of the qualitative research. From these, data is collected and interpreted until a conceptual and theoretical work is defined. Finally, a conclusion is drawn. This sequence is illustrated in Figure 3.1:

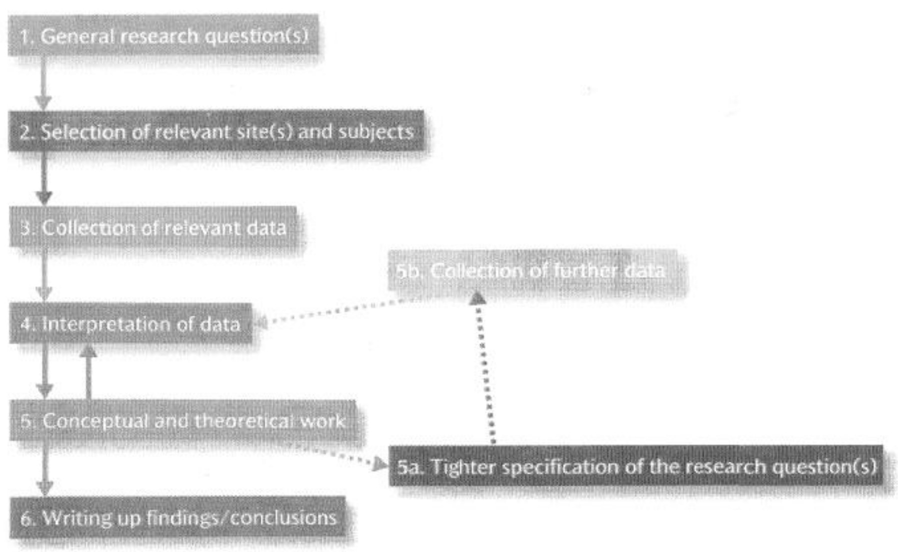


Figure 3.1. An Outline of the Main Steps of Qualitative Research (Bryman, 2012).

This research's main topic, which is around the feasibility of utilising 3DP as a way of reducing inventory, was streamlined to a single question – "Which items of a company's stock should be 3D printed as opposed to being purchased via TM suppliers?". With this question as a starting point, and after a literature review was conducted, a conceptual model in the form of an inequation was developed.

It is noteworthy stating that, even though equations and inequations tend to have some degree of objectivity, one cannot neglect that as the inequation is populated with data from a particular business, the results are considerably subjective and need to be interpreted rather than coldly analysed. Such is the influence of the company's past decisions on the results, that they will need to be filtered before further generalisation can be drawn. For instance, the obsolescence cost C_{OB} and the inventory carrying cost I_{CC} can vary substantially depending on the person in charge of the supply chain within that organisation. Not only the data itself, but also the quality and completeness of this data (such as SKU Masterdata, stock movement, among others) are also affected by the company strategies and focus in the past.

3.5 Research Design

The research design is a framework that establishes how the research will be conducted. It is a detailed explanation of how the chosen approach will be considered and therefore which method will be applied to guide the researcher (Cooper & Schindler, 2008). Regardless of what is the research approach, a well-defined and structured research design allows other researches to fully understand, build knowledge upon or even replicate the research if required.

3.5.1 Operationalisation.

An important step in a research process is the operationalisation in which the variables stated in the conceptual model will become concrete and measurable. They will be quantified to allow not only the research to be conducted, but also to allow the research replication by other researchers if necessary.

Phase 1 – choosing the data provider. The operationalisation in this research starts with the selection of the business that will be a data provider. In order for a business to qualify as a data provider, its inventory must meet the following criteria:

1) Large assortment of SKUs that can be 3D printed with the existing technology;
2) SKUs with different levels of manufacturing complexities, allowing this research to compare results between simple and complex sub-groups;
3) Long inventory tail due to the nature of the business/industry.

In addition to the above, the researcher must also have access to the business and be allowed to interact with its stakeholders whenever necessary.

Phase 2 – data collection. As described by David and Sutton (2011), the operationalisation is followed by the data collection. This data, which will be later processed, may have two different sources: others (secondary data) or the researcher him/herself (primary data) (Ghauri & Gronhaug, 2005). If, on one hand, users of secondary data may benefit from a quicker source of information that saves time, on the other hand, time should be spent assessing whether the data is reliable, unbiased, actual, and is applicable to the research purpose (Ghauri & Gronhaug, 2005). According to these authors, secondary data may have been produced and published for different objectives and may not even represent thoroughly the idea that was drawn from it. They however acknowledge that if properly sourced, the data can be greatly useful as there will be a rigorous sourcing process behind it.

Different from secondary data, primary data is collected by the primary researcher for the specific purpose of the research and is therefore more robust as it reflects the research objective. However, it may not be easily accessible, may demand time and costs that are not available, or may contain sensitive information (Ghauri & Gronhaug, 2005).

The next step after the business has been selected is to start the data collection. At this stage, the data to be collected is essentially secondary and corresponds to the SKU Masterdata and other information pertaining to the company's operations. Most of it is generally stored within the company's Enterprise Resource Planning (ERP) System and needs to be requested. In detail, the data to be requested is as follows:

- SKU Masterdata: allows the researcher to understand each item's specification and, in general, includes information such as item code, item description, weight, size, material, unit of measurement, item supplier, unit cost, among others.
- Stock Movement: transactional history that details every movement of items of the stock, such as transfers, bin replenishments and sales.
- Historical Stock Value: periodical snapshots that allow the researcher to understand the fluctuations in stock for each particular item.
- Obsolescence History: historical write-offs of stock items that became obsolete.
- Warehouse Plant & Warehousing Related Costs

The first data collection is then followed by the selection of groups and/or sub-groups within the inventory portfolio. It is expected that the large assortment (pre-stated criterion) will comprise items that could be 3D printed and items that for some limitation could not be 3D printed such as material, complexity, size, warranty, etc. The selection will also take into account the completeness and quality of the data pertaining to these groups in particular. Finally, the item's complexity will also be considered in order to allow this research to explore the influence of the manufacturing complexity in the aforementioned tipping point.

Further data collection may be required in case the SKU Masterdata or other data collected at the first stage is not complete. In this case, the data collection is expected to be primary, i.e., collected by the researcher itself aiming to gather information that could not be found in the company's database.

Phase 3 – populating the inequation. This sub-section describes how Inequation (2) is populated, i.e., what is the source of data for each one of the variables. Given that some costs can be directly assigned to an item's unit such as the TM cost U_{TM}, and other costs, on the other hand, are on-going costs that do not have such a straight-forward relation to each item's unit, such as C_{3DP}, this research will describe in detail the methodology applied.

Through the SKU Masterdata and the primary data collection, the material composition of every item will be known in detail. The corresponding raw material or its closest equivalent will then be quoted with the highest number of suppliers and the cost per kilogram will be then averaged. $\mathbf{C_{RAW}}$ is then calculated as a proportion to the item's weight, i.e., if an item weights 100g, its $\mathbf{C_{RAW}}$ corresponds to 10% of the cost per kilogram of raw material.

$\mathbf{T_{RAW}}$ corresponds to the cost of transporting the raw material (in proportion to the item's weight). This transport cost will be obtained from the rate schedule of the raw material supplier(s) that provided the cost C_{RAW} above. In order to preserve the identity of supplier and the company providing data to this research, their site locations will not be mentioned herein, but only the distance in kilometres from one to the other.

$\mathbf{C_{FIN}}$ is the cost related to the time spent to finish a 3D printed item. Finishing in this context means any kind of smoothing, polishing or post 3DP work that is necessary for the item to be ready to be utilised. In order to support the validation of this research, items from different complexity groups will be selected to be CAD drawn and one of these items will be 3D printed. Thus, the time spent to post process it will be measured. The ability to 3D print items and time the corresponding activities is however limited by the researcher's budget, hence as a simplification, each complexity group is assigned a $\mathbf{C_{FIN}}$.

$\mathbf{C_{3DP}}$ is a cost associated to the use of the 3DP machine and other requirements such as software and training. The longer the time to print an item's unit, the higher $\mathbf{C_{3DP}}$ is for that particular item. Firstly, this research will identify a 3D printer that is able to meet the requirements of this industrial application in terms of:

- Item's material;
- Item's dimensions;
- Required printing speed;
- Item's quality and endurance;

In possession of the monthly lease cost of the 3D printer, this research will aim to identify the cost per minute for utilising the machine. A multiplier referred to as μ named herein as 'utilisation coefficient' will represent the time utilisation of the machine under two different scenarios. Due to the fact that the investment in a 3D printer will not be justified unless the machine has a high utilisation rate, μ will assume two distinct values: 80% and 85%, which in the researcher's view represent two high and practical utilisation rates. Finally, this research will collect the 3DP time duration of the item that will be physically 3D printed as part of the validation process, and will collect the remaining through an estimation of the 3DP times.

$\mathbf{U_{TM}}$, the TM cost of the item, will be directly extracted from the company's SKU

Masterdata. In case there are multiple suppliers, the most frequently used supplier will be considered. In case fluctuations of prices over time cannot be tracked, this research will consider the latest cost of the product.

$\mathbf{T_{TM}}$ is the shipping cost of the item from the supplier to the business in question. $\mathbf{T_{TM}}$ is highly dependable of the Incoterms the business trades under. Different Incoterms define different shipping costs. As well as U_{TM}, $\mathbf{T_{TM}}$ is likely to be collected from the company's SKU Masterdata.

The inventory carrying cost $\mathbf{I_{CC}}$ is perhaps the most complex cost to be determined as it depends on:

- The item's unit price U_{TM};
- The rate the item is sold at;
- The item's inventory level over time;
- The investment rate to be considered, i.e., the missed opportunity of investing the money locked in the form of inventory;

In this research, $\mathbf{I_{CC}}$ will be calculated through the following methodology:

a. The item's annual demand will be extracted from the company's Stock Movement data. The Cost of Goods Sold (COGS) can then be calculated given that U_{TM} is known (COGS = U_{TM} x annual demand);

b. The average stock value can be calculated through a simple average operation over the monthly snapshots of the Historical Stock Value data, followed by a normalisation, that aims to round this averaged stock value to the closest multiple of U_{TM};

c. Following, the stock turn of each item can then be calculated as:

$$ST = \frac{Cost\ of\ Goods\ Sold}{Normalised\ Average\ Stock\ Level}$$

The process until this stage is illustrated in Figure 3.2:

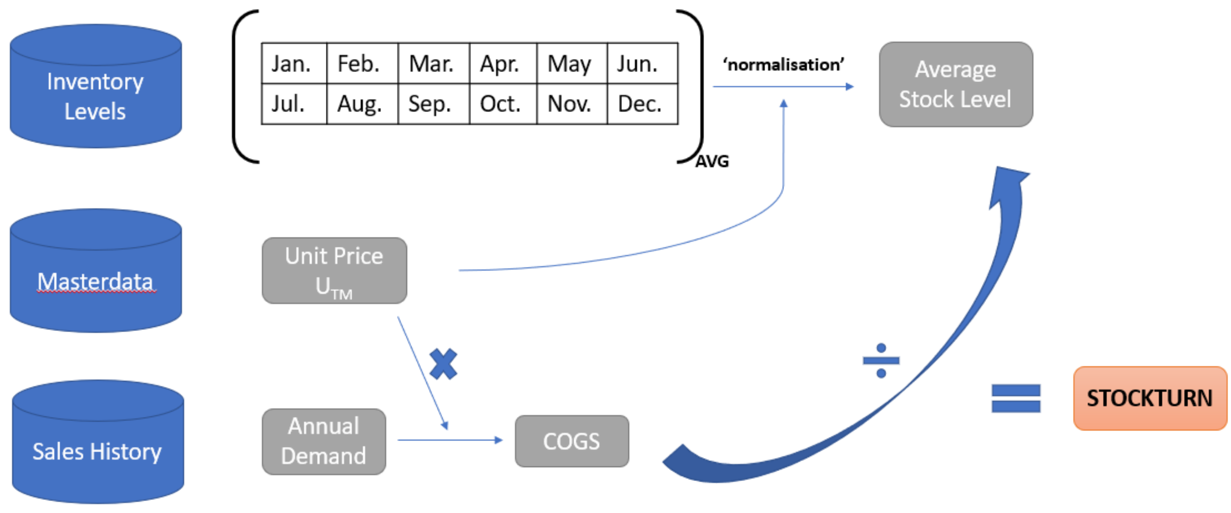


Figure 3.2. Stockturn Calculation for I_{CC}.

d. 1/ST yields the period over which that particular item of the stock is carried until it is thoroughly consumed;

e. Finally, an investment rate I_R is considered and the inventory carrying cost is accrued over time for the period determined in item d above. For simplicity of calculation, the annual demand will be equally divided over 12 months, i.e., the sell rate will be deemed to be constant.

Considering that the investment rate I_R used in the calculation of $\mathbf{I_{CC}}$ is of crucial importance and is highly subjective, similarly to μ (the utilisation coefficient), it will be varied and will assume two different values: 5% and 10%, respectively a conservative and a less conservative rate.

$\mathbf{C_{WH}}$ is the cost related to the warehouse storage space required for the inventory to be carried. The higher the number of items carried in stock, larger is the space required for storage. On the contrary, storage costs decrease in case inventory levels also decline. This research considers that every SKU accounts for a portion of the warehouse lease cost (the warehouse area will be calculated through the warehouse plant) and other related on-going costs such as electricity, council rates, among others. Firstly, all these costs are identified, summed and finally normalised to represent a 1-month period spend. This monthly cost is then proportionally assigned to each SKU according to its dimension, i.e., small items do not account for the same storage cost as large items. Given that the company may not have dimensional details of all the SKU's within the SKU Masterdata and that the extension of the portfolio coupled with the limited time of this research makes it unpractical for the entire assortment to be measured, it is anticipated that a simplification of some sort is likely to occur in order for $\mathbf{C_{WH}}$ to be calculated.

Finally, $\mathbf{C_{OB}}$, the cost of obsolescence, represents the periodical write-offs of items that become obsolete and can no longer be utilised. This research will consider the obsolescence cases of the last 5 years and will average these, followed by a monthly normalisation. Thereafter, the cost will be equally divided and assigned to each one of the company's SKUs. It is also possible that the company keeps no history of items that became obsolete. In this case, in order for the research to be conducted taking into account $\mathbf{C_{OB}}$ in some way, it will be calculated as a percentage of the average stock level of each SKU. Given that this methodology is highly subjective, this percentage, represented by β, will be 0.5% in a more conservative scenario and 1% in a non-conservative scenario, which are both estimates based on the researcher's experience given that no better indication was found in the literature.

Table 3.1 shows which piece of data is required to populate each one of the variables of Inequation (2) and whether other source of information is also necessary:

Table 3.1 - *Variables and their Source of Data*

	Masterdata	Stock Movement	Historical Inventory	Other Source	Variation
C_{RAW}	✓			3D Printing Supplier	
T_{RAW}				3D Printing Supplier	
C_{FIN}				Validation Test	
C_{3DP}				3D Printing Supplier & Validation Test	Utilisation Coefficient (μ) 80% ; 85%
U_{TM}	✓				
T_{TM}	✓				
I_{CC}	✓	✓	✓		Investment Rate (I_R) 5% ; 10%
C_{WH}	✓			Warehouse Plant	
C_{OB}				Obsolescence History	Absence of Obsolesc. Cost (β) 0.5% ; 1%

Phase 4 – determining the tipping point. After populating the variables and determining the result of the inequation for each SKU of the stock, it is then necessary to classify each one of these SKUs in three different categories according to their turnover frequencies, i.e., their annual demand, through an ABC Classification. Given the lack of a commonly used methodology for the ABC Classification in scientific articles, in case of the absence of a well-defined threshold between turnover frequencies, this research will use the following SKU percentages: (A Class – 15%; B Class – 35%; C Class – 50%). The ABC Classification will be performed for each one of the selected groups/sub-groups.

3.6 Ethical Considerations

Ethical aspects of a research are usually outlined to guarantee that the participants, respondents, sponsors or any other entities are not harmed in any way (Cooper & Schindler, 2008). There are some aspects that must be clearly stated prior to conducting the research to make sure that the parties involved do not suffer any kind of harm. In the context of this research, the most important ethical aspect to be respected is the transparency between the researcher and the company that volunteers to provide the data to be collected. The research scope and objective should be clearly outlined and both parties should agree on the extent of the confidentiality to be kept.

The researcher should clearly state that the requested data will serve to an academic purpose and therefore will be treated as such, and at the same time the company's manager should let the researcher know the extent to which the company wants to be involved in the research as well as how the research will refer to the company, i.e., generically or specifically. Concerns should be also raised regarding the company data, which is likely to be highly confidential and financially sensitive. A proper security system should be utilised to keep the information away from any person not allowed to access it. Finally, aiming to guard the university's credibility, the researcher undertakes to act within the law and consult the university in all events where a conflict of interest may potentially arise.

4. Analysis

4.1 Introduction

The scope of this research requires that a data collection be performed prior to the definitive selection of the business, and thereafter studied in depth. The inventory of the company to which this research will be applied needs to meet the list of criteria highlighted within the Research Design sub-section and a superficial analysis of the company data is required to understand whether this business would be suitable or not to be evaluated further in this research. The reason that lead the researcher to consider this business in particular is not only due to his access to the business, but also the fact that the researcher believes the three criteria will be completely met. The business in question is a New Zealand Hydraulic Equipment Supplier. In order to preserve the business identity, no further information will be provided in this respect.

4.2 Data Collection

This sub-section primarily describes the initial secondary data collection that relates to the data pertaining to the Hydraulic Equipment business. The next set of data to be collected, which relates to the 3DP technology, is described later once the criteria listed in the Research Design sub-section have been checked.

4.2.1 Secondary data collection.

Essentially, four pieces of data and the warehouse plant were requested. Given that the SKU Masterdata comprises the description of more than 6,000 SKUs, the Stock Movement data includes all the company transactions during an entire year and the Historical Stock Value data lists the inventory value of all the stock items several times, it is not feasible for the data collected to be included in this research. The researcher however has endeavoured to include all critical information that may be required for the reader to comprehend each one of the stages of this research.

SKU masterdata. The SKU Masterdata comprises detailed information of every single item in stock - 6,089 SKUs. It is therefore not uncommon for it to be incomplete as sometimes information is simply not available, or the company has not made all possible efforts to ensure its completeness. Table 4.1 details the relevant information that is comprised within the Masterdata file received and a categorisation regarding the completeness of this data.

Table 4.1 - *Completeness of the SKU Masterdata*

Information	Completeness		
	Complete	Incomplete	Non-existent
Stock Code	✓		
Description	✓		
Unit of Measurement	✓		
Weight		✓	
Dimensions			✓
Latest Cost		✓	
Supplier	✓		
Material Composition			✓

Stock movement data. The Stock Movement data details all the stock transactions that happened during the time span from 03/10/2016 to 30/09/2017, i.e., a period of one year. In total, 58,544 transactions occurred - product sales, product receipts, stock transfers, stock count, and stock adjustments. Sales transactions in particular corresponded to 67% of the total. For every sale transaction, the following relevant information was provided:

- Transaction Date
- Sequence Number (Reference Number)
- Stock Code
- Transaction Type (only sales transactions are relevant to this research)
- Quantity
- Customer (when applicable)

As this piece of data is populated whenever a sales transaction occurs, there are no concerns around completeness of information.

Historical stock value. The Historical Stock Value data lists all the SKUs of the stock and provides daily snapshots of their inventory value. Fluctuations in inventory levels occur, for instance, after a sale has been processed or after stock has been receipted. In order to calculate the average stock value (which is used in the stock turn calculation), it is necessary that a day of the month be defined for the historical stock value of each item to be retrieved. To be consistent, the ‘closing balance’ is the chosen snapshot day, i.e., the last day of every month. There are also no concerns around the completeness of information within this piece of data.

Obsolescence history. No write-off data has historically been recorded within the company’s ERP System. As an alternative way of populating C_{OB}, the variable will be calculated as a percentage of the averaged inventory value as already described.

Warehouse plant & warehousing related costs. In order to calculate the cost per square metre of the property, a copy of the warehouse plant was requested. Other costs closely related to warehousing are also relevant when the opportunity to decrease the warehouse size is explored. A view of the warehouse plant is provided on Figure 4.1 below:

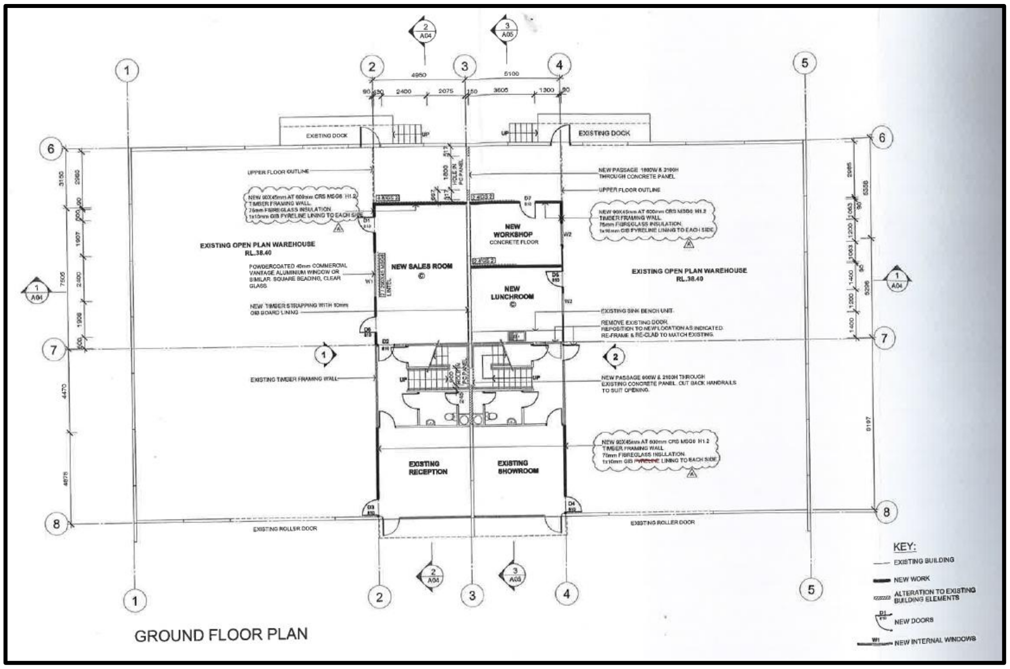


Figure 4.1. Warehouse Plant

The property is divided in three areas:

- Area 1: region between the markers 1 and 2 that stores the items analysed within this research;
- Area 2: region between the markers 2 and 4 that corresponds to the office, hence this area is not considered in this research;
- Area 3: region between the markers 4 and 5 that stores the lengthy items that are not analysed within this research, such as the hoses, therefore this area is not considered.

Table 4.2 shows the warehousing-related costs that were collected with the management team:

Table 4.2 - *Warehousing Monthly Costs*

Expense Type	Monthly Cost
Property Lease	$7,745.56
Electricity Cost	$540.89
Council Rate	$889.89

Note. Costs are in NZD.

Having collected the data pertaining to the Hydraulic business in question, it is now possible to assess whether or not the company is suitable to be analysed in depth in this research.

4.2.2 Criteria requirement.

As per the research design, there are three criteria that need to be fulfilled in order for a company to be considered an interesting case and suitable for study by the researcher.

Criteria 1

- Large assortment of SKUs that can be 3D printed with the existing technology;

Analysing the Masterdata, it can be seen that the business offers to its clients 6,089 different SKUs in its inventory, sub-divided in 8 large groups:

a. Hoses
b. Ferrules
c. Fittings
d. Adaptors
e. QRC & PBR
f. Stainless Steel
g. Accessories
h. Other Products

Such is the extension of the portfolio that the researcher has chosen to select sub-groups to be analysed individually, as an analysis of the entire inventory at once is not practical due to time constraints. Also, through an initial conversation with the business' management team, it was possible to identify that the items of the stock are composed by one of the following three materials: rubber, steel and stainless steel. While it is not possible to enter into the details of every material composition, materials such as steel, stainless steel and rubber-like plastic are being currently 3D printed ("Rubber-Like Plastic", n.d.). Apart from group a. Hoses, which are clearly out of the scope of this research due to the product's length, all the other items are composed by one of the two metals described above. Hence, this research will focus on groups b. Ferrules, c. Fittings, d. Adaptors and e. QRC & PBR. The groups f. Stainless Steel, g. Accessories and h. Other Products have low relevance to the business according to the management team and hence do not have a significant number of items grouped under them.

Criteria 2

- SKU's with different levels of manufacturing complexities, allowing this research to compare results between simple and complex groups;

It has been identified that there are different characteristics in the SKU's comprised within stock. These distinct characteristics allowed the items to be categorised under five different manufacturing complexity groups:

Complexity 1 - SKUs classified within this group have a relatively simple shape and are nearly two-dimensional, i.e., the third dimension is not significant. For these items, the different layers have the same orthogonal projection. The items are constituted of a single piece and there are no assemblies. An illustration of products within Complexity Group 1 (CG1) can be seen in Figure 4.2:

Figure 4.2. – Complexity Group 1

Complexity 2 - SKUs within this group are still deemed to be simple in shape, however have a significant third dimension that runs along a single axis and has multiple cross-sections with different sizes. Items are still constituted of a single piece and there are no assemblies. An illustration of products within Complexity Group 2 (CG2) can be seen in Figure 4.3:

Figure 4.3. Complexity Group 2

Complexity 3 - SKUs classified within the third group of complexity have the same characteristics of those belonging to CG2, however their shape runs along two or more axes. Items are still constituted of a single piece and there are no assemblies. An illustration of products within Complexity Group 3 (CG3) can be seen in Figure 4.4:

Figure 4.4. Complexity Group 3

Complexity 4 - Items classified within group 4 tend to have a similar pattern of items within CG2 and CG3, however these items are made of two or more pieces, which is a distinguishable feature of group four (and five), but are not highly complex in shape. An illustration of products within Complexity Group 4 (CG4) can be seen in Figure 4.5:

Figure 4.5. Complexity Group 4

Complexity 5 - SKU's within group 5 have the characteristics of the items in group 4, and in addition are considered to be highly complex in shape. An illustration of products within Complexity Group 5 (CG5) can be seen in Figure 4.6:

Figure 4.6. Complexity Group 5

Table 4.3 summarises the characteristics of the five complexity groups.

Table 4.3 - *The Five Complexity Groups and their Characteristics*

	Complexity Group				
Features	**1**	**2**	**3**	**4**	**5**
3rd dimension	Negligible	Considerable	Considerable	Considerable	Considerable
Axes	0	1	2+	2+	2+
Assemblies	No	No	No	Yes	Yes
Highly Complex	No	No	No	No	Yes

Criteria 3

- Long inventory tail due to the nature of the business/industry;

The long tail is a remarkable feature of the business in question. The majority of the items – fittings, adaptors, ferrules, among others – are not significantly different from each other, but rather have variations of their characteristics (size, connector type, etc.). An illustration extracted from the SKU Masterdata is shown on Table 4.4. It can be seen that for the same type of adaptor, there are numerous possible combinations of SKU configuration. The headings T1 and T2 correspond to the two ends of the adaptor.

Table 4.4 - *The combinations of BS – BSPP Male X BSPP Female Swivel*

BC - BSPP MALE X BSPP FEMALE SWIVEL			
ITEM NUMBER	**T1**	**T2**	**DESCRIPTION**
BC0202	1/8”	1/8”	1/8” BSPP MALE X 1/8” BSPP FEMALE SWIVEL
BC0402	1/4”	1/8”	1/4” BSPP MALE X 1/8” BSPP FEMALE SWIVEL
BC0404	1/4”	1/4”	1/4” BSPP MALE X 1/4” BSPP FEMALE SWIVEL
BC0406	1/4”	3/8”	1/4” BSPP MALE X 3/8” BSPP FEMALE SWIVEL
BC0408	1/4”	1/2”	1/4” BSPP MALE X 1/2” BSPP FEMALE SWIVEL
BC0412	1/4”	3/4”	1/4” BSPP MALE X 3/4” BSPP FEMALE SWIVEL
BC0604	3/8”	1/4”	3/8” BSPP MALE X 1/4” BSPP FEMALE SWIVEL
BC0606	3/8”	3/8”	3/8” BSPP MALE X 3/8” BSPP FEMALE SWIVEL
BC0608	3/8”	1/2”	3/8” BSPP MALE X 1/2” BSPP FEMALE SWIVEL
BC0612	3/8”	3/4”	3/8” BSPP MALE X 3/4” BSPP FEMALE SWIVEL
BC0806	1/2”	3/8”	1/2” BSPP MALE X 3/8” BSPP FEMALE SWIVEL
BC0808	1/2”	1/2”	1/2” BSPP MALE X 1/2” BSPP FEMALE SWIVEL
BC0812	1/2”	3/4”	1/2” BSPP MALE X 3/4” BSPP FEMALE SWIVEL
BC1010	5/8”	5/8”	5/8” BSPP MALE X 5/8” BSPP FEMALE SWIVEL
BC1204	3/4”	1/4”	3/4” BSPP MALE X 1/4” BSPP FEMALE SWIVEL
BC1206	3/4”	3/8”	3/4” BSPP MALE X 3/8” BSPP FEMALE SWIVEL
BC1208	3/4”	1/2”	3/4” BSPP MALE X 1/2” BSPP FEMALE SWIVEL
BC1210	3/4”	5/8”	3/4” BSPP MALE X 5/8” BSPP FEMALE SWIVEL
BC1212	3/4”	3/4”	3/4” BSPP MALE X 3/4” BSPP FEMALE SWIVEL
BC1216	3/4”	1”	3/4” BSPP MALE X 1” BSPP FEMALE SWIVEL
BC1220	3/4”	1 - 1/4”	3/4” BSPP MALE X 1 - 1/4” BSPP FEMALE SWIVEL
BC1612	1”	3/4”	1” BSPP MALE X 3/4” BSPP FEMALE SWIVEL
BC1616	1”	1”	1” BSPP MALE X 1” BSPP FEMALE SWIVEL

To check the length of the inventory tail and to test Pareto’s law applicability to the business in question, an ABC Analysis has also been conducted using the Stock Movement data (transactions that were not sales have been filtered out) dated from 3/10/2016 to 30/09/2017, i.e., a time span of one year. The analysis yielded the following results:

- 0.55% of the items analysed (15/2734) account for 20.05% of the units (32,265/160,953) sold during the period;
- 4.10% of the items analysed (112/2734) account for 50.14% of the units

(80,703/160,953) sold during the period;

- 20.01% of the items analysed (547/2734) account for 82.90% of the units (133,430/160,953) sold during the period (in accordance to Pareto's Law);
- 50.00% of the items analysed (1367/2734) account for 96.36% of the units (155,091/160,953) sold during the period;

Observation: excluded from the ABC analysis were those items that are not measured in units, such as hoses, which are measured in metres. The gap between 6,089, the total number of SKUs offered by the business, and 2,734, the total number of items considered in this analysis, also show that a significant number of items were not present in the sales data, therefore were not sold during the period, increasing thus the inventory tail even further. The results above can be seen in the Figures 4.7 and 4.8. For purposes of visibility, only the top 200 items were included:

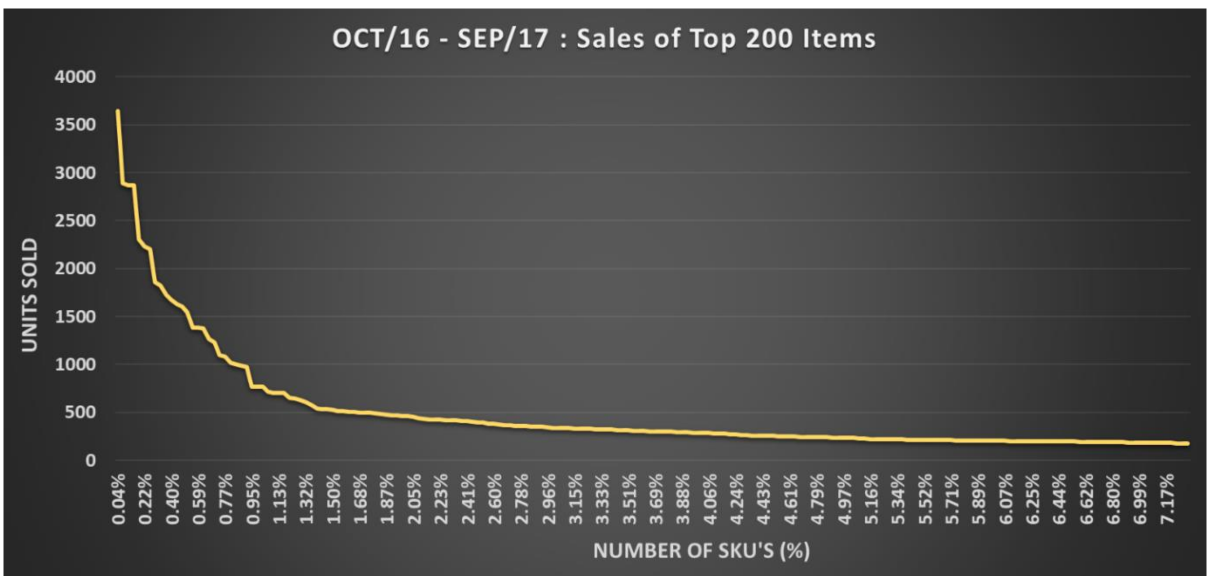


Figure 4.7. Sales of the Top 200 Items from Oct/16 to Set/17

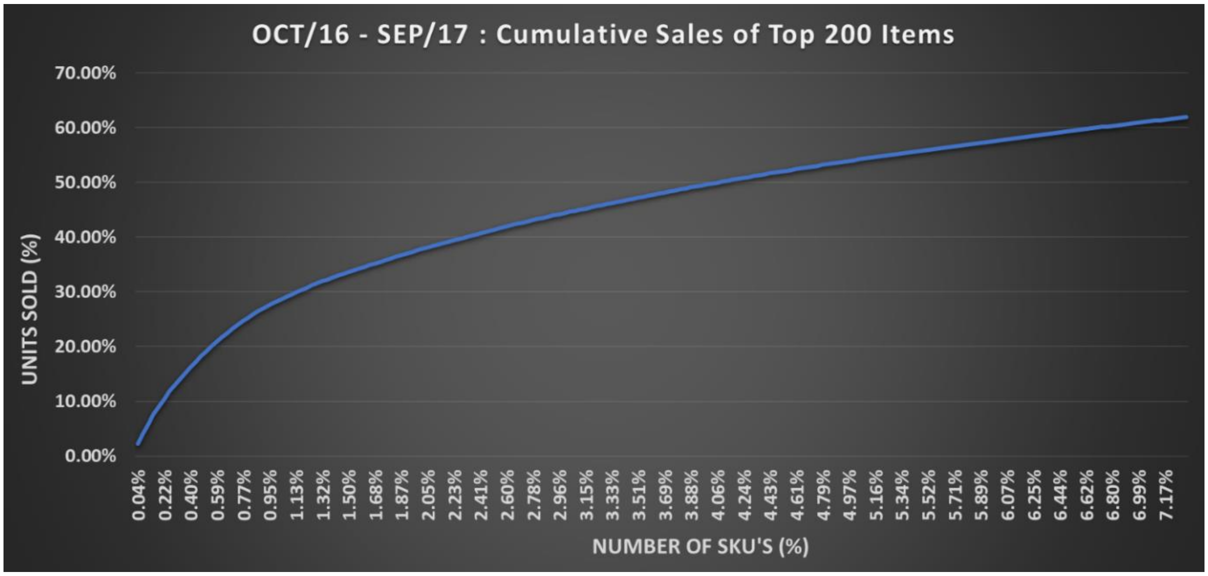


Figure 4.8. Cumulative Sales of the Top 200 Items from Oct/16 to Set/17

It can be noticed on Figure 4.7 a fast decline of the curve, indicating that only a small amount of the SKUs account for a significant portion of the sales. Similarly to Figure 4.7, Figure 4.8 shows the same information regarding the sales pattern, however on a cumulative perspective. It can be noticed that the curve tends to become flat as the number of SKUs considered increase. With the three criteria above met, the business in question can be considered suitable to be analysed in this case study.

4.2.3 Primary data collection.

The primary data collection follows the initial secondary data collection and aims to fill the gaps that were encountered in the data described in Table 4.1 in addition to collect further information that is required. For instance, items' dimensions and their material composition details, which are not comprised within the SKU Masterdata provided, are crucial in determining the most appropriate 3D printer machine to consider in this research. Before collecting this data, the SKU sub-groups that will be analysed in this study were selected.

Selecting the SKU sub-groups. The selection of the SKU sub-groups aims to narrow down the inventory portfolio to a more manageable number of items that can be analysed within the timeframe of this research. In order to reduce the bias and influence of the selection of these sub-groups, the only two factors that influenced the choice of the researcher were:

1) SKU's with a higher data completeness were given priority over items that lacked essential information in the SKU Masterdata;
2) The categories were chosen in order to populate the aforementioned five complexity groups;

The sub-groups selected to be analysed are listed in Appendix 1.

Filling the SKU masterdata gaps. The dimensions of the items analysed in this research need to be taken into consideration at the time of the selection of the 3D printer as each machine has its constraints in terms of build volume. In addition, each machine is designed to work with a specific range of materials, hence the importance of understanding the material composition of the items to be 3D printed. In order to collect information about item's material composition and dimensions, which are not comprised in the SKU Masterdata and to fill the gaps highlighted in Table 4.1, a primary data collection was conducted, where items were weighted, measured and the researcher referred to the management team for information that could not be collected without previous product knowledge. Given the extensive number of items included in this analysis, a few examples were included from Appendix 2 to Appendix 9 to illustrate how this data collection was registered.

4.2.4 Further data collection - 3D printing.

Given that 3D printers are relatively new to the market and the technology is not yet widespread, the researcher has found some resistance from suppliers to provide data for this research. There was however one supplier who was willing to collaborate and has released detailed information. Given that the content provided is financially sensitive, the identity of this supplier will not be disclosed.

Raw material. The material composition of the items analysed in this research is either steel or stainless steel (information obtained in the primary data collection). Thus, the researcher has looked for a raw material that is equivalent to the materials above, or at least that presents a high degree of similarity. The most similar option of raw material available in the market is the following: PS4542A: Stainless steel 17-4 PH (4 kg Container - 540 cm3), which costs $507.20 (NZD).

In regard to the transport cost of raw material, it has been informed by the supplier that the cost to deliver 25kg of raw material powder to the company in question, which is approximately 35km away corresponds to $30.00 (NZD).

3DP technology. There are four options of Direct Metal Printing, technology that allow the 3DP of custom metal parts from the CAD file, that are offered by the supplier. These machines are manufactured by 3D Systems and are the following:

- ProX DMP 100
- ProX DMP 200
- ProX DMP 300
- ProX DMP 320

The first two options would not qualify to be utilised as their build envelope capacities are (100 x 100 x 100mm) and (140 x 140 x 125mm) respectively, and the largest dimension measured during the primary data collection is 162mm. Another important requirement to consider is the

3DP speed of the machine. While the speed to print an item largely depends on its shape, weight, and material, the supplier has confirmed the researcher initial thoughts and has highlighted that the ProX DMP 320 would suit better this research given that this machine would cope better with such an industrial application. Technical specifications of this 3DP machine are available at: https://www.3dsystems.com/sites/default/files/2017-01/3D-Systems_DMP_SpecSheet_US_A4_2017.01.23_a_WEB.pdf.

The option considered in this research is therefore a monthly lease of the ProX DMP 320 machine and other requirements such as CAD software and on-going support and training. According to the supplier, the cost for the above solution corresponds to $12,222.00 (NZD) per month.

Validation process. The time an item takes to be 3D printed, which influences C_{3DP}, and the time the same item takes to be post processed, which influences C_{FIN}, are two aspects that depend on a multitude of factors such as the item's shape, complexity, design, material, among others. It is not possible to obtain the exact 3DP and the post processing times of each item analysed in this research unless they have been physically 3D printed and post processed, which is beyond the capabilities of this research in terms of time and budget. For this reason, both of the times above are estimated as a function of the complexity group the item being evaluated has been grouped under.

The validation process is an important phase of this research where three items of the stock were CAD drawn and one of these items was selected to be 3D printed in stainless steel. The objectives of the validation process were:

- Provide the researcher with a better understanding of the 3DP process;
- Collect data relating to the finishing costs of each item C_{FIN};

- Support or reject the idea that the items studied in this research can be 3D printed;

Chapter 5 describes the validation process thoroughly in detail. The next two sub-chapters describes the data collection relating to C_{FIN} and C_{3DP}.

3DP times. As will be further described in Chapter 5, the items SMSNS-16 (CG2), AAA080808 (CG3), and AC901616 (CG4) have been CAD drawn and the first has been selected to be 3D printed with Massey's University 3D printing machine ProX DMP 100, which is a model designed for researches and not industrial applications. Hence, no 3DP times could be collected as the printing speed is significantly lower. However, as the supplier has access to the ProX DMP 320 software, it was possible to estimate via software the 3DP times of the items that were CAD drawn. The 3DP corresponding to CG1 and CG5 were estimated by the researcher and the supplier in conjunction. The results are shown I Table 4.5:

Table 4.5 - *3DP Times of the Five Complexity Groups*

Complexity Group	**Item Number**	**3D Printing Time (minutes)**	**Method**
Complexity 1	-	35	Estimated
Complexity 2	SMSNS-16	63	Collected
Complexity 3	AAA080808	71	Collected
Complexity 4	AC901616	85	Collected
Complexity 5	-	140	Estimated

Finishing times. For the items analysed in this research, the finishing times correspond to the activities of releasing the item from the steel plate, breaking the support structures, and finally smoothing or polishing the item. Similar to the 3DP times above, the acquisition of the finishing times is a blend of times collected and estimated.

Table 4.6 - *Finishing Times of the Five Complexity Groups*

Complexity Group	**Item Number**	**Finishing Time (minutes)**	**Method**
Complexity 1	-	20	Estimated
Complexity 2	SMSNS-16	30	Collected
Complexity 3	-	30	Estimated
Complexity 4	-	35	Estimated
Complexity 5	-	45	Estimated

While the estimations above add some level of subjectivity to the research, as opposed to times being in fact measured, these are a consequence of the infeasibility of 3D printing a significant number of samples that can be collected and averaged due to the research's limited budget.

4.3 Populating the Inequation

This sub-section applies the methodology described during the operationalisation to illustrate how Inequation (2) is populated.

4.3.1 Adjusting the inequation.

As stated previously, the variable T_{TM} depends directly on the Incoterms the business trades under. The Hydraulic Equipment Supplier here analysed trades, with the majority of its supplier under the Free On Board (FOB) Incoterm. Thus, the 'Latest Cost' data comprised in the SKU Masterdata corresponds to what is referred to as the ‘landing cost’, i.e., the cost of the item plus any transportation costs and fees. Therefore, the inequation can be simplified in this particular case to:

$$\mathbf{C_{RAW} + T_{RAW} + C_{FIN} + C_{3DP} < U_{TM} + I_{CC} + C_{WH} + C_{OB}} \qquad (3)$$

4.3.2 Variables evaluation.

Having iterated from Inequation (2), the general inequation to Inequation (3), which incorporates a particularity of this case study, it is now possible to populate the variables. This is described in detail in the next sub-section, starting for C_{RAW}.

C_{RAW}. The cost of 4kg of the raw material ‘Stainless Steel’ 17-4 PH is $507.20. It can then be easily concluded that the price per kilogram of raw material powder is in this case $126.80. Thus, C_{RAW}, in NZD, is yielded by:

$$\mathbf{C_{RAW} = \$126.80 * I_W}$$

Where I_W is the item’s weight in kilograms.

T_{RAW}. The transport cost of 25kg of raw material powder from the supplier to the business in question corresponds to $30.00. It can be simply concluded that the transport cost per kilogram is $1.20. Thus, T_{RAW} is, in NZD, yielded by:

$$\mathbf{T_{RAW} = \$1.20 * I_W}$$

Where I_W is the item’s weight in kilograms.

C_{FIN}. Having collected the finishing times, it is then necessary to quantify the cost of the workforce that will perform the post processing activities. Given that these are menial tasks, it is not unreasonable to assume an hourly cost corresponding to the minimum wage in New Zealand, which at the time this research was written was $15.75. Using the values on Table 4.6, it can then be concluded that the post processing cost C_{FIN} per complexity groups is:

- CG1: $15.75/hour * 20 minutes => **C_{FIN} (CG1) = $5.25**
- CG2: $15.75/hour * 30 minutes => **C_{FIN} (CG2) = $7.88**
- CG3: $15.75/hour * 30 minutes => **C_{FIN} (CG3) = $7.88**
- CG4: $15.75/hour * 35 minutes => **C_{FIN} (CG4) = $9.19**
- CG5: $15.75/hour * 45 minutes => **C_{FIN} (CG5) = $11.81**

***C_{3DP}*.** Considering, for example, μ = 50% and that a month has 43,200 minutes (30 days/month * 24 hours/day * 60 minutes/hour), the cost per minute for utilising the 3DP technology is given by: $12,222 / (50% * 43,200) = $0.57/minute (costs in NZD).

Thus, taking into consideration the 3DP times of Table 4.5, C_{3DP} is, for each complexity group, the following:

- CG1: $0.57 * 35 minutes => **$C_{3DP}$ (CG1) = $19.80**
- CG2: $0.57 * 63 minutes => **$C_{3DP}$ (CG2) = $35.65**
- CG3: $0.57 * 71 minutes => **$C_{3DP}$ (CG3) = $40.17**
- CG4: $0.57 * 85 minutes => **$C_{3DP}$ (CG4) = $48.10**
- CG5: $0.57 * 140 minutes => **$C_{3DP}$ (CG5) = $79.22**

***I_{CC}*.** The calculation of I_{CC} is not as straight-forward as the other variables and has required the programming of a code script. As the analysis is being carried out in Excel, the programming language is Visual Basic for Applications (VBA). The initial stage of the calculation of I_{CC} has been detailed on the Research Design chapter, and the rest of the calculation with a detailed explanation of each variable of the code is shown on Appendix 10. Note that the investment rate considered in that case is 0.8% per month.

***C_{WH}*.** Utilising the warehousing related expenses listed in Table 4.2, it is possible to obtain

C_{WH}, the warehousing costs assigned to each SKU per month, through the following steps listed in Table 4.7:

Table 4.7 - *Calculating C_{WH}*

Information	**Calculation**	**Result**
Total Warehousing Costs	$7,745.56 + $540.89 + $9,176.33	$9,176.33
Total Property Size (m2)	(Retrieved from warehouse plant)	707.5
Area 1 (m2)	(Retrieved from warehouse plant)	254.0
Fraction (Area 1 / Total)	254.0 / 707.5	35.9%
Area 1 Cost Portion	35.9% * $9,176.33	$3,294.73
Number of SKU's in Area 1	(Retrieved from Masterdata)	4,682
COST PER SKU PER MONTH*	**$3,294.73 / 4,682**	**$0.70**

Note 1. SKU's were deemed to have a similar size.

Note 2. Costs are in NZD.

For clarity, an example has been provided on sub-section 4.4, where the variables of Inequation (3) are calculated step by step.

4.4 Example – Item Number SMSH-24

The item SMSH-24 is a ferrule that weights 0.43kg (information retrieved from the Masterdata).

C_{RAW} = $126.80/kg * 0.43kg => **$C_{RAW}$ = $54.52**

T_{RAW} = $1.20/kg * 0.43kg => **$T_{RAW}$ = $0.51**

Considering that the SKU is grouped under CG2, it then follows that:

C_{FIN} = $7.88

As an example, if μ = 50%, then:

C_{3DP} = $35.65

From the SKU Masterdata, the traditional manufacturing cost can be extracted:

U_{TM} = $9.72

The monthly closing stock value of the item during the 1-year time span from October 2016 to September 2017 and its corresponding quantity in units on stock is described in Table 4.8:

Table 4.8 - *SMSH-24 Monthly Closing Stock*

Month	**Oct/16**	**Nov/16**	**Dec/16**	**Jan/17**	**Feb/17**	**Mar/17**
Stock on Hand ($)	$106.87	$106.87	$106.87	$106.87	$165.16	$165.16
Stock on Hand (units)	11	11	11	11	17	17
Month	**Apr/17**	**May/17**	**Jun/17**	**Jul/17**	**Aug/17**	**Sep/17**
Stock on Hand ($)	$106.87	$106.87	$106.87	$106.87	$106.87	$106.87
Stock on Hand (units)	11	11	11	11	11	11

Note. Costs are in NZD.

Considering the above, the aforementioned item has an average stock on hand value of $116.58. As the value is already a multiple of the item unit cost, the adjusted average stock on hand value remains the same. Given that 6 units were sold during the period, the stock turn of this particular item is 0.5, i.e., when the average is considered, it takes approximately two years (24 months) for the stock to be completely consumed. The variables in the code of Appendix 10 are then initially populated as follows:

adjusted_stock_avg = $116.58

monthly_demand = 0.5

investment rate = 0.8% (per month, per example)

period_months = 24

manufacturing_cost = $9.72

Once the code is run, the inventory carrying cost yielded is:

I_{CC} = $0.55

The warehousing cost assigned to the items is standard as lengthy items were not considered in the analysis, and hence the total costs were distributed equally as per Table 4.7. The warehousing related costs per SKU is then:

C_{WH} = $0.70

Finally, if for example, $\beta = 5\%$, the obsolescence cost is given by:

C_{OB} = 0.05 * $116.58 => **$C_{OB}$ = $5.83**

The result of Inequation (3) is then the following:

$$C_{RAW} + T_{RAW} + C_{FIN} + C_{3DP} < U_{TM} + I_{CC} + C_{WH} + C_{OB} \qquad (3)$$

$54.52 + $0.51 + $7.88 + $35.65 < $9.72 + $0.55 + $0.70 + $5.83

$98.56 < $16.80 (False)

Given that the statement is false, this SKU should not be 3D printed under the conditions considered. The methodology above has been applied to 247 SKU's distributed between the five complexity groups: 9 SKU's in CG1, 63 SKU's in CG2, 44 SKU's in CG3, 87 SKU's in CG4 and finally 44 SKU's in CG5. The results and further discussions are shown on chapters 6 and 7.

It is important to note that while this research has established a methodology to populate each one of the variables of Inequation (2), there is the need to challenge and filter the results obtained due to the subjectivity involved in the qualitative approach of this research. While U_{TM}, the traditional manufacturing cost, is inarguably the cost of the item's unit as it has been collected in the SKU Masterdata, I_{CC} and C_{OB}, on the other hand, are highly related to the subjectivity of the company in question. If for instance, the business has not historically performed any inventory management work, it is then expected that the stock levels would not be set to a level where efficiency is maximised, in other words, stock shortage and overage would be commonplace.

Filtering the ‘data noise’ is therefore not an easy task as subjectivity is involved. During the evaluation of the results of each variable, the research will need to assess whether the final result of the inequation has been influenced or not by the subjectivity of the company in question. One of these assessments relates to the stock levels of each SKU and their influence on the values of I_{CC} and C_{OB}. In terms of stock turn, the researcher has considered the following: if an item has a stock turn lower than 1, i.e., the COGS is lower than the average stock level, then it will be considered that there is an overstock unless the annual demand is lower than the Minimum Order Quantity (MOQ).

4.5 Validation Process

4.5.1 Introduction

As already mentioned, in order to support the research validation some of the items were selected to be 3D printed. The idea was to familiarise with the 3DP process, verify that the items studied in this research can in fact be 3D printed, and also collect data around printing and finishing times whenever possible. Due to budget constraints, in the validation process, the following has been undertaken:

- Three items from three different complexity groups were CAD drawn. With the drawings ready, the printing times could be estimated by the 3DP software;
- One of the three items was 3D printed in stainless steel, post processed and compared to the original item.

Pictures and a description of the validation process can be seen below. The initial stage of the process corresponded to the CAD drawings, followed by the 3DP process and finally the post-processing stage.

4.5.2 Phase 1 – CAD Drawing

Item 1: SMSNS-16 – complexity group 2.

The different stages of the CAD drawing process of the item SMSNS-16 can be seen on Figures 4.9 and 4.10. Figure 4.11 shows the final render.

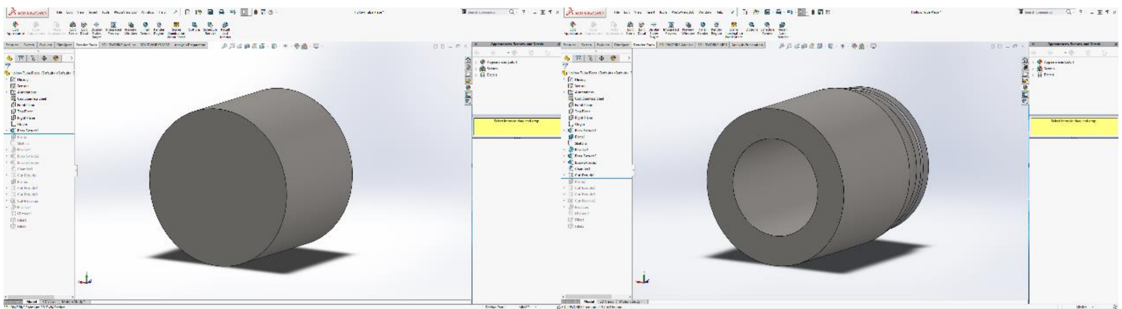


Figure 4.9. SMSNS-16: CAD Drawing (Stages 1 & 2)

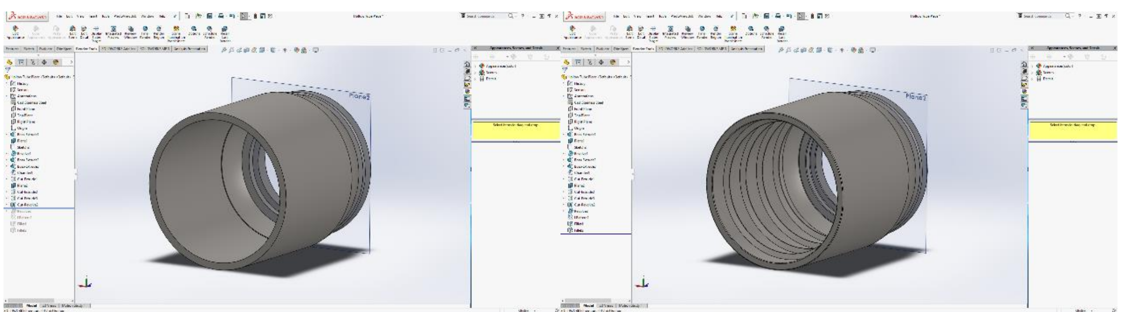


Figure 4.10. SMSNS-16: CAD Drawing (Stages 3 & 4)

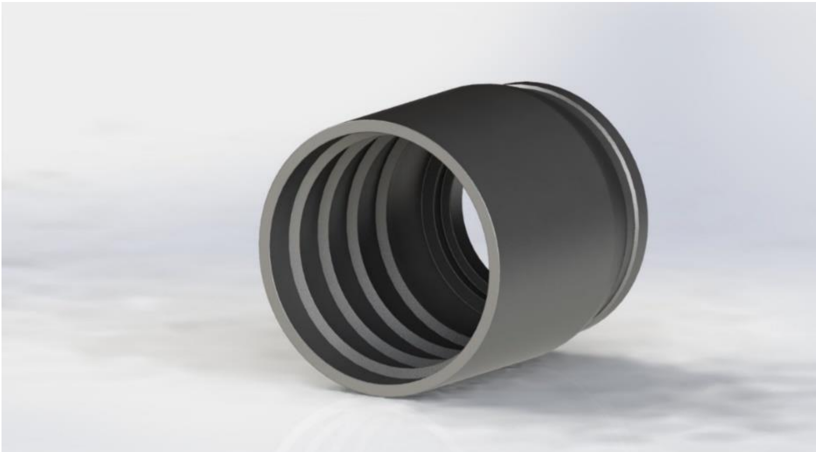


Figure 4.11. SMSNS-16: CAD Drawing (Final Render)

Item 2: AAA080808 – complexity group 3.

The different stages of the CAD drawing process of the item AAA080808 can be seen on Figures 4.12 and 4.13. Figure 4.14 shows the final render.

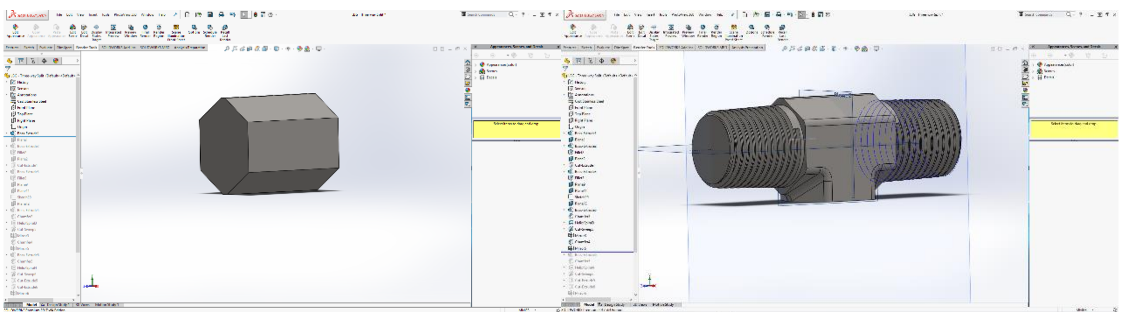


Figure 4.12. AAA080808: CAD Drawing (Stages 1 & 2)

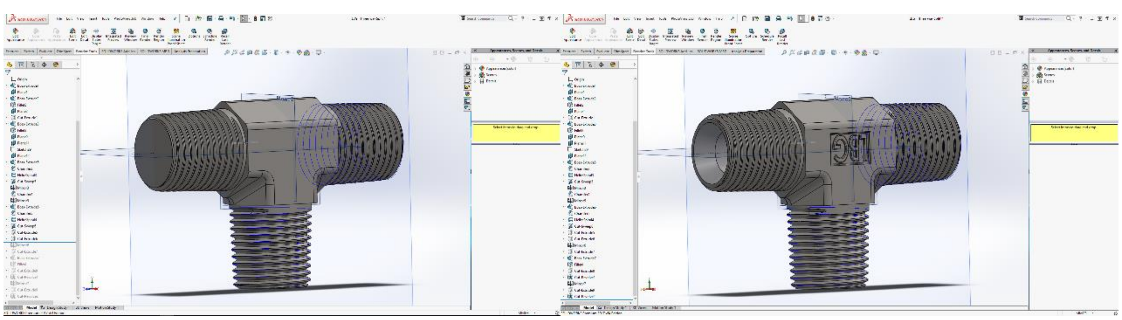


Figure 4.13. AAA080808: CAD Drawing (Stages 3 & 4)

Figure 4.14. AAA080808: CAD Drawing (Final Render)

Item 3: AC901616 – complexity group 4 (2 pieces).

The different stages of the CAD drawing process of the item AC901616 can be seen on Figures 4.15, 4.16, 4.17 and 4.18. As can be seen, this item is constituted of 2 assembles. The final render is seen on Figure 4.19.

Piece 1

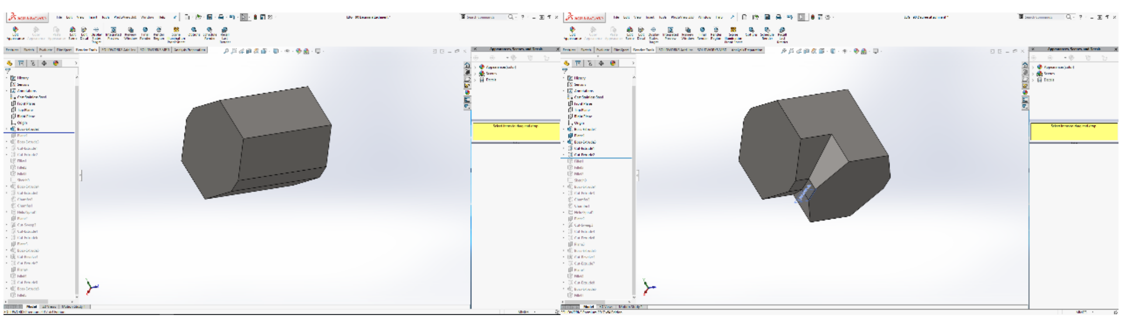


Figure 4.15. AC901616: CAD Drawing (Stages 1 & 2)

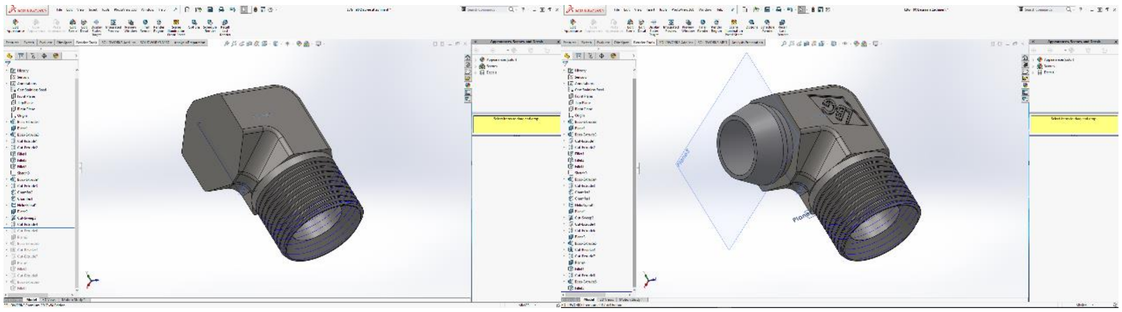


Figure 4.16. AC901616: CAD Drawing (Stages 3 & 4)

Piece 2

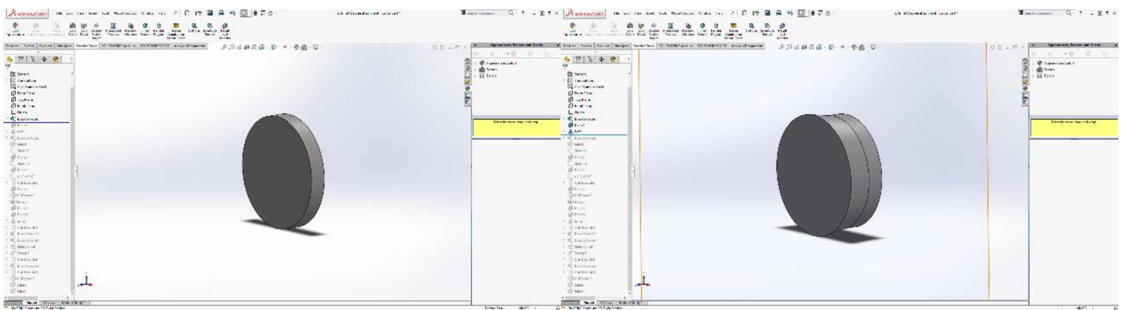


Figure 4.17. AC901616: CAD Drawing (Stages 5 & 6)

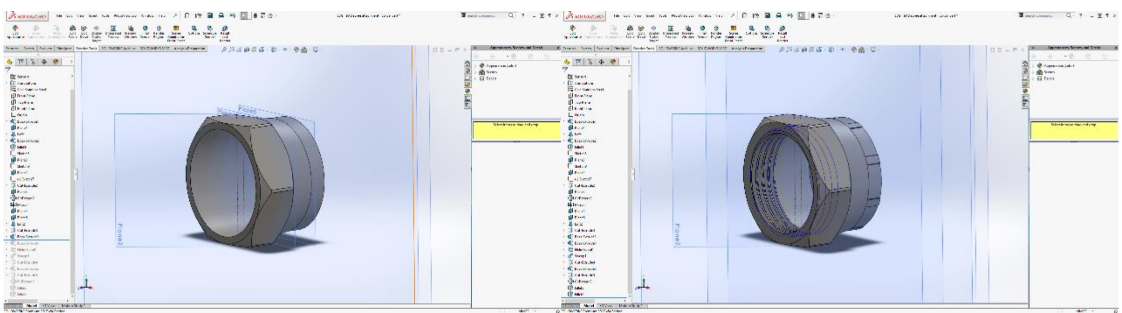


Figure 4.18. AC901616: CAD Drawing (Stages 7 & 8)

Figure 4.19. AC901616: CAD Drawing (Final Render)

4.5.3 Phases 2 & 3 – 3D Printing & Post Processing

Even though this research has collected data that refers to the use of the industrial 3D printer ProX DMP 320, the SKU SMSNS-16 CAD drawn was 3D printed with a ProX DMP 100, which is a 3D printer manufactured for research purposes (i.e., lower printing speed and not suitable for industrial applications) and is available to be used at the Albany Campus of Massey University. Due to the 3D Printer machine structure, which aims to protect the users from hazards, it was not possible to photograph the 3DP process while the layers were being deposited. An image of the ProX DMP 100 can be seen on Figure 4.20.

Figure 4.20. ProX DMP 100 at Massey University

The item was printed over a steel plate, a support for the layers to be deposited on. Prior to the sintering process, a support structure also made of stainless steel was created between the item and the plate, which is later broken, allowing the item to be detached from the plate. At the end of the 3D printing process, the item had the following appearance as shown on Figure 4.21:

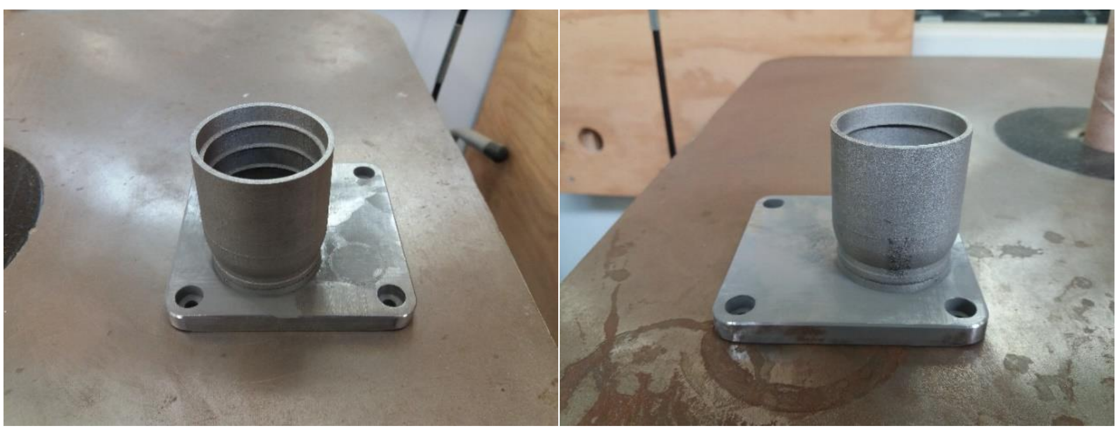


Figure 4.21. Item SMSNS-16 After Being 3D Printed

It can be noticed that not only the item's surface is rough, but there is also an imperfection that can be seen on the picture to the right on Figure 5.13. Both of the issues were fixed later on during the post processing phase. The post processing stage, which can comprise different activities depending on the 3D printed item, started in this case with the detachment of the item from the steel plate through the use of a hammer and a chisel, followed by the removal of the support structure from the item's base as shown on Figure 4.22.

Figure 4.22. Item SMSNS-16: Detachment and Support Removal

With the support completely removed, the next steps were smoothing and polishing the item's surface. The different stages of this process can be seen on Figures 4.23, 4.24 and 4.25.

Figure 4.23. Item SMSNS-16: Polishing Process

Figure 4.24. Item SMSNS-16: Before & After Polishing

Figure 4.25. Item SMSNS-16: The Traditional Manufactured (left) and the 3D Printed (right) Items

The post processing activity of items 3D printed in metal is a labour-intensive task as it requires detachment of the part from the plate, breaking the support structure and later polishing, thus the benefits of utilising AM need to exceed this additional finishing costs. The duration of the entire post processing activity illustrated on Figures 4.22 to 4.24 lasted approximately 22 minutes, similar to the expected 20 minutes timeframe estimated earlier in this research. While no endurance tests were undertaken, the appearance of the item imitates with perfection the original item.

5. Results & Findings

5.1 Introduction

This chapter shows the results for each TM and 3DP cost components of the 247 SKUs categorised under the five complexity groups analysed in this research. The subtotal results for each side of Inequation (3) are then obtained, followed by the final answer as to whether a particular item should or should not be 3D printed. Different cases were considered, where μ, I_R, and β were varied.

5.2 Starting Point

As a starting point and in order to draw some initial conclusions, this research firstly explored the results of Inequation (3) when μ=80%, I_R = 10% and β = 1%.

5.2.1 Complexity group 1.

Nine SKUs were grouped under CG1. Table 5.1 shows the results relating to TM costs:

Table 5.1 - *Quantification of TM Costs for SKU's of Complexity Group 1*

Item Number	U_{TM}	I_{CC}	C_{WH}	C_{OB}	Subtotal
DS02	$ 0.08	$ 0.10	$ 0.70	$ 0.21	**$ 1.09**
DS04	$ 0.38	$ 0.82	$ 0.70	$ 1.83	**$ 3.73**
DS06	$ 0.10	$ 0.77	$ 0.70	$ 1.69	**$ 3.26**
DS08	$ 0.11	$ 0.95	$ 0.70	$ 2.10	**$ 3.86**
DS10	$ 0.12	$ 0.12	$ 0.70	$ 0.25	**$ 1.19**
DS12	$ 0.15	$ 0.43	$ 0.70	$ 0.86	**$ 2.15**
DS16	$ 0.28	$ 0.21	$ 0.70	$ 0.48	**$ 1.67**
DS20	$ 0.37	$ 0.18	$ 0.70	$ 0.38	**$ 1.63**
DS24	$ 5.57	$ 0.76	$ 0.70	$ 1.50	**$ 8.54**

Note. Costs are in NZD.

The items grouped under CG1 are significantly simple in shape and have therefore a low U_{TM} (except from DS24) as can be seen on Table 5.1. Given that U_{TM} is relativity low, the contribution of I_{CC} is consequently not significant in terms of dollar value for the majority of the SKUs. Figure 5.1 illustrates the four TM costs stacked. Given the low unit cost of the items, it is noticed that the warehousing related costs C_{WH} and the cost of obsolescence C_{OB} account in general for a large percentage of the total cost, even though not significant in terms of dollar value, the first being a standard cost of $0.70.

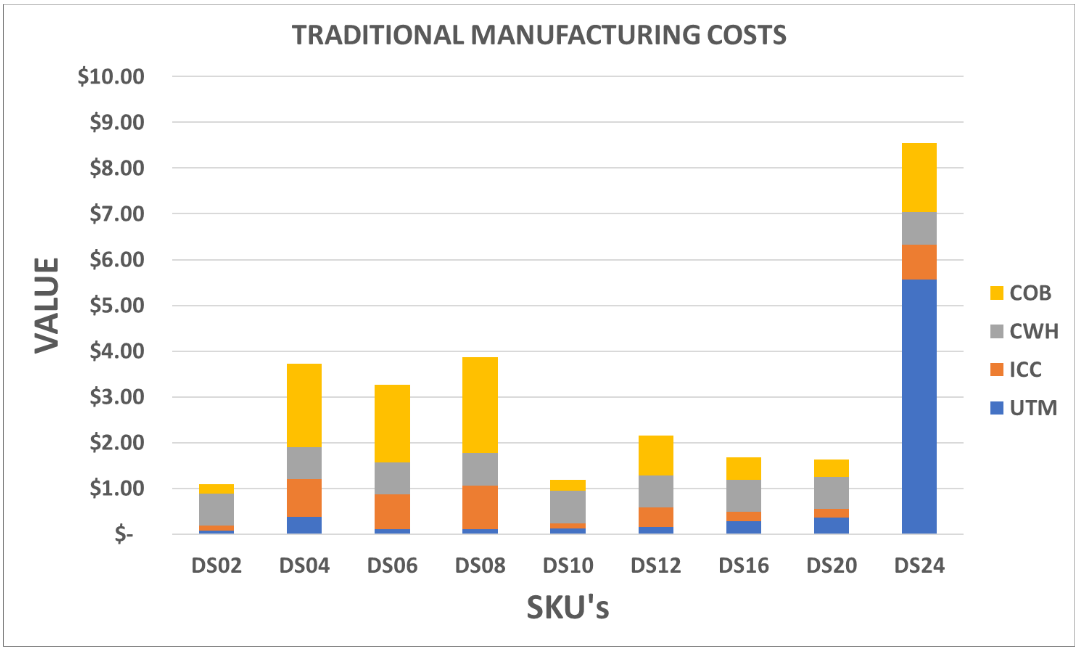


Figure 5.1. Traditional Manufacturing Costs (CG1)

Similarly, Table 5.2 shows the results relating to the 3DP costs:

Table 5.2 - *Quantification of 3DP Costs for SKUs of Complexity Group 1*

Item Number	C_{RAW}	T_{RAW}	C_{FIN}	C_{3DP}	Subtotal
DS02	$ 0.19	$ 0.00	$ 5.25	$ 12.38	**$ 17.82**
DS04	$ 0.33	$ 0.00	$ 5.25	$ 12.38	**$ 17.96**
DS06	$ 0.39	$ 0.00	$ 5.25	$ 12.38	**$ 18.02**
DS08	$ 0.63	$ 0.01	$ 5.25	$ 12.38	**$ 18.27**
DS10	$ 0.82	$ 0.01	$ 5.25	$ 12.38	**$ 18.46**
DS12	$ 0.86	$ 0.01	$ 5.25	$ 12.38	**$ 18.50**
DS16	$ 1.48	$ 0.01	$ 5.25	$ 12.38	**$ 19.13**
DS20	$ 2.13	$ 0.02	$ 5.25	$ 12.38	**$ 19.78**
DS24	$ 2.43	$ 0.02	$ 5.25	$ 12.38	**$ 20.09**

Note. Costs are in NZD.

There are a few important conclusions that can be drawn from Table 5.2:

- For items of CG1, the transport cost T_{RAW} is negligible, as these are relatively light items;
- For the majority of the SKUs, C_{RAW} is higher than U_{TM}, which means that the cost of manufacturing the items via traditional methods is lower than the cost of raw material in proportion to the items' weight;
- C_{FIN} and C_{3DP} are relatively large cost components, fact that can be seen on Figure 5.2.

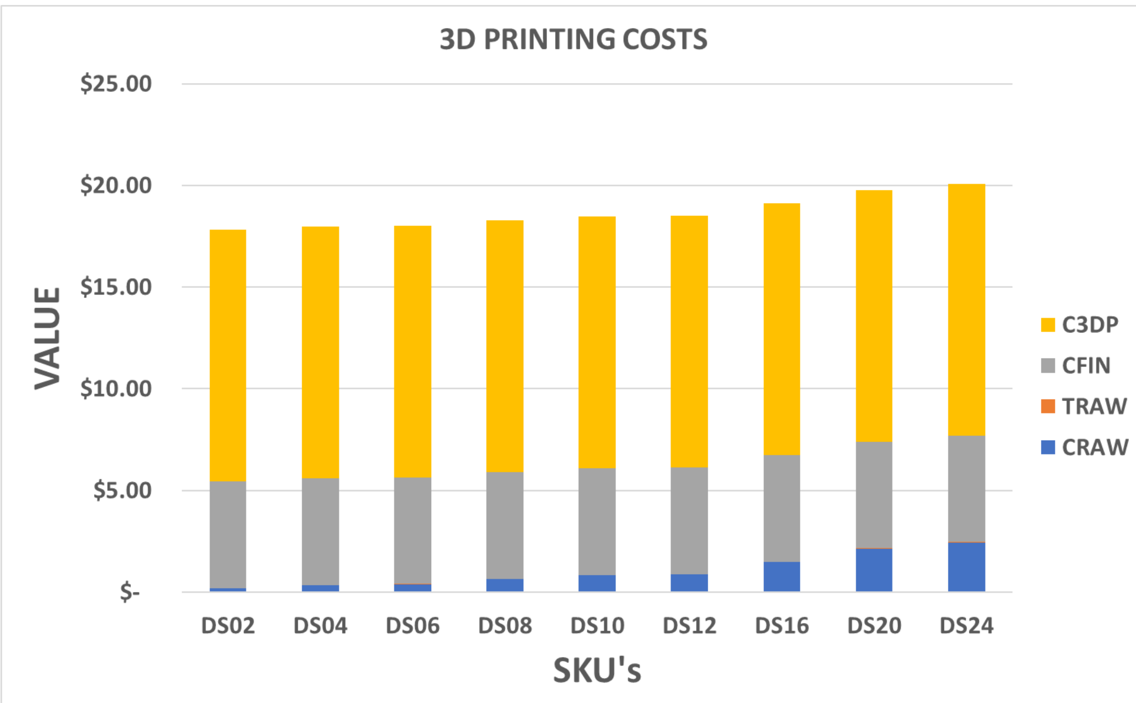


Figure 5.2. 3D Printing Costs (CG1)

After analysing the results of Inequation (3), and interpreting the 3DP and TM cost components, it can be seen that the answer for the question "which items of a company's stock should be 3D printed as opposed to being purchased via TM suppliers?" is 'none' undeniably for the items of CG1. These items are simple to an extent that the cost to finish C_{FIN}, for the SKU DS04 for instance, is 13 times higher than the unit cost U_{TM}, and the cost C_{3DP} is more than 32 times higher than U_{TM}. Such discrepancy in costs can be seen in Figure 5.3 where two examples, DS10 and DS20, are illustrated.

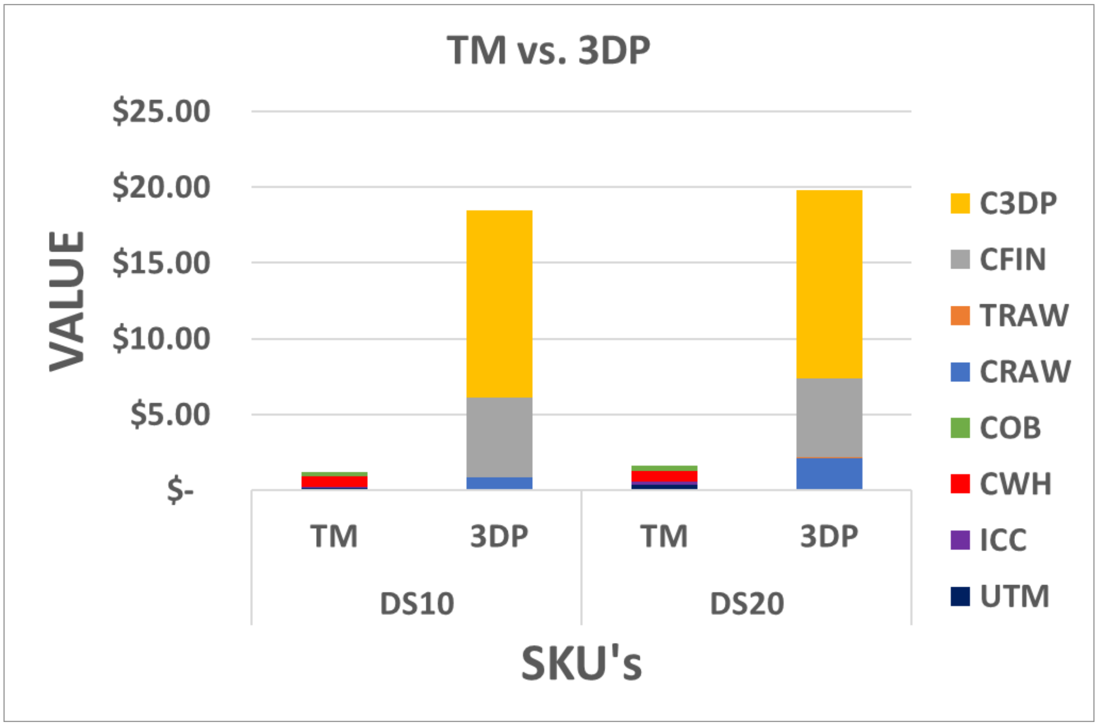


Figure 5.3. DS10 & DS20: Traditional Manufacturing vs. 3D Printing Costs

5.2.2 Complexity groups 2, 3 4 & 5.

An analogue analysis has been performed with the remaining complexity groups. The tables and graphs illustrating the results can be seen in Appendix 11 to Appendix 20. A summary of the results is provided below.

For items of CG2, as expected, there is in general an increase in U_{TM} in comparison to the items of CG1 as a consequence of the higher manufacturing complexity (Appendixes 11 and 12), thus I_{CC} also tends to be higher. The warehousing related cost C_{WH} is not significant, a pattern that is expected to recur as this is a fixed cost of $0.70 and the three other cost components are variable and tend to be higher for the remaining complexity groups. It can be seen that as the manufacturing complexity of the items increase, the 3DP and finishing labour become more intensive

(Appendixes 13 and 14). When the entire CG2 range is analysed, there are 4 items to which the total costs to 3D print are lower than the sum of the TM costs, and these are: SN1-08, SN8-12, TEF-PTCS12 and TEF-PTCS24. For SKU SN1-08, the cost I_{CC} is significantly large in comparison to the I_{CC} component of the other SKUs of the same sub-group. Investigating further, it can be seen that this is a consequence of the low stock turn of the item: 0.025. In other words, if the sales rate does not change, the amount in stock of this SKU will be carried for approximately 39 years. While the inventory carrying cost is an important aspect of stock to be considered in this analysis, this is a clear case of excessive stock overage, given that the annual demand is significantly higher than the MOQ. Therefore, even though the initial results pointed out to the direction of 3DP this particular SKU, this is not the case. The same analogy is true for SN8-12 and TEF-PTCS12. The result is however different for SKU TEF-PTCS24, and it indicates that this particular item should in fact be 3D printed. A comparison of its cost components can be seen on Figure 5.4:

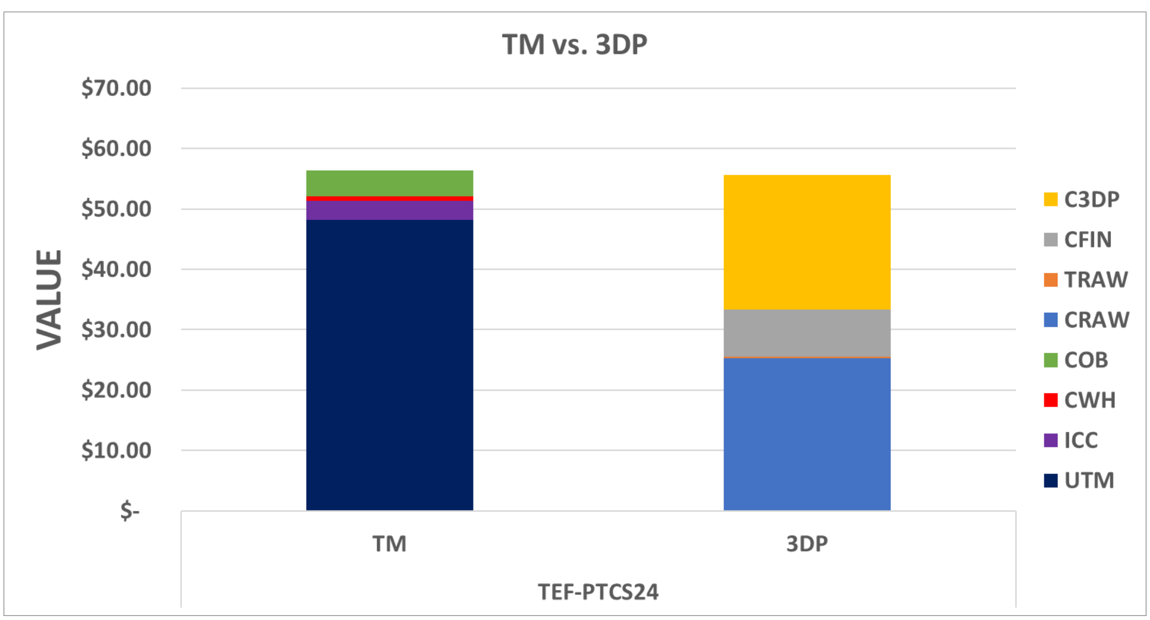


Figure 5.4. TEF-PTCS24: Traditional Manufacturing vs. 3D Printing Costs

While the SKU above yields a positive answer in regard to the use of the 3DP technology, the inequation's result indicates that the benefit is relatively low and equates to $0.74.

Regarding CG3, while not a compulsory trend, it can be seen that in general the unit cost U_{TM} of the items has increased when compared to those of CG1 and CG2 (Appendix 15). Once again it can be seen that T_{RAW} is not a significant cost and can be considered negligible when compared to other 3DP costs such as C_{FIN} or C_{3DP} (Appendix 16). In particular for the items of CG3, T_{RAW} corresponds on average to 0.45% of the total 3DP costs. While the finishing cost C_{FIN} remained the same in comparison to CG2, C_{3DP} increased. Selecting the sub-group EEE to be analysed in detail as per Figure 5.5:

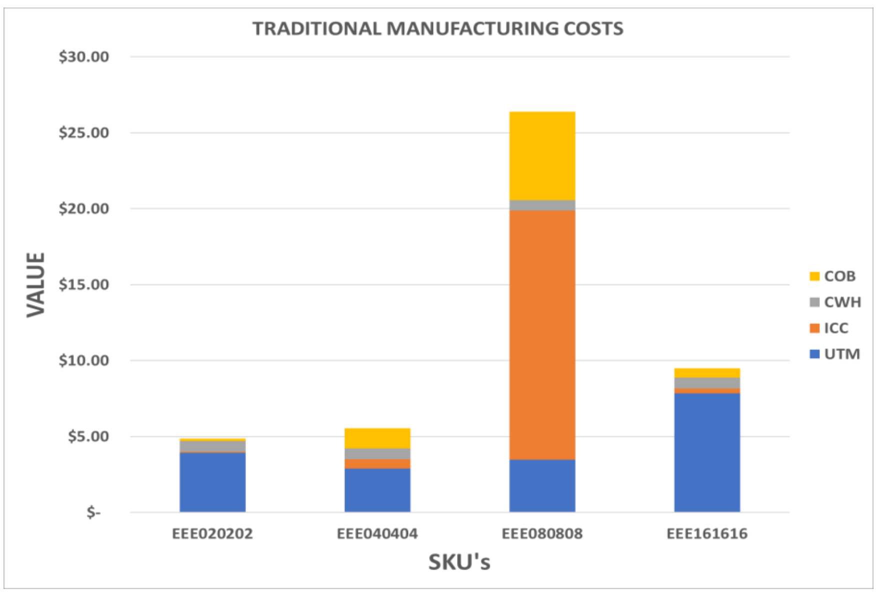


Figure 5.5. Sub-Group EEE: Traditional Manufacturing Costs (CG3)

The corresponding 3DP costs are shown on Figure 5.6:

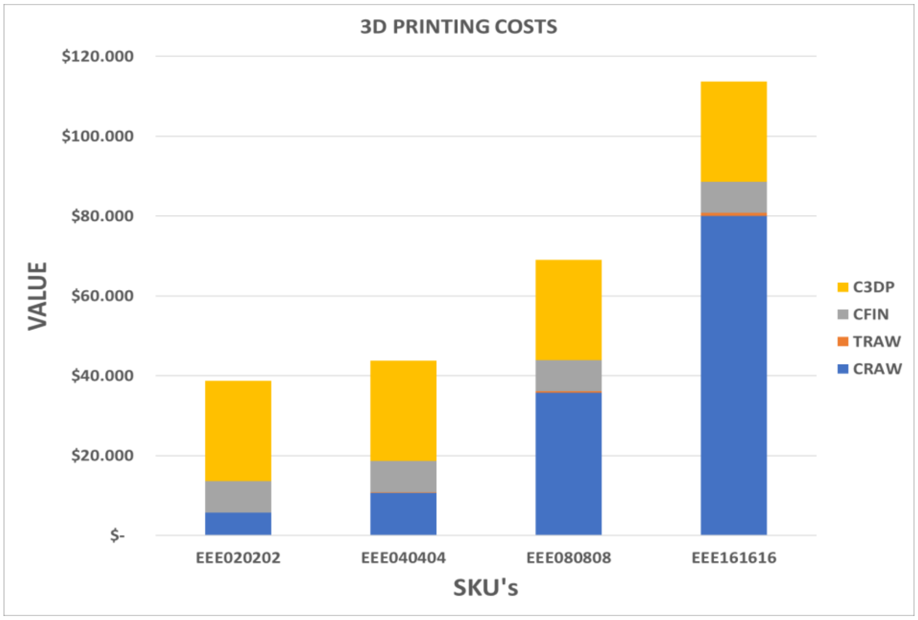


Figure 5.6. Sub-Group EEE: 3D Printing Costs (CG3)

The cost component U_{TM} accounts for a large portion of the total manufacturing cost in comparison to the items of CG1 and CG2. For SKUs EEE020202, EEE040404, EEE080808, and EEE161616 of the sub-group analysed, the 3DP costs exceed the TM costs in $33.88, $38.20, $42.69 and $104.25, respectively, hence none of these four items should be 3D printed, on the contrary the 3DP costs in excess are considerably high.

Analysing the entire range of SKUs within CG3, there are five items that at first sight qualify to be 3D printed: AAA060606, AAA080808, AAA121212, AAA161616 and AAC080808. However, similarly to the SKU SN1-08 of CG2, this result is a consequence of the low stock turn (i.e. stock not being managed efficiently) rather than the benefits of 3DP exceeding the costs of TM.

CG4 comprises SKUs that are composed of at least 2 assemblies. This means that while these parts can be 3D printed as a single item, via manufacturing means there is the need of extra labour to attach the parts, work that may be performed by a worker or a machine. From a 3DP perspective however, items grouped under CG4 require longer 3DP and finishing times (Appendixes 17 and 18), therefore increasing the total 3DP cost of the SKU. The sub-group K025 has been chosen to be analysed in detail and is shown on Figure 5.7:

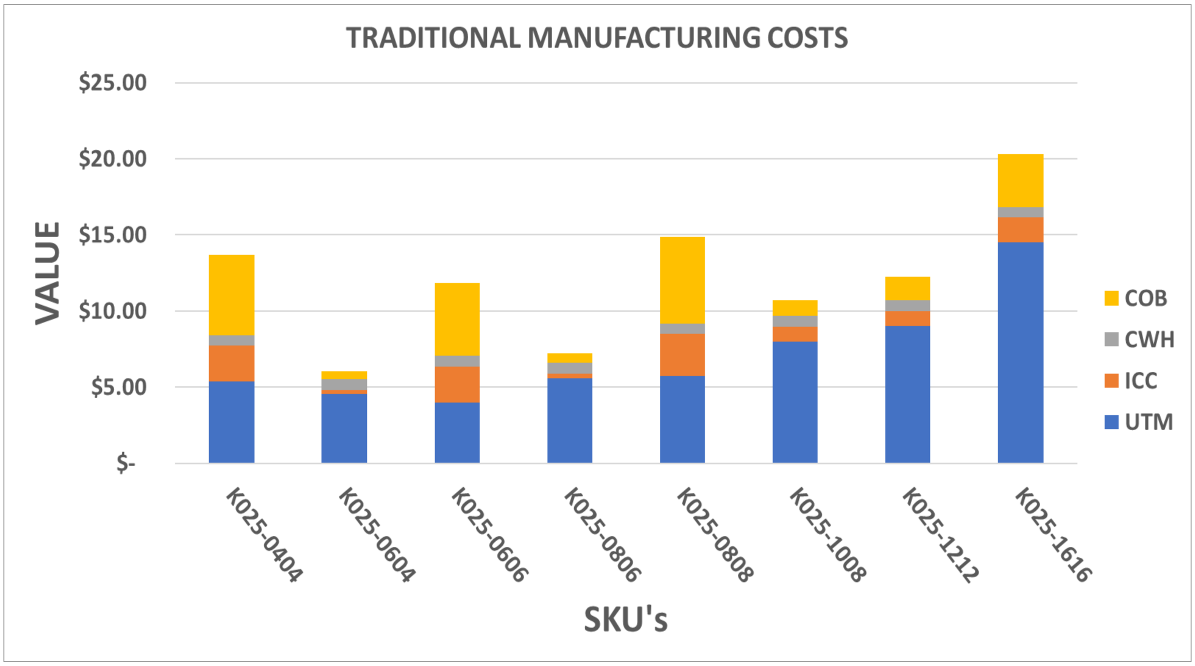


Figure 5.7. Sub-Group K025: Traditional Manufacturing Costs (CG4)

Figure 5.7 shows that for the SKUs of sub-group K025, U_{TM} is the largest cost component. followed by the cost of obsolescence C_{OB}. Similar to Figure 5.7, Figure 5.8 shows the 3DP costs:

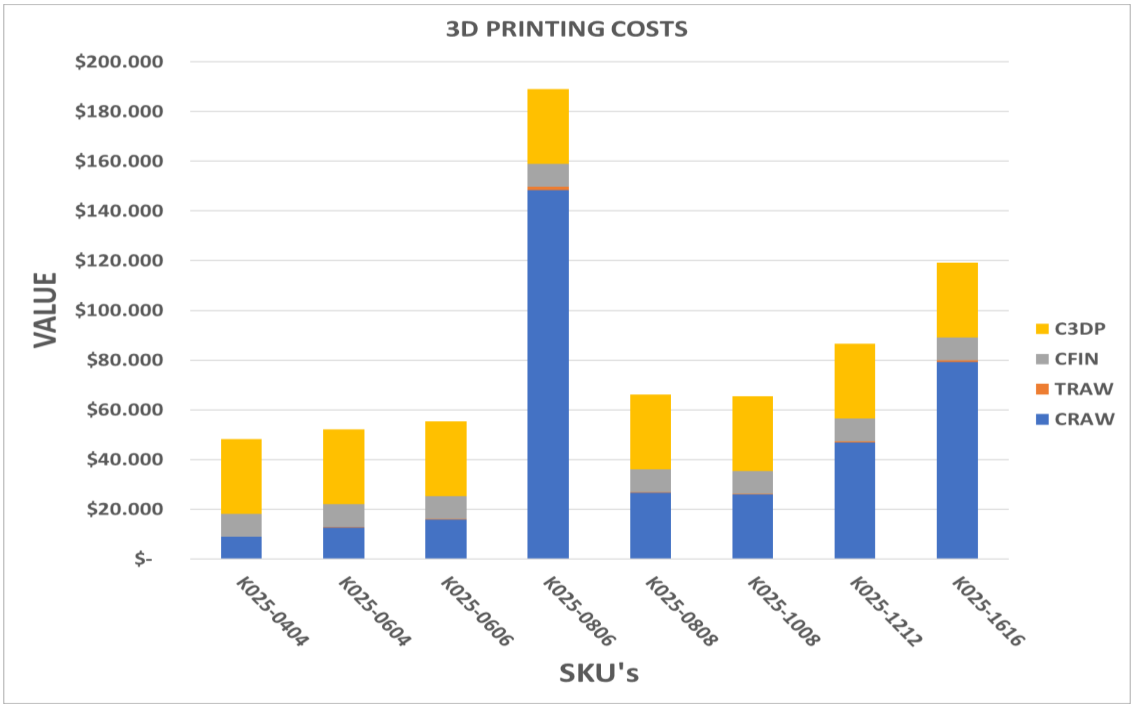


Figure 5.8. Sub-Group K025: 3D Printing Costs (CG4)

It is noticeable that as a result of the higher item's weight, the cost component C_{RAW} overtakes or approximates C_{FIN}. SKU's K025-0808 and K025-1008 have been selected and a comparison between TM and 3DP costs is made on Figure 5.9:

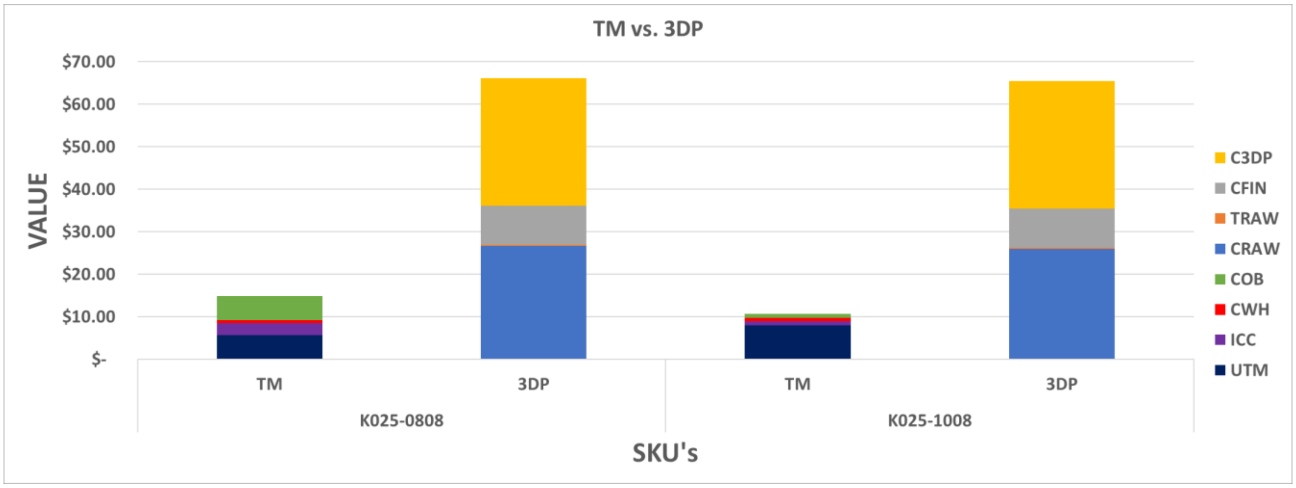


Figure 5.9. Sub Group K025: Traditional Manufacturing vs. 3D Printing Costs

Even though the items grouped under CG4 are deemed to have a higher manufacturing complexity, the same trend that is observed in CG1, CG2 and CG3 repeats for CG4: the sum of the costs associated with 3DP exceed considerably the TM costs. In particular, due to the relatively long 3DP times of CG4, the cost component C_{3DP} by its own would in general suffice. Analysing the results on both sides of Inequation (3), it can be seen that no items would qualify to be 3D printed.

Items comprised within CG5 have a U_{TM} on average approximately three times higher than those items of CG2 and CG3 for instance (Appendix 19). In comparison to the other complexity groups, CG5 has the highest C_{FIN} and C_{3DP}, $11.81 and $49.51 respectively (Appendix 20). While the complexity of an item tends to favour the use of 3DP according to the literature review, it is still not the case for the items of CG5 in question. The sub-group PVV3 has been chosen to be analysed in detail:

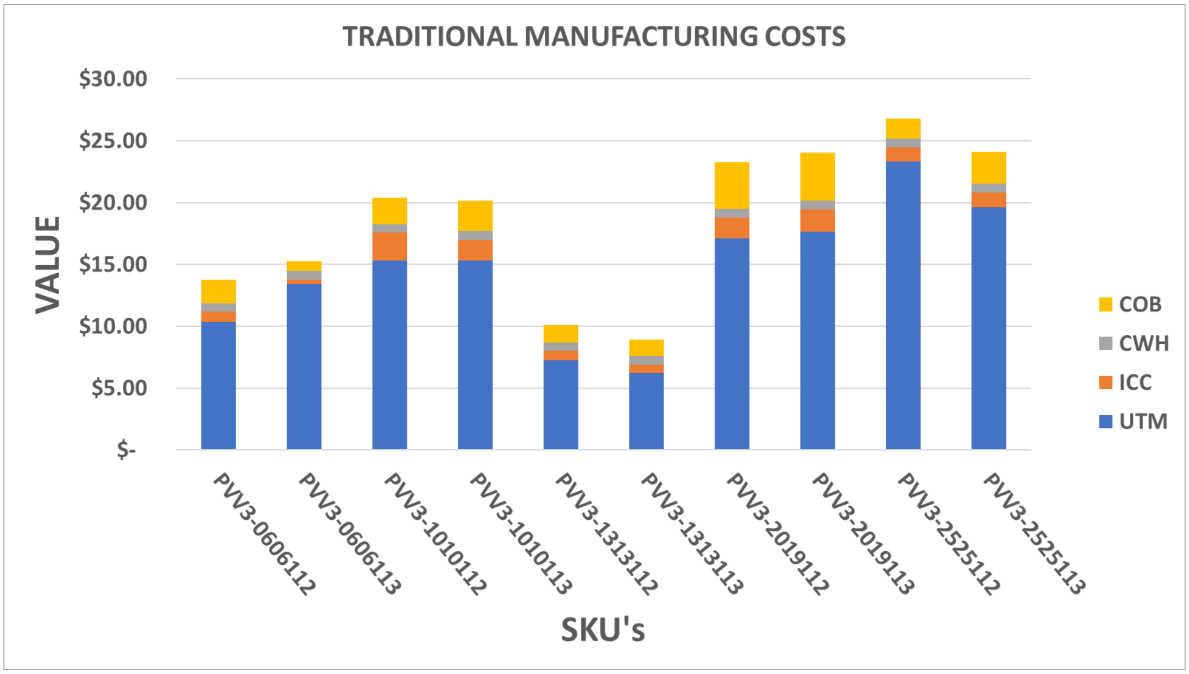


Figure 5.10. Sub-Group PVV3: Traditional Manufacturing Costs (CG5)

Figure 5.10 shows that for the first time, the unit cost U_{TM} is higher than the sum of the three other cost components I_{CC}, C_{WH} and C_{OB}, fact that partly reflects the high manufacturing complexity of the item. For the items of CG5, the cost component C_{WH} accounts for 2.4% of the total, therefore not as significant as for the items of the other complexity groups. The corresponding 3DP costs are as follows:

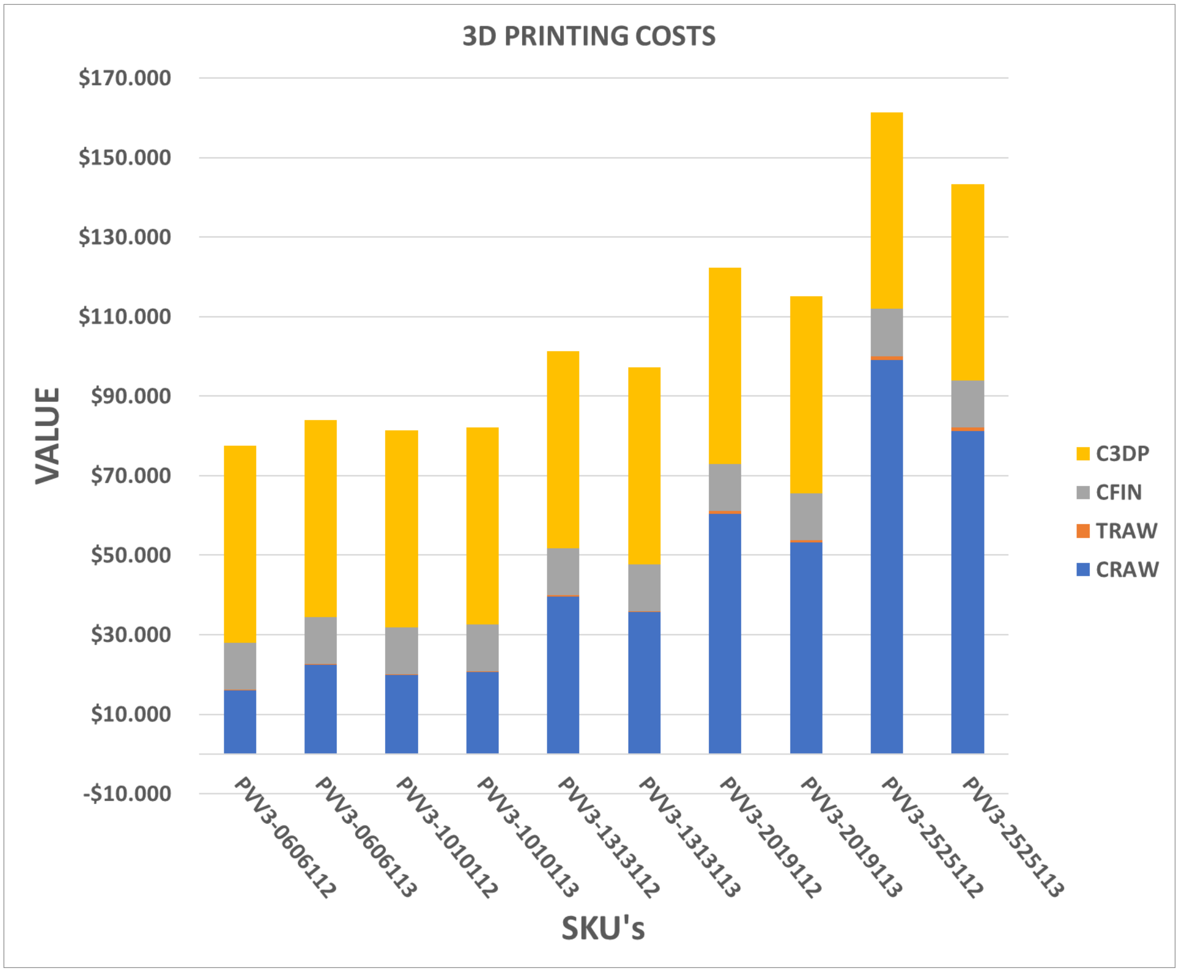


Figure 5.11. Sub-Group PVV3: 3D Printing Costs (CG5)

From Figure 5.11 it can be extracted that C_{RAW} and C_{3DP} are the two largest cost components, followed by $C_{FIN.}$ It can be seen that the costs of 3DP the items of CG5 exceed the TM costs by a substantial amount. When the whole CG5 range is analysed, once again no items would qualify to be 3D printed.

As could be seen above, the analysis of the scenario μ=80%, I_R = 10% and β = 1% yielded negative results regarding the use of 3DP to manufacture the items of the stock of the business analysed in this research.

5.3 Sensitivity Analysis

In order to evaluate the results of Inequation (3) when different scenarios are considered, a sensitivity analysis has been performed. The tables below detail the results for both of the sides of the inequation when I_R, β and μ are varied within the range considered relevant by the researcher. When the result of the inequation points to the use of AM for a particular item under a specific scenario, the total 3DP cost is highlighted. The results for CG1 are illustrated on Tables 5.3 and 5.4.

Table 5.3 - *Sensitivity Analysis: Complexity Group 1 (I_R = 5%)*

I_R	5%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
DS02	$ 0.93	$ 17.82	$ 1.04	$ 17.82	$ 0.93	$ 17.09	$ 1.04	$ 17.09
DS04	$ 2.41	$ 17.96	$ 3.32	$ 17.96	$ 2.41	$ 17.23	$ 3.32	$ 17.23
DS06	$ 2.03	$ 18.02	$ 2.87	$ 18.02	$ 2.03	$ 17.30	$ 2.87	$ 17.30
DS08	$ 2.34	$ 18.27	$ 3.38	$ 18.27	$ 2.34	$ 17.54	$ 3.38	$ 17.54
DS10	$ 1.01	$ 18.46	$ 1.13	$ 18.46	$ 1.01	$ 17.73	$ 1.13	$ 17.73
DS12	$ 1.50	$ 18.50	$ 1.93	$ 18.50	$ 1.50	$ 17.77	$ 1.93	$ 17.77
DS16	$ 1.33	$ 19.13	$ 1.57	$ 19.13	$ 1.33	$ 18.40	$ 1.57	$ 18.40
DS20	$ 1.35	$ 19.78	$ 1.54	$ 19.78	$ 1.35	$ 19.05	$ 1.54	$ 19.05
DS24	$ 7.37	$ 20.09	$ 8.12	$ 20.09	$ 7.37	$ 19.36	$ 8.12	$ 19.36

Note. Costs are in NZD.

Table 5.4 - *Sensitivity Analysis: Complexity Group 1 (I_R = 10%)*

I_R	10%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
DS02	$ 0.99	$ 17.82	$ 1.09	$ 17.82	$ 0.99	$ 17.09	$ 1.09	$ 17.09
DS04	$ 2.82	$ 17.96	$ 3.73	$ 17.96	$ 2.82	$ 17.23	$ 3.73	$ 17.23
DS06	$ 2.41	$ 18.02	$ 3.26	$ 18.02	$ 2.41	$ 17.30	$ 3.26	$ 17.30
DS08	$ 2.81	$ 18.27	$ 3.86	$ 18.27	$ 2.81	$ 17.54	$ 3.86	$ 17.54
DS10	$ 1.07	$ 18.46	$ 1.19	$ 18.46	$ 1.07	$ 17.73	$ 1.19	$ 17.73
DS12	$ 1.72	$ 18.50	$ 2.15	$ 18.50	$ 1.72	$ 17.77	$ 2.15	$ 17.77
DS16	$ 1.43	$ 19.13	$ 1.67	$ 19.13	$ 1.43	$ 18.40	$ 1.67	$ 18.40
DS20	$ 1.44	$ 19.78	$ 1.63	$ 19.78	$ 1.44	$ 19.05	$ 1.63	$ 19.05
DS24	$ 7.79	$ 20.09	$ 8.54	$ 20.09	$ 7.79	$ 19.36	$ 8.54	$ 19.36

Note. Costs are in NZD.

As can be seen on Tables 5.3 and 5.4, none of the items comprised within CG1 yielded results in favour of the utilisation of the 3DP technology.

The analysis of CG2 under multiple scenarios (Appendixes 21 and 22) has not yielded different results than those obtained when the first scenario was considered in sub-section 5.2. Only one out of the four highlighted items should in fact be 3D printed: TEF-PTCS24. The results in favour of the 3DP technology occurred in three different cases: I_R = 5%, μ = 85%, and β = 1%; I_R = 10%, μ = 80%, and β = 1%; and I_R = 10%, μ = 85%, and β = 1%, however the benefits are low and correspond to \$0.07, \$0.74 and \$2.05 respectively.

The analysis of CG3 under multiple scenarios has also not yielded different results than those obtained when the first scenario was considered in sub-section 5.2. While five SKUs would qualify to be 3D printed at first sight, that is a result of a stock turn lower than 1, and as stated earlier, the researcher disregarded these cases as it is understood that this is a consequence of the influence of the particularities of the business in question, and not an indication that these particular items should in fact be 3D printed.

The analysis of CG4 under the eight different scenarios indicated that none of the items should be 3D printed, as the sum of the 3DP costs exceed the sum of the TM costs. Finally, the analysis of CG5 shows that one SKU yielded results in favour the use of 3D printers under two different scenarios: PLT1-2019002. However, the benefits once again are low and correspond to $0.89 and $2.43 only.

Overall, none of the groups yielded positive results regarding the use of the 3DP technology, as the 3DP costs exceeded the TM costs for practically all SKUs under all the scenarios considered. The researcher understands that there is no merit in performing an ABC Classification given that the results of this analysis indicated that practically no items of the stock of this company should be 3D printed.

5.4 Findings

In general, the sensitivity analysis described in Chapter 6 has yielded negative results regarding the use of the 3DP technology to manufacture items of the stock of the company evaluated in this research. While there were a few items that at first indication would qualify to be 3D printed, the results were either influenced by the stock overage of that particular SKU, or the benefits were too small in terms of dollar value to in fact be significant. After considering eight different scenarios where the utilisation rate of the 3DP machine, the investment rate that influences the inventory carrying cost, and the cost of obsolescence were varied, this research concludes that for this particular business, the use of the 3DP machine to manufacture items and mitigate the problematic aspects of the long tail is not an advantage and would, on the contrary, increase the manufacturing costs.

The SKU K025-0808 has been selected to illustrate, summarise and finally justify the reasons why the items of the company in question should not be 3D printed. A breakdown of the TM and 3DP costs is provided on Figure 5.12:

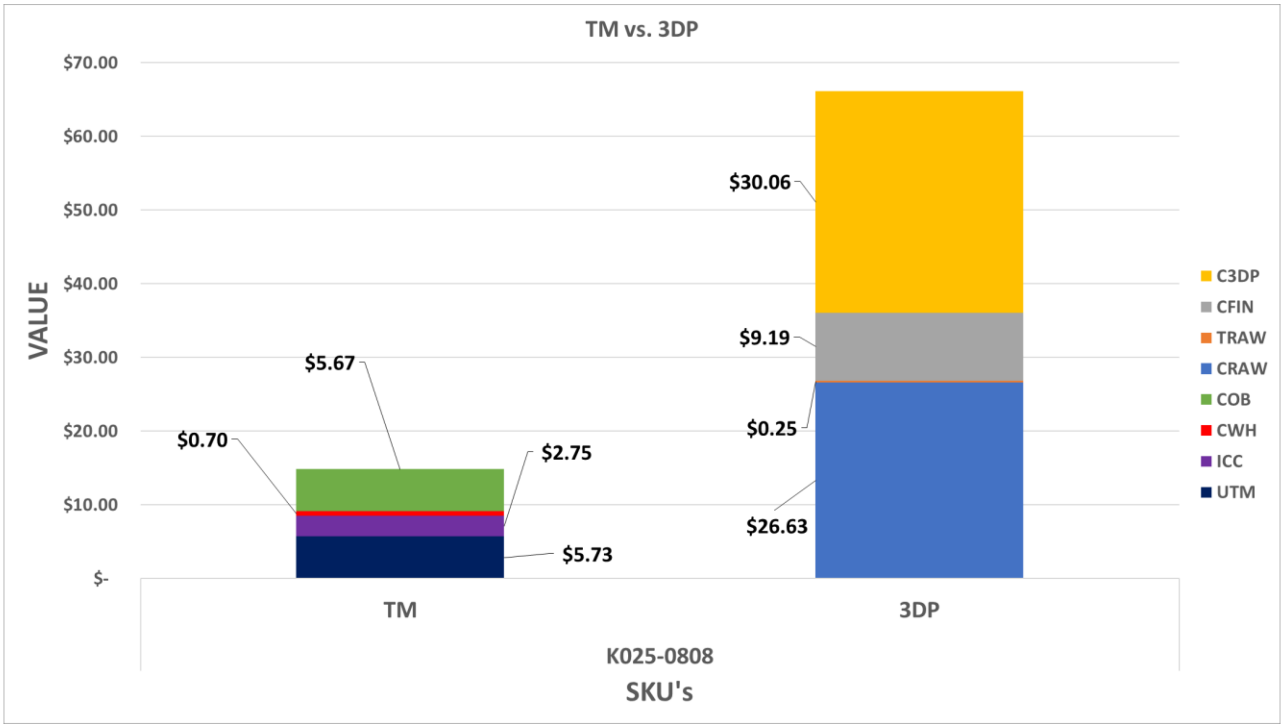


Figure 5.12. K025-0808: Traditional Manufacturing vs. 3D Printing

The use of the 3D printer machine requires that the capital invested in the technology be paid back, as well as requires that the items 3D printed be post processed thereafter. In the case analysed in this research and detailed in the Validation Process chapter, the post processing task is labour intensive and comprises a few phases, from the release of the item from the steel plate to the final polishing. There is therefore a minimum 'offset' that composes the total 3DP costs that needs to be exceeded in order for the use of the 3DP machine to be an advantage. In addition, the cost of the raw material is currently high valued at $126.80/kg, which contributes to increase the 3DP costs substantially with a small increase in the item's weight.

For the SKU K025-0808, grouped under CG4, C_{FIN} and C_{3DP} correspond to $9.19 and $30.06 respectively, adding up to $39.25. This means that for 3DP to be an advantage, the sum of the TM costs need to exceed $39.25 + C_{RAW} + T_{RAW}. Considering that the unit cost of the item U_{TM} is $5.73, that I_{CC} and C_{OB} are costs directly influenced by the value of U_{TM}, and that C_{WH} has been diluted into several items and corresponds to $0.70, it is then clear to understand the reasons behind the results of this research. The items of the inventory analysed are low-cost to an extent that, unless their stock levels are excessively high, the costs related to stock being carried are not significant.

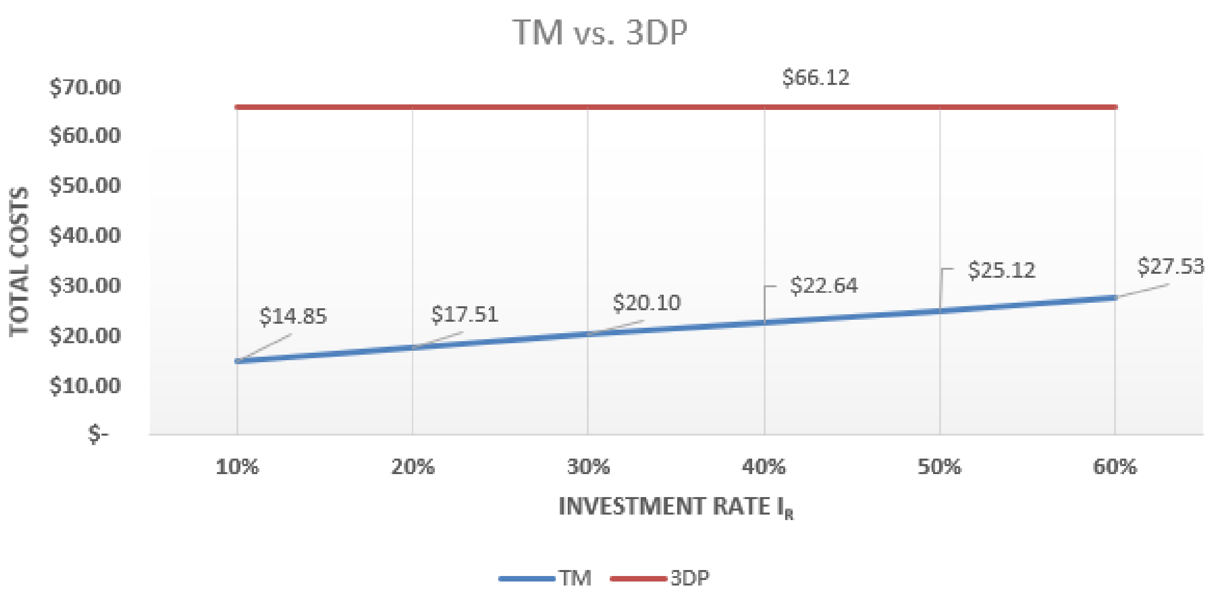


Figure 5.13. K025-0808: Traditional Manufacturing vs. 3D Printing (varying I_R)

Figure 5.13 uses the same SKU K025-0808 to illustrate that the variation of the investment rate I_R does not affect significantly the total TM costs. Given the low U_{TM}, the increase in the total TM costs is relatively slow and it does not reach the total 3DP costs even at a rate of 60%. In other words, the item analysed is not complex enough to trigger the benefits of the use of the 3DP technology, which is also true for the rest of the items of the inventory.

6. Discussion

6.1 Introduction

The researcher had primarily estimated during the Conceptual Model and the Research Gap sub-section that the tipping point of the inequation would occur in the threshold between the B Class and the C Class, and also stated that there could be items, likely to belong to the B Class, that would qualify to be 3D printed due to their higher value. When stating this, the researcher believed that the cost component I_{CC}, the inventory carrying cost, would be significant and would have an impact in the TM side of the inequation, which was clearly not the case for the study case in question.

With the results obtained through the evaluation of Inequation (2) under multiple scenarios, it can be concluded that the answer for the research question "Which items of a company's stock should be 3D printed as opposed to being purchased via TM suppliers?" is, for the business analysed in this research, practically 'none'. There are no items that in fact trigger the benefits of utilising the 3DP technology and the reasons for this were illustrated in Figure 5.12 and thoroughly explained in Chapter 5.

With the traditional and 3DP costs scrutinised, it can be concluded that the items analysed are too simple to trigger the benefits of AM. As already pointed out by Bourell (2016) and other authors, 3DP is more suitable for items with high manufacturing complexities. While such statement is already well known – the concept of complexity is naturally relative and subjective.

6.2 The Importance of Each Variable

Earlier in this research, it has been stated that some variables may be more relevant to Inequation's (2) result than others. This sub-section analyses the importance of each variable.

Regarding the 3DP costs, the low relevance of the component T_{RAW} in the whole is a noticeable aspect. On average, T_{RAW} is a cost component that accounts, for the five complexity groups, for less than 0.5% of the total 3DP costs. This lower importance can also be drawn from the equations C_{RAW} = \$126.80 * I_W and T_{RAW} = \$1.20 * I_W. Dividing the first by the latter, it is yielded that T_{RAW} is 105x smaller than C_{RAW}, therefore negligible in terms of percentage of the whole.

With the raw material cost per kilogram at \$126.80, it can be concluded that the mass/weight is a factor that does not favour the use of the 3DP technology. Regardless of the shape or complexity, an item weighting for instance 500g would cost in excess of \$63.40. C_{RAW} is therefore a variable that plays an important role in the whole, in conjunction with C_{FIN} and C_{3DP}, which can be seen as 'offset' costs that need to be exceeded in order for the use of the 3DP technology to be an advantage.

U_{TM} is perhaps the most important of the cost components on the TM side of the inequation as it directly affects the inventory carrying cost I_{CC} and the cost of obsolescence C_{OB} (as calculated in this research). The higher U_{TM}, the higher I_{CC} and C_{OB}.

The warehousing related cost C_{WH}, on the other hand, does not have such a significant influence in the total TM costs as it is diluted over a greater quantity of items. The better the storage space utilisation, smaller will be C_{WH} and therefore less influence on the whole it has.

The inequation developed is not a 'one size fits all', and adjustments may need to be made depending on the case to be studied. For instance, if a high-valued storage equipment is involved, then an extra variable relating to such factor cannot be neglected. In the light of the findings, the only adjustment to be made to Inequation (2) is the potential removal of T_{RAW}, which depending on the items' nature is likely to be negligible.

6.3 Review of Findings

Even though the content of this research is biased by the subjectivity of the company's stakeholders, and to some extent biased by the researcher's understanding of the nature, the conclusions herein drawn are not altogether limited. While no direct and trustworthy recommendation can be made for businesses of other industries, this is not true for businesses trading similar items to those of the company in question. Through the results of this research it has been inferred that the items analysed are too simple to trigger the benefits of utilising the 3DP technology, and this fact is true regardless of the company being evaluated. Therefore, the findings of this research are directly valid to other companies within the same industry, i.e., the utilisation of 3DP is not an advantage.

In regard to companies belonging to other industries that not the hydraulic in question, the contribution of this research is primarily the creation of a mechanism to assess the tipping point between TM and AM – Inequation (2), and the results around the importance of each variable, especially U_{TM}, the item's unit cost. Hence, the findings of this research are useful but not generalisable for business of other industries.

Finally, it is important to highlight that the findings of this research are strongly aligned with the literature: item's that are simple to some extent tend not to trigger the benefits of 3DP (Bourell, 2016; Grynol, 2013). While this is well known and known by the researcher prior to conducting this research, it is not possible to judge with certainty the complexity of an item before the 3DP and TM costs are compared and analysed.

7. Conclusions

7.1 Contributions

From a theoretical perspective, this research contributed to the literature by introducing a mechanism that allows the analysis of the logistics trade-offs between traditional and additive manufacturing:

$$\mathbf{C_{RAW} + T_{RAW} + C_{FIN} + C_{3DP} < U_{TM} + T_{TM} + I_{CC} + C_{WH} + C_{OB}} \quad (2)$$

In particular, this research provided a better understanding of the costs comprised on both sides of the inequation. While at a first glance no assumptions could be made, it is now known that there are costs that play a more important role in the trade-off such as U_{TM} and C_{3DP}, and other costs that are likely to be negligible such as T_{RAW} and C_{WH}. The negative results of this research also indicated which items are more likely to trigger the benefits of AM, complex and high-valued items (Bourell, 2016; Bourell et al., 2009), as already extensively described within the literature, as opposed to simple and low-valued items (the concepts of complexity and low/high value are however highly subjective and relative).

From a practical point of view, the inequation is an assessment tool that allows the first step to be taken towards the adoption of 3DP, as prior to the adoption of any disruptive technology by businesses (or universities and other entities), a careful assessment is necessary in order to ensure the benefits exceed the associated investment costs. In case the results of a similar research (utilising this methodology or an equivalent) happen to be positive regarding the utilisation of a 3D printer machine, then the company in question would reduce its procurement costs and become more competitive, therefore instigating its competitors within the same supply chain to also investigate the use of the technology. Particularly for this case study, it can be concluded that the acquisition of a 3D printer machine by the company analysed and others within the same industry is not beneficial as the manufacturing costs would in fact increase. The negative results herein obtained are also likely to occur for business within industries trading items of a similar nature, such as those commercialising other types of adaptors (e.g. business trading house accessories).

This assessment methodology can be refined or even modified according to the understanding of the trade-off by another researcher. In addition to applying the same methodology to another case study, it is also possible to create a different methodology and compare the results against those herein obtained. Given that this research enabled a better understanding of the different components that are comprised within the TM and 3DP costs, it is then possible to better select the next case to be studied. A further study and analysis of this research could also lead to the creation of a fourth criterion to be added to the list provided in the Research Design sub-section, establishing a minimum threshold for U_{TM}, given that it plays such an important role in the inequation as a whole.

Research opportunities for the future would be to further explore the idea behind this research, applying Inequation (2) or an equivalent version to a company where items are high-valued in comparison to the one's in this research. For instance, the aviation industry (Wagner & Walton, 2016) or industries where maintenance, repair and operations (MRO) inventory is a reality and parts are frequently stocked 'just in case' are good example of interesting cases to be considered and extensively supported by the literature review.

In case numerous researches similar to this are undertaken and a significantly high number of businesses are assessed, it is then possible to develop a quantitative methodology that makes use of the multiple results acquired with the researches to establish a straight-forward method of deciding whether 3DP is or is not an advantage for the case in question.

Given that the researcher has not found other examples of articles exploring the trade-offs between AM and TM and the potential adoption of the technology by business, it is not possible to compare the results of the assessment tool developed herein with other results.

7.2 Critical Review

As this research was designed to be conducted under a qualitative approach, it has the weaknesses of most of the qualitative researches (Bryman & Bell, 2011). It is subjective and hence filtering of content was needed in order for the researcher to separate the results that were useful from those that have been 'contaminated' and could have misled him (Bryman & Bell, 2011). This filtering however was biased by the researcher understanding and this is highly interpretative. For instance, there were cases where the researcher had to make a call regarding the stock levels of the company in question to ascertain whether or not the result of the inequation had been influenced simply by poor inventory management. The methodology applied in determining this answer is subjective and is naturally affected by the researcher's view and experience.

It is to some extent non-generalizable given that the thesis proposed was applied to a specific business and the results cannot be directly applied to other cases, hence a limited statistical validity (Bryman & Bell, 2011). However, while the results cannot be directly applied, important conclusions can still be drawn from the results, providing a contribution to other researches of the same type. It is believed that once a significant number of researches of the same type have been conducted, a further and more significant conclusion that can be generalisable to some degree would be realisable.

In some cases, qualitative research is also deemed to be non-transparent (Bryman & Bell, 2011) and there are concerns around the collection and interpretation of data, however this can be to some extent mitigated by the researcher's description of the utilised methodology, as it was done throughout this research.

7.3 Strengths & Weaknesses

The primary strength of this research is that the results are closely aligned with the discussions within the literature – complex items are those more suitable to be 3D printed (Bourell, 2016; Bourell et al., 2009), as opposed to simple items that have a low cost via TM. While this is well known in the literature, what is and is not a complex item will not have been ascertained until a study has been done.

During this research, the researcher has been given full access to the company's ERP system and has been supported by the management team throughout the entire research. This enabled the collection of data and information that is in general hard to be accessed due to its financial sensitiveness. It is then a privilege of this research that the data herein utilised is 'real' data and not data artificially created for the purpose of this research, which increase the reliability of the acquired results.

It is also a strength of this research the fact that Inequation (2) incorporates the most relevant 3DP and TM cost components and that a sensitivity analysis was performed when the necessary data was not directly available. This consideration of multiple scenarios where some variables were varied, strengthens the validity of the results of this research and the consequent conclusions. The researcher however acknowledges that there are other minor cost components that were not taken into account in the inequation such as the cost of raising purchase orders, which would favour the 3D printing approach, as a significant amount of items would not have to be ordered from multiple suppliers anymore, and the potential segregation of an area within the warehouse to be dedicated to the 3DP machine and its accessories, which if taken into account, would have increased the total cost of utilising the 3DP technology. Also, not considered is the initial cost corresponding to the labour of CAD drawing each individual SKU of the stock. However, as a significant quantity of items would be 3D printed from each drawing, this cost would be diluted over time and can therefore be deemed to be negligible.

In a robust research approach, when an aspect of a single element needs to represent the different and diverse aspects of a whole group of elements, a significant number of individuals of this group needs to be studied and data needs to be collected prior to this representative sample to be elected. For instance, this representative may be the average of the aspects of the individuals studied. In this research, time and especially budget limitations prevented the researcher from collecting sufficient data pertaining to the 3DP technology, in particular the 3DP and post processing times of the items in stock. For this to happen, a large range of items would need to be 3D printed, which was not economically viable during this specific research. While the 3DP time of a unique item is not ideal to be used as a representative for an entire complexity group, the research budget limited the researcher’s ability to collect more data.

The subjectivity of this research and the qualitative approach can also be added to the list of weaknesses. Decisions of the research around the variation range of β, μ, and I_R are based on the researchers understanding and experience and could be to some extent questioned. The criterion relating to an item being overstock due to a poor inventory management approach is also highly subjective and therefore diminishes to some extent the generalisation and reliability of this research.

APPENDIX 1– The Five Complexity Groups

CG1 (Adaptors)

- DS – DOWTY SEAL

CG2 (Ferrules)

- SN1 – 1 – WIRE FERRULE
- SN2 – 2 – WIRE FERRULE
- SN3 – UNIVERSAL FERRULE (1-2 WIRE)
- SMSH – 4SH SKIVE FERRULE
- SMSP – 4SP SKIVE FERRULE
- SMSR13 – R13/R15 SKIVE FERRULE
- SMSHv2 – 4SH/4SP POWERTRAK SKIVE FERRULE
- SN8 – THERMOPLASTIC FERRULE
- SN9 – SEWER JETTING FERRULE – SUITS 2500 – 4000 PSI
- PTCS – STAINLESS STEEL CONVOLUTED FERRULE
- PTTB – MILD STEEL SMOOTH BORE FERRULE

CG3 (Adaptors - Tees)

- AAA – BSPT MALE X BSPT MALE X BSPT MALE
- AAC – BSPT MALE X BSPT MALE X BSPP FEMALE SWIVEL
- ACA – BSPT MALE X BSPP FEMALE SWIVEL X BSPT MALE
- BBB – BSPP MALE X BSPP MALE X BSPP MALE
- BBC – BSPP MALE X BSPP MALE X BSPP FEMALE SWIVEL
- BCB – BSPP MALE X BSPP FEMALE SWIVEL X BSPP MALE
- BCC – BSPP MALE X BSPP FEMALE SWIVEL X BSPP FEMALE SWIVEL
- CCB – BSPP FEMALE SWIVEL X BSPP FEMALE SWIVEL X BSPP MALE
- CCC – BSPP FEMALE SWIVEL X BSPP FEMALE SWIVEL X BSPP FEMALE SWIVEL
- EEE – BSPT FIXED FEMALE X BSPT FIXED FEMALE X BSPT FIXED FEMALE

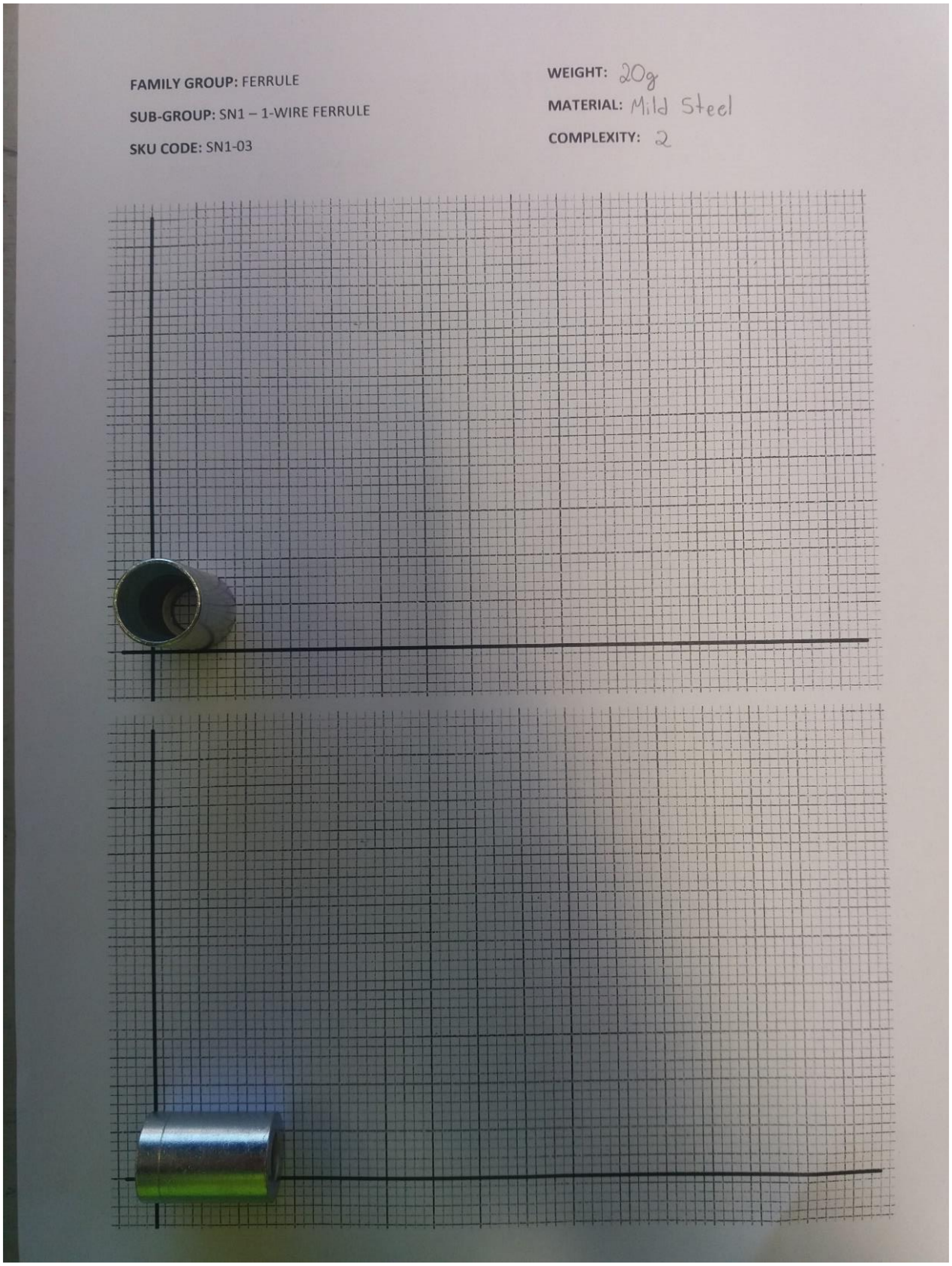
CG4 (Fittings – 1 Piece BSP)

- K001 – BSPP FEMALE X ONE PIECE TAIL
- K012 – BSPP MALE X ONE PIECE TAIL
- K015 – BSPT MALE X ONE PIECE TAIL
- K025 – BSPP FEMALE X ONE PIECE TAIL - 90° COMPACT
- K051 – BSPP FEMALE X ONE PIECE TAIL - 90° SWEPT
- K060 – BSPP FEMALE X ONE PIECE TAIL - 45° SWEPT
- K005 – JIC FEMALE X ONE PIECE TAIL
- K018 – JIC MALE X ONE PIECE TAIL
- K029 – JIC FEMALE X ONE PIECE TAIL - 90° COMPACT
- K055 – JIC FEMALE X ONE PIECE TAIL - 90° SWEPT
- K064 – JIC FEMALE X ONE PIECE TAIL - 45° SWEPT

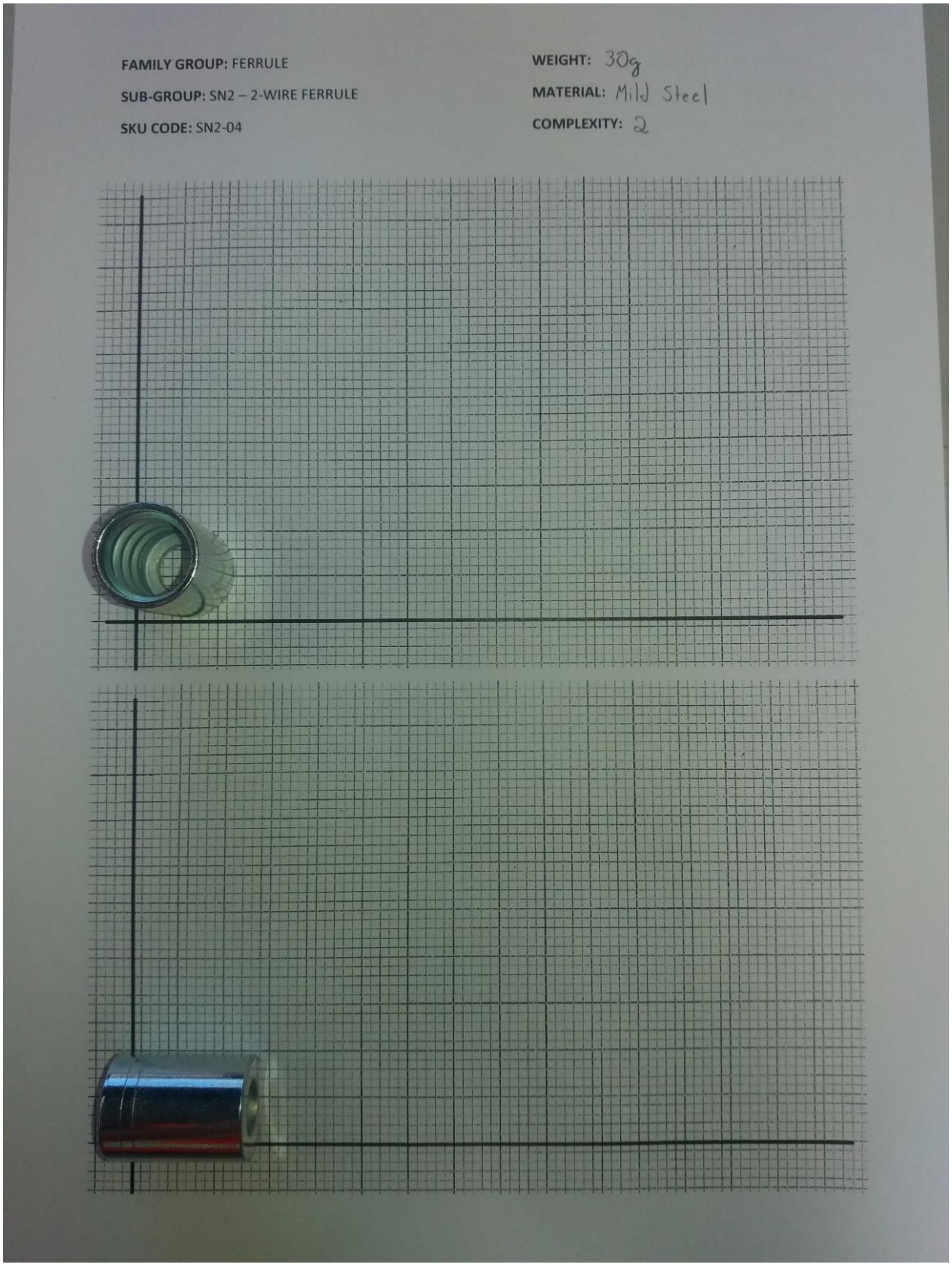
CG5 (QRC & PBR)

- PDV1 – QRC POPPET X BSPP FEMALE THREAD
- PPV1 – PUSH/PULL QRC X BSPP FEMALE THREAD
- PKKL – PRESSURE RELEASE QRC X BSPP FEMALE THREAD
- PDS1 – BALL TYPE QRC X BSPP FEMALE THREAD
- PLT1 – FLAT FACE QRC X BSPP FEMALE THREAD
- PVV3 – SCREW TYPE QRC X BSPP FEMALE THREAD
- PBR – PBR COUPLER X BSPP FEMALE THREAD

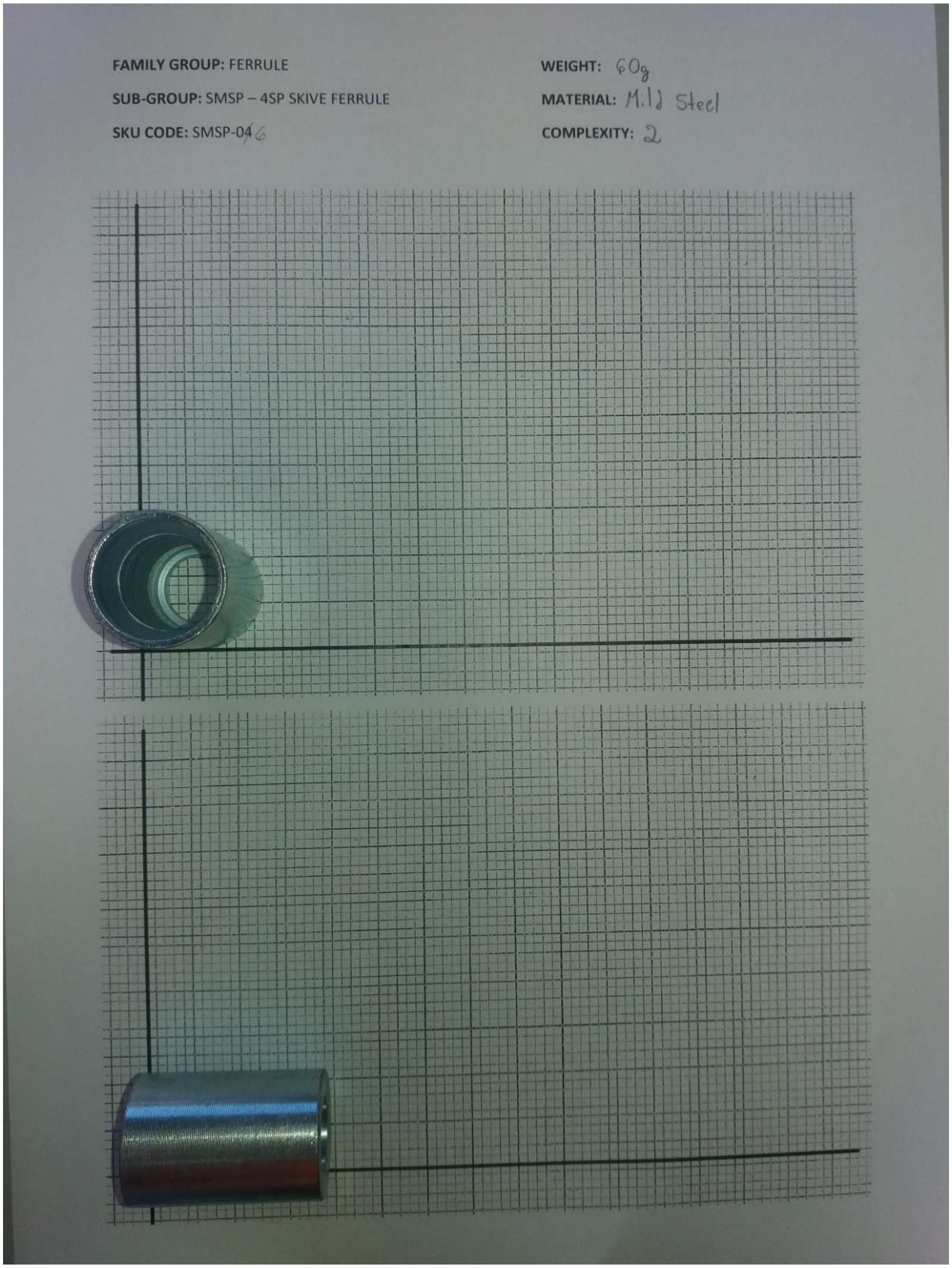
APPENDIX 2 – Primary Data Collection: SN1-03



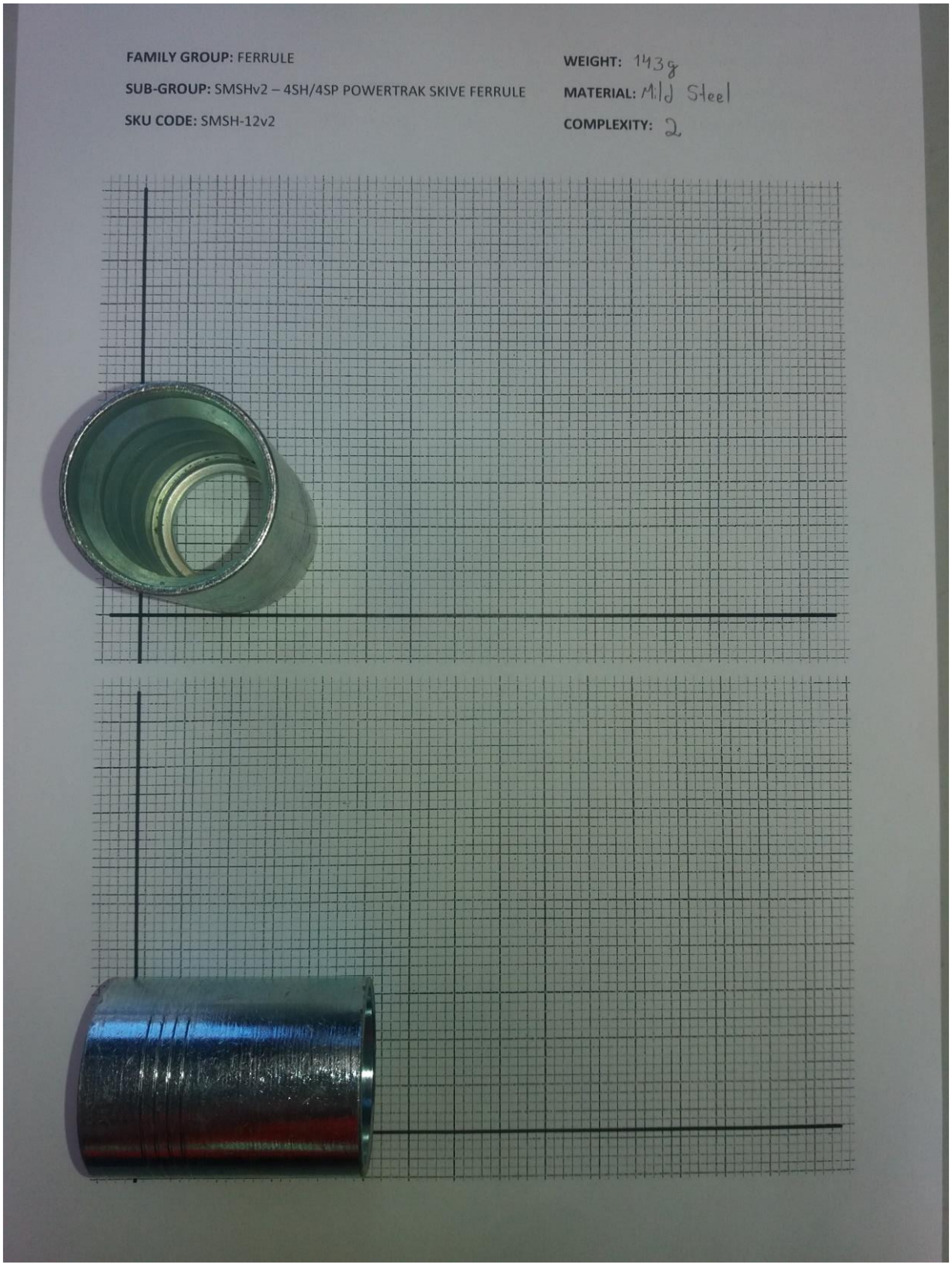
APPENDIX 3 – Primary Data Collection: SN2-04



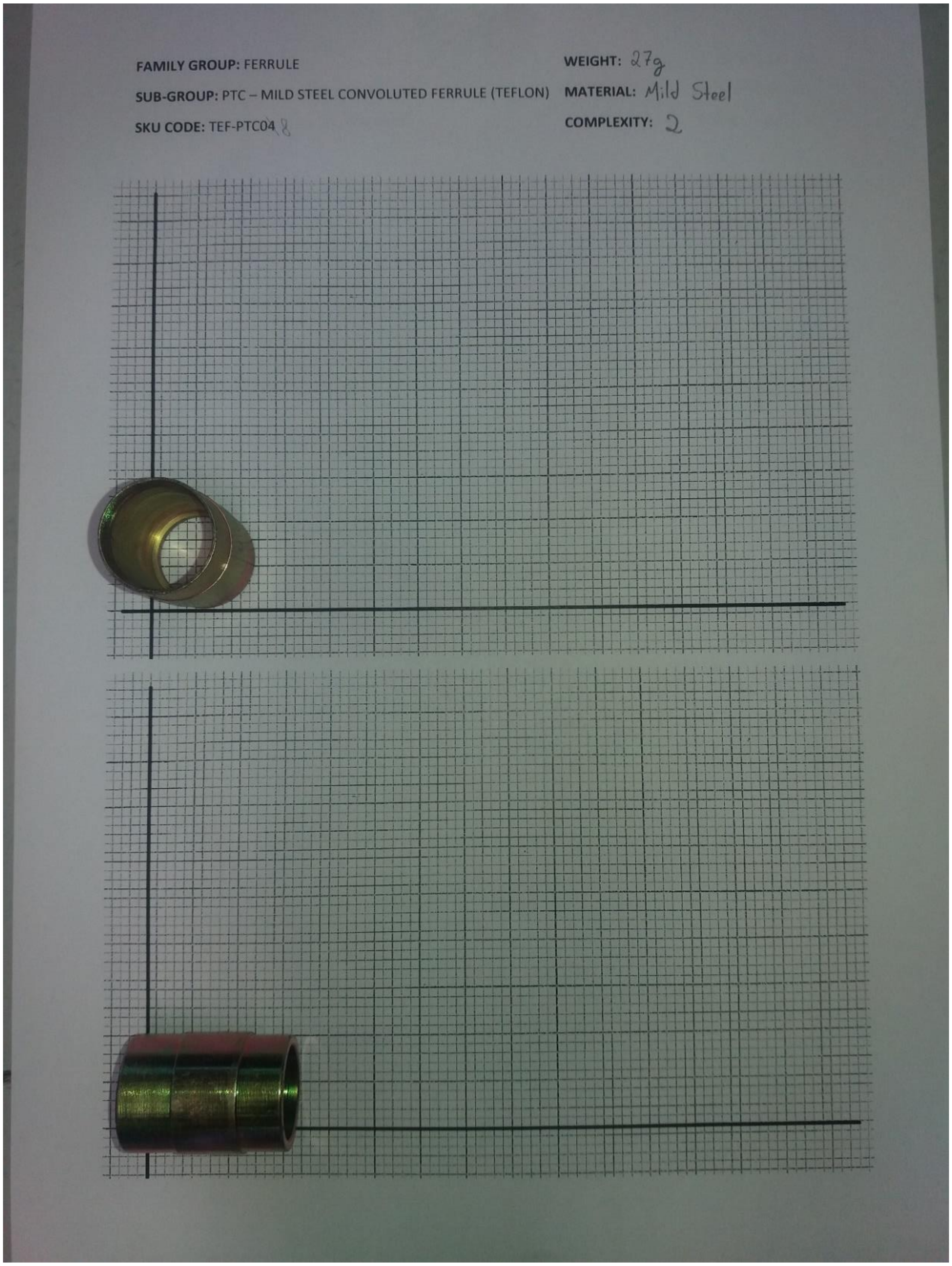
APPENDIX 4 – Primary Data Collection: SMSP-06



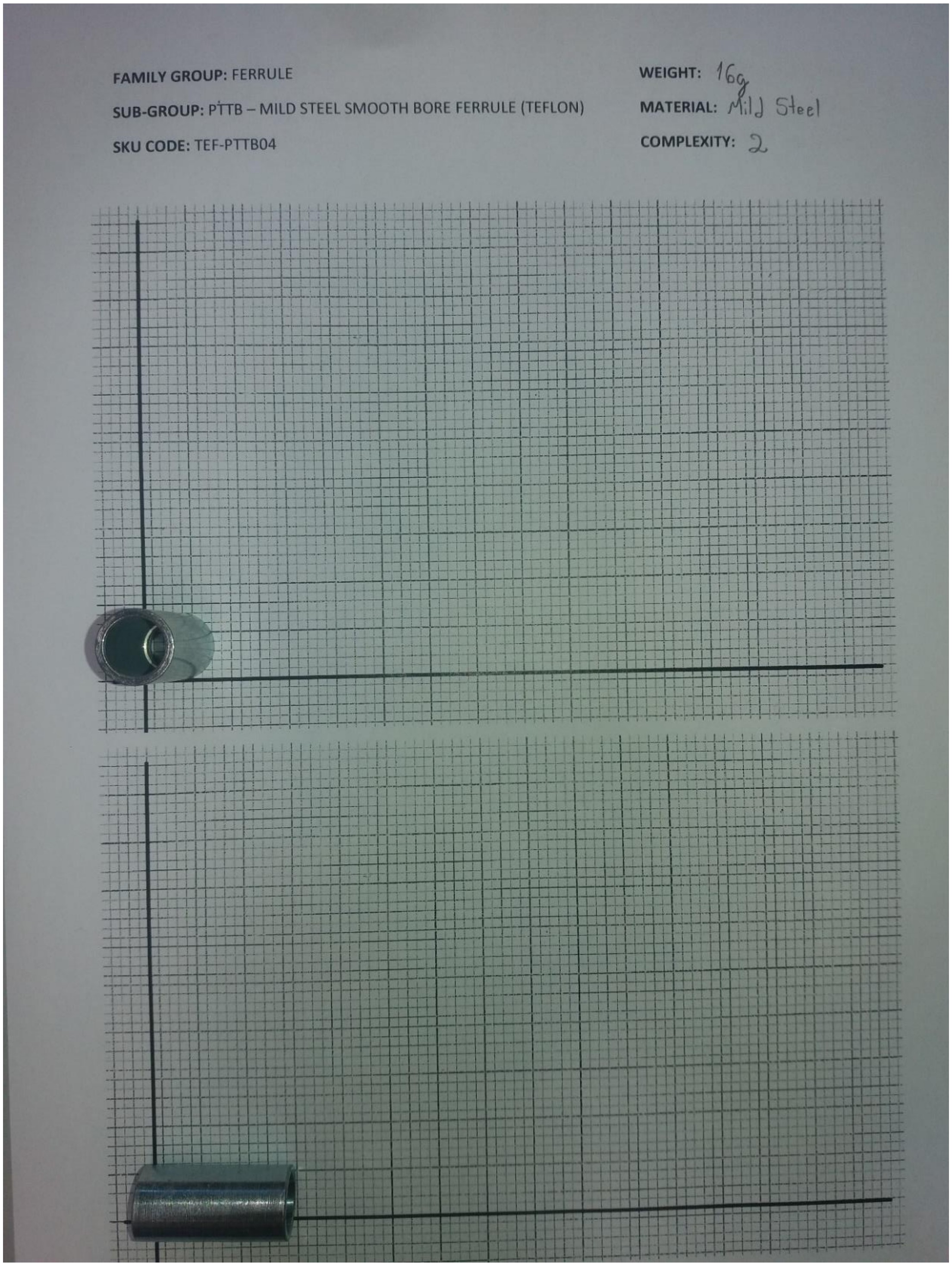
APPENDIX 5 – Primary Data Collection: SMSH-12v2



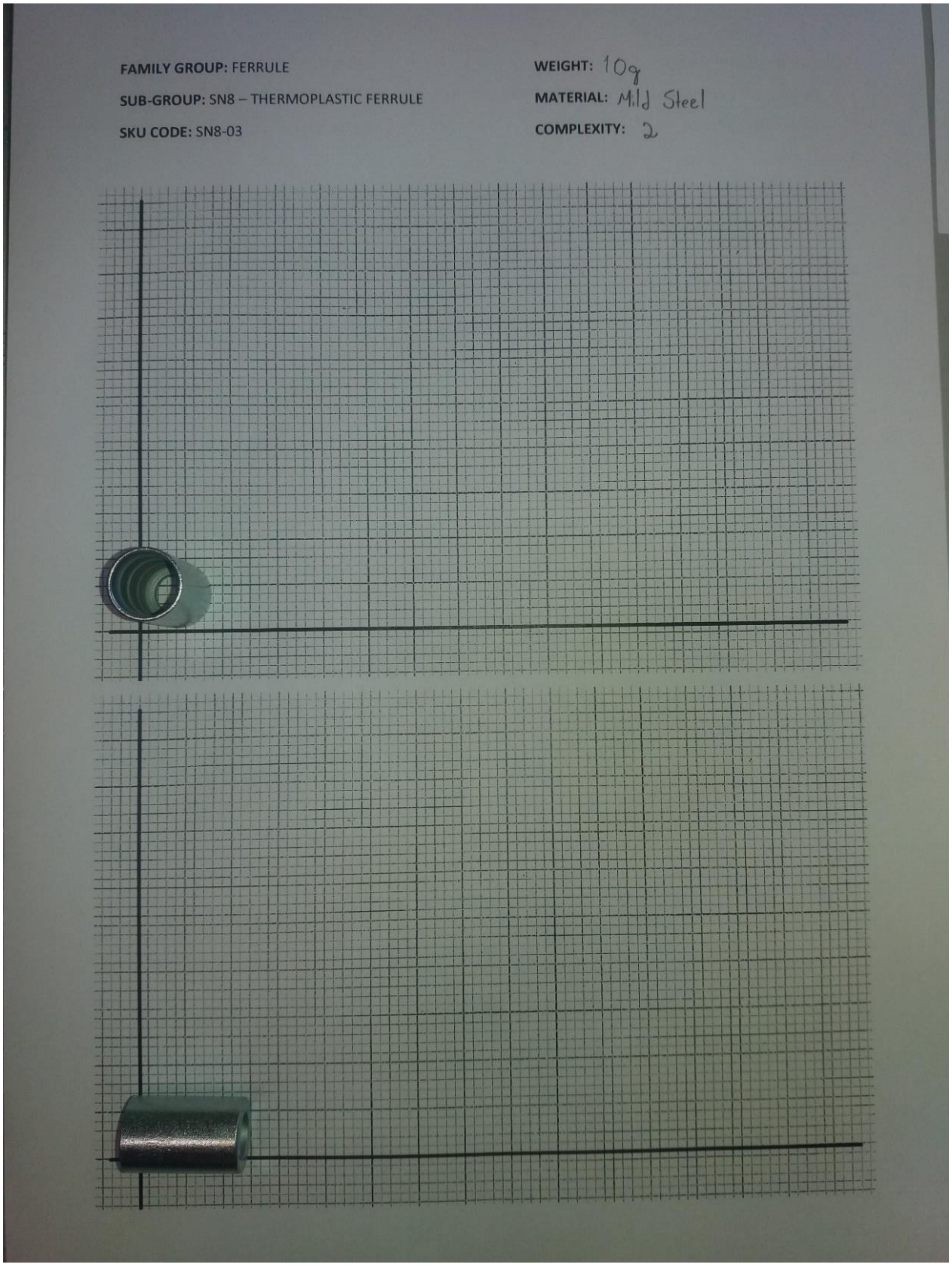
APPENDIX 6 – Primary Data Collection: TEF-PTC08



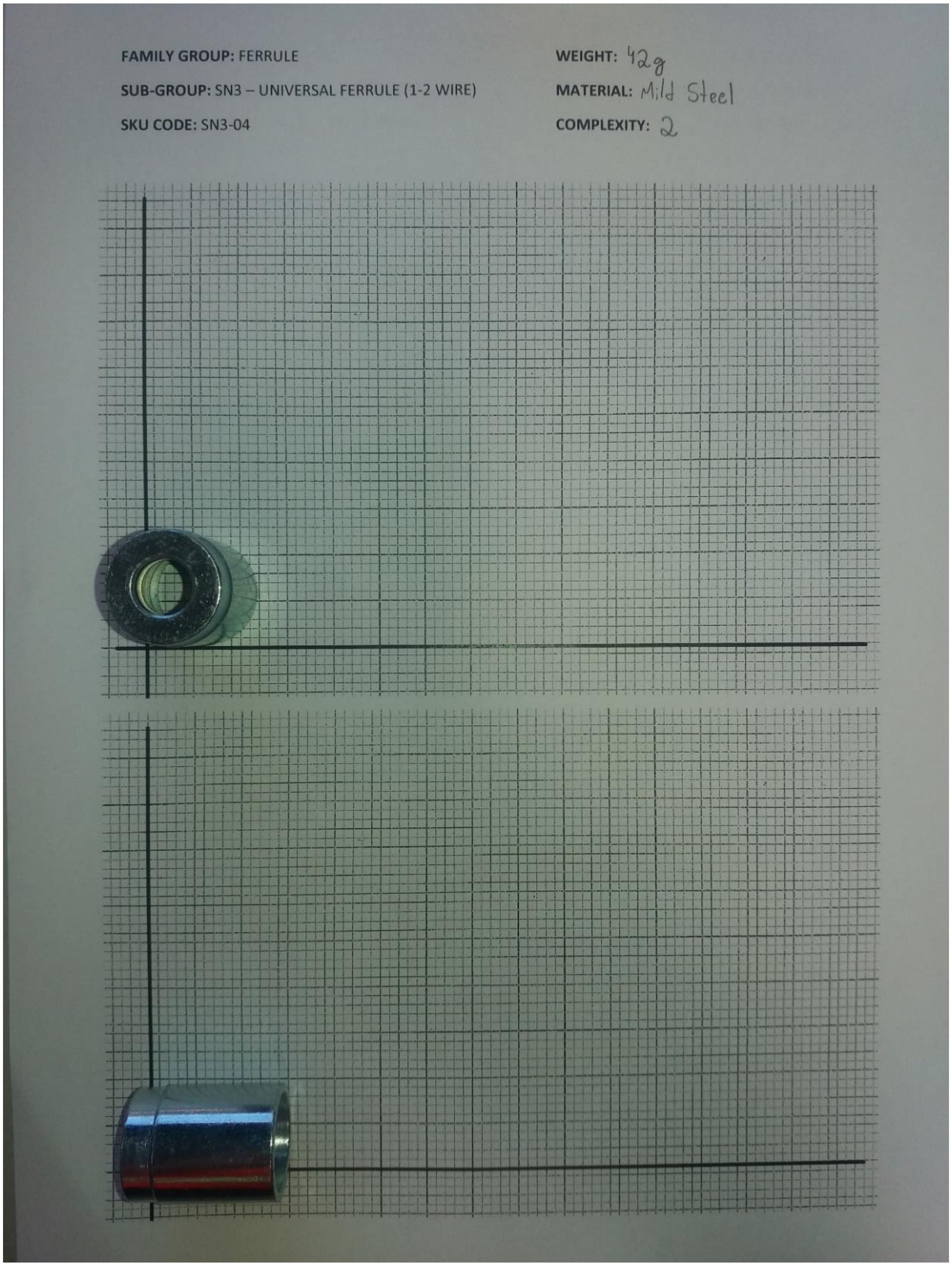
APPENDIX 7 – Primary Data Collection: TEF-PTTB04



APPENDIX 8 – Primary Data Collection: SN8-03



APPENDIX 9 – Primary Data Collection: SN3-04



APPENDIX 10 – I_{CC} Calculation (VBA Programming)

```
Sub Inventory()

Worksheets("Complexity Groups").Activate
For j = 3 To 253
adjusted_stock_avg = Range("U" & j).Value
monthly_demand = Range("X" & j).Value
investment_rate = 0.008
period_months = Range("AC" & j).Value
manufacturing_cost = Range("AH" & j).Value
Total = adjusted_stock_avg
ICC_cum = 0
For i = period_months To 0 Step -1
        ICC_cum = ICC_cum + Total * (investment_rate)
                adjusted_stock_avg = adjusted_stock_avg - (monthly_demand *
                manufacturing_cost)
        Total = ICC_cum + adjusted_stock_avg
Next
ICC = ICC_cum / period_months
Range("AI" & j) = ICC
Next
End Sub

' Where:
'  "Complexity Groups" worksheet is the spreadsheet containing the data of this research;
'  Lines 3 to 253 correspond to the 251 items analysed in this research;
'  adjusted_stock_avg is the average stock level yielded after the normalisation;
'  monthly_demand is the annual demand of the item considered divided by 12;
'  investment_rate is the missed opportunity of investing the money (starting point = 0.8% per
month);
'  period_months (column AC) corresponds to the time span that the item considered will be
carried for before it is thoroughly sold;
'  manufacturing_cost (column AH) is the manufacturing cost UTM;
'  Total is an auxiliary variable;
'  ICC_cum is the cummulative inventory carrying cost;
'  ICC is the inventory carrying cost of the item;
```

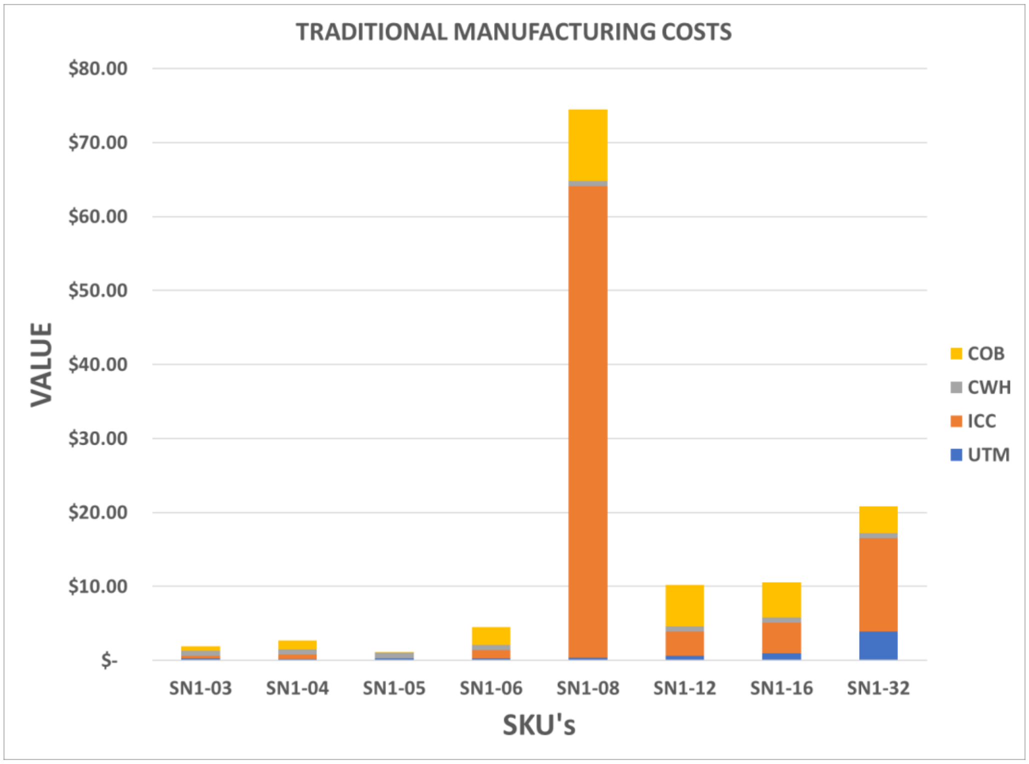
APPENDIX 11 – Quantification of TM Costs for SKUs of CG2

Item Number	U_{TM}	I_{CC}	C_{WH}	C_{OB}	Subtotal
SN1-03	$ 0.27	$ 0.32	$ 0.70	$ 0.62	**$ 1.92**
SN1-04	$ 0.22	$ 0.54	$ 0.70	$ 1.19	**$ 2.66**
SN1-05	$ 0.27	$ 0.05	$ 0.70	$ 0.10	**$ 1.12**
SN1-06	$ 0.26	$ 1.14	$ 0.70	$ 2.42	**$ 4.52**
SN1-08	$ 0.38	$ 63.71	$ 0.70	$ 9.67	**$ 74.46**
SN1-12	$ 0.62	$ 3.29	$ 0.70	$ 5.59	**$ 10.20**
SN1-16	$ 0.96	$ 4.15	$ 0.70	$ 4.71	**$ 10.53**
SN1-32	$ 3.92	$ 12.63	$ 0.70	$ 3.60	**$ 20.85**
SN2-04	$ 0.23	$ 3.33	$ 0.70	$ 7.12	**$ 11.38**
SN2-05	$ 0.31	$ 0.17	$ 0.70	$ 0.38	**$ 1.56**
SN2-06	$ 0.25	$ 3.49	$ 0.70	$ 7.71	**$ 12.15**
SN2-08	$ 0.32	$ 3.58	$ 0.70	$ 7.17	**$ 11.77**
SN2-10	$ 0.51	$ 0.18	$ 0.70	$ 0.39	**$ 1.79**
SN2-12	$ 0.68	$ 1.74	$ 0.70	$ 3.58	**$ 6.70**
SN2-16	$ 1.00	$ 0.78	$ 0.70	$ 1.72	**$ 4.20**
SN2-20	$ 2.17	$ 0.90	$ 0.70	$ 1.91	**$ 5.68**
SN2-32	$ 3.89	$ 12.10	$ 0.70	$ 5.02	**$ 21.71**
SN3-04	$ 0.47	$ 2.79	$ 0.70	$ 6.01	**$ 9.97**
SN3-05	$ 0.26	$ 0.27	$ 0.70	$ 0.58	**$ 1.82**
SN3-06	$ 0.58	$ 5.38	$ 0.70	$ 11.33	**$ 17.99**
SN3-08	$ 0.71	$ 6.14	$ 0.70	$ 13.05	**$ 20.60**
SN3-10	$ 0.66	$ 0.20	$ 0.70	$ 0.39	**$ 1.96**
SN3-12	$ 0.89	$ 4.07	$ 0.70	$ 8.24	**$ 13.91**
SN3-16	$ 1.16	$ 1.42	$ 0.70	$ 3.01	**$ 6.28**
SN3-20	$ 2.26	$ 1.04	$ 0.70	$ 2.08	**$ 6.07**
SN3-24	$ 2.89	$ 3.71	$ 0.70	$ 1.50	**$ 8.80**
SN3-32	$ 20.46	$ 2.47	$ 0.70	$ 3.48	**$ 27.11**
SMSH-10	$ 0.75	$ 0.23	$ 0.70	$ 0.49	**$ 2.17**
SMSH-12	$ 1.00	$ 1.12	$ 0.70	$ 2.42	**$ 5.24**
SMSH-16	$ 1.52	$ 1.15	$ 0.70	$ 2.51	**$ 5.89**
SMSH-20	$ 2.77	$ 0.86	$ 0.70	$ 1.91	**$ 6.24**
SMSH-24	$ 9.72	$ 0.55	$ 0.70	$ 1.17	**$ 12.14**
SMSH-32	$ 8.24	$ 1.19	$ 0.70	$ 1.15	**$ 11.28**
SMSP-06	$ 6.15	$ 1.82	$ 0.70	$ 3.63	**$ 12.30**
SMSP-08	$ 0.56	$ 0.56	$ 0.70	$ 1.25	**$ 3.07**
SMSP-10	$ 0.72	$ 0.21	$ 0.70	$ 0.44	**$ 2.08**
SMSP-12	$ 0.87	$ 0.30	$ 0.70	$ 0.61	**$ 2.48**
SMSP-16	$ 1.06	$ 0.30	$ 0.70	$ 0.64	**$ 2.71**
SMSP-20	$ 4.33	$ 2.35	$ 0.70	$ 2.03	**$ 9.42**

SMSP-24	$ 8.47	$ 0.67	$ 0.70	$ 0.85	**$ 10.69**
SMSP-32	$ 15.12	$ 1.19	$ 0.70	$ 1.51	**$ 18.52**
SMSR13-12	$ 0.99	$ 11.75	$ 0.70	$ 0.53	**$ 13.97**
SMSR13-16	$ 1.59	$ 12.36	$ 0.70	$ 1.37	**$ 16.03**
SMSR13-20	$ 9.09	$ 5.37	$ 0.70	$ 3.55	**$ 18.71**
SMSR13-24	$ 14.35	$ 1.01	$ 0.70	$ 1.87	**$ 17.93**
SMSR13-32	$ 22.73	$ 12.96	$ 0.70	$ 5.68	**$ 42.07**
SMSH-20v2	$ 9.84	$ 3.51	$ 0.70	$ 2.07	**$ 16.12**
SMSH-24v2	$ 40.19	$ 0.85	$ 0.70	$ 1.61	**$ 43.35**
SN8-03	$ 0.20	$ 0.21	$ 0.70	$ 0.46	**$ 1.57**
SN8-04	$ 0.23	$ 0.29	$ 0.70	$ 0.60	**$ 1.83**
SN8-06	$ 0.29	$ 0.18	$ 0.70	$ 0.40	**$ 1.57**
SN8-08	$ 0.36	$ 4.96	$ 0.70	$ 4.86	**$ 10.89**
SN8-12	$ 5.41	$ 290.79	$ 0.70	$ 3.73	**$ 300.64**
SN9-08	$ 2.23	$ 0.06	$ 0.70	$ 0.11	**$ 3.11**
SN9-12	$ 3.98	$ 0.31	$ 0.70	$ 0.40	**$ 5.40**
SN9-16	$ 5.31	$ 0.23	$ 0.70	$ 0.48	**$ 6.72**
TEF-PTCS08	$ 4.33	$ 0.34	$ 0.70	$ 0.69	**$ 6.07**
TEF-PTCS12	$ 9.16	$ 42.19	$ 0.70	$ 6.96	**$ 59.01**
TEF-PTCS20	$ 19.98	$ 6.22	$ 0.70	$ 4.00	**$ 30.91**
TEF-PTCS24	$ 48.16	$ 3.18	$ 0.70	$ 4.33	**$ 56.37**
TEF-PTTB06	$ 0.30	$ 0.19	$ 0.70	$ 0.29	**$ 1.48**
TEF-PTTB08	$ 0.42	$ 0.79	$ 0.70	$ 0.66	**$ 2.57**
TEF-PTTB12	$ 5.21	$ 0.69	$ 0.70	$ 0.94	**$ 7.54**

Note. Costs are in NZD.

APPENDIX 12 – Sub-Group SN1: Traditional Manufacturing Costs (CG2)



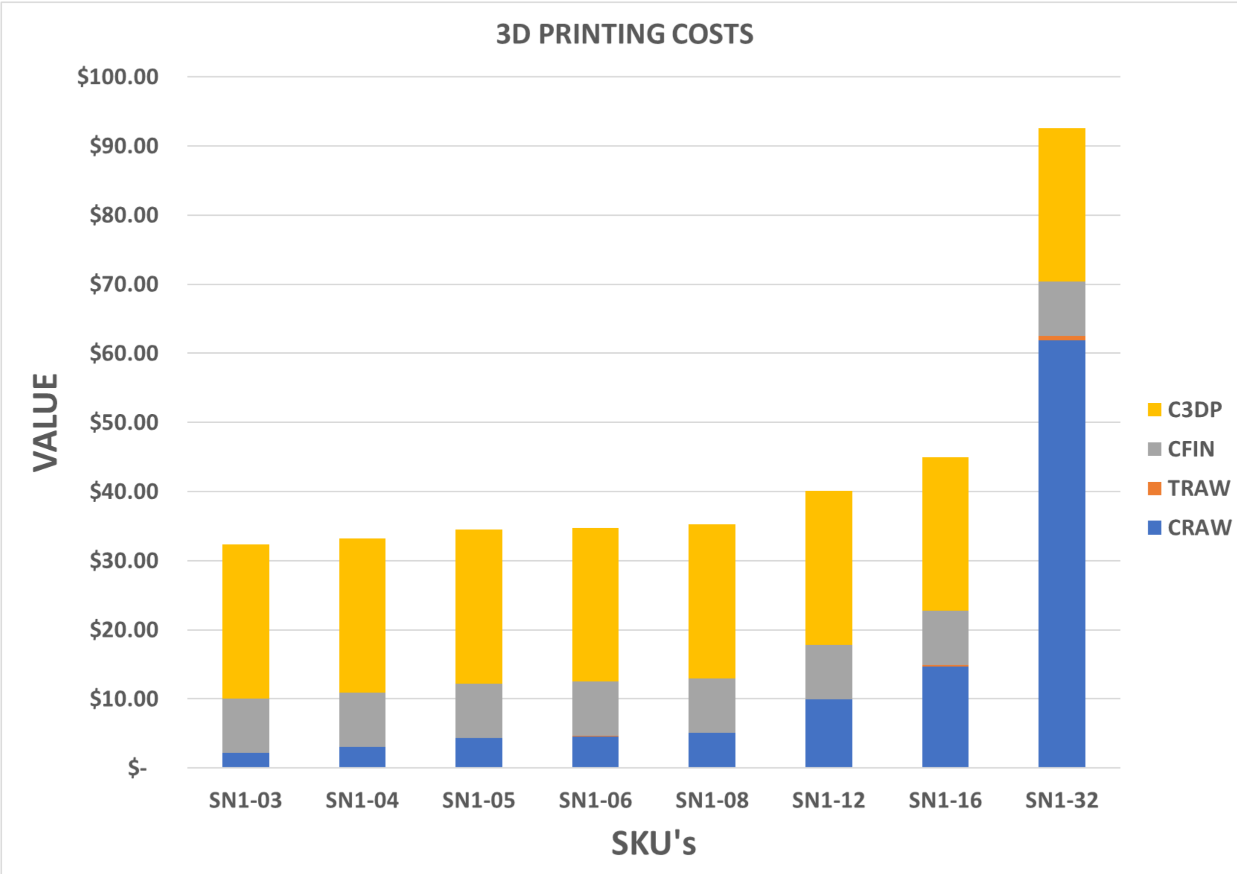
APPENDIX 13 – Quantification of 3DP Costs for SKU's of Complexity Group 2

Item Number	C_{RAW}	T_{RAW}	C_{FIN}	C_{3DP}	Subtotal
SN1-03	$ 2.16	$ 0.02	$ 7.88	$ 22.28	**$ 32.33**
SN1-04	$ 3.04	$ 0.03	$ 7.88	$ 22.28	**$ 33.23**
SN1-05	$ 4.31	$ 0.04	$ 7.88	$ 22.28	**$ 34.51**
SN1-06	$ 4.56	$ 0.04	$ 7.88	$ 22.28	**$ 34.76**
SN1-08	$ 5.07	$ 0.05	$ 7.88	$ 22.28	**$ 35.27**
SN1-12	$ 9.89	$ 0.09	$ 7.88	$ 22.28	**$ 40.14**
SN1-16	$ 14.71	$ 0.14	$ 7.88	$ 22.28	**$ 45.00**
SN1-32	$ 61.88	$ 0.59	$ 7.88	$ 22.28	**$ 92.62**
SN2-04	$ 3.30	$ 0.03	$ 7.88	$ 22.28	**$ 33.48**
SN2-05	$ 4.44	$ 0.04	$ 7.88	$ 22.28	**$ 34.63**
SN2-06	$ 4.82	$ 0.05	$ 7.88	$ 22.28	**$ 35.02**
SN2-08	$ 5.07	$ 0.05	$ 7.88	$ 22.28	**$ 35.27**
SN2-10	$ 9.38	$ 0.09	$ 7.88	$ 22.28	**$ 39.63**
SN2-12	$ 13.44	$ 0.13	$ 7.88	$ 22.28	**$ 43.72**
SN2-16	$ 20.03	$ 0.19	$ 7.88	$ 22.28	**$ 50.38**
SN2-20	$ 27.64	$ 0.26	$ 7.88	$ 22.28	**$ 58.06**
SN2-32	$ 60.10	$ 0.57	$ 7.88	$ 22.28	**$ 90.83**
SN3-04	$ 5.58	$ 0.05	$ 7.88	$ 22.28	**$ 35.79**
SN3-05	$ 5.33	$ 0.05	$ 7.88	$ 22.28	**$ 35.53**
SN3-06	$ 5.83	$ 0.06	$ 7.88	$ 22.28	**$ 36.04**
SN3-08	$ 5.83	$ 0.06	$ 7.88	$ 22.28	**$ 36.04**
SN3-10	$ 8.12	$ 0.08	$ 7.88	$ 22.28	**$ 38.35**
SN3-12	$ 10.27	$ 0.10	$ 7.88	$ 22.28	**$ 40.52**
SN3-16	$ 19.65	$ 0.19	$ 7.88	$ 22.28	**$ 49.99**
SN3-20	$ 35.50	$ 0.34	$ 7.88	$ 22.28	**$ 65.99**
SN3-24	$ 55.16	$ 0.52	$ 7.88	$ 22.28	**$ 85.83**
SN3-32	$ 59.98	$ 0.57	$ 7.88	$ 22.28	**$ 90.70**
SMSH-10	$ 13.44	$ 0.13	$ 7.88	$ 22.28	**$ 43.72**
SMSH-12	$ 18.26	$ 0.17	$ 7.88	$ 22.28	**$ 48.59**
SMSH-16	$ 30.94	$ 0.29	$ 7.88	$ 22.28	**$ 61.39**
SMSH-20	$ 45.39	$ 0.43	$ 7.88	$ 22.28	**$ 75.98**
SMSH-24	$ 54.52	$ 0.52	$ 7.88	$ 22.28	**$ 85.19**
SMSH-32	$ 108.03	$ 1.02	$ 7.88	$ 22.28	**$ 139.21**
SMSP-06	$ 6.59	$ 0.06	$ 7.88	$ 22.28	**$ 36.81**
SMSP-08	$ 9.13	$ 0.09	$ 7.88	$ 22.28	**$ 39.37**
SMSP-10	$ 12.17	$ 0.12	$ 7.88	$ 22.28	**$ 42.44**
SMSP-12	$ 17.75	$ 0.17	$ 7.88	$ 22.28	**$ 48.07**

SMSP-16	$ 24.09	$ 0.23	$ 7.88	$ 22.28	**$ 54.47**
SMSP-20	$ 46.16	$ 0.44	$ 7.88	$ 22.28	**$ 76.75**
SMSP-24	$ 47.42	$ 0.45	$ 7.88	$ 22.28	**$ 78.03**
SMSP-32	$ 69.49	$ 0.66	$ 7.88	$ 22.28	**$ 100.30**
SMSR13-12	$ 30.31	$ 0.29	$ 7.88	$ 22.28	**$ 60.75**
SMSR13-16	$ 37.28	$ 0.35	$ 7.88	$ 22.28	**$ 67.79**
SMSR13-20	$ 62.39	$ 0.59	$ 7.88	$ 22.28	**$ 93.13**
SMSR13-24	$ 79.63	$ 0.75	$ 7.88	$ 22.28	**$ 110.54**
SMSR13-32	$ 173.46	$ 1.64	$ 7.88	$ 22.28	**$ 205.26**
SMSH-20v2	$ 41.84	$ 0.40	$ 7.88	$ 22.28	**$ 72.39**
SMSH-24v2	$ 62.64	$ 0.59	$ 7.88	$ 22.28	**$ 93.39**
SN8-03	$ 1.27	$ 0.01	$ 7.88	$ 22.28	**$ 31.43**
SN8-04	$ 2.03	$ 0.02	$ 7.88	$ 22.28	**$ 32.20**
SN8-06	$ 3.30	$ 0.03	$ 7.88	$ 22.28	**$ 33.48**
SN8-08	$ 5.58	$ 0.05	$ 7.88	$ 22.28	**$ 35.79**
SN8-12	$ 10.14	$ 0.10	$ 7.88	$ 22.28	**$ 40.39**
SN9-08	$ 8.75	$ 0.08	$ 7.88	$ 22.28	**$ 38.99**
SN9-12	$ 15.09	$ 0.14	$ 7.88	$ 22.28	**$ 45.39**
SN9-16	$ 24.09	$ 0.23	$ 7.88	$ 22.28	**$ 54.47**
TEF-PTCS08	$ 4.31	$ 0.04	$ 7.88	$ 22.28	**$ 34.51**
TEF-PTCS12	$ 9.89	$ 0.09	$ 7.88	$ 22.28	**$ 40.14**
TEF-PTCS20	$ 22.44	$ 0.21	$ 7.88	$ 22.28	**$ 52.81**
TEF-PTCS24	$ 25.23	$ 0.24	$ 7.88	$ 22.28	**$ 55.63**
TEF-PTTB06	$ 3.17	$ 0.03	$ 7.88	$ 22.28	**$ 33.35**
TEF-PTTB08	$ 5.20	$ 0.05	$ 7.88	$ 22.28	**$ 35.40**
TEF-PTTB12	$ 9.76	$ 0.09	$ 7.88	$ 22.28	**$ 40.01**

Note. Costs are in NZD.

APPENDIX 14 – Sub-Group SN1: 3D Printing Costs (CG2)



APPENDIX 15 – Quantification of TM Costs for SKUs of CG3

Item Number	U_{TM}	I_{CC}	C_{WH}	C_{OB}	Subtotal
AAA020202	$ 4.02	$ 2.96	$ 0.70	$ 1.09	**$ 8.77**
AAA060606	$ 1.37	$ 444,151.28	$ 0.70	$ 2.18	**$ 444,155.54**
AAA080808	$ 1.82	$ 171.18	$ 0.70	$ 2.47	**$ 176.17**
AAA121212	$ 6.68	$ 679.53	$ 0.70	$ 5.08	**$ 691.99**
AAA161616	$ 12.24	$ 865.08	$ 0.70	$ 8.81	**$ 886.83**
AAC060606	$ 1.75	$ 4.32	$ 0.70	$ 1.48	**$ 8.26**
AAC080808	$ 2.42	$ 88.16	$ 0.70	$ 1.57	**$ 92.85**
AAC121212	$ 4.43	$ 0.36	$ 0.70	$ 0.58	**$ 6.07**
AAC161616	$ 6.39	$ 0.59	$ 0.70	$ 0.70	**$ 8.39**
ACA040404	$ 1.32	$ 0.78	$ 0.70	$ 1.24	**$ 4.04**
ACA060606	$ 1.59	$ 0.59	$ 0.70	$ 1.25	**$ 4.14**
ACA080804	$ 2.74	$ 1.33	$ 0.70	$ 1.78	**$ 6.56**
ACA080808	$ 2.25	$ 0.71	$ 0.70	$ 1.49	**$ 5.15**
ACA121212	$ 4.46	$ 0.77	$ 0.70	$ 1.70	**$ 7.63**
ACA161604	$ 13.44	$ 0.49	$ 0.70	$ 0.81	**$ 15.44**
ACA161616	$ 7.03	$ 1.19	$ 0.70	$ 1.90	**$ 10.83**
BBB040404	$ 4.75	$ 0.42	$ 0.70	$ 0.66	**$ 6.54**
BBB060606	$ 2.25	$ 0.42	$ 0.70	$ 0.90	**$ 4.28**
BBB080808	$ 2.06	$ 0.33	$ 0.70	$ 0.70	**$ 3.80**
BBB121212	$ 8.01	$ 0.34	$ 0.70	$ 0.64	**$ 9.70**
BBB161616	$ 6.61	$ 0.19	$ 0.70	$ 0.33	**$ 7.83**
BBC040404	$ 6.35	$ 0.14	$ 0.70	$ 0.32	**$ 7.50**
BBC060606	$ 3.87	$ 0.14	$ 0.70	$ 0.27	**$ 4.99**
BBC080808	$ 2.09	$ 0.17	$ 0.70	$ 0.38	**$ 3.35**
BBC121212	$ 7.84	$ 1.29	$ 0.70	$ 1.18	**$ 11.01**
BBC161616	$ 26.74	$ 0.12	$ 0.70	$ 0.27	**$ 27.83**
BCB040404	$ 9.89	$ 4.97	$ 0.70	$ 7.91	**$ 23.46**
BCB060606	$ 1.48	$ 0.10	$ 0.70	$ 0.21	**$ 2.49**
BCB080808	$ 2.31	$ 4.00	$ 0.70	$ 3.53	**$ 10.54**
BCC040404	$ 1.51	$ 0.07	$ 0.70	$ 0.11	**$ 2.38**
BCC080808	$ 3.51	$ 0.06	$ 0.70	$ 0.14	**$ 4.41**
CCB040404	$ 5.79	$ 0.53	$ 0.70	$ 0.64	**$ 7.67**
CCB080808	$ 3.48	$ 0.07	$ 0.70	$ 0.14	**$ 4.39**
CCB101010	$ 12.44	$ 0.19	$ 0.70	$ 0.37	**$ 13.70**
CCC020202	$ 5.55	$ 1.20	$ 0.70	$ 0.94	**$ 8.40**
CCC040404	$ 8.13	$ 0.92	$ 0.70	$ 1.87	**$ 11.62**
CCC060606	$ 2.71	$ 0.24	$ 0.70	$ 0.49	**$ 4.14**
CCC080808	$ 3.93	$ 0.47	$ 0.70	$ 0.94	**$ 6.04**

CCC121212	$	8.65	$	0.92	$	0.70	$	1.99	**$**	**12.26**
CCC161616	$	7.90	$	1.00	$	0.70	$	1.03	**$**	**10.63**
EEE020202	$	3.94	$	0.07	$	0.70	$	0.16	**$**	**4.86**
EEE040404	$	2.88	$	0.63	$	0.70	$	1.33	**$**	**5.54**
EEE080808	$	3.48	$	16.39	$	0.70	$	5.82	**$**	**26.39**
EEE161616	$	7.85	$	0.33	$	0.70	$	0.63	**$**	**9.50**

Note. Costs are in NZD.

APPENDIX 16 – Quantification of 3DP Costs for SKUs of CG3

Item Number	C_{RAW}	T_{RAW}	C_{FIN}	C_{3DP}	Subtotal
AAA020202	$ 3.93	$ 0.03	$ 7.88	$ 25.11	**$ 36.95**
AAA060606	$ 12.80	$ 0.12	$ 7.88	$ 25.11	**$ 45.91**
AAA080808	$ 21.81	$ 0.20	$ 7.88	$ 25.11	**$ 55.00**
AAA121212	$ 39.68	$ 0.37	$ 7.88	$ 25.11	**$ 73.04**
AAA161616	$ 63.40	$ 0.60	$ 7.88	$ 25.11	**$ 96.98**
AAC060606	$ 19.27	$ 0.18	$ 7.88	$ 25.11	**$ 52.44**
AAC080808	$ 25.36	$ 0.24	$ 7.88	$ 25.11	**$ 58.58**
AAC121212	$ 42.60	$ 0.40	$ 7.88	$ 25.11	**$ 75.99**
AAC161616	$ 68.09	$ 0.64	$ 7.88	$ 25.11	**$ 101.72**
ACA040404	$ 8.87	$ 0.08	$ 7.88	$ 25.11	**$ 41.94**
ACA060606	$ 13.94	$ 0.13	$ 7.88	$ 25.11	**$ 47.06**
ACA080804	$ 22.95	$ 0.21	$ 7.88	$ 25.11	**$ 56.15**
ACA080808	$ 26.37	$ 0.25	$ 7.88	$ 25.11	**$ 59.60**
ACA121212	$ 44.88	$ 0.42	$ 7.88	$ 25.11	**$ 78.29**
ACA161604	$ 70.62	$ 0.66	$ 7.88	$ 25.11	**$ 104.28**
ACA161616	$ 67.33	$ 0.63	$ 7.88	$ 25.11	**$ 100.95**
BBB040404	$ 8.74	$ 0.08	$ 7.88	$ 25.11	**$ 41.81**
BBB060606	$ 14.96	$ 0.14	$ 7.88	$ 25.11	**$ 48.08**
BBB080808	$ 20.66	$ 0.19	$ 7.88	$ 25.11	**$ 53.84**
BBB121212	$ 41.33	$ 0.39	$ 7.88	$ 25.11	**$ 74.71**
BBB161616	$ 71.38	$ 0.67	$ 7.88	$ 25.11	**$ 105.04**
BBC040404	$ 10.39	$ 0.09	$ 7.88	$ 25.11	**$ 43.48**
BBC060606	$ 16.23	$ 0.15	$ 7.88	$ 25.11	**$ 49.36**
BBC080808	$ 24.21	$ 0.22	$ 7.88	$ 25.11	**$ 57.43**
BBC121212	$ 42.73	$ 0.40	$ 7.88	$ 25.11	**$ 76.12**
BBC161616	$ 70.62	$ 0.66	$ 7.88	$ 25.11	**$ 104.28**
BCB040404	$ 8.87	$ 0.08	$ 7.88	$ 25.11	**$ 41.94**
BCB060606	$ 12.68	$ 0.12	$ 7.88	$ 25.11	**$ 45.78**
BCB080808	$ 23.20	$ 0.22	$ 7.88	$ 25.11	**$ 56.40**
BCC040404	$ 10.65	$ 0.10	$ 7.88	$ 25.11	**$ 43.73**
BCC080808	$ 27.00	$ 0.25	$ 7.88	$ 25.11	**$ 60.24**
CCB040404	$ 10.65	$ 0.10	$ 7.88	$ 25.11	**$ 43.73**
CCB080808	$ 28.78	$ 0.27	$ 7.88	$ 25.11	**$ 62.04**
CCB101010	$ 29.41	$ 0.27	$ 7.88	$ 25.11	**$ 62.68**
CCC020202	$ 8.62	$ 0.08	$ 7.88	$ 25.11	**$ 41.68**
CCC040404	$ 12.68	$ 0.12	$ 7.88	$ 25.11	**$ 45.78**
CCC060606	$ 19.27	$ 0.18	$ 7.88	$ 25.11	**$ 52.44**
CCC080808	$ 26.24	$ 0.24	$ 7.88	$ 25.11	**$ 59.48**

CCC121212	$ 51.10	$ 0.48	$ 7.88	$ 25.11	**$ 84.56**
CCC161616	$ 90.78	$ 0.85	$ 7.88	$ 25.11	**$ 124.63**
EEE020202	$ 5.70	$ 0.05	$ 7.88	$ 25.11	**$ 38.74**
EEE040404	$ 10.65	$ 0.10	$ 7.88	$ 25.11	**$ 43.73**
EEE080808	$ 35.75	$ 0.33	$ 7.88	$ 25.11	**$ 69.08**
EEE161616	$ 80.01	$ 0.75	$ 7.88	$ 25.11	**$ 113.75**

Note. Costs are in NZD.

APPENDIX 17 – Quantification of TM Costs for SKUs of CG4

Item Number	U_{TM}	I_{CC}	C_{WH}	C_{OB}	Subtotal
K001-0204	$ 1.36	$ 0.08	$ 0.70	$ 0.14	**$ 2.28**
K001-0404	$ 1.23	$ 2.13	$ 0.70	$ 3.17	**$ 7.24**
K001-0406	$ 1.56	$ 0.17	$ 0.70	$ 0.33	**$ 2.76**
K001-0604	$ 1.37	$ 0.32	$ 0.70	$ 0.61	**$ 3.00**
K001-0606	$ 1.42	$ 2.79	$ 0.70	$ 5.84	**$ 10.76**
K001-0608	$ 2.76	$ 0.22	$ 0.70	$ 0.44	**$ 4.12**
K001-0806	$ 1.77	$ 0.42	$ 0.70	$ 0.81	**$ 3.71**
K001-0808	$ 1.79	$ 3.99	$ 0.70	$ 8.01	**$ 14.50**
K001-1208	$ 3.07	$ 0.35	$ 0.70	$ 0.71	**$ 4.83**
K001-1212	$ 3.25	$ 1.11	$ 0.70	$ 2.18	**$ 7.25**
K001-1616	$ 4.93	$ 2.61	$ 0.70	$ 5.47	**$ 13.71**
K012-0404	$ 1.35	$ 0.24	$ 0.70	$ 0.51	**$ 2.81**
K012-0606	$ 1.39	$ 0.51	$ 0.70	$ 1.08	**$ 3.68**
K012-0806	$ 1.53	$ 0.80	$ 0.70	$ 1.76	**$ 4.79**
K012-0808	$ 1.80	$ 1.14	$ 0.70	$ 2.44	**$ 6.08**
K015-0404	$ 1.07	$ 0.77	$ 0.70	$ 1.73	**$ 4.27**
K015-0406	$ 1.30	$ 0.15	$ 0.70	$ 0.32	**$ 2.47**
K015-0604	$ 1.21	$ 0.25	$ 0.70	$ 0.57	**$ 2.73**
K015-0606	$ 1.25	$ 1.33	$ 0.70	$ 2.90	**$ 6.19**
K015-0608	$ 1.59	$ 0.20	$ 0.70	$ 0.40	**$ 2.88**
K015-0806	$ 1.46	$ 0.52	$ 0.70	$ 0.95	**$ 3.64**
K015-0808	$ 1.65	$ 1.15	$ 0.70	$ 2.08	**$ 5.59**
K015-1208	$ 3.59	$ 0.21	$ 0.70	$ 0.43	**$ 4.92**
K015-1212	$ 3.87	$ 0.78	$ 0.70	$ 1.66	**$ 7.01**
K015-1616	$ 8.39	$ 0.50	$ 0.70	$ 1.01	**$ 10.60**
K025-0404	$ 5.37	$ 2.33	$ 0.70	$ 5.26	**$ 13.67**
K025-0604	$ 4.56	$ 0.24	$ 0.70	$ 0.55	**$ 6.05**
K025-0606	$ 4.01	$ 2.34	$ 0.70	$ 4.77	**$ 11.81**
K025-0806	$ 5.59	$ 0.29	$ 0.70	$ 0.61	**$ 7.20**
K025-0808	$ 5.73	$ 2.75	$ 0.70	$ 5.67	**$ 14.85**
K025-1008	$ 7.98	$ 1.00	$ 0.70	$ 1.04	**$ 10.72**
K025-1212	$ 9.04	$ 0.96	$ 0.70	$ 1.54	**$ 12.23**
K025-1616	$ 14.51	$ 1.61	$ 0.70	$ 3.48	**$ 20.31**
K051-0404	$ 1.99	$ 1.60	$ 0.70	$ 3.35	**$ 7.65**
K051-0604	$ 2.17	$ 0.07	$ 0.70	$ 0.13	**$ 3.07**
K051-0606	$ 2.27	$ 1.60	$ 0.70	$ 3.20	**$ 7.77**
K051-0806	$ 2.71	$ 0.25	$ 0.70	$ 0.52	**$ 4.18**
K051-0808	$ 2.79	$ 2.77	$ 0.70	$ 5.02	**$ 11.28**

K051-1212	$	4.33	$	1.61	$	0.70	$	3.42	**$**	**10.07**
K051-1616	$	7.38	$	1.07	$	0.70	$	2.36	**$**	**11.52**
K060-0404	$	2.93	$	1.01	$	0.70	$	2.19	**$**	**6.83**
K060-0604	$	2.18	$	0.14	$	0.70	$	0.30	**$**	**3.32**
K060-0606	$	2.13	$	0.76	$	0.70	$	1.56	**$**	**5.15**
K060-0806	$	2.70	$	1.02	$	0.70	$	1.32	**$**	**5.75**
K060-0808	$	4.55	$	1.40	$	0.70	$	2.78	**$**	**9.43**
K060-1212	$	4.32	$	0.54	$	0.70	$	1.21	**$**	**6.78**
K060-1616	$	6.35	$	1.08	$	0.70	$	2.22	**$**	**10.36**
K005-0704	$	1.20	$	0.94	$	0.70	$	2.09	**$**	**4.94**
K005-0706	$	1.53	$	0.49	$	0.70	$	0.98	**$**	**3.71**
K005-0804	$	1.87	$	0.24	$	0.70	$	0.50	**$**	**3.32**
K005-0904	$	2.06	$	1.20	$	0.70	$	1.19	**$**	**5.15**
K005-0906	$	2.17	$	1.86	$	0.70	$	2.69	**$**	**7.42**
K005-1206	$	1.67	$	0.73	$	0.70	$	1.50	**$**	**4.60**
K005-1208	$	2.80	$	3.41	$	0.70	$	3.55	**$**	**10.46**
K005-1408	$	3.71	$	4.61	$	0.70	$	10.58	**$**	**19.60**
K005-1708	$	3.25	$	0.97	$	0.70	$	2.05	**$**	**6.97**
K005-1712	$	3.77	$	0.94	$	0.70	$	1.92	**$**	**7.34**
K005-2116	$	5.29	$	0.61	$	0.70	$	1.27	**$**	**7.88**
K018-0704	$	1.59	$	0.09	$	0.70	$	0.16	**$**	**2.54**
K018-0804	$	1.15	$	0.10	$	0.70	$	0.22	**$**	**2.17**
K018-0904	$	1.70	$	0.17	$	0.70	$	0.32	**$**	**2.90**
K018-0906	$	2.14	$	0.24	$	0.70	$	0.49	**$**	**3.57**
K018-1206	$	2.08	$	0.19	$	0.70	$	0.35	**$**	**3.32**
K018-1208	$	1.44	$	0.25	$	0.70	$	0.52	**$**	**2.91**
K018-1408	$	1.74	$	0.34	$	0.70	$	0.75	**$**	**3.54**
K018-1712	$	3.02	$	0.32	$	0.70	$	0.66	**$**	**4.71**
K018-2116	$	5.00	$	0.19	$	0.70	$	0.40	**$**	**6.29**
K029-0704	$	3.84	$	0.56	$	0.70	$	1.23	**$**	**6.33**
K029-0904	$	5.95	$	0.52	$	0.70	$	1.01	**$**	**8.18**
K029-0906	$	5.86	$	0.64	$	0.70	$	1.05	**$**	**8.25**
K029-1206	$	5.52	$	0.33	$	0.70	$	0.72	**$**	**7.28**
K029-1408	$	7.62	$	0.66	$	0.70	$	1.45	**$**	**10.43**
K055-0704	$	2.27	$	0.84	$	0.70	$	1.20	**$**	**5.01**
K055-0804	$	2.50	$	0.17	$	0.70	$	0.40	**$**	**3.78**
K055-0904	$	3.27	$	0.36	$	0.70	$	0.49	**$**	**4.83**
K055-0906	$	2.36	$	0.91	$	0.70	$	1.30	**$**	**5.28**
K055-1206	$	3.57	$	0.41	$	0.70	$	0.75	**$**	**5.44**
K055-1208	$	4.33	$	1.90	$	0.70	$	2.68	**$**	**9.62**
K055-1408	$	3.35	$	1.38	$	0.70	$	2.75	**$**	**8.18**
K055-1712	$	7.46	$	0.70	$	0.70	$	1.27	**$**	**10.14**
K055-2116	$	8.60	$	0.40	$	0.70	$	0.86	**$**	**10.56**
K064-0704	$	2.15	$	0.55	$	0.70	$	1.05	**$**	**4.46**

K064-0904	$ 2.19	$ 0.26	$ 0.70	$ 0.53	**$ 3.68**
K064-0906	$ 2.35	$ 0.38	$ 0.70	$ 0.61	**$ 4.04**
K064-1206	$ 2.54	$ 0.59	$ 0.70	$ 1.32	**$ 5.16**
K064-1208	$ 2.67	$ 1.25	$ 0.70	$ 1.76	**$ 6.38**
K064-1408	$ 3.69	$ 1.80	$ 0.70	$ 3.73	**$ 9.93**

Note. Costs are in NZD.

APPENDIX 18 – Quantification of 3DP Costs for SKUs of CG4

Item Number	C_{RAW}	T_{RAW}	C_{FIN}	C_{3DP}	Subtotal
K001-0204	$ 5.07	$ 0.04	$ 9.19	$ 30.06	**$ 44.36**
K001-0404	$ 6.97	$ 0.06	$ 9.19	$ 30.06	**$ 46.28**
K001-0406	$ 10.14	$ 0.09	$ 9.19	$ 30.06	**$ 49.48**
K001-0604	$ 8.87	$ 0.08	$ 9.19	$ 30.06	**$ 48.20**
K001-0606	$ 12.04	$ 0.11	$ 9.19	$ 30.06	**$ 51.40**
K001-0608	$ 14.58	$ 0.13	$ 9.19	$ 30.06	**$ 53.96**
K001-0806	$ 15.85	$ 0.15	$ 9.19	$ 30.06	**$ 55.24**
K001-0808	$ 18.38	$ 0.17	$ 9.19	$ 30.06	**$ 57.80**
K001-1208	$ 24.09	$ 0.22	$ 9.19	$ 30.06	**$ 63.56**
K001-1212	$ 31.06	$ 0.29	$ 9.19	$ 30.06	**$ 70.60**
K001-1616	$ 44.38	$ 0.42	$ 9.19	$ 30.06	**$ 84.04**
K012-0404	$ 6.97	$ 0.06	$ 9.19	$ 30.06	**$ 46.28**
K012-0606	$ 12.68	$ 0.12	$ 9.19	$ 30.06	**$ 52.04**
K012-0806	$ 15.21	$ 0.14	$ 9.19	$ 30.06	**$ 54.60**
K012-0808	$ 17.75	$ 0.16	$ 9.19	$ 30.06	**$ 57.16**
K015-0404	$ 6.97	$ 0.06	$ 9.19	$ 30.06	**$ 46.28**
K015-0406	$ 9.51	$ 0.09	$ 9.19	$ 30.06	**$ 48.84**
K015-0604	$ 7.60	$ 0.07	$ 9.19	$ 30.06	**$ 46.92**
K015-0606	$ 10.77	$ 0.10	$ 9.19	$ 30.06	**$ 50.12**
K015-0608	$ 13.94	$ 0.13	$ 9.19	$ 30.06	**$ 53.32**
K015-0806	$ 15.21	$ 0.14	$ 9.19	$ 30.06	**$ 54.60**
K015-0808	$ 27.26	$ 0.25	$ 9.19	$ 30.06	**$ 66.76**
K015-1208	$ 19.02	$ 0.18	$ 9.19	$ 30.06	**$ 58.44**
K015-1212	$ 27.89	$ 0.26	$ 9.19	$ 30.06	**$ 67.40**
K015-1616	$ 50.72	$ 0.48	$ 9.19	$ 30.06	**$ 90.44**
K025-0404	$ 8.87	$ 0.08	$ 9.19	$ 30.06	**$ 48.20**
K025-0604	$ 12.68	$ 0.12	$ 9.19	$ 30.06	**$ 52.04**
K025-0606	$ 15.85	$ 0.15	$ 9.19	$ 30.06	**$ 55.24**
K025-0806	$ 148.35	$ 1.40	$ 9.19	$ 30.06	**$ 189.00**
K025-0808	$ 26.62	$ 0.25	$ 9.19	$ 30.06	**$ 66.12**
K025-1008	$ 25.99	$ 0.24	$ 9.19	$ 30.06	**$ 65.48**
K025-1212	$ 46.91	$ 0.44	$ 9.19	$ 30.06	**$ 86.60**
K025-1616	$ 79.25	$ 0.75	$ 9.19	$ 30.06	**$ 119.24**
K051-0404	$ 8.62	$ 0.08	$ 9.19	$ 30.06	**$ 47.95**
K051-0604	$ 10.77	$ 0.10	$ 9.19	$ 30.06	**$ 50.12**
K051-0606	$ 14.58	$ 0.13	$ 9.19	$ 30.06	**$ 53.96**
K051-0806	$ 17.75	$ 0.16	$ 9.19	$ 30.06	**$ 57.16**
K051-0808	$ 21.55	$ 0.20	$ 9.19	$ 30.06	**$ 61.00**

K051-1212	$ 45.01	$ 0.42	$ 9.19	$ 30.06	**$ 84.68**
K051-1616	$ 74.17	$ 0.70	$ 9.19	$ 30.06	**$ 114.12**
K060-0404	$ 8.24	$ 0.07	$ 9.19	$ 30.06	**$ 47.56**
K060-0604	$ 10.14	$ 0.09	$ 9.19	$ 30.06	**$ 49.48**
K060-0606	$ 13.94	$ 0.13	$ 9.19	$ 30.06	**$ 53.32**
K060-0806	$ 17.11	$ 0.16	$ 9.19	$ 30.06	**$ 56.52**
K060-0808	$ 20.92	$ 0.19	$ 9.19	$ 30.06	**$ 60.36**
K060-1212	$ 39.94	$ 0.37	$ 9.19	$ 30.06	**$ 79.56**
K060-1616	$ 65.93	$ 0.62	$ 9.19	$ 30.06	**$ 105.80**
K005-0704	$ 5.70	$ 0.05	$ 9.19	$ 30.06	**$ 45.00**
K005-0706	$ 8.87	$ 0.08	$ 9.19	$ 30.06	**$ 48.20**
K005-0804	$ 6.34	$ 0.06	$ 9.19	$ 30.06	**$ 45.64**
K005-0904	$ 6.97	$ 0.06	$ 9.19	$ 30.06	**$ 46.28**
K005-0906	$ 10.14	$ 0.09	$ 9.19	$ 30.06	**$ 49.48**
K005-1206	$ 13.94	$ 0.13	$ 9.19	$ 30.06	**$ 53.32**
K005-1208	$ 17.11	$ 0.16	$ 9.19	$ 30.06	**$ 56.52**
K005-1408	$ 18.38	$ 0.17	$ 9.19	$ 30.06	**$ 57.80**
K005-1708	$ 20.92	$ 0.19	$ 9.19	$ 30.06	**$ 60.36**
K005-1712	$ 29.16	$ 0.27	$ 9.19	$ 30.06	**$ 68.68**
K005-2116	$ 45.64	$ 0.43	$ 9.19	$ 30.06	**$ 85.32**
K018-0704	$ 5.07	$ 0.04	$ 9.19	$ 30.06	**$ 44.36**
K018-0804	$ 5.70	$ 0.05	$ 9.19	$ 30.06	**$ 45.00**
K018-0904	$ 6.34	$ 0.06	$ 9.19	$ 30.06	**$ 45.64**
K018-0906	$ 10.14	$ 0.09	$ 9.19	$ 30.06	**$ 49.48**
K018-1206	$ 11.41	$ 0.10	$ 9.19	$ 30.06	**$ 50.76**
K018-1208	$ 13.94	$ 0.13	$ 9.19	$ 30.06	**$ 53.32**
K018-1408	$ 16.48	$ 0.15	$ 9.19	$ 30.06	**$ 55.88**
K018-1712	$ 28.53	$ 0.27	$ 9.19	$ 30.06	**$ 68.04**
K018-2116	$ 51.35	$ 0.48	$ 9.19	$ 30.06	**$ 91.08**
K029-0704	$ 7.60	$ 0.07	$ 9.19	$ 30.06	**$ 46.92**
K029-0904	$ 11.41	$ 0.10	$ 9.19	$ 30.06	**$ 50.76**
K029-0906	$ 14.58	$ 0.13	$ 9.19	$ 30.06	**$ 53.96**
K029-1206	$ 21.55	$ 0.20	$ 9.19	$ 30.06	**$ 61.00**
K029-1408	$ 27.26	$ 0.25	$ 9.19	$ 30.06	**$ 66.76**
K055-0704	$ 7.60	$ 0.07	$ 9.19	$ 30.06	**$ 46.92**
K055-0804	$ 8.24	$ 0.07	$ 9.19	$ 30.06	**$ 47.56**
K055-0904	$ 8.87	$ 0.08	$ 9.19	$ 30.06	**$ 48.20**
K055-0906	$ 13.31	$ 0.12	$ 9.19	$ 30.06	**$ 52.68**
K055-1206	$ 16.48	$ 0.15	$ 9.19	$ 30.06	**$ 55.88**
K055-1208	$ 21.55	$ 0.20	$ 9.19	$ 30.06	**$ 61.00**
K055-1408	$ 21.55	$ 0.20	$ 9.19	$ 30.06	**$ 61.00**
K055-1712	$ 45.01	$ 0.42	$ 9.19	$ 30.06	**$ 84.68**
K055-2116	$ 75.44	$ 0.71	$ 9.19	$ 30.06	**$ 115.40**
K064-0704	$ 6.34	$ 0.06	$ 9.19	$ 30.06	**$ 45.64**

K064-0904	$ 8.24	$ 0.07	$ 9.19	$ 30.06	**$ 47.56**
K064-0906	$ 12.68	$ 0.12	$ 9.19	$ 30.06	**$ 52.04**
K064-1206	$ 15.85	$ 0.15	$ 9.19	$ 30.06	**$ 55.24**
K064-1208	$ 20.28	$ 0.19	$ 9.19	$ 30.06	**$ 59.72**
K064-1408	$ 21.55	$ 0.20	$ 9.19	$ 30.06	**$ 61.00**

Note. Costs are in NZD.

APPENDIX 19 – Quantification of TM Costs for SKUs of CG5

Item Number	U_{TM}	I_{CC}	C_{WH}	C_{OB}	Subtotal
PDV1-0606002	$ 4.51	$ 2.74	$ 0.70	$ 5.46	**$ 13.42**
PDV1-0606003	$ 2.07	$ 2.91	$ 0.70	$ 6.16	**$ 11.83**
PDV1-1010002	$ 5.14	$ 1.84	$ 0.70	$ 4.06	**$ 11.73**
PDV1-1010003	$ 2.54	$ 3.60	$ 0.70	$ 7.91	**$ 14.74**
PDV1-1313002	$ 5.42	$ 24.15	$ 0.70	$ 53.45	**$ 83.71**
PDV1-1313003	$ 2.13	$ 12.59	$ 0.70	$ 27.13	**$ 42.56**
PDV1-2019002	$ 11.16	$ 6.20	$ 0.70	$ 12.50	**$ 30.56**
PDV1-2019003	$ 5.09	$ 3.70	$ 0.70	$ 7.63	**$ 17.12**
PDV1-2525002	$ 27.74	$ 3.27	$ 0.70	$ 6.93	**$ 38.65**
PDV1-2525003	$ 11.81	$ 2.14	$ 0.70	$ 4.72	**$ 19.38**
PPV1-1313002	$ 6.12	$ 2.56	$ 0.70	$ 5.26	**$ 14.65**
PKKL-1313003	$ 4.51	$ 0.19	$ 0.70	$ 0.41	**$ 5.81**
PDS1-0606002	$ 6.68	$ 25.40	$ 0.70	$ 4.81	**$ 37.59**
PDS1-0606003	$ 3.32	$ 12.46	$ 0.70	$ 2.39	**$ 18.87**
PDS1-1010002	$ 7.90	$ 1.83	$ 0.70	$ 3.24	**$ 13.68**
PDS1-1010003	$ 3.87	$ 1.61	$ 0.70	$ 2.28	**$ 8.47**
PDS1-1313002	$ 8.28	$ 1.99	$ 0.70	$ 3.48	**$ 14.45**
PDS1-1313003	$ 3.00	$ 13.55	$ 0.70	$ 4.96	**$ 22.21**
PDS1-2019002	$ 12.64	$ 0.88	$ 0.70	$ 1.90	**$ 16.12**
PDS1-2019003	$ 5.63	$ 0.21	$ 0.70	$ 0.34	**$ 6.88**
PDS1-2525002	$ 37.38	$ 19.34	$ 0.70	$ 8.97	**$ 66.39**
PDS1-2525003	$ 21.14	$ 29.07	$ 0.70	$ 6.97	**$ 57.88**
PLT1-0606002	$ 11.30	$ 1.43	$ 0.70	$ 2.82	**$ 16.26**
PLT1-0606003	$ 4.76	$ 1.15	$ 0.70	$ 1.62	**$ 8.23**
PLT1-1310002	$ 12.90	$ 5.45	$ 0.70	$ 10.19	**$ 29.24**
PLT1-1310003	$ 6.99	$ 0.21	$ 0.70	$ 0.42	**$ 8.33**
PLT1-1313002	$ 58.65	$ 7.83	$ 0.70	$ 17.59	**$ 84.77**
PLT1-1313003	$ 33.85	$ 2.44	$ 0.70	$ 4.06	**$ 41.05**
PLT1-2019002	$ 108.57	$ 3.10	$ 0.70	$ 5.43	**$ 117.80**
PLT1-2019003	$ 61.49	$ 1.64	$ 0.70	$ 3.69	**$ 67.52**
PLT1-2525002	$ 45.17	$ 4.17	$ 0.70	$ 4.97	**$ 55.01**
PLT1-2525003	$ 18.82	$ 4.55	$ 0.70	$ 3.39	**$ 27.46**
PVV3-0606112	$ 10.32	$ 0.85	$ 0.70	$ 1.86	**$ 13.73**
PVV3-0606113	$ 13.41	$ 0.34	$ 0.70	$ 0.80	**$ 15.26**
PVV3-1010112	$ 15.33	$ 2.24	$ 0.70	$ 2.15	**$ 20.41**
PVV3-1010113	$ 15.32	$ 1.68	$ 0.70	$ 2.45	**$ 20.16**
PVV3-1313112	$ 7.27	$ 0.73	$ 0.70	$ 1.38	**$ 10.09**

PVV3-1313113	$ 6.24	$ 0.64	$ 0.70	$ 1.31	**$ 8.89**
PVV3-2019112	$ 17.08	$ 1.71	$ 0.70	$ 3.76	**$ 23.25**
PVV3-2019113	$ 17.63	$ 1.81	$ 0.70	$ 3.88	**$ 24.02**
PVV3-2525112	$ 23.29	$ 1.18	$ 0.70	$ 1.63	**$ 26.81**
PVV3-2525113	$ 19.63	$ 1.19	$ 0.70	$ 2.55	**$ 24.07**
PBR16-FB	$ 31.67	$ 14.02	$ 0.70	$ 27.87	**$ 74.27**
PBR16-MP	$ 13.87	$ 4.90	$ 0.70	$ 9.15	**$ 28.62**

Note. Costs are in NZD.

APPENDIX 20 – Quantification of 3DP Costs for SKUs of CG5

Item Number	C_{RAW}	T_{RAW}	C_{FIN}	C_{3DP}	Subtotal
PDV1-0606002	$ 14.962	$ 0.142	$ 11.81	$ 49.51	**$ 76.427**
PDV1-0606003	$ 5.833	$ 0.055	$ 11.81	$ 49.51	**$ 67.211**
PDV1-1010002	$ 25.360	$ 0.240	$ 11.81	$ 49.51	**$ 86.923**
PDV1-1010003	$ 10.144	$ 0.096	$ 11.81	$ 49.51	**$ 71.563**
PDV1-1313002	$ 33.982	$ 0.322	$ 11.81	$ 49.51	**$ 95.627**
PDV1-1313003	$ 12.300	$ 0.116	$ 11.81	$ 49.51	**$ 73.739**
PDV1-2019002	$ 59.976	$ 0.568	$ 11.81	$ 49.51	**$ 121.867**
PDV1-2019003	$ 23.204	$ 0.220	$ 11.81	$ 49.51	**$ 84.747**
PDV1-2525002	$ 93.325	$ 0.883	$ 11.81	$ 49.51	**$ 155.531**
PDV1-2525003	$ 35.758	$ 0.338	$ 11.81	$ 49.51	**$ 97.419**
PPV1-1313002	$ 37.786	$ 0.358	$ 11.81	$ 49.51	**$ 99.467**
PKKL-1313003	$ 12.173	$ 0.115	$ 11.81	$ 49.51	**$ 73.611**
PDS1-0606002	$ 16.104	$ 0.152	$ 11.81	$ 49.51	**$ 77.579**
PDS1-0606003	$ 5.960	$ 0.056	$ 11.81	$ 49.51	**$ 67.339**
PDS1-1010002	$ 26.248	$ 0.248	$ 11.81	$ 49.51	**$ 87.819**
PDS1-1010003	$ 10.905	$ 0.103	$ 11.81	$ 49.51	**$ 72.331**
PDS1-1313002	$ 34.616	$ 0.328	$ 11.81	$ 49.51	**$ 96.267**
PDS1-1313003	$ 12.807	$ 0.121	$ 11.81	$ 49.51	**$ 74.251**
PDS1-2019002	$ 62.639	$ 0.593	$ 11.81	$ 49.51	**$ 124.555**
PDS1-2019003	$ 25.994	$ 0.246	$ 11.81	$ 49.51	**$ 87.563**
PDS1-2525002	$ 97.382	$ 0.922	$ 11.81	$ 49.51	**$ 159.627**
PDS1-2525003	$ 38.294	$ 0.362	$ 11.81	$ 49.51	**$ 99.979**
PLT1-0606002	$ 22.951	$ 0.217	$ 11.81	$ 49.51	**$ 84.491**
PLT1-0606003	$ 12.173	$ 0.115	$ 11.81	$ 49.51	**$ 73.611**
PLT1-1310002	$ 32.461	$ 0.307	$ 11.81	$ 49.51	**$ 94.091**
PLT1-1310003	$ 19.781	$ 0.187	$ 11.81	$ 49.51	**$ 81.291**
PLT1-1313002	$ 32.080	$ 0.304	$ 11.81	$ 49.51	**$ 93.707**
PLT1-1313003	$ 19.147	$ 0.181	$ 11.81	$ 49.51	**$ 80.651**
PLT1-2019002	$ 56.426	$ 0.534	$ 11.81	$ 49.51	**$ 118.283**
PLT1-2019003	$ 35.758	$ 0.338	$ 11.81	$ 49.51	**$ 97.419**
PLT1-2525002	$ 100.045	$ 0.947	$ 11.81	$ 49.51	**$ 162.315**
PLT1-2525003	$ 53.636	$ 0.508	$ 11.81	$ 49.51	**$ 115.467**
PVV3-0606112	$ 15.977	$ 0.151	$ 11.81	$ 49.51	**$ 77.451**
PVV3-0606113	$ 22.444	$ 0.212	$ 11.81	$ 49.51	**$ 83.979**
PVV3-1010112	$ 19.908	$ 0.188	$ 11.81	$ 49.51	**$ 81.419**
PVV3-1010113	$ 20.542	$ 0.194	$ 11.81	$ 49.51	**$ 82.059**
PVV3-1313112	$ 39.562	$ 0.374	$ 11.81	$ 49.51	**$ 101.259**

PVV3-1313113	$ 35.631	$ 0.337	$ 11.81	$ 49.51	**$ 97.291**
PVV3-2019112	$ 60.484	$ 0.572	$ 11.81	$ 49.51	**$ 122.379**
PVV3-2019113	$ 53.256	$ 0.504	$ 11.81	$ 49.51	**$ 115.083**
PVV3-2525112	$ 99.158	$ 0.938	$ 11.81	$ 49.51	**$ 161.419**
PVV3-2525113	$ 81.279	$ 0.769	$ 11.81	$ 49.51	**$ 143.371**
PBR16-FB	$ 158.754	$ 1.502	$ 11.81	$ 49.51	**$ 221.579**
PBR16-MP	$ 58.201	$ 0.551	$ 11.81	$ 49.51	**$ 120.075**

Note. Costs are in NZD.

APPENDIX 21 – Sensitivity Analysis: Complexity Group 2 (I_R = 5%)

I_R	5%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
SN1-03	$ 1.43	$ 32.33	$ 1.74	$ 32.33	$ 1.43	$ 31.02	$ 1.74	$ 31.02
SN1-04	$ 1.79	$ 33.23	$ 2.39	$ 33.23	$ 1.79	$ 31.92	$ 2.39	$ 31.92
SN1-05	$ 1.05	$ 34.51	$ 1.10	$ 34.51	$ 1.05	$ 33.20	$ 1.10	$ 33.20
SN1-06	$ 2.71	$ 34.76	$ 3.92	$ 34.76	$ 2.71	$ 33.45	$ 3.92	$ 33.45
SN1-08	$ 13.58	$ 35.27	$ 18.41	$ 35.27	$ 13.58	$ 33.96	$ 18.41	$ 33.96
SN1-12	$ 5.51	$ 40.14	$ 8.31	$ 40.14	$ 5.51	$ 38.83	$ 8.31	$ 38.83
SN1-16	$ 5.44	$ 45.00	$ 7.80	$ 45.00	$ 5.44	$ 43.69	$ 7.80	$ 43.69
SN1-32	$ 8.53	$ 92.62	$ 10.34	$ 92.62	$ 8.53	$ 91.31	$ 10.34	$ 91.31
SN2-04	$ 6.13	$ 33.48	$ 9.69	$ 33.48	$ 6.13	$ 32.17	$ 9.69	$ 32.17
SN2-05	$ 1.28	$ 34.63	$ 1.47	$ 34.63	$ 1.28	$ 33.32	$ 1.47	$ 33.32
SN2-06	$ 6.52	$ 35.02	$ 10.37	$ 35.02	$ 6.52	$ 33.71	$ 10.37	$ 33.71
SN2-08	$ 6.40	$ 35.27	$ 9.98	$ 35.27	$ 6.40	$ 33.96	$ 9.98	$ 33.96
SN2-10	$ 1.50	$ 39.63	$ 1.70	$ 39.63	$ 1.50	$ 38.32	$ 1.70	$ 38.32
SN2-12	$ 4.04	$ 43.72	$ 5.83	$ 43.72	$ 4.04	$ 42.41	$ 5.83	$ 42.41
SN2-16	$ 2.95	$ 50.38	$ 3.81	$ 50.38	$ 2.95	$ 49.07	$ 3.81	$ 49.07
SN2-20	$ 4.26	$ 58.06	$ 5.21	$ 58.06	$ 4.26	$ 56.75	$ 5.21	$ 56.75
SN2-32	$ 9.57	$ 90.83	$ 12.08	$ 90.83	$ 9.57	$ 89.52	$ 12.08	$ 89.52
SN3-04	$ 5.56	$ 35.79	$ 8.56	$ 35.79	$ 5.56	$ 34.48	$ 8.56	$ 34.48
SN3-05	$ 1.39	$ 35.53	$ 1.68	$ 35.53	$ 1.39	$ 34.22	$ 1.68	$ 34.22
SN3-06	$ 9.61	$ 36.04	$ 15.27	$ 36.04	$ 9.61	$ 34.73	$ 15.27	$ 34.73
SN3-08	$ 10.95	$ 36.04	$ 17.48	$ 36.04	$ 10.95	$ 34.73	$ 17.48	$ 34.73
SN3-10	$ 1.65	$ 38.35	$ 1.85	$ 38.35	$ 1.65	$ 37.04	$ 1.85	$ 37.04
SN3-12	$ 7.61	$ 40.52	$ 11.73	$ 40.52	$ 7.61	$ 39.21	$ 11.73	$ 39.21
SN3-16	$ 4.05	$ 49.99	$ 5.56	$ 49.99	$ 4.05	$ 48.68	$ 5.56	$ 48.68
SN3-20	$ 4.48	$ 65.99	$ 5.52	$ 65.99	$ 4.48	$ 64.68	$ 5.52	$ 64.68
SN3-24	$ 5.09	$ 85.83	$ 5.84	$ 85.83	$ 5.09	$ 84.52	$ 5.84	$ 84.52
SN3-32	$ 23.85	$ 90.70	$ 25.59	$ 90.70	$ 23.85	$ 89.39	$ 25.59	$ 89.39
SMSH-10	$ 1.81	$ 43.72	$ 2.06	$ 43.72	$ 1.81	$ 42.41	$ 2.06	$ 42.41
SMSH-12	$ 3.47	$ 48.59	$ 4.68	$ 48.59	$ 3.47	$ 47.28	$ 4.68	$ 47.28
SMSH-16	$ 4.05	$ 61.39	$ 5.31	$ 61.39	$ 4.05	$ 60.08	$ 5.31	$ 60.08
SMSH-20	$ 4.85	$ 75.98	$ 5.80	$ 75.98	$ 4.85	$ 74.67	$ 5.80	$ 74.67
SMSH-24	$ 11.27	$ 85.19	$ 11.85	$ 85.19	$ 11.27	$ 83.88	$ 11.85	$ 83.88
SMSH-32	$ 9.89	$ 139.21	$ 10.47	$ 139.21	$ 9.89	$ 137.90	$ 10.47	$ 137.90
SMSP-06	$ 9.51	$ 36.81	$ 11.32	$ 36.81	$ 9.51	$ 35.50	$ 11.32	$ 35.50
SMSP-08	$ 2.16	$ 39.37	$ 2.79	$ 39.37	$ 2.16	$ 38.06	$ 2.79	$ 38.06
SMSP-10	$ 1.75	$ 42.44	$ 1.97	$ 42.44	$ 1.75	$ 41.13	$ 1.97	$ 41.13
SMSP-12	$ 2.02	$ 48.07	$ 2.32	$ 48.07	$ 2.02	$ 46.76	$ 2.32	$ 46.76

SMSP-16	$ 2.23	$ 54.47	$ 2.55	$ 54.47	$ 2.23	$ 53.16	$ 2.55	$ 53.16
SMSP-20	$ 6.75	$ 76.75	$ 7.77	$ 76.75	$ 6.75	$ 75.44	$ 7.77	$ 75.44
SMSP-24	$ 9.84	$ 78.03	$ 10.27	$ 78.03	$ 9.84	$ 76.72	$ 10.27	$ 76.72
SMSP-32	$ 17.01	$ 100.30	$ 17.77	$ 100.30	$ 17.01	$ 98.99	$ 17.77	$ 98.99
SMSR13-12	$ 2.71	$ 60.75	$ 2.97	$ 60.75	$ 2.71	$ 59.44	$ 2.97	$ 59.44
SMSR13-16	$ 4.24	$ 67.79	$ 4.92	$ 67.79	$ 4.24	$ 66.48	$ 4.92	$ 66.48
SMSR13-20	$ 12.97	$ 93.13	$ 14.74	$ 93.13	$ 12.97	$ 91.82	$ 14.74	$ 91.82
SMSR13-24	$ 16.43	$ 110.54	$ 17.37	$ 110.54	$ 16.43	$ 109.23	$ 17.37	$ 109.23
SMSR13-32	$ 29.00	$ 205.26	$ 31.84	$ 205.26	$ 29.00	$ 203.95	$ 31.84	$ 203.95
SMSH-20v2	$ 12.43	$ 72.39	$ 13.47	$ 72.39	$ 12.43	$ 71.08	$ 13.47	$ 71.08
SMSH-24v2	$ 42.08	$ 93.39	$ 42.88	$ 93.39	$ 42.08	$ 92.08	$ 42.88	$ 92.08
SN8-03	$ 1.24	$ 31.43	$ 1.46	$ 31.43	$ 1.24	$ 30.12	$ 1.46	$ 30.12
SN8-04	$ 1.38	$ 32.20	$ 1.69	$ 32.20	$ 1.38	$ 30.89	$ 1.69	$ 30.89
SN8-06	$ 1.28	$ 33.48	$ 1.48	$ 33.48	$ 1.28	$ 32.17	$ 1.48	$ 32.17
SN8-08	$ 5.08	$ 35.79	$ 7.51	$ 35.79	$ 5.08	$ 34.48	$ 7.51	$ 34.48
SN8-12	$ 17.42	$ 40.39	$ 19.28	$ 40.39	$ 17.42	$ 39.08	$ 19.28	$ 39.08
SN9-08	$ 3.02	$ 38.99	$ 3.08	$ 38.99	$ 3.02	$ 37.68	$ 3.08	$ 37.68
SN9-12	$ 5.00	$ 45.39	$ 5.20	$ 45.39	$ 5.00	$ 44.08	$ 5.20	$ 44.08
SN9-16	$ 6.37	$ 54.47	$ 6.61	$ 54.47	$ 6.37	$ 53.16	$ 6.61	$ 53.16
TEF-PTCS08	$ 5.54	$ 34.51	$ 5.89	$ 34.51	$ 5.54	$ 33.20	$ 5.89	$ 33.20
TEF-PTCS12	$ 18.65	$ 40.14	$ 22.13	$ 40.14	$ 18.65	$ 38.83	$ 22.13	$ 38.83
TEF-PTCS20	$ 24.29	$ 52.81	$ 26.29	$ 52.81	$ 24.29	$ 51.50	$ 26.29	$ 51.50
TEF-PTCS24	$ 52.23	$ 55.63	$ 54.39	$ 55.63	$ 52.23	$ 54.32	$ 54.39	$ 54.32
TEF-PTTB06	$ 1.23	$ 33.35	$ 1.37	$ 33.35	$ 1.23	$ 32.04	$ 1.37	$ 32.04
TEF-PTTB08	$ 1.68	$ 35.40	$ 2.02	$ 35.40	$ 1.68	$ 34.09	$ 2.02	$ 34.09
TEF-PTTB12	$ 6.65	$ 40.01	$ 7.11	$ 40.01	$ 6.65	$ 38.70	$ 7.11	$ 38.70

Note. Costs are in NZD.

APPENDIX 22 – Sensitivity Analysis: Complexity Group 2 (I_R = 10%)

I_R	10%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
SN1-03	$ 1.61	$ 32.33	$ 1.92	$ 32.33	$ 1.61	$ 31.02	$ 1.92	$ 31.02
SN1-04	$ 2.06	$ 33.23	$ 2.66	$ 33.23	$ 2.06	$ 31.92	$ 2.66	$ 31.92
SN1-05	$ 1.07	$ 34.51	$ 1.12	$ 34.51	$ 1.07	$ 33.20	$ 1.12	$ 33.20
SN1-06	$ 3.31	$ 34.76	$ 4.52	$ 34.76	$ 3.31	$ 33.45	$ 4.52	$ 33.45
SN1-08	$ 69.63	$ 35.27	$ 74.46	$ 35.27	$ 69.63	$ 33.96	$ 74.46	$ 33.96
SN1-12	$ 7.40	$ 40.14	$ 10.20	$ 40.14	$ 7.40	$ 38.83	$ 10.20	$ 38.83
SN1-16	$ 8.17	$ 45.00	$ 10.53	$ 45.00	$ 8.17	$ 43.69	$ 10.53	$ 43.69
SN1-32	$ 19.05	$ 92.62	$ 20.85	$ 92.62	$ 19.05	$ 91.31	$ 20.85	$ 91.31
SN2-04	$ 7.82	$ 33.48	$ 11.38	$ 33.48	$ 7.82	$ 32.17	$ 11.38	$ 32.17
SN2-05	$ 1.37	$ 34.63	$ 1.56	$ 34.63	$ 1.37	$ 33.32	$ 1.56	$ 33.32
SN2-06	$ 8.30	$ 35.02	$ 12.15	$ 35.02	$ 8.30	$ 33.71	$ 12.15	$ 33.71
SN2-08	$ 8.19	$ 35.27	$ 11.77	$ 35.27	$ 8.19	$ 33.96	$ 11.77	$ 33.96
SN2-10	$ 1.60	$ 39.63	$ 1.79	$ 39.63	$ 1.60	$ 38.32	$ 1.79	$ 38.32
SN2-12	$ 4.91	$ 43.72	$ 6.70	$ 43.72	$ 4.91	$ 42.41	$ 6.70	$ 42.41
SN2-16	$ 3.34	$ 50.38	$ 4.20	$ 50.38	$ 3.34	$ 49.07	$ 4.20	$ 49.07
SN2-20	$ 4.73	$ 58.06	$ 5.68	$ 58.06	$ 4.73	$ 56.75	$ 5.68	$ 56.75
SN2-32	$ 19.21	$ 90.83	$ 21.71	$ 90.83	$ 19.21	$ 89.52	$ 21.71	$ 89.52
SN3-04	$ 6.96	$ 35.79	$ 9.97	$ 35.79	$ 6.96	$ 34.48	$ 9.97	$ 34.48
SN3-05	$ 1.53	$ 35.53	$ 1.82	$ 35.53	$ 1.53	$ 34.22	$ 1.82	$ 34.22
SN3-06	$ 12.32	$ 36.04	$ 17.99	$ 36.04	$ 12.32	$ 34.73	$ 17.99	$ 34.73
SN3-08	$ 14.08	$ 36.04	$ 20.60	$ 36.04	$ 14.08	$ 34.73	$ 20.60	$ 34.73
SN3-10	$ 1.76	$ 38.35	$ 1.96	$ 38.35	$ 1.76	$ 37.04	$ 1.96	$ 37.04
SN3-12	$ 9.79	$ 40.52	$ 13.91	$ 40.52	$ 9.79	$ 39.21	$ 13.91	$ 39.21
SN3-16	$ 4.78	$ 49.99	$ 6.28	$ 49.99	$ 4.78	$ 48.68	$ 6.28	$ 48.68
SN3-20	$ 5.03	$ 65.99	$ 6.07	$ 65.99	$ 5.03	$ 64.68	$ 6.07	$ 64.68
SN3-24	$ 8.05	$ 85.83	$ 8.80	$ 85.83	$ 8.05	$ 84.52	$ 8.80	$ 84.52
SN3-32	$ 25.37	$ 90.70	$ 27.11	$ 90.70	$ 25.37	$ 89.39	$ 27.11	$ 89.39
SMSH-10	$ 1.93	$ 43.72	$ 2.17	$ 43.72	$ 1.93	$ 42.41	$ 2.17	$ 42.41
SMSH-12	$ 4.03	$ 48.59	$ 5.24	$ 48.59	$ 4.03	$ 47.28	$ 5.24	$ 47.28
SMSH-16	$ 4.63	$ 61.39	$ 5.89	$ 61.39	$ 4.63	$ 60.08	$ 5.89	$ 60.08
SMSH-20	$ 5.28	$ 75.98	$ 6.24	$ 75.98	$ 5.28	$ 74.67	$ 6.24	$ 74.67
SMSH-24	$ 11.56	$ 85.19	$ 12.14	$ 85.19	$ 11.56	$ 83.88	$ 12.14	$ 83.88
SMSH-32	$ 10.71	$ 139.21	$ 11.28	$ 139.21	$ 10.71	$ 137.90	$ 11.28	$ 137.90
SMSP-06	$ 10.49	$ 36.81	$ 12.30	$ 36.81	$ 10.49	$ 35.50	$ 12.30	$ 35.50
SMSP-08	$ 2.45	$ 39.37	$ 3.07	$ 39.37	$ 2.45	$ 38.06	$ 3.07	$ 38.06
SMSP-10	$ 1.86	$ 42.44	$ 2.08	$ 42.44	$ 1.86	$ 41.13	$ 2.08	$ 41.13
SMSP-12	$ 2.18	$ 48.07	$ 2.48	$ 48.07	$ 2.18	$ 46.76	$ 2.48	$ 46.76

SMSP-16	$ 2.39	$ 54.47	$ 2.71	$ 54.47	$ 2.39	$ 53.16	$ 2.71	$ 53.16
SMSP-20	$ 8.40	$ 76.75	$ 9.42	$ 76.75	$ 8.40	$ 75.44	$ 9.42	$ 75.44
SMSP-24	$ 10.26	$ 78.03	$ 10.69	$ 78.03	$ 10.26	$ 76.72	$ 10.69	$ 76.72
SMSP-32	$ 17.77	$ 100.30	$ 18.52	$ 100.30	$ 17.77	$ 98.99	$ 18.52	$ 98.99
SMSR13-12	$ 13.71	$ 60.75	$ 13.97	$ 60.75	$ 13.71	$ 59.44	$ 13.97	$ 59.44
SMSR13-16	$ 15.34	$ 67.79	$ 16.03	$ 67.79	$ 15.34	$ 66.48	$ 16.03	$ 66.48
SMSR13-20	$ 16.94	$ 93.13	$ 18.71	$ 93.13	$ 16.94	$ 91.82	$ 18.71	$ 91.82
SMSR13-24	$ 17.00	$ 110.54	$ 17.93	$ 110.54	$ 17.00	$ 109.23	$ 17.93	$ 109.23
SMSR13-32	$ 39.23	$ 205.26	$ 42.07	$ 205.26	$ 39.23	$ 203.95	$ 42.07	$ 203.95
SMSH-20v2	$ 15.09	$ 72.39	$ 16.12	$ 72.39	$ 15.09	$ 71.08	$ 16.12	$ 71.08
SMSH-24v2	$ 42.55	$ 93.39	$ 43.35	$ 93.39	$ 42.55	$ 92.08	$ 43.35	$ 92.08
SN8-03	$ 1.34	$ 31.43	$ 1.57	$ 31.43	$ 1.34	$ 30.12	$ 1.57	$ 30.12
SN8-04	$ 1.53	$ 32.20	$ 1.83	$ 32.20	$ 1.53	$ 30.89	$ 1.83	$ 30.89
SN8-06	$ 1.37	$ 33.48	$ 1.57	$ 33.48	$ 1.37	$ 32.17	$ 1.57	$ 32.17
SN8-08	$ 8.46	$ 35.79	$ 10.89	$ 35.79	$ 8.46	$ 34.48	$ 10.89	$ 34.48
SN8-12	$ 298.77	$ 40.39	$ 300.64	$ 40.39	$ 298.77	$ 39.08	$ 300.64	$ 39.08
SN9-08	$ 3.05	$ 38.99	$ 3.11	$ 38.99	$ 3.05	$ 37.68	$ 3.11	$ 37.68
SN9-12	$ 5.20	$ 45.39	$ 5.40	$ 45.39	$ 5.20	$ 44.08	$ 5.40	$ 44.08
SN9-16	$ 6.48	$ 54.47	$ 6.72	$ 54.47	$ 6.48	$ 53.16	$ 6.72	$ 53.16
TEF-PTCS08	$ 5.72	$ 34.51	$ 6.07	$ 34.51	$ 5.72	$ 33.20	$ 6.07	$ 33.20
TEF-PTCS12	$ 55.53	$ 40.14	$ 59.01	$ 40.14	$ 55.53	$ 38.83	$ 59.01	$ 38.83
TEF-PTCS20	$ 28.91	$ 52.81	$ 30.91	$ 52.81	$ 28.91	$ 51.50	$ 30.91	$ 51.50
TEF-PTCS24	$ 54.20	$ 55.63	$ 56.37	$ 55.63	$ 54.20	$ 54.32	$ 56.37	$ 54.32
TEF-PTTB06	$ 1.34	$ 33.35	$ 1.48	$ 33.35	$ 1.34	$ 32.04	$ 1.48	$ 32.04
TEF-PTTB08	$ 2.24	$ 35.40	$ 2.57	$ 35.40	$ 2.24	$ 34.09	$ 2.57	$ 34.09
TEF-PTTB12	$ 7.07	$ 40.01	$ 7.54	$ 40.01	$ 7.07	$ 38.70	$ 7.54	$ 38.70

Note. Costs are in NZD.

APPENDIX 23 – Sensitivity Analysis: Complexity Group 3 (I_R = 5%)

I_R	5%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
AAA020202	$ 5.83	$ 36.95	$ 6.37	$ 36.95	$ 5.83	$ 35.47	$ 6.37	$ 35.47
AAA060606	$ 238.48	$ 45.91	$ 239.57	$ 45.91	$ 238.48	$ 44.43	$ 239.57	$ 44.43
AAA080808	$ 9.68	$ 55.00	$ 10.91	$ 55.00	$ 9.68	$ 53.52	$ 10.91	$ 53.52
AAA121212	$ 26.52	$ 73.05	$ 29.06	$ 73.05	$ 26.52	$ 71.57	$ 29.06	$ 71.57
AAA161616	$ 42.21	$ 96.98	$ 46.61	$ 96.98	$ 42.21	$ 95.51	$ 46.61	$ 95.51
AAC060606	$ 3.99	$ 52.44	$ 4.74	$ 52.44	$ 3.99	$ 50.96	$ 4.74	$ 50.96
AAC080808	$ 7.30	$ 58.58	$ 8.09	$ 58.58	$ 7.30	$ 57.11	$ 8.09	$ 57.11
AAC121212	$ 5.57	$ 75.99	$ 5.86	$ 75.99	$ 5.57	$ 74.51	$ 5.86	$ 74.51
AAC161616	$ 7.65	$ 101.72	$ 8.01	$ 101.72	$ 7.65	$ 100.24	$ 8.01	$ 100.24
ACA040404	$ 2.96	$ 41.94	$ 3.58	$ 41.94	$ 2.96	$ 40.47	$ 3.58	$ 40.47
ACA060606	$ 3.21	$ 47.06	$ 3.83	$ 47.06	$ 3.21	$ 45.59	$ 3.83	$ 45.59
ACA080804	$ 4.84	$ 56.15	$ 5.73	$ 56.15	$ 4.84	$ 54.67	$ 5.73	$ 54.67
ACA080808	$ 4.05	$ 59.61	$ 4.79	$ 59.61	$ 4.05	$ 58.13	$ 4.79	$ 58.13
ACA121212	$ 6.39	$ 78.30	$ 7.23	$ 78.30	$ 6.39	$ 76.82	$ 7.23	$ 76.82
ACA161604	$ 14.75	$ 104.28	$ 15.16	$ 104.28	$ 14.75	$ 102.80	$ 15.16	$ 102.80
ACA161616	$ 9.17	$ 100.95	$ 10.12	$ 100.95	$ 9.17	$ 99.47	$ 10.12	$ 99.47
BBB040404	$ 5.95	$ 41.82	$ 6.28	$ 41.82	$ 5.95	$ 40.34	$ 6.28	$ 40.34
BBB060606	$ 3.61	$ 48.09	$ 4.06	$ 48.09	$ 3.61	$ 46.61	$ 4.06	$ 46.61
BBB080808	$ 3.28	$ 53.85	$ 3.63	$ 53.85	$ 3.28	$ 52.37	$ 3.63	$ 52.37
BBB121212	$ 9.19	$ 74.71	$ 9.51	$ 74.71	$ 9.19	$ 73.23	$ 9.51	$ 73.23
BBB161616	$ 7.56	$ 105.05	$ 7.72	$ 105.05	$ 7.56	$ 103.57	$ 7.72	$ 103.57
BBC040404	$ 7.27	$ 43.48	$ 7.43	$ 43.48	$ 7.27	$ 42.00	$ 7.43	$ 42.00
BBC060606	$ 4.77	$ 49.37	$ 4.91	$ 49.37	$ 4.77	$ 47.89	$ 4.91	$ 47.89
BBC080808	$ 3.07	$ 57.43	$ 3.26	$ 57.43	$ 3.07	$ 55.95	$ 3.26	$ 55.95
BBC121212	$ 9.53	$ 76.12	$ 10.12	$ 76.12	$ 9.53	$ 74.64	$ 10.12	$ 74.64
BBC161616	$ 27.64	$ 104.28	$ 27.77	$ 104.28	$ 27.64	$ 102.80	$ 27.77	$ 102.80
BCB040404	$ 16.57	$ 41.94	$ 20.53	$ 41.94	$ 16.57	$ 40.47	$ 20.53	$ 40.47
BCB060606	$ 2.34	$ 45.78	$ 2.44	$ 45.78	$ 2.34	$ 44.31	$ 2.44	$ 44.31
BCB080808	$ 5.99	$ 56.41	$ 7.75	$ 56.41	$ 5.99	$ 54.93	$ 7.75	$ 54.93
BCC040404	$ 2.29	$ 43.74	$ 2.34	$ 43.74	$ 2.29	$ 42.26	$ 2.34	$ 42.26
BCC080808	$ 4.31	$ 60.25	$ 4.38	$ 60.25	$ 4.31	$ 58.77	$ 4.38	$ 58.77
CCB040404	$ 7.00	$ 43.74	$ 7.32	$ 43.74	$ 7.00	$ 42.26	$ 7.32	$ 42.26
CCB080808	$ 4.28	$ 62.04	$ 4.35	$ 62.04	$ 4.28	$ 60.56	$ 4.35	$ 60.56
CCB101010	$ 13.41	$ 62.68	$ 13.60	$ 62.68	$ 13.41	$ 61.20	$ 13.60	$ 61.20
CCC020202	$ 7.07	$ 41.69	$ 7.54	$ 41.69	$ 7.07	$ 40.21	$ 7.54	$ 40.21
CCC040404	$ 10.20	$ 45.78	$ 11.14	$ 45.78	$ 10.20	$ 44.31	$ 11.14	$ 44.31
CCC060606	$ 3.77	$ 52.44	$ 4.01	$ 52.44	$ 3.77	$ 50.96	$ 4.01	$ 50.96

CCC080808	$ 5.32	$ 59.48	$ 5.79	$ 59.48	$ 5.32	$ 58.00	$ 5.79	$ 58.00
CCC121212	$ 10.79	$ 84.57	$ 11.78	$ 84.57	$ 10.79	$ 83.09	$ 11.78	$ 83.09
CCC161616	$ 9.44	$ 124.63	$ 9.95	$ 124.63	$ 9.44	$ 123.15	$ 9.95	$ 123.15
EEE020202	$ 4.75	$ 38.74	$ 4.83	$ 38.74	$ 4.75	$ 37.27	$ 4.83	$ 37.27
EEE040404	$ 4.56	$ 43.74	$ 5.22	$ 43.74	$ 4.56	$ 42.26	$ 5.22	$ 42.26
EEE080808	$ 10.18	$ 69.08	$ 13.09	$ 69.08	$ 10.18	$ 67.60	$ 13.09	$ 67.60
EEE161616	$ 9.01	$ 113.75	$ 9.32	$ 113.75	$ 9.01	$ 112.27	$ 9.32	$ 112.27

Note. Costs are in NZD.

APPENDIX 24 – Sensitivity Analysis: Complexity Group 3 (I_R = 10%)

I_R	10%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
AAA020202	$ 8.22	$ 36.95	$ 8.77	$ 36.95	$ 8.22	$ 35.47	$ 8.77	$ 35.47
AAA060606	$ 444,154	$ 45.91	$ 444,155	$ 45.91	$ 444,154	$ 44.43	$ 444,155	$ 44.43
AAA080808	$ 174.93	$ 55.00	$ 176.17	$ 55.00	$ 174.93	$ 53.52	$ 176.17	$ 53.52
AAA121212	$ 689.45	$ 73.05	$ 691.99	$ 73.05	$ 689.45	$ 71.57	$ 691.99	$ 71.57
AAA161616	$ 882.43	$ 96.98	$ 886.83	$ 96.98	$ 882.43	$ 95.51	$ 886.83	$ 95.51
AAC060606	$ 7.51	$ 52.44	$ 8.26	$ 52.44	$ 7.51	$ 50.96	$ 8.26	$ 50.96
AAC080808	$ 92.06	$ 58.58	$ 92.85	$ 58.58	$ 92.06	$ 57.11	$ 92.85	$ 57.11
AAC121212	$ 5.78	$ 75.99	$ 6.07	$ 75.99	$ 5.78	$ 74.51	$ 6.07	$ 74.51
AAC161616	$ 8.04	$ 101.72	$ 8.39	$ 101.72	$ 8.04	$ 100.24	$ 8.39	$ 100.24
ACA040404	$ 3.42	$ 41.94	$ 4.04	$ 41.94	$ 3.42	$ 40.47	$ 4.04	$ 40.47
ACA060606	$ 3.51	$ 47.06	$ 4.14	$ 47.06	$ 3.51	$ 45.59	$ 4.14	$ 45.59
ACA080804	$ 5.67	$ 56.15	$ 6.56	$ 56.15	$ 5.67	$ 54.67	$ 6.56	$ 54.67
ACA080808	$ 4.41	$ 59.61	$ 5.15	$ 59.61	$ 4.41	$ 58.13	$ 5.15	$ 58.13
ACA121212	$ 6.78	$ 78.30	$ 7.63	$ 78.30	$ 6.78	$ 76.82	$ 7.63	$ 76.82
ACA161604	$ 15.04	$ 104.28	$ 15.44	$ 104.28	$ 15.04	$ 102.80	$ 15.44	$ 102.80
ACA161616	$ 9.88	$ 100.95	$ 10.83	$ 100.95	$ 9.88	$ 99.47	$ 10.83	$ 99.47
BBB040404	$ 6.20	$ 41.82	$ 6.54	$ 41.82	$ 6.20	$ 40.34	$ 6.54	$ 40.34
BBB060606	$ 3.83	$ 48.09	$ 4.28	$ 48.09	$ 3.83	$ 46.61	$ 4.28	$ 46.61
BBB080808	$ 3.45	$ 53.85	$ 3.80	$ 53.85	$ 3.45	$ 52.37	$ 3.80	$ 52.37
BBB121212	$ 9.38	$ 74.71	$ 9.70	$ 74.71	$ 9.38	$ 73.23	$ 9.70	$ 73.23
BBB161616	$ 7.66	$ 105.05	$ 7.83	$ 105.05	$ 7.66	$ 103.57	$ 7.83	$ 103.57
BBC040404	$ 7.35	$ 43.48	$ 7.50	$ 43.48	$ 7.35	$ 42.00	$ 7.50	$ 42.00
BBC060606	$ 4.85	$ 49.37	$ 4.99	$ 49.37	$ 4.85	$ 47.89	$ 4.99	$ 47.89
BBC080808	$ 3.16	$ 57.43	$ 3.35	$ 57.43	$ 3.16	$ 55.95	$ 3.35	$ 55.95
BBC121212	$ 10.42	$ 76.12	$ 11.01	$ 76.12	$ 10.42	$ 74.64	$ 11.01	$ 74.64
BBC161616	$ 27.70	$ 104.28	$ 27.83	$ 104.28	$ 27.70	$ 102.80	$ 27.83	$ 102.80
BCB040404	$ 19.51	$ 41.94	$ 23.46	$ 41.94	$ 19.51	$ 40.47	$ 23.46	$ 40.47
BCB060606	$ 2.39	$ 45.78	$ 2.49	$ 45.78	$ 2.39	$ 44.31	$ 2.49	$ 44.31
BCB080808	$ 8.78	$ 56.41	$ 10.54	$ 56.41	$ 8.78	$ 54.93	$ 10.54	$ 54.93
BCC040404	$ 2.33	$ 43.74	$ 2.38	$ 43.74	$ 2.33	$ 42.26	$ 2.38	$ 42.26
BCC080808	$ 4.34	$ 60.25	$ 4.41	$ 60.25	$ 4.34	$ 58.77	$ 4.41	$ 58.77
CCB040404	$ 7.35	$ 43.74	$ 7.67	$ 43.74	$ 7.35	$ 42.26	$ 7.67	$ 42.26
CCB080808	$ 4.32	$ 62.04	$ 4.39	$ 62.04	$ 4.32	$ 60.56	$ 4.39	$ 60.56
CCB101010	$ 13.51	$ 62.68	$ 13.70	$ 62.68	$ 13.51	$ 61.20	$ 13.70	$ 61.20
CCC020202	$ 7.93	$ 41.69	$ 8.40	$ 41.69	$ 7.93	$ 40.21	$ 8.40	$ 40.21
CCC040404	$ 10.69	$ 45.78	$ 11.62	$ 45.78	$ 10.69	$ 44.31	$ 11.62	$ 44.31
CCC060606	$ 3.89	$ 52.44	$ 4.14	$ 52.44	$ 3.89	$ 50.96	$ 4.14	$ 50.96

CCC080808	$ 5.57	$ 59.48	$ 6.04	$ 59.48	$ 5.57	$ 58.00	$ 6.04	$ 58.00
CCC121212	$ 11.26	$ 84.57	$ 12.26	$ 84.57	$ 11.26	$ 83.09	$ 12.26	$ 83.09
CCC161616	$ 10.12	$ 124.63	$ 10.63	$ 124.63	$ 10.12	$ 123.15	$ 10.63	$ 123.15
EEE020202	$ 4.78	$ 38.74	$ 4.86	$ 38.74	$ 4.78	$ 37.27	$ 4.86	$ 37.27
EEE040404	$ 4.88	$ 43.74	$ 5.54	$ 43.74	$ 4.88	$ 42.26	$ 5.54	$ 42.26
EEE080808	$ 23.48	$ 69.08	$ 26.39	$ 69.08	$ 23.48	$ 67.60	$ 26.39	$ 67.60
EEE161616	$ 9.19	$ 113.75	$ 9.50	$ 113.75	$ 9.19	$ 112.27	$ 9.50	$ 112.27

Note. Costs are in NZD.

APPENDIX 25 – Sensitivity Analysis: Complexity Group 4 (I_R = 5%)

I_R	5%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
K001-0204	$ 2.17	$ 44.37	$ 2.24	$ 44.37	$ 2.17	$ 42.60	$ 2.24	$ 42.60
K001-0404	$ 4.60	$ 46.29	$ 6.18	$ 46.29	$ 4.60	$ 44.52	$ 6.18	$ 44.52
K001-0406	$ 2.51	$ 49.49	$ 2.67	$ 49.49	$ 2.51	$ 47.72	$ 2.67	$ 47.72
K001-0604	$ 2.54	$ 48.21	$ 2.85	$ 48.21	$ 2.54	$ 46.44	$ 2.85	$ 46.44
K001-0606	$ 6.44	$ 51.41	$ 9.36	$ 51.41	$ 6.44	$ 49.64	$ 9.36	$ 49.64
K001-0608	$ 3.79	$ 53.97	$ 4.01	$ 53.97	$ 3.79	$ 52.20	$ 4.01	$ 52.20
K001-0806	$ 3.09	$ 55.25	$ 3.50	$ 55.25	$ 3.09	$ 53.48	$ 3.50	$ 53.48
K001-0808	$ 8.51	$ 57.81	$ 12.51	$ 57.81	$ 8.51	$ 56.04	$ 12.51	$ 56.04
K001-1208	$ 4.30	$ 63.57	$ 4.65	$ 63.57	$ 4.30	$ 61.80	$ 4.65	$ 61.80
K001-1212	$ 5.61	$ 70.61	$ 6.70	$ 70.61	$ 5.61	$ 68.84	$ 6.70	$ 68.84
K001-1616	$ 9.64	$ 84.05	$ 12.38	$ 84.05	$ 9.64	$ 82.28	$ 12.38	$ 82.28
K012-0404	$ 2.43	$ 46.29	$ 2.69	$ 46.29	$ 2.43	$ 44.52	$ 2.69	$ 44.52
K012-0606	$ 2.88	$ 52.05	$ 3.42	$ 52.05	$ 2.88	$ 50.28	$ 3.42	$ 50.28
K012-0806	$ 3.50	$ 54.61	$ 4.38	$ 54.61	$ 3.50	$ 52.84	$ 4.38	$ 52.84
K012-0808	$ 4.29	$ 57.17	$ 5.51	$ 57.17	$ 4.29	$ 55.40	$ 5.51	$ 55.40
K015-0404	$ 3.02	$ 46.29	$ 3.88	$ 46.29	$ 3.02	$ 44.52	$ 3.88	$ 44.52
K015-0406	$ 2.24	$ 48.85	$ 2.40	$ 48.85	$ 2.24	$ 47.08	$ 2.40	$ 47.08
K015-0604	$ 2.32	$ 46.93	$ 2.61	$ 46.93	$ 2.32	$ 45.16	$ 2.61	$ 45.16
K015-0606	$ 4.07	$ 50.13	$ 5.52	$ 50.13	$ 4.07	$ 48.36	$ 5.52	$ 48.36
K015-0608	$ 2.59	$ 53.33	$ 2.78	$ 53.33	$ 2.59	$ 51.56	$ 2.78	$ 51.56
K015-0806	$ 2.90	$ 54.61	$ 3.38	$ 54.61	$ 2.90	$ 52.84	$ 3.38	$ 52.84
K015-0808	$ 3.98	$ 66.77	$ 5.02	$ 66.77	$ 3.98	$ 65.00	$ 5.02	$ 65.00
K015-1208	$ 4.61	$ 58.45	$ 4.82	$ 58.45	$ 4.61	$ 56.68	$ 4.82	$ 56.68
K015-1212	$ 5.79	$ 67.41	$ 6.62	$ 67.41	$ 5.79	$ 65.64	$ 6.62	$ 65.64
K015-1616	$ 9.85	$ 90.45	$ 10.35	$ 90.45	$ 9.85	$ 88.68	$ 10.35	$ 88.68
K025-0404	$ 9.88	$ 48.21	$ 12.51	$ 48.21	$ 9.88	$ 46.44	$ 12.51	$ 46.44
K025-0604	$ 5.65	$ 52.05	$ 5.93	$ 52.05	$ 5.65	$ 50.28	$ 5.93	$ 50.28
K025-0606	$ 8.26	$ 55.25	$ 10.65	$ 55.25	$ 8.26	$ 53.48	$ 10.65	$ 53.48
K025-0806	$ 6.74	$ 189.01	$ 7.05	$ 189.01	$ 6.74	$ 187.24	$ 7.05	$ 187.24
K025-0808	$ 10.64	$ 66.13	$ 13.48	$ 66.13	$ 10.64	$ 64.36	$ 13.48	$ 64.36
K025-1008	$ 9.53	$ 65.49	$ 10.05	$ 65.49	$ 9.53	$ 63.72	$ 10.05	$ 63.72
K025-1212	$ 10.99	$ 86.61	$ 11.76	$ 86.61	$ 10.99	$ 84.84	$ 11.76	$ 84.84
K025-1616	$ 17.75	$ 119.25	$ 19.49	$ 119.25	$ 17.75	$ 117.48	$ 19.49	$ 117.48
K051-0404	$ 5.17	$ 47.95	$ 6.85	$ 47.95	$ 5.17	$ 46.18	$ 6.85	$ 46.18
K051-0604	$ 2.97	$ 50.13	$ 3.04	$ 50.13	$ 2.97	$ 48.36	$ 3.04	$ 48.36
K051-0606	$ 5.37	$ 53.97	$ 6.97	$ 53.97	$ 5.37	$ 52.20	$ 6.97	$ 52.20

K051-0806	$ 3.80	$ 57.17	$ 4.06	$ 57.17	$ 3.80	$ 55.40	$ 4.06	$ 55.40
K051-0808	$ 7.40	$ 61.01	$ 9.90	$ 61.01	$ 7.40	$ 59.24	$ 9.90	$ 59.24
K051-1212	$ 7.56	$ 84.69	$ 9.27	$ 84.69	$ 7.56	$ 82.92	$ 9.27	$ 82.92
K051-1616	$ 9.79	$ 114.13	$ 10.97	$ 114.13	$ 9.79	$ 112.36	$ 10.97	$ 112.36
K060-0404	$ 5.23	$ 47.57	$ 6.32	$ 47.57	$ 5.23	$ 45.80	$ 6.32	$ 45.80
K060-0604	$ 3.10	$ 49.49	$ 3.25	$ 49.49	$ 3.10	$ 47.72	$ 3.25	$ 47.72
K060-0606	$ 3.99	$ 53.33	$ 4.77	$ 53.33	$ 3.99	$ 51.56	$ 4.77	$ 51.56
K060-0806	$ 4.44	$ 56.53	$ 5.10	$ 56.53	$ 4.44	$ 54.76	$ 5.10	$ 54.76
K060-0808	$ 7.35	$ 60.37	$ 8.74	$ 60.37	$ 7.35	$ 58.60	$ 8.74	$ 58.60
K060-1212	$ 5.90	$ 79.57	$ 6.50	$ 79.57	$ 5.90	$ 77.80	$ 6.50	$ 77.80
K060-1616	$ 8.67	$ 105.81	$ 9.78	$ 105.81	$ 8.67	$ 104.04	$ 9.78	$ 104.04
K005-0704	$ 3.42	$ 45.01	$ 4.47	$ 45.01	$ 3.42	$ 43.24	$ 4.47	$ 43.24
K005-0706	$ 2.95	$ 48.21	$ 3.44	$ 48.21	$ 2.95	$ 46.44	$ 3.44	$ 46.44
K005-0804	$ 2.95	$ 45.65	$ 3.20	$ 45.65	$ 2.95	$ 43.88	$ 3.20	$ 43.88
K005-0904	$ 3.96	$ 46.29	$ 4.56	$ 46.29	$ 3.96	$ 44.52	$ 4.56	$ 44.52
K005-0906	$ 5.16	$ 49.49	$ 6.50	$ 49.49	$ 5.16	$ 47.72	$ 6.50	$ 47.72
K005-1206	$ 3.49	$ 53.33	$ 4.24	$ 53.33	$ 3.49	$ 51.56	$ 4.24	$ 51.56
K005-1208	$ 7.01	$ 56.53	$ 8.78	$ 56.53	$ 7.01	$ 54.76	$ 8.78	$ 54.76
K005-1408	$ 12.03	$ 57.81	$ 17.32	$ 57.81	$ 12.03	$ 56.04	$ 17.32	$ 56.04
K005-1708	$ 5.46	$ 60.37	$ 6.48	$ 60.37	$ 5.46	$ 58.60	$ 6.48	$ 58.60
K005-1712	$ 5.91	$ 68.69	$ 6.87	$ 68.69	$ 5.91	$ 66.92	$ 6.87	$ 66.92
K005-2116	$ 6.94	$ 85.33	$ 7.57	$ 85.33	$ 6.94	$ 83.56	$ 7.57	$ 83.56
K018-0704	$ 2.42	$ 44.37	$ 2.50	$ 44.37	$ 2.42	$ 42.60	$ 2.50	$ 42.60
K018-0804	$ 2.01	$ 45.01	$ 2.12	$ 45.01	$ 2.01	$ 43.24	$ 2.12	$ 43.24
K018-0904	$ 2.65	$ 45.65	$ 2.81	$ 45.65	$ 2.65	$ 43.88	$ 2.81	$ 43.88
K018-0906	$ 3.21	$ 49.49	$ 3.45	$ 49.49	$ 3.21	$ 47.72	$ 3.45	$ 47.72
K018-1206	$ 3.05	$ 50.77	$ 3.23	$ 50.77	$ 3.05	$ 49.00	$ 3.23	$ 49.00
K018-1208	$ 2.53	$ 53.33	$ 2.79	$ 53.33	$ 2.53	$ 51.56	$ 2.79	$ 51.56
K018-1408	$ 2.99	$ 55.89	$ 3.37	$ 55.89	$ 2.99	$ 54.12	$ 3.37	$ 54.12
K018-1712	$ 4.21	$ 68.05	$ 4.54	$ 68.05	$ 4.21	$ 66.28	$ 4.54	$ 66.28
K018-2116	$ 5.99	$ 91.09	$ 6.19	$ 91.09	$ 5.99	$ 89.32	$ 6.19	$ 89.32
K029-0704	$ 5.43	$ 46.93	$ 6.04	$ 46.93	$ 5.43	$ 45.16	$ 6.04	$ 45.16
K029-0904	$ 7.42	$ 50.77	$ 7.92	$ 50.77	$ 7.42	$ 49.00	$ 7.92	$ 49.00
K029-0906	$ 7.41	$ 53.97	$ 7.94	$ 53.97	$ 7.41	$ 52.20	$ 7.94	$ 52.20
K029-1206	$ 6.75	$ 61.01	$ 7.11	$ 61.01	$ 6.75	$ 59.24	$ 7.11	$ 59.24
K029-1408	$ 9.37	$ 66.77	$ 10.10	$ 66.77	$ 9.37	$ 65.00	$ 10.10	$ 65.00
K055-0704	$ 4.00	$ 46.93	$ 4.60	$ 46.93	$ 4.00	$ 45.16	$ 4.60	$ 45.16
K055-0804	$ 3.49	$ 47.57	$ 3.69	$ 47.57	$ 3.49	$ 45.80	$ 3.69	$ 45.80
K055-0904	$ 4.40	$ 48.21	$ 4.65	$ 48.21	$ 4.40	$ 46.44	$ 4.65	$ 46.44
K055-0906	$ 4.18	$ 52.69	$ 4.83	$ 52.69	$ 4.18	$ 50.92	$ 4.83	$ 50.92
K055-1206	$ 4.86	$ 55.89	$ 5.23	$ 55.89	$ 4.86	$ 54.12	$ 5.23	$ 54.12
K055-1208	$ 7.33	$ 61.01	$ 8.67	$ 61.01	$ 7.33	$ 59.24	$ 8.67	$ 59.24
K055-1408	$ 6.12	$ 61.01	$ 7.49	$ 61.01	$ 6.12	$ 59.24	$ 7.49	$ 59.24
K055-1712	$ 9.15	$ 84.69	$ 9.79	$ 84.69	$ 9.15	$ 82.92	$ 9.79	$ 82.92

K055-2116	$ 9.93	$ 115.41	$ 10.36	$ 115.41	$ 9.93	$ 113.64	$ 10.36	$ 113.64
K064-0704	$ 3.65	$ 45.65	$ 4.18	$ 45.65	$ 3.65	$ 43.88	$ 4.18	$ 43.88
K064-0904	$ 3.29	$ 47.57	$ 3.55	$ 47.57	$ 3.29	$ 45.80	$ 3.55	$ 45.80
K064-0906	$ 3.55	$ 52.05	$ 3.86	$ 52.05	$ 3.55	$ 50.28	$ 3.86	$ 50.28
K064-1206	$ 4.20	$ 55.25	$ 4.86	$ 55.25	$ 4.20	$ 53.48	$ 4.86	$ 53.48
K064-1208	$ 4.88	$ 59.73	$ 5.76	$ 59.73	$ 4.88	$ 57.96	$ 5.76	$ 57.96
K064-1408	$ 7.17	$ 61.01	$ 9.03	$ 61.01	$ 7.17	$ 59.24	$ 9.03	$ 59.24

Note. Costs are in NZD.

APPENDIX 26– Sensitivity Analysis: Complexity Group 4 (I_R = 10%)

I_R	10%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
K001-0204	$ 2.21	$ 44.37	$ 2.28	$ 44.37	$ 2.21	$ 42.60	$ 2.28	$ 42.60
K001-0404	$ 5.65	$ 46.29	$ 7.24	$ 46.29	$ 5.65	$ 44.52	$ 7.24	$ 44.52
K001-0406	$ 2.59	$ 49.49	$ 2.76	$ 49.49	$ 2.59	$ 47.72	$ 2.76	$ 47.72
K001-0604	$ 2.70	$ 48.21	$ 3.00	$ 48.21	$ 2.70	$ 46.44	$ 3.00	$ 46.44
K001-0606	$ 7.83	$ 51.41	$ 10.76	$ 51.41	$ 7.83	$ 49.64	$ 10.76	$ 49.64
K001-0608	$ 3.90	$ 53.97	$ 4.12	$ 53.97	$ 3.90	$ 52.20	$ 4.12	$ 52.20
K001-0806	$ 3.30	$ 55.25	$ 3.71	$ 55.25	$ 3.30	$ 53.48	$ 3.71	$ 53.48
K001-0808	$ 10.49	$ 57.81	$ 14.50	$ 57.81	$ 10.49	$ 56.04	$ 14.50	$ 56.04
K001-1208	$ 4.47	$ 63.57	$ 4.83	$ 63.57	$ 4.47	$ 61.80	$ 4.83	$ 61.80
K001-1212	$ 6.16	$ 70.61	$ 7.25	$ 70.61	$ 6.16	$ 68.84	$ 7.25	$ 68.84
K001-1616	$ 10.98	$ 84.05	$ 13.71	$ 84.05	$ 10.98	$ 82.28	$ 13.71	$ 82.28
K012-0404	$ 2.55	$ 46.29	$ 2.81	$ 46.29	$ 2.55	$ 44.52	$ 2.81	$ 44.52
K012-0606	$ 3.14	$ 52.05	$ 3.68	$ 52.05	$ 3.14	$ 50.28	$ 3.68	$ 50.28
K012-0806	$ 3.91	$ 54.61	$ 4.79	$ 54.61	$ 3.91	$ 52.84	$ 4.79	$ 52.84
K012-0808	$ 4.87	$ 57.17	$ 6.08	$ 57.17	$ 4.87	$ 55.40	$ 6.08	$ 55.40
K015-0404	$ 3.40	$ 46.29	$ 4.27	$ 46.29	$ 3.40	$ 44.52	$ 4.27	$ 44.52
K015-0406	$ 2.31	$ 48.85	$ 2.47	$ 48.85	$ 2.31	$ 47.08	$ 2.47	$ 47.08
K015-0604	$ 2.45	$ 46.93	$ 2.73	$ 46.93	$ 2.45	$ 45.16	$ 2.73	$ 45.16
K015-0606	$ 4.74	$ 50.13	$ 6.19	$ 50.13	$ 4.74	$ 48.36	$ 6.19	$ 48.36
K015-0608	$ 2.68	$ 53.33	$ 2.88	$ 53.33	$ 2.68	$ 51.56	$ 2.88	$ 51.56
K015-0806	$ 3.16	$ 54.61	$ 3.64	$ 54.61	$ 3.16	$ 52.84	$ 3.64	$ 52.84
K015-0808	$ 4.55	$ 66.77	$ 5.59	$ 66.77	$ 4.55	$ 65.00	$ 5.59	$ 65.00
K015-1208	$ 4.71	$ 58.45	$ 4.92	$ 58.45	$ 4.71	$ 56.68	$ 4.92	$ 56.68
K015-1212	$ 6.18	$ 67.41	$ 7.01	$ 67.41	$ 6.18	$ 65.64	$ 7.01	$ 65.64
K015-1616	$ 10.10	$ 90.45	$ 10.60	$ 90.45	$ 10.10	$ 88.68	$ 10.60	$ 88.68
K025-0404	$ 11.04	$ 48.21	$ 13.67	$ 48.21	$ 11.04	$ 46.44	$ 13.67	$ 46.44
K025-0604	$ 5.78	$ 52.05	$ 6.05	$ 52.05	$ 5.78	$ 50.28	$ 6.05	$ 50.28
K025-0606	$ 9.43	$ 55.25	$ 11.81	$ 55.25	$ 9.43	$ 53.48	$ 11.81	$ 53.48
K025-0806	$ 6.89	$ 189.01	$ 7.20	$ 189.01	$ 6.89	$ 187.24	$ 7.20	$ 187.24
K025-0808	$ 12.01	$ 66.13	$ 14.85	$ 66.13	$ 12.01	$ 64.36	$ 14.85	$ 64.36
K025-1008	$ 10.20	$ 65.49	$ 10.72	$ 65.49	$ 10.20	$ 63.72	$ 10.72	$ 63.72
K025-1212	$ 11.46	$ 86.61	$ 12.23	$ 86.61	$ 11.46	$ 84.84	$ 12.23	$ 84.84
K025-1616	$ 18.57	$ 119.25	$ 20.31	$ 119.25	$ 18.57	$ 117.48	$ 20.31	$ 117.48
K051-0404	$ 5.97	$ 47.95	$ 7.65	$ 47.95	$ 5.97	$ 46.18	$ 7.65	$ 46.18
K051-0604	$ 3.01	$ 50.13	$ 3.07	$ 50.13	$ 3.01	$ 48.36	$ 3.07	$ 48.36
K051-0606	$ 6.17	$ 53.97	$ 7.77	$ 53.97	$ 6.17	$ 52.20	$ 7.77	$ 52.20
K051-0806	$ 3.92	$ 57.17	$ 4.18	$ 57.17	$ 3.92	$ 55.40	$ 4.18	$ 55.40

K051-0808	$ 8.77	$ 61.01	$ 11.28	$ 61.01	$ 8.77	$ 59.24	$ 11.28	$ 59.24
K051-1212	$ 8.36	$ 84.69	$ 10.07	$ 84.69	$ 8.36	$ 82.92	$ 10.07	$ 82.92
K051-1616	$ 10.34	$ 114.13	$ 11.52	$ 114.13	$ 10.34	$ 112.36	$ 11.52	$ 112.36
K060-0404	$ 5.73	$ 47.57	$ 6.83	$ 47.57	$ 5.73	$ 45.80	$ 6.83	$ 45.80
K060-0604	$ 3.17	$ 49.49	$ 3.32	$ 49.49	$ 3.17	$ 47.72	$ 3.32	$ 47.72
K060-0606	$ 4.37	$ 53.33	$ 5.15	$ 53.33	$ 4.37	$ 51.56	$ 5.15	$ 51.56
K060-0806	$ 5.09	$ 56.53	$ 5.75	$ 56.53	$ 5.09	$ 54.76	$ 5.75	$ 54.76
K060-0808	$ 8.04	$ 60.37	$ 9.43	$ 60.37	$ 8.04	$ 58.60	$ 9.43	$ 58.60
K060-1212	$ 6.17	$ 79.57	$ 6.78	$ 79.57	$ 6.17	$ 77.80	$ 6.78	$ 77.80
K060-1616	$ 9.25	$ 105.81	$ 10.36	$ 105.81	$ 9.25	$ 104.04	$ 10.36	$ 104.04
K005-0704	$ 3.89	$ 45.01	$ 4.94	$ 45.01	$ 3.89	$ 43.24	$ 4.94	$ 43.24
K005-0706	$ 3.22	$ 48.21	$ 3.71	$ 48.21	$ 3.22	$ 46.44	$ 3.71	$ 46.44
K005-0804	$ 3.07	$ 45.65	$ 3.32	$ 45.65	$ 3.07	$ 43.88	$ 3.32	$ 43.88
K005-0904	$ 4.55	$ 46.29	$ 5.15	$ 46.29	$ 4.55	$ 44.52	$ 5.15	$ 44.52
K005-0906	$ 6.08	$ 49.49	$ 7.42	$ 49.49	$ 6.08	$ 47.72	$ 7.42	$ 47.72
K005-1206	$ 3.85	$ 53.33	$ 4.60	$ 53.33	$ 3.85	$ 51.56	$ 4.60	$ 51.56
K005-1208	$ 8.69	$ 56.53	$ 10.46	$ 56.53	$ 8.69	$ 54.76	$ 10.46	$ 54.76
K005-1408	$ 14.31	$ 57.81	$ 19.60	$ 57.81	$ 14.31	$ 56.04	$ 19.60	$ 56.04
K005-1708	$ 5.95	$ 60.37	$ 6.97	$ 60.37	$ 5.95	$ 58.60	$ 6.97	$ 58.60
K005-1712	$ 6.38	$ 68.69	$ 7.34	$ 68.69	$ 6.38	$ 66.92	$ 7.34	$ 66.92
K005-2116	$ 7.24	$ 85.33	$ 7.88	$ 85.33	$ 7.24	$ 83.56	$ 7.88	$ 83.56
K018-0704	$ 2.46	$ 44.37	$ 2.54	$ 44.37	$ 2.46	$ 42.60	$ 2.54	$ 42.60
K018-0804	$ 2.06	$ 45.01	$ 2.17	$ 45.01	$ 2.06	$ 43.24	$ 2.17	$ 43.24
K018-0904	$ 2.73	$ 45.65	$ 2.90	$ 45.65	$ 2.73	$ 43.88	$ 2.90	$ 43.88
K018-0906	$ 3.33	$ 49.49	$ 3.57	$ 49.49	$ 3.33	$ 47.72	$ 3.57	$ 47.72
K018-1206	$ 3.15	$ 50.77	$ 3.32	$ 50.77	$ 3.15	$ 49.00	$ 3.32	$ 49.00
K018-1208	$ 2.65	$ 53.33	$ 2.91	$ 53.33	$ 2.65	$ 51.56	$ 2.91	$ 51.56
K018-1408	$ 3.16	$ 55.89	$ 3.54	$ 55.89	$ 3.16	$ 54.12	$ 3.54	$ 54.12
K018-1712	$ 4.37	$ 68.05	$ 4.71	$ 68.05	$ 4.37	$ 66.28	$ 4.71	$ 66.28
K018-2116	$ 6.09	$ 91.09	$ 6.29	$ 91.09	$ 6.09	$ 89.32	$ 6.29	$ 89.32
K029-0704	$ 5.71	$ 46.93	$ 6.33	$ 46.93	$ 5.71	$ 45.16	$ 6.33	$ 45.16
K029-0904	$ 7.68	$ 50.77	$ 8.18	$ 50.77	$ 7.68	$ 49.00	$ 8.18	$ 49.00
K029-0906	$ 7.73	$ 53.97	$ 8.25	$ 53.97	$ 7.73	$ 52.20	$ 8.25	$ 52.20
K029-1206	$ 6.92	$ 61.01	$ 7.28	$ 61.01	$ 6.92	$ 59.24	$ 7.28	$ 59.24
K029-1408	$ 9.71	$ 66.77	$ 10.43	$ 66.77	$ 9.71	$ 65.00	$ 10.43	$ 65.00
K055-0704	$ 4.41	$ 46.93	$ 5.01	$ 46.93	$ 4.41	$ 45.16	$ 5.01	$ 45.16
K055-0804	$ 3.58	$ 47.57	$ 3.78	$ 47.57	$ 3.58	$ 45.80	$ 3.78	$ 45.80
K055-0904	$ 4.58	$ 48.21	$ 4.83	$ 48.21	$ 4.58	$ 46.44	$ 4.83	$ 46.44
K055-0906	$ 4.63	$ 52.69	$ 5.28	$ 52.69	$ 4.63	$ 50.92	$ 5.28	$ 50.92
K055-1206	$ 5.06	$ 55.89	$ 5.44	$ 55.89	$ 5.06	$ 54.12	$ 5.44	$ 54.12
K055-1208	$ 8.27	$ 61.01	$ 9.62	$ 61.01	$ 8.27	$ 59.24	$ 9.62	$ 59.24
K055-1408	$ 6.81	$ 61.01	$ 8.18	$ 61.01	$ 6.81	$ 59.24	$ 8.18	$ 59.24
K055-1712	$ 9.50	$ 84.69	$ 10.14	$ 84.69	$ 9.50	$ 82.92	$ 10.14	$ 82.92
K055-2116	$ 10.13	$ 115.41	$ 10.56	$ 115.41	$ 10.13	$ 113.64	$ 10.56	$ 113.64

K064-0704	$ 3.93	$ 45.65	$ 4.46	$ 45.65	$ 3.93	$ 43.88	$ 4.46	$ 43.88
K064-0904	$ 3.42	$ 47.57	$ 3.68	$ 47.57	$ 3.42	$ 45.80	$ 3.68	$ 45.80
K064-0906	$ 3.74	$ 52.05	$ 4.04	$ 52.05	$ 3.74	$ 50.28	$ 4.04	$ 50.28
K064-1206	$ 4.50	$ 55.25	$ 5.16	$ 55.25	$ 4.50	$ 53.48	$ 5.16	$ 53.48
K064-1208	$ 5.50	$ 59.73	$ 6.38	$ 59.73	$ 5.50	$ 57.96	$ 6.38	$ 57.96
K064-1408	$ 8.07	$ 61.01	$ 9.93	$ 61.01	$ 8.07	$ 59.24	$ 9.93	$ 59.24

Note. Costs are in NZD.

APPENDIX 27– Sensitivity Analysis: Complexity Group 5 (I_R = 5%)

I_R	5%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
PDV1-0606002	$ 9.32	$ 76.43	$ 12.05	$ 76.43	$ 9.32	$ 73.51	$ 12.05	$ 73.51
PDV1-0606003	$ 7.26	$ 67.21	$ 10.34	$ 67.21	$ 7.26	$ 64.30	$ 10.34	$ 64.30
PDV1-1010002	$ 8.79	$ 86.92	$ 10.82	$ 86.92	$ 8.79	$ 84.01	$ 10.82	$ 84.01
PDV1-1010003	$ 8.94	$ 71.56	$ 12.90	$ 71.56	$ 8.94	$ 68.65	$ 12.90	$ 68.65
PDV1-1313002	$ 44.85	$ 95.63	$ 71.57	$ 95.63	$ 44.85	$ 92.71	$ 71.57	$ 92.71
PDV1-1313003	$ 22.68	$ 73.74	$ 36.25	$ 73.74	$ 22.68	$ 70.83	$ 36.25	$ 70.83
PDV1-2019002	$ 21.21	$ 121.87	$ 27.46	$ 121.87	$ 21.21	$ 118.95	$ 27.46	$ 118.95
PDV1-2019003	$ 11.45	$ 84.75	$ 15.27	$ 84.75	$ 11.45	$ 81.83	$ 15.27	$ 81.83
PDV1-2525002	$ 33.53	$ 155.53	$ 37.00	$ 155.53	$ 33.53	$ 152.62	$ 37.00	$ 152.62
PDV1-2525003	$ 15.92	$ 97.42	$ 18.28	$ 97.42	$ 15.92	$ 94.51	$ 18.28	$ 94.51
PPV1-1313002	$ 10.73	$ 99.47	$ 13.37	$ 99.47	$ 10.73	$ 96.55	$ 13.37	$ 96.55
PKKL-1313003	$ 5.51	$ 73.61	$ 5.72	$ 73.61	$ 5.51	$ 70.70	$ 5.72	$ 70.70
PDS1-0606002	$ 13.22	$ 77.58	$ 15.62	$ 77.58	$ 13.22	$ 74.67	$ 15.62	$ 74.67
PDS1-0606003	$ 6.91	$ 67.34	$ 8.10	$ 67.34	$ 6.91	$ 64.43	$ 8.10	$ 64.43
PDS1-1010002	$ 11.01	$ 87.82	$ 12.63	$ 87.82	$ 11.01	$ 84.91	$ 12.63	$ 84.91
PDS1-1010003	$ 6.34	$ 72.33	$ 7.48	$ 72.33	$ 6.34	$ 69.42	$ 7.48	$ 69.42
PDS1-1313002	$ 11.58	$ 96.27	$ 13.32	$ 96.27	$ 11.58	$ 93.35	$ 13.32	$ 93.35
PDS1-1313003	$ 8.78	$ 74.25	$ 11.26	$ 74.25	$ 8.78	$ 71.34	$ 11.26	$ 71.34
PDS1-2019002	$ 14.72	$ 124.55	$ 15.67	$ 124.55	$ 14.72	$ 121.64	$ 15.67	$ 121.64
PDS1-2019003	$ 6.61	$ 87.56	$ 6.77	$ 87.56	$ 6.61	$ 84.65	$ 6.77	$ 84.65
PDS1-2525002	$ 46.72	$ 159.63	$ 51.21	$ 159.63	$ 46.72	$ 156.71	$ 51.21	$ 156.71
PDS1-2525003	$ 29.78	$ 99.98	$ 33.26	$ 99.98	$ 29.78	$ 97.07	$ 33.26	$ 97.07
PLT1-0606002	$ 14.06	$ 84.49	$ 15.47	$ 84.49	$ 14.06	$ 81.58	$ 15.47	$ 81.58
PLT1-0606003	$ 6.72	$ 73.61	$ 7.53	$ 73.61	$ 6.72	$ 70.70	$ 7.53	$ 70.70
PLT1-1310002	$ 21.12	$ 94.09	$ 26.21	$ 94.09	$ 21.12	$ 91.18	$ 26.21	$ 91.18
PLT1-1310003	$ 8.01	$ 81.29	$ 8.22	$ 81.29	$ 8.01	$ 78.38	$ 8.22	$ 78.38
PLT1-1313002	$ 72.08	$ 93.71	$ 80.88	$ 93.71	$ 72.08	$ 90.79	$ 80.88	$ 90.79
PLT1-1313003	$ 37.81	$ 80.65	$ 39.84	$ 80.65	$ 37.81	$ 77.74	$ 39.84	$ 77.74
PLT1-2019002	$ 113.55	$ 118.28	$ 116.26	$ 118.28	$ 113.55	$ 115.37	$ 116.26	$ 115.37
PLT1-2019003	$ 64.86	$ 97.42	$ 66.70	$ 97.42	$ 64.86	$ 94.51	$ 66.70	$ 94.51
PLT1-2525002	$ 49.84	$ 162.31	$ 52.33	$ 162.31	$ 49.84	$ 159.40	$ 52.33	$ 159.40
PLT1-2525003	$ 22.49	$ 115.47	$ 24.19	$ 115.47	$ 22.49	$ 112.55	$ 24.19	$ 112.55
PVV3-0606112	$ 12.38	$ 77.45	$ 13.31	$ 77.45	$ 12.38	$ 74.54	$ 13.31	$ 74.54
PVV3-0606113	$ 14.68	$ 83.98	$ 15.09	$ 83.98	$ 14.68	$ 81.07	$ 15.09	$ 81.07
PVV3-1010112	$ 17.80	$ 81.42	$ 18.87	$ 81.42	$ 17.80	$ 78.51	$ 18.87	$ 78.51
PVV3-1010113	$ 17.91	$ 82.06	$ 19.13	$ 82.06	$ 17.91	$ 79.15	$ 19.13	$ 79.15
PVV3-1313112	$ 9.03	$ 101.26	$ 9.72	$ 101.26	$ 9.03	$ 98.35	$ 9.72	$ 98.35

PVV3-1313113	$ 7.92	$ 97.29	$ 8.57	$ 97.29	$ 7.92	$ 94.38	$ 8.57	$ 94.38
PVV3-2019112	$ 20.51	$ 122.38	$ 22.39	$ 122.38	$ 20.51	$ 119.47	$ 22.39	$ 119.47
PVV3-2019113	$ 21.18	$ 115.08	$ 23.12	$ 115.08	$ 21.18	$ 112.17	$ 23.12	$ 112.17
PVV3-2525112	$ 25.41	$ 161.42	$ 26.22	$ 161.42	$ 25.41	$ 158.51	$ 26.22	$ 158.51
PVV3-2525113	$ 22.20	$ 143.37	$ 23.48	$ 143.37	$ 22.20	$ 140.46	$ 23.48	$ 140.46
PBR16-FB	$ 53.31	$ 221.58	$ 67.24	$ 221.58	$ 53.31	$ 218.67	$ 67.24	$ 218.67
PBR16-MP	$ 21.60	$ 120.07	$ 26.18	$ 120.07	$ 21.60	$ 117.16	$ 26.18	$ 117.16

Note. Costs are in NZD.

APPENDIX 28– Sensitivity Analysis: Complexity Group 5 (I_R = 10%)

I_R	10%							
μ	80%				85%			
β	0.5%		1.0%		0.5%		1.0%	
SKU	TM	3DP	TM	3DP	TM	3DP	TM	3DP
PDV1-0606002	$ 10.69	$ 76.43	$ 13.42	$ 76.43	$ 10.69	$ 73.51	$ 13.42	$ 73.51
PDV1-0606003	$ 8.75	$ 67.21	$ 11.83	$ 67.21	$ 8.75	$ 64.30	$ 11.83	$ 64.30
PDV1-1010002	$ 9.71	$ 86.92	$ 11.73	$ 86.92	$ 9.71	$ 84.01	$ 11.73	$ 84.01
PDV1-1010003	$ 10.79	$ 71.56	$ 14.74	$ 71.56	$ 10.79	$ 68.65	$ 14.74	$ 68.65
PDV1-1313002	$ 56.99	$ 95.63	$ 83.71	$ 95.63	$ 56.99	$ 92.71	$ 83.71	$ 92.71
PDV1-1313003	$ 29.00	$ 73.74	$ 42.56	$ 73.74	$ 29.00	$ 70.83	$ 42.56	$ 70.83
PDV1-2019002	$ 24.31	$ 121.87	$ 30.56	$ 121.87	$ 24.31	$ 118.95	$ 30.56	$ 118.95
PDV1-2019003	$ 13.31	$ 84.75	$ 17.12	$ 84.75	$ 13.31	$ 81.83	$ 17.12	$ 81.83
PDV1-2525002	$ 35.18	$ 155.53	$ 38.65	$ 155.53	$ 35.18	$ 152.62	$ 38.65	$ 152.62
PDV1-2525003	$ 17.01	$ 97.42	$ 19.38	$ 97.42	$ 17.01	$ 94.51	$ 19.38	$ 94.51
PPV1-1313002	$ 12.02	$ 99.47	$ 14.65	$ 99.47	$ 12.02	$ 96.55	$ 14.65	$ 96.55
PKKL-1313003	$ 5.61	$ 73.61	$ 5.81	$ 73.61	$ 5.61	$ 70.70	$ 5.81	$ 70.70
PDS1-0606002	$ 35.18	$ 77.58	$ 37.59	$ 77.58	$ 35.18	$ 74.67	$ 37.59	$ 74.67
PDS1-0606003	$ 17.67	$ 67.34	$ 18.87	$ 67.34	$ 17.67	$ 64.43	$ 18.87	$ 64.43
PDS1-1010002	$ 12.06	$ 87.82	$ 13.68	$ 87.82	$ 12.06	$ 84.91	$ 13.68	$ 84.91
PDS1-1010003	$ 7.33	$ 72.33	$ 8.47	$ 72.33	$ 7.33	$ 69.42	$ 8.47	$ 69.42
PDS1-1313002	$ 12.71	$ 96.27	$ 14.45	$ 96.27	$ 12.71	$ 93.35	$ 14.45	$ 93.35
PDS1-1313003	$ 19.73	$ 74.25	$ 22.21	$ 74.25	$ 19.73	$ 71.34	$ 22.21	$ 71.34
PDS1-2019002	$ 15.17	$ 124.55	$ 16.12	$ 124.55	$ 15.17	$ 121.64	$ 16.12	$ 121.64
PDS1-2019003	$ 6.71	$ 87.56	$ 6.88	$ 87.56	$ 6.71	$ 84.65	$ 6.88	$ 84.65
PDS1-2525002	$ 61.90	$ 159.63	$ 66.39	$ 159.63	$ 61.90	$ 156.71	$ 66.39	$ 156.71
PDS1-2525003	$ 54.39	$ 99.98	$ 57.88	$ 99.98	$ 54.39	$ 97.07	$ 57.88	$ 97.07
PLT1-0606002	$ 14.85	$ 84.49	$ 16.26	$ 84.49	$ 14.85	$ 81.58	$ 16.26	$ 81.58
PLT1-0606003	$ 7.42	$ 73.61	$ 8.23	$ 73.61	$ 7.42	$ 70.70	$ 8.23	$ 70.70
PLT1-1310002	$ 24.15	$ 94.09	$ 29.24	$ 94.09	$ 24.15	$ 91.18	$ 29.24	$ 91.18
PLT1-1310003	$ 8.12	$ 81.29	$ 8.33	$ 81.29	$ 8.12	$ 78.38	$ 8.33	$ 78.38
PLT1-1313002	$ 75.98	$ 93.71	$ 84.77	$ 93.71	$ 75.98	$ 90.79	$ 84.77	$ 90.79
PLT1-1313003	$ 39.01	$ 80.65	$ 41.05	$ 80.65	$ 39.01	$ 77.74	$ 41.05	$ 77.74
PLT1-2019002	$ 115.08	$ 118.28	$ 117.80	$ 118.28	$ 115.08	$ 115.37	$ 117.80	$ 115.37
PLT1-2019003	$ 65.68	$ 97.42	$ 67.52	$ 97.42	$ 65.68	$ 94.51	$ 67.52	$ 94.51
PLT1-2525002	$ 52.53	$ 162.31	$ 55.01	$ 162.31	$ 52.53	$ 159.40	$ 55.01	$ 159.40
PLT1-2525003	$ 25.77	$ 115.47	$ 27.46	$ 115.47	$ 25.77	$ 112.55	$ 27.46	$ 112.55
PVV3-0606112	$ 12.80	$ 77.45	$ 13.73	$ 77.45	$ 12.80	$ 74.54	$ 13.73	$ 74.54
PVV3-0606113	$ 14.85	$ 83.98	$ 15.26	$ 83.98	$ 14.85	$ 81.07	$ 15.26	$ 81.07
PVV3-1010112	$ 19.34	$ 81.42	$ 20.41	$ 81.42	$ 19.34	$ 78.51	$ 20.41	$ 78.51
PVV3-1010113	$ 18.93	$ 82.06	$ 20.16	$ 82.06	$ 18.93	$ 79.15	$ 20.16	$ 79.15
PVV3-1313112	$ 9.40	$ 101.26	$ 10.09	$ 101.26	$ 9.40	$ 98.35	$ 10.09	$ 98.35

PVV3-1313113	$ 8.23	$ 97.29	$ 8.89	$ 97.29	$ 8.23	$ 94.38	$ 8.89	$ 94.38
PVV3-2019112	$ 21.37	$ 122.38	$ 23.25	$ 122.38	$ 21.37	$ 119.47	$ 23.25	$ 119.47
PVV3-2019113	$ 22.08	$ 115.08	$ 24.02	$ 115.08	$ 22.08	$ 112.17	$ 24.02	$ 112.17
PVV3-2525112	$ 25.99	$ 161.42	$ 26.81	$ 161.42	$ 25.99	$ 158.51	$ 26.81	$ 158.51
PVV3-2525113	$ 22.80	$ 143.37	$ 24.07	$ 143.37	$ 22.80	$ 140.46	$ 24.07	$ 140.46
PBR16-FB	$ 60.33	$ 221.58	$ 74.27	$ 221.58	$ 60.33	$ 218.67	$ 74.27	$ 218.67
PBR16-MP	$ 24.04	$ 120.07	$ 28.62	$ 120.07	$ 24.04	$ 117.16	$ 28.62	$ 117.16

Note. Costs are in NZD.

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