Tailored Supply Chain Architecture:
A Case Evaluation of DWV^3 Clustering Method

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ABSTRACT

The volatility of the global economy pushes transnational enterprises to look into new opportunities represented by areas in which they have not acted before. These international investments raise competition in all markets, regardless of their size, which requires companies to shift their focus towards customer needs. These days efficiency and effectiveness are not mutually exclusive supply chain concepts, but aspects whose synergy acts as a powerful tool that develops competitive advantages and assists in reaching an ultimate goal. Fast response to market needs and operational efficiency are vital attributes required to be incorporated in the design of a robust and competitive supply chain.

The complexity of modern supply chains requires various strategies to be tailored to multiple pipelines ("one size does not fit all"). The objective of this research is to offer a framework aimed at the design of a market-focused supply chain that is able to embrace building blocks, design decisions and influencers on different levels. The proposed three-step approach allows researchers to study the effects of market-specific factors on the design of supply chain channels without higher level decisions being obstructed by lower level influencers. The proposed design approach provides supply chain decision-makers with a methodology that presents an analysis of strategic and operational level supply chain activities where strategic, linear network optimisation is followed by a detailed simulation of supply chain processes. The integration of the DWV3 analytical tool provides an opportunity to tailor multiple supply chain pipelines in accordance with specific market needs. The findings of the research can be employed by experts and supply chain professionals aimed at gaining competitive advantage through the building of market-oriented supply chain channels.

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Chapter I: Introduction

1.1 Research objectives/Questions

Many scholars define supply chain management (SCM) as a complex and sophisticated tool aimed at improving company performance and increase profitability and customer satisfaction (Treleven, 1987). Since the concept was introduced in the 1980s, SCM's complexity has kept pace with its popularity. These days SCM involves the integration of a large number of stakeholders, actors and upstream/downstream processes. Moreover, market concepts are constantly changing. The increase of complexity, sharpened by continuously modifying market situations, calls for the evolution of supply chain models. Supply chain network design, therefore, needs to consider all these trends to bring supply chains to a competitive edge.

Researchers have created numerous decision systems to solve supply chain dilemmas at different levels (Tako & Robinson, 2012). These modelling tools offer an opportunity to explore and improve systems performance in accordance with the goal they intend to achieve. Modelling tools employed to deal with the increased diversity of supply chain components vary from single echelon linear optimisation to complex hybrid models.

These days, for many businesses, being customer-focused is a synonym for being successful. As stated by Fuller et al. (1993), today's customers are in the driving seat. Therefore, supply chain processes need to be focused on market requirements. To satisfy the various needs, companies operate with a large assortment of products that have different market-specific characteristics. The statement "One size does not fit all" (Shewchuk, 1989), highlights the importance for multiple supply chain channels with a choice of decoupling points, transport modes, degree of postponement and stock levels, to be tailored to market needs.

On the other hand, being competitive requires supply chains to satisfy customers at the lowest possible cost. According to Fisher (1997), supply chain models must balance costs and service levels to achieve required advantages. Decision-makers may raise the question of how this can be achieved for a diverse product range and what strategy needs to be applied. The study will observe *decisions affecting different levels of supply chain design,* and aims at a deeper understanding of *methods required to build market-focused supply chain pipelines.* This research plans to explore *market-specific classification that is able to allocate products to specific strategies aligned with market requirements.* Another objective of the study is to find a *way to marry different strategies in a supply chain to meet the best outcome and gain* *competitive advantages by aligning supply chain pipelines with market and customer requirements.*

1.2 Importance of the research and potential contribution to knowledge

The volatility of the global market caused by Brexit and the US-China trade war makes smaller markets more attractive for many global players. For instance, the New Zealand economy is forecasted to grow from 2.5 percent to 3.1 percent per year (OECD, 2019; Gross domestic product: Stats NZ, 2019). This increases competition between companies in such markets. Consequently, companies are constantly seeking ways to improve their performance and deliver superior value to customers through personalised interaction and organising capabilities around customer requirements. In this instance, solutions offered by the supply chain management concept have become vital factors for achieving competitive advantage through increased performance in terms of both cost-focused efficiency and customer-oriented effectiveness. The diversity of markets and products requires specific solutions based on particular market needs. Hence, building an efficient market-driven supply chain that is well aligned with customer needs could be identified as a crucial part of future firm success.

Unique characteristics, such as required product range and complexity, price, demand pattern, lead time, service level, innovation and limitations have significant implications for a supply chain structure. Formulation of company strategies and aligning SC channels with market conditions based on market-specific characteristics helps to achieve both proficiency and effectiveness (Christopher, 2016).

Multiple supply chain design concepts described by scholars (Ohno, 1988; Womack et al., 1990; Goldman et al., 1995), to some extent focus on either productivity or response and agility. However, there is a scarcity of concepts embracing both paradigms. Moreover, those few frameworks that explore the configuration of a supply chain network by balancing efficiency and effectiveness against market requirements are somewhat general in nature or explore design on a certain decision level. This research will explore a strategic and operational level design framework that includes the integration of market-specific analysis into the design model. Hence, the outcome of the research may contribute to academic knowledge and understanding of a multiple pipeline supply chain design by uncovering and filling existing gaps in the topic.

The proposed supply chain network design framework will be tested and verified by applying a New Zealand importer case study that may provide insight on application of market-centred strategies in the commercial sector. Research is aimed to develop a theoretical approach able to integrate market-specific analysis in the supply chain design process and separate different decision levels. Findings may have positive implications for supply chain practitioners seeking ways to adapt supply chain networks to market conditions. The study aims to provide a conceptual framework and tools for experts who wish to create a competent and competitive market-oriented supply chain.

The study relies mainly on the quantitative methodology of data collection and analysis. However, due to limitations represented by the quantitative concept, some elements of the qualitative approach will be used to increase data reliability and triangulate findings. The external and internal data for the first and second stage analyses will be obtained using the ERP of the case company, data from freight service providers and commercial real estate open sources, as well as information from questionnaires. At the experimental stage, manipulating and controlling variables will be applied to the continuous simulation of various scenarios.

1.3 Limitations of the research

It is important to acknowledge limitations to the existing research. As the concept of supply chain design is broad and complex, embracing processes from raw material to delivery of finished products (CSCMP, 2019), it might be difficult to determine relationships for whole chain components between manufacturers and their distributors. For such situations, a primary supplier will be considered as the first sourcing point. The study will aggregate products into groups. Products may be clustered according to many aspects (e.g., demand pattern, cost, margin, localisation, life span), creating additional challenges for the exploration. Backwards and forward supply chain operations have different natures and characteristics even though they may exploit the same network. Due to time constraints, the study will disregard backwards flow and focus on the traditional forward supply chain activities.

Even though research tools are constantly evolving, no methodology can reflect the full complexity of the world and explore all the factors affecting decisions to be made. For instance, the nature of case studies might create some outcome bias. This research will use information from the case company as a New Zealand importer and distributor. Thus, the research covers commercial industry in the New Zealand context and therefore, its application to other business or geographical areas may require specific alteration of variables. Another limitation is that the quantitative approach adopted by the study does not allow for a full survey of the cultural and behavioural aspects that might also affect supply chain design decisions.

1.4 Flow and content of thesis

The following chapters start with the scope of the relevant literature, presenting SC design concepts and an overview of the modelling approaches, metrics and strategies that will have implications for the design of a market-oriented supply chain network. The literature will be summarised with a view to identifying research gaps and developing a study framework. The literature review will be followed by evaluation of ontological and epistemological perspectives and their connection to research goals. This chapter will discuss research methodology and alignment between analysis methods and research objectives. Finally, ethical considerations and chosen research methodology and tools will be discussed. Chapters four, five and six will provide the steps of the proposed market-specific network design and introduce the numerical outcome and analysis of studied models: chapter four will focus on developing strategic linear network optimisation as a base for further application of the DWV3 methodology; chapter five will deliver insight into market-specific classification and network allocation, and chapter six will provide detailed simulation analysis of proposed network. The next chapter will discuss implications of the findings of the conducted study for scholars and practitioners, as well as debate limitations and potential guidelines and targets for further research. The conclusion of the research will be summarised in chapter eight.

Chapter II: Literature review

2.1 Introduction

The considerable expansion of supply chains over past decades has increased both academic and practitioner interest in SCM ideas and practice. Prasad and Babbar (2000) noted a growth in the number of articles in leading management journals researching the concept. The supply chain structure and network are substantial parts of the concept that attract the attention of many scholars. Being market-oriented calls for a specific framework to be defined to create a design model that complies with market requirements.

The following literature review presents academic papers available on supply chain design components. Firstly, the review will focus on the supply chain design concept and integration of the main SC interrelated aspects alongside the different models, modelling approaches that create a base for network design. Secondly, the review will focus on supply chain paradigms and strategies aimed to meet different supply chain goals as well as product characteristics-based classification systems. The next section will describe supply chain measures in terms of components, areas and levels. Finally, the exploration area is summarised to identify a research gap and proposed conceptual framework.

2.2 The concept of supply chain design

The supply chain concept brings significant benefits to companies through improved practices in capital investments, execution and design. Even though the ideas of SCM have been a "hot topic" for more than 20 years, the concept is still evolving in response to various threats, challenges and opportunities. For example, Melnyk et al. (2014) noted that strategic decisions move from a decoupled/price-driven supply chain to a value-driven supply chain. The concept of SC design can be found at the very heart of strategic management decisions, aimed to configure, procure and develop proper SC assets that will help a company gain marketplace advantages through appropriate processes and resource integration. Supply chain design is a broad part of SCM that goes beyond purely buyer/supplier relationships, buy/make issues and vertical integration, and which defines an approach to shape a designed network in accordance with a supply chain goal.

Fine (2010) suggests talking about supply chain architecture rather than supply chain design, as the concept embraces a broad range of considerations, such as firm culture, technology, geography and many others. Therefore, to maximise the benefits provided by SCM paradigms companies need to plan and build suitably complex forms of the supply chain that vary in accordance with these considerations. Even though SC design and SC architecture have a close relationship, some scholars argue they are not the same. Rivera (2007) defines SC architecture as a system-oriented and need-driven process, while SC design is a less broad-based process, shaped by architecture and focusing on implementation problems such as efficiency/effectiveness, feasibility and technological problems and issues. Therefore, building an efficient supply chain could be considered a concept that consists of two interlinking stages; architecture (planning) and design (execution). In this context, supply chain architecture may be considered a macro process that shapes the design of operations.

Most researchers agree that "one size does not fit all" when building an efficient and effective supply chain. Hull (2005) and Hussain et al. (2006) explain that the practices and channels well deployed in demand-driven SC, such as Toyota and Wal-Mart, are less likely to fit the petroleum industry or supply-driven SCs. In turn, the nature of disaster and humanitarian relief requires a unique alignment of SC resources and funds (Tatham & Spens, 2011).

Supply chain actors and processes have different natures, play different roles in supply chain networks and have different influences on supply chain performance. In terms of design, they might be considered in groups, in accordance with their role in the supply chain. Melnyk et al. (2014) suggest the SC design is a process formed by a hierarchical relationship of building blocks, design decisions and influencers (Figure 2.1), where influencers are environmental aspects that constrain the nature of the SC, such as critical customers, life-cycle considerations, business models, desired SC goals and overall environment. Design decisions can be defined as choices regarding the structure of SC constrained by influencers. They include decisions regarding facility dispersion and channel networks, procurement strategy, spend allocation and behavioural policy. Building blocks are specific investments needed to implement SC design decisions. These are physical assets (e.g., warehouse and production capacity), logistics capacities, ERP, sourcing procedures and tools, contracts and CRM/VRM processes.

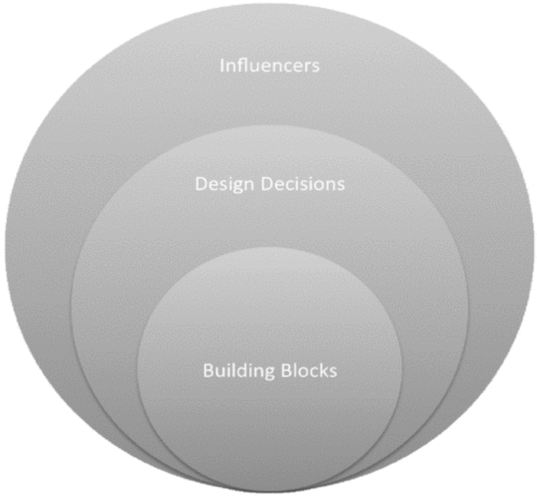

Figure 2.1 Supply chain design - interrelated parts (Melnyk et al., 2014)

Much recent research has explored these influencers, decisions and blocks in terms of SC design. Below is an overview of papers that provide methodologies across industries to achieve outcomes for supply chain design. Authors develop models that show decision levels, product types, complexity, network balance and actors’ interaction play a significant role in SC design. Table 2.1 represents architecture aspects covered by these studies.

Supply chain architecture represents a hierarchy of decisions made at different levels, from strategic to operational. However, different decision types may absorb or enhance each other, and thus need to be studied together as a complex. Complying with different decision levels might be a serious task for the supply chain design process. Askin et al. (2014) provide a generic algorithm for a single model of integration of strategic and operational decision-making for a three-echelon SC. The algorithm addresses building blocks and design decisions.

Due to specific demand characteristics, supply chains often require different design approaches. Fisher (1993) suggests the nature of these characteristics need to be considered in SC design. Product life cycle, lead time, product complexity and service level shown in the models below are important design aspects that need to be aligned with the SC goal. There is a noticeable difference in aligning design concepts across supply chain participants depending on product type. Lyons and Ma’aram (2014) empirically tested the framework defined by Fisher (2003) for functional products, and compared it with the reactive SC for pioneering products by surveying numerous food companies across Malaysia and the UK. They found that while a traditional product supply chain is aligned across all levels of the chain, the innovative product-responsive SC mainly aligns with downstream participants, whereas upstream partners such as manufacturers tend to pursue efficient supply chain concepts. The research studied a purposeful design versus a decoupling concept. The researchers explored the natural decoupling points and the possibility of optimising cost in one part of the supply chain and innovation output optimisation in the other part. In other words, the concept highlights the difference in the market between functional and pioneering products. In terms of the design concept above it addresses building blocks and design decisions.

Product complexity is another factor affecting supply chain network modelling, and needs to be considered in the supply chain architecture process. Inman and Blumenfeld (2014) explore the effect of product complexity on the possibility of supply chain failure using the analytical modelling approach. They define shipping modes/routes, make/buy decisions, vendor location and consolidation/deconsolidation points as key factors affecting performance in the occurrence of product complexity. The authors maintain that SC architecture should consider the level of product complexity, and if the level of the complexity changes, so should the SC design. This paper encompasses design decisions (transportation and inventory) and influencers in terms of a desired outcome.

Customer satisfaction is a key aspect responsible for supply chain success. However, customer service level needs to be balanced with network efficiency. Research by Wilhite (2014) reveals that the supply chain's desired outcome may differ significantly depending on the supply chain goal, and develops a framework for balancing decisions based on this goal. The study embraces design decisions (sourcing strategy) and influencers (critical customers, business model desired outcome).

Along with product-related aspects, supply chain actors and their mutual influences play a considerable role in supply chain performance. The supply chain is a complex process where the synergy of different activities or parties can improve the efficiency and effectiveness of designed operations. Massow and Canbolat's (2014) model investigates the impact of sourcing collaboration on supply chain outcome. The model covers sourcing strategy as design decisions and desired outcome as influencers.

Table 2.1 shows that all the concepts defined above embrace one or two design factors. These design blocks have a hierarchical relationship and need to be considered in supply chain architecture according to their mutual influence. There is a clear need for a design approach able to incorporate all three design aspects.

	Building blocks			Design decisions		Influencers	
	Inventory	Transportation	Capacity	Physical design	Sourcing strategy	Desired outcome	Business model/critical customers
Lyons & Ma'aram (2014)	X			X			
Inman & Blumenfeld (2014)	X	X				X	
Askin et al. (2014)	X	X	X	X			
Massow & Canbolat (2014)					X	X	
Wilhite et al. (2014)					X	X	X

Table 2.1 Supply chain design parts covered in existing literature

2.3 Supply chain model types

Supply chain architecture is a complex, integrated process comprising facility location, logistics network, stock policies and flows of product and information. Many approaches have been developed to address supply chain problems with the best possible solution aimed at achieving SC objectives. Sabri and Beamon (2000) suggest models be categorised into four groups according to the nature of inputs.

Deterministic - models where parameters are fixed, and no randomness is involved

Over the years deterministic models have progressed toward a complexity of optimised network and input parameters. A heuristic algorithm by Williams (1981) for scheduling manufacturing and distribution operations, aimed to determine a cost-effective distribution schedule that satisfied final demand. It used performance (set up, ordering and delivery) cost to define network structure. The model, however, provided a cost-focused approach that itself is not sufficient for designing a modern supply chain. This dilemma was later studied by Ishii et al. (1988). Their model focused on the lowest cost solution based on lead time and base stock level. The model applied a customer-focused approach and was designed for a linear, demand-driven, pull-type ordering system.

Complexity of supply chain requires studying how multiple factors interact, what parameter are major influencers and how averaging effect may be avoided. Cohen and Moon (1990) examined the effect of multiple parameters using a model called PILOT. The model was developed to determine which available distribution centres and manufacturing facilities should be open, and to define initial and intermediate transaction quantities based on the characteristics of a product. The model confirmed transportation costs play a substantial role in the total cost of SC operations, and require close attention in SC design. The complex GSCM (global supply chain model) suggested by Arntzen et al. (1995) deals with various echelons, transport modes, time periods and products. This model defines a number of stages (echelons), the quantity and location of facilities, and customer-plant and customer to DC allocation. Voudouris's (1996) model aimed at satisfying customers by simultaneously improving efficiency and responsiveness. It increased supply chain flexibility by studying the sum of differences between the utilisation and capacities of two types of resources (inventory and capacities) required to maintain the flow of products. The model inputs BOM (bill of material) data and information about product-based resource consumption to generate inventory level objectives and a manufacturing, transport and delivery schedule for each product. Ma and Suo (2006) presented a two-stage, multiple-product, logistics network design. In the first stage they determined network configuration using an LP model and later used LP model output to define the ordering cycle and batch size for each product at each hub, and optimal transport routing. The approach adopted allowed for the segregation of input parameters on different levels.

Over the years deterministic models have become more complex and embrace almost all areas of the supply chain. However, while deterministic models are not able to deal with unpredictable resources or randomness, modern systems often have random variations of one or more parameters. Researchers have found the stochastic models discussed below may overcome drawbacks inherent in deterministic concepts and could add value to SC design.

Stochastic - models with random fluctuation of inputs

As with deterministic models, stochastic models progress over time with an aim of covering more aspects of the supply chain. Cohen and Lee (1988) studied the impact of random input for multi-echelon models. The researchers used one of four minimum-cost, objective, stochastic sub-models (material control, production control, finished goods stockpile and distribution) for each production stage to determine the approximate optimum for ordering policies. The model provided a framework for studying supply chain activities. However, their interaction was not studied. It is worth noticing that the model's objectives focused on the cost effectiveness of a system, but did not take in account customer satisfaction.

Later, when service level started to gain popularity in the supply chain world, a heuristic, pull-type model was developed by Lee and Billington (1993) for dealing with product streams on a side-by-side basis. The model either defined the service level for each product at each facility based on the ordering policy or defined the policy by computing a desired inventory level to achieve a required service level for each product at each facility. This approach could be useful for systems that benefit from multiple fulcrum points. However, it did not embrace environmental network influencers. This issue could be resolved by the model developed by Lee et al. (1993), who suggested an approach that considered environmental, language or legal policy differences in target market structures. The study focused on designing SC processes aimed at the highest customer service level with the lowest cost.

The majority of existing supply chains include product diversity in the pipeline. Pyke and Cohen (1994) extended the integrated SC model they had developed the previous year by considering multiple product types. The model outputs are a replenishment ordering size, minimum-cost reorder interval and order-up-to product levels. This model provides insights that supply chain processes and their outcomes depend on the characteristics of the products in the flow.

Some supply chain participants act independently and may compete within the supply chain. It is important their interaction is considered in the supply chain design process. Nagurney et al. (2003) researched an integrated, three-tier supply chain. The model considers possible competition between tiers, and is aimed at profit maximisation at each tier constrained by manufacturing cost, the cost of transaction and fluctuating exchange rates. In contrast with the model developed by Pyke and Cohen (1994), Nagurney et al.'s product characteristics were not considered and the model was limited by products that do not change during transaction.

Risk is another challenge that supply chains constantly confront. Risk identification and mitigation are tasks supply chain practitioners face often. Azaron et al. (2008) optimised a total cost, total cost variance and cost of financial risk in a three-echelon supply chain where stochastic parameters were suppliers, processing, demand and the cost of capacity extension. The model included minimisation of the amount of existing investment costs and expected future costs, minimisation of the total cost variance and minimisation of risks of not meeting a certain budget. Even though the model focused on cost minimisation, the method might be adopted by researchers who focus on stakeholder relationships, service level or responsiveness.

Stochastic models provide an opportunity to deal with an unpredictable environment and cover many areas of supply chain design, including risks and product complexity. However, one of the most critical issues of this approach is model stability, which has its roots in the nature of the method.

Strategies simulation models: dynamic approach where different alternatives can be compared and evaluated through a simulation of SC processes

The deterministic and stochastic models described above do not reflect supply chain performance over a long period of time. They focus mostly on optimisation, but not the continuous interaction of supply chain actors and processes. This dilemma was resolved by applying a simulation approach. Wikner et al. (1991) found, using simulation, that the integration of information flow and demand separation was most effective in the environment of a three-stage reference supply chain model. Simulation also allowed the researcher to assess different approaches in one supply chain environment. Later, Towill et al. (1992) defined a theoretical structure for a simulation process to evaluate the outcome of several optimisation strategies. The study revealed the dependency of demand variability on network structure.

The simulation modelling approach is a useful tool for developing new or restructuring existing models. The approach has gained popularity due to the appearance of new computer programmes able to continuously manipulate a large number of variables and assess different strategies without significant investment in a model change.

Appendix 1 represents specifications of SC models in terms of a model type. All the models mentioned above have their own benefits and drawbacks. Deterministic models provide a holistic view on modelled processes where all the inputs are able to be amended mathematically, and results verified at any stage. The advantages of these models come at the cost of decreased realism however, due to predetermined inputs that might be affected by uncertainty and risk. In contrast, stochastic models cope with various data, dimensions, parameters, specifications, process disruptions and other uncertainties and randomness with a certain confidence level. However, as models represent a series of interdependent events there is little opportunity to incorporate peripheral factors and intermediate output results into the model. Also, they require complex computation and hard work in continuous time. Simulation (nowadays computer simulation) embodies part of the real world and conducts experiments with output that predicts what will happen in reality for an almost endless period. However, most simulation models consist of a countless number of interrelated and interchangeable variables and, therefore, narrowing the number of variables requires a simulation model to be constructed around a core concept rather than de novo.

2.4 Supply chain design paradigms and classification systems

2.4.1 SC strategies

Since interest in the supply chain paradigm sparked in the academic community in the 1980s, diverse strategy approaches have been suggested, numerous guidelines developed and multiple reviews conducted. Research studies have different opinions and methodologies to address the strategy problem in various contexts. However, all methods apply fundamental approaches that are worth examining to provide necessary insights for the design of market-orientated SC.

Push and pull

Some researchers define push and pull as contrasting approaches. Spearman and Zazanis (1990) describe these approaches as antagonistic ways of manufacturing, but it can be argued contrasts are relevant for the whole supply chain. These two concepts define the nature of flows and the character of the supply chain. In the downstream pull strategy, a succeeding component initiates activities at the preceding actor. In contrast, the push concept, which has its roots in Western production planning, moves on finished components irrespective of the state of the succeeding process. According to Näslund and Williamson (2010), the nature of the flows in these two concepts may create a lack of components in the pull strategy and a build-up of components in the push strategy. Material resource planning branded as MRP and just-in-time (JIT) are well-known examples of push and pull strategies respectively.

Decoupling point

The supply chain often embraces segments where both downstream (pull) and upstream (push) concepts are used. Hoekstra and Romme (1992) describe decoupling points as the place where forecast-driven and demand-driven activities meet. In other words, these are points that respond directly to customer demand. This makes the market eventually driving the flow of products in supply chains after the fulcrum. Naylor et al. (1999) tie the location of decoupling points to the longest lead time a consumer will accept. However, this is arguable as other influencers might affect the location of decoupling points and therefore need to be studied alongside the desired delivery window.

Postponement

The concept of postponement is closely connected with decoupling points. Naylor et al. (1999) suggest that postponement is aimed at increasing supply chain efficiency by shifting product differentiation closer to the consumer. It could be emphasised that production/assembly postponement increases service level by reducing the risk of stock-outs as well as the risk of overstock; however, this might increase supply delays depending on production time and failure risks. It may also affect customer satisfaction based on desired delivery time. Naylor et al. (1999) claim that postponement is a crucial aspect for products with a short life cycle.

The fierce race in contemporary global markets puts pressure on supply chain designers to look for solutions that help companies to reduce cost, improve throughput and increase responsiveness and flexibility in a fast-moving, competitive environment. Since the supply chain concept gained popularity many specific SC strategies have been developed to create or enhance competitive advantage. The most popular concepts are *Six Sigma* developed by Motorola in the 1980s, the *Lean* strategy which originated from the Toyota production system (TPS) in the 1990s, the *Theory of constraints (TOC),* introduced in the 1980s by physicist Eliyahu M. Goldratt, the *Total Quality Management (TQM)* approach popular in the 1980s when American and European enterprises were faced with competition from their Japanese counterparts, and *Agile* manufacturing and *Business Process Reengineering (BPR),* which was quite prominent in the early 1990s. All these systems have their own distinctive characteristics, strengths and weaknesses, as shown in Table 2.2

	Lean	TQM	Six Sigma	TOC	Agile	BPR
Objectives	Reduce waste	Meet company`s standards	Meet customer expectation	Improve throughput	Increase responsiveness and flexibility	Improve company`s performance
	Improve profitability	Improve quality	Improve quality	Increase net profit	Improve performance in the fast-changing environment	Provide better profitability
Core principles	Holistic view on the enterprise	High corporative standards based on customer expectations	Reducing variability	Concentration on throughput	Meeting customer needs	Enterprise reinvention
	Waste elimination	Continuous quality improvement	Customer-focused culture	Focusing on system`s weakest points	Virtual organisation	"Clean-sheet" redesign
	Synchronised flow	Develop employee training and empowerment	Teamwork	Protection against fluctuations	Flexibility and adaptiveness	Advanced solutions
	Continuous improvement		Data-driven structured approach			
Focus	All local operations and processes and their interdependence	Core business processes and customer expectations	All sources of variation	System`s constraints	Flexible solutions and enterprise integration	Enterprise processes through radical redesign
Processes direction	Top-down	Top-down	Top-down	Top-down	Top-down	Top-down
Process management	Top management + staff participation	Multi-level management	Structured management	Multi-level management	Top management	Autocratic top management + process owner participation

Table 2.2 Summary of key characteristics of SC design paradigms

Efficiency focused

Earlier, cost or production efficiency was applied as a cornerstone for supply chain strategies. Womack et al. (1990) popularised Lean ideas used by the Toyota production system as earlier described by Ohno (1988) and Krafcik (1989). Often the concept is linked with Eastern manufacturing initiatives that arose at the end of the twentieth century. However, Towill et al. (2000) argue that ideas of Lean were used in the manufacturing of Spitfire aircraft in World War II. The concept focuses on the elimination of non-value adding activities (waste), including time, visibility of processes and continuous improvement. The concept aims at cost minimisation. Many scholars use just-in-time (JIT) as a synonym for the Lean paradigm. The concept initially concentrated on manufacturing operations (Womack, Jones & Roos, 1991).

However, it was later found that the integration of processes plays an essential role in total performance and the proposed system was extended to Lean enterprise (Womack, & Jones, 2010).

The theory of constraints (TOC) developed by Goldratt (1984), uses the algorithm of optimised production technology (OPT). The concept defines throughput as the key goal of the system. TOC describes the interrelation between throughput and both operating expenses and inventory, where operating expenses are costs of turning inventory into throughput dollars and investment is the money invested in things to be sold (Bozdogan, 2011; Wright, 2014). The system focuses on the identification and maintenance of different bottlenecks (physical, rational, and administrative), and concentrates on the overall company goal rather than local improvements and optimisation. In contrast with Lean waste reduction, TOC focuses on system bottlenecks and achieves efficiency through creating required buffers.

The TOC system is not perfect; it has disadvantages. According to Marton and Paulova (2010), TOC is difficult to apply when bottleneck processes have a complex or permanently moving nature. Another limitation of the concept is possible disagreement on the issue and problem-solving between stakeholders (individuals understand differently).

Customer focused

The *Agile/Responsive* paradigm was initially proposed as an alternative to Lean and presented ideas of exceedingly efficient, adaptive and elastic manufacturing that gained success in a fast-moving and quick changing competitive environment. It allowed switching between products without significant investment, but later it was extended and applied to a much broader business context (Nagel & Dove, 1991). Researchers argued that the ability to be flexible might be a winning characteristic in modern, fast-changing markets. The concept represents the ability to quickly react to changes in demand variability and/or product range variety (Christopher et al., 2001).

Nowadays, some researchers nominate highly customised products as the main feature of Agile systems, while others define agility as a combination of two main factors: responding to alteration in an appropriate way in due time and taking advantage from fluctuations as from opportunities. Other scholars contend that the key point of Agile systems is the speed new products can be introduced to the market. Hallgren and Olhager (2009) claim the differences between all three approaches are not substantial and largely connected to product type.

Quality focused

Total quality management (TQM) perspectives shape the quality movement as well as the evolving notion of quality. TQM transforms customer requirements into quantifiable characteristics. It may be traced back to 1930s statistical process control (SPC). Many researchers claim that quality standards (ISO) adopted by companies across the world have their roots in TQM, and appoint TQM as one of the most effective current concepts (Hoyle, 2009; Bozdogan, 2010). Baudin (2013), however, argues that pure TQM is now little more than an historical footnote and that some TQM awards aimed to improve national competitiveness are losing their appeal.

As with TQM, the Six Sigma system focuses on gaining competitive advantage through quality products. While, however, TQM describes quality in terms of the company's standards, Six Sigma quality management philosophy applies probability theory to the aim of reducing recognisable sources of variation in processes critical to quality (Chiarini, 2012). The concept has been evaluated in hi-tech production and later has spread into other segments. The system usually successfully fixes existing processes but may show lack of stability with innovative products. Furthermore, Hindo (2007) claims the strategy often stifles creativity, which may make application of the concept undesirable for companies in fast-changing markets.

On the one hand, these two concepts are not generally considered independent design paradigms and focus largely on internal supply chain operations. However, they are responsible for aspects accountable for customer satisfaction and may be successfully incorporated in SC design on an operational level.

Business process reengineering (BPR)

BPR relates mostly to the restructuring of existing SC strategies rather than to the design of a new supply chain network. As Hammer (1990) explains; it is "a radical redesign of business processes to achieve dramatic improvements in critical measures of performance". Siha and Saad (2008) suggest the goal of BPR is not to take small and cautious steps and fix existent issues, but the "retirement" of predominant business practices and principles by starting from a "clean sheet of paper" that allows the achievement of positive outcomes; for example, cut costs, raise output, reduce time, improve quality, develop business cycle, increase income and turnover and reduce response time. BPR is able to restructure an existing supply chain by applying different supply chain paradigms. It provides a useful framework for the identification of areas and concepts to be applied.

Cultural aspects may create significant challenges for deploying BPR methods. For instance, it is a top-down, hierarchical process that treats workers and workplace supervisors as dependents. Historically, strong employee participation and workplace democracy impeded the setting of BPR ideas in Scandinavian companies (Siha & Saad, 2008). However, as Bozdogan (2010) suggests, a combination of BPR and TQM concepts could be very successful for these countries.

2.4.2 SC classification systems

Supply chain channels need to be designed in accordance with attributes that shape the network. The characteristics of products in pipelines can not only shape supply chain channels but also define flow strategy. It is critical, therefore, that system capabilities are aligned with specific product characteristics that affect system performance. For instance, a supply chain designed for petrol products applies strategies different from one created for fast-moving consumer goods (FMCG). Over the years, numerous methods have been developed to group products based on specific attributes. Among the most popular in the existing literature are the classification of products by activity, business objective-based classification, and the DWV3 classification system.

Classification of products by activity (CPA) is the official classification of the European Union. It applies a six-level categorisation in accordance with the physical characteristics of products or services depending on their nature and originating activities. The system is used mostly by governmental and international organisations to categorise products for international trade, logistics and production. CPA is also widely used for collecting statistics across countries and in different domains. The complexity of the system creates application difficulties for smaller businesses, although the methodology can be scaled down to comply with business size.

In contrast with CPA, ABC classification segregates products and materials based on the Pareto 80/20 rule where items are ranked according to their importance to business objectives. This classification is widely used by companies for managing inventory. It identifies and prioritises the valuable or critical 20 percent segment. Teunter et al. (2010) remark that, even though many scholars explore multi-criteria ABC analysis, most businesses tend to adopt a single criterion approach due to its simplicity, where demand is the most commonly applied value. Finding the criteria that reflect actual market needs is a challenge for many businesses. For example, the application of 80/20 rule to one characteristic only may not take into account other factors that affect supply chain activities.

The DWV3 framework was designed by Christopher et al. (2001), and later verified by Aitken et al. (2005). The principles of DWV3 portfolio classification are based on specific product characteristics, resulting in a focused demand chain. In contrast to the efficiency driven systems described above, the concept offers segmentation of a product portfolio in accordance with the requirements of the value-focused demand chain based on life cycle, time window for delivery, volume, product variety and variability. Fisher (1997) argued that innovative and functional products benefit from different approaches. For instance, short life-cycle, innovative products require a short end-to-end channel. Also, product market-specific characteristics change during the product life. Aitken et al. (2003) argue that at the introductory and growth stages products benefit from design capabilities and service level, while at maturity cost becomes the most focused factor. *Duration of life cycle* separates innovative and functional products and defines a current life-cycle phase. It allows the choice of the most beneficial production and distribution approach from which a group can profit. *Delivery window* shows delivery lead-time and defines the desired responsiveness to customer needs. This characteristic helps position the finished goods or components and the choosing of Lean, Agile or mixed strategy. *Volume* is another key market-dependent attribute that segregates “strangers”, “repeaters” and “runners”. In terms of SC design, volume is associated with economies of scale and defines planning and control strategies to be implemented. *Variety* shows the extent of variants for stock-keeping units. A high level of variety spreads demand across a number of configurations, thus increasing the complexity at the Bill of Material (BOM) level. This characteristic is closely connected with strategies responsible for assembly postponement. Demand *variability*, defined by the relationship between demand standard deviation and mean, captures unpredictability and fluctuation. The characteristic determines stock policies and forecast strategies. For instance, products with a high coefficient of variation (CV) might require extra capacities or application of agile principles to satisfy “spikes” in demand.

2.5 Supply chain performance measures

The efficiency and/or effectiveness of a model cannot be evaluated, nor can progress be achieved, without the setting of proper performance measurement. Kaplan (1990) states improvement is impossible without measurement. Neely et al. (1995) advise that systems require a set of metrics that quantify their efficiency and/or effectiveness. As with the "right product in the right place at the right time", it is essential that designed supply chain activities are measured in the right way at the right time in the right sectors. Therefore, supply chain design metrics (SCDM) shall be considered a vital part of supply chain architecture.

Choosing suitable measurements is a significant challenge for supply chain architecture. According to Gunasekaran and Kobu (2007), identifying key value-adding areas and processes to be measured, and appropriate metrics for these, can be problematic. Due to the diversity of supply chain KPIs mentioned in the literature, it is a task to narrow them to the minimum required to avoid a designed system overloaded with insignificant or overlapping KPIs. Besides, the constantly evolving, supply chain management concept requires measurement systems in accordance with new trends and requirements. The core dilemma for the supply chain measurement system (SCMS) is to find suitable and reliable metric *components*, to identify supply chain *areas and processes* to which these indicators are to be applied, and to align them to an appropriate *decision level*.

SCDM components

The growth in popularity of the SC concept has triggered the growth of exploration in the SCMS area. Globerson (1985) and Maskel (2013) developed principles to guide the selection of preferred performance indicators. Later Fitzgerald et al. (1991) consolidated performance metrics into two groups: result related (monetary performance and competitiveness) and result determinants (quality, efficiency of resources, flexibility and innovations), although this was useful mainly for companies involved in services. Another approach was taken by Kaplan (1990), who segregated metrics used by IT equipment suppliers in eight groups with 3-8 KPIs in each. This approach provided an insight into the grouping of metrics depending on the area and KPI nature.

These eight groups were later narrowed to four categories. Bagchi (1996) suggested focussing on the competitiveness of business via measuring: cost, time, quality and efficiency. Even though time and quality are customer-related KPI, the system itself centred on company efficiency and provided a functional tool for companies who focus on productivity. The widespread balanced score card (BSC) approach suggested by Kaplan and Norton (1996) included customers, innovation, and improvement in strategic agenda the metrics need to focus on. Even though the system was developed to pursue strategic business goals it could be applied on a smaller scale to define specific metrics for particular business areas.

Existing literature shows the growing interest in being customer-centric, which necessitated the development of metrics that reflect this trend. Beamon (1999) suggested a set of flexibility measures to cope with markets and customers that require agility in terms of products and services. De Toni and Tonchia (2001) stressed the importance of non-cost SCMS, and advised that traditional performance metrics need to be separated from innovative customer-focused measures. The trend was also supported by Van Landeghen and Persons (2001), who categorised SCDM in accordance with flexibility, response time, quality and cost objectives that help the SCDM system to focus more on ongoing market trends. Hassini et al. (2012) noted the growth in popularity of sustainable supply chains as a competitive advantage, and suggested this tendency be reflected in SCMS.

SCDM areas

Most SCDMS systems encompass four supply chain stages: plan, source, produce and distribute, in order to develop relevant system KPIs that allow a simple application of measurement, and some researchers study the location of measures along with these phases. Porter (1985), in his value chain, identified primary activities (inbound logistics, operations, outbound logistics, marketing and sales, and service) and support activities (infrastructure, HRM, technology and procurement) that provided clear guidelines for SCDM application. Stewart (1995) applied a different approach, and named four zones for measurement: policies, practices, and procedures (PPP); organisation; structure, and systems.

Later, La Londe and Pohlen (1996) found that many SCMS focus on particular segments and do not support the integration of functional areas in a company or extended enterprises and their integration along the value chain. Lambert and Cooper (2000) claimed many metrics employed by SCMS are often metrics for company logistics rather than supply chain processes. They provided a framework that facilitated identification of opportunities and aligning objectives across all SC participants. Lockamy and McCormack (2004) studied performance metrics through the supply chain operations reference (SCOR) model developed by the SC Council, and identified collaboration as the most important activity across all four SC phases.

Globalisation enhances the effect of external factors on a supply chain. Therefore, modern metrics need to be extended beyond supply chain participants. Contemporary SCDM systems encompass external aspects that provide the most influence on SC processes. Bhatanagar and Sohal (2005) developed a framework that incorporated external factors, such as political situation, market and social trends, key competitors, risks and uncertainties. Application of external area KPIs is useful for large-scale research, but often increases complexity for smaller scale systems.

SCDM decision level

Developing SCDM at strategical, tactical and operational levels facilitates the achievement of the overall business objective. Some researchers focus on operation-based KPIs; others on strategy-based KPIs. However, they need to support each other provide the best outcome. Van Donselaar et al (1998) studied critical success factors (CFS) and identified company-level financial and operational performances and segment-level operational performance as key factors responsible for economic and process excellence in transportation and distribution supply chains where operational performance measures work to integrate decision levels.

It is essential to understand the vitality of a balanced approach to SCDM. For instance, focusing on financial indices shift SCDM towards the strategic level while non-financial KPIs are mostly responsible for evaluating day-to-day control and distribution operations (Maskell, 2013).

As previously discussed, carefully selected performance indicators are essential to achieve efficiency and effectiveness in a supply chain, which confirms their importance in the SC design process. A crucial selection of SCDM components needs to be aligned with company goals, internal and external influencers, trends and market requirements. It worth mentioning that current supply chain concepts shift priorities towards customer needs, which make customer satisfaction, service level, agility and flexibility more important. Robust modern supply chains need to embrace both efficiency and effectiveness and be both economically efficient and customer-based. Therefore, existing research will apply metric components that measure cost efficiency, responsiveness and service level. The limitations of the existing study make it hard to explore external areas of supply chain. Thus, only metrics related to direct supply chain activities will be applied. Selected metrics need to be well balanced and provide reliable feedback across required decision levels.

2.6 Literature review summary

Existing literature indicates the increasing importance of SC design. All stakeholders pursue their own objectives, and it is important for their goals to be fully integrated into SC architecture, so designing a robust, market-oriented supply chain is a complex process that includes models, methods and tools.

It is important for supply chain architecture to create a base for further supply chain design, and to embrace aspects that affect the SC network. The hierarchical relationship of these aspects, as noted by Melnyk et al. (2014), shows that the architecture should embrace all three interdependent parts, represented by building blocks (physical assets and capacities), shaped by design decisions (facility dispersion, structure and network), and in turn influenced by environmental aspects. Several studies have been completed in this area. Table 2.1 shows the areas of focus. However, analysis reveals that much of the research focuses on one or two areas, rather than integrate all three. For example, Massow and Canbolat (2014) study SC design in terms of influencers, such as market-specific characteristics (volume) and design decisions (integration and consolidation), but do not connect them with building blocks. Vigorous supply chain architecture requires a model that embraces all three concepts, and ties blocks to influencers through design decisions. Figure 2.2 represents the interrelated parts to be considered in supply chain architecture. Some aspects within these blocks, such as positioning of the network, have determining value for supply-chain strategic goals while others, for instance sourcing strategies, shape supply-chain operations. These factors need to be considered in accordance with specific decision levels.

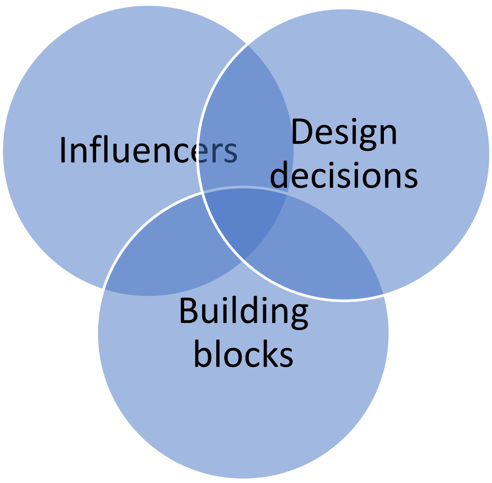

Figure 2.2 Proposed SC design concept

Existing literature shows that approaches to SC architecture could be consolidated in groups depending on the nature of the approach. Appendix 1 presents a matrix that summarises the specifications of SC models in terms of model type, performance measurement and decision variables. Papers suggest respecting different decision levels (Askin et al., 2014), product type and complexity (Lyons & Ma’aram, 2014; Inman & Blumenfeld, 2014). They also describe that the interaction of stakeholders has significant impact on supply chain design (Massow &

Canbolat, 2014). The approach developed by Wilhite et al. (2014) reveals the importance of the right balance of efficiency and effectiveness in the SC network.

Despite the diversity of models in Appendix 1, most are cost-based and focus on order size and inventory level while risk management and customer satisfaction are not broadly covered. Also, there is a lack of research on models on SC elasticity in an unpredictable environment currently required by volatile markets.

The review of existing texts revealed that although multiple modelling approaches have been developed since SCM gained popularity, all the models have inherent weaknesses that create challenges for practitioners to apply supply chain design in real life. Deterministic models do not deal with many risks while stochastic models provide a less stable outcome. OSE models address non-dynamic strategic decisions while simulation may be overloaded from the number of interdependent variables affecting the outcome. For instance, according to Garcia and You (2015), multiple scaling affects the accuracy of the modelling of material and information flows and creates combinatorial optimisation problems; therefore, utilisation of simulation-based technics might be preferable. Uncertainty at each scale creates additional challenges and may be enhanced by uncertainties across temporal scales. The dilemma might be addressed, however, by the integration of different types of models (e.g., a combination of simulation and deterministic algebraic models could be used for a high level of detail and higher-level strategic decisions respectively.

The review of literature exposed vital strategies that could be used for optimal SC design (Table 2.3). However, these systems are not universal and each has strong advocates. For example, supporters of TOC argue that creating inventory buffers gives better overall optimisation than lean waste reduction and the Kanban system (Bozdogan, 2011). Others contend that the TOC approach is limited if bottleneck processes have dynamic nature while claiming that the Agile approach can solve this dilemma (Marton & Paulova, 2010).

Lean and Agile concepts are often used as opposed strategies due to the difference in primary goals. The Lean strategy sees the elimination of waste as predominant while the Agile strategy tolerates adding non-value activities in favour of increasing SC responsiveness. However, they have common characteristics equally important for both Lean and Agile supply chains that highlight parallels between these two approaches. Both strategies aim for compression of lead time, use an integration of SC participants and utilise market knowledge. Christopher et al. (2001) point out that volatility and unpredictability of demand for low-volume products can be addressed by applying ideas of responsive SC while high-volume and low-variety products often benefit from JIT. This shows that contradictions between concepts are not insurmountable and strategies can be harmonised to enhance each other and provide better outcomes.

As defined above, “one size does not fit all supply chains”. Some supply chains have clear distinctions and can be easily separated from others, such as military supply chains which have special characteristics, but such distinctions are not always clear. For instance, it may appear initially that supply chains for computers and mobile phones require similar channels. However, they often apply different assembly postponement concepts. Furthermore, a supply chain may include several products that benefit from different approaches and require specific strategies, tailored to multiple pipelines in accordance with product-specific characteristics. Designing such channels calls for the segregation and analysis of products to group them according to specific attributes and align them with the most beneficial strategy.

The building of a market-oriented supply chain requires a specific product to be aligned with market need, therefore utilising product characteristics that reflect market requirements. Product-focused CPA classification can be valuable from a statistical point of view or to define physical constraints from a logistics perspective. However, this type of classification provides little connection to actual market requirements. Furthermore, CPA characteristics can be changed as products proceed from one SC stage to another. On the one hand, the widely used ABC segmentation focuses on business goals such as profitability even though it might be adjusted to deal with other criteria. At the design stage, it is hard to define what ABC criterion would be the appropriate contributor to market-specific goals (Teunter et al., 2010). In contrast, DWV3 provides insight into criteria closely connected with market needs (Christopher et al., 2001). *Life cycle* duration separates distribution for innovative and functional products, *delivery window* expresses customer desired lead time, v*olum*e is an attribute that differentiates high and low runners in terms of demand, *variability* deals with demand fluctuations and *variety* captures the complexity of product variants. These characteristics help to separate value streams. Unlike the two other approaches, DWV3 provides the opportunity to study specific characteristics and develop focused strategies that deliver the best outcome for each segregated cluster of products. The ability to deal with different value streams makes this approach applicable for the design of market-focused SC while CPA and ABC might be used later in continuous improvement programmes.

Classification might be subject to additional challenges if businesses are affected by seasonality. DWV3 variables that experience the largest seasonal changes are *Volume* and *Variability;* as seen, for example, in fashion apparel or the sports goods industry. These two characteristics may vary significantly over the year and their averaging often leads to inaccurate classification. To overcome this challenge, products with cyclical demand might be assessed for each period in the year. The other three criteria are less affected by seasonality but may also experience the impact of cyclical changes. For instance, *Delivery Window* in some areas might be affected by seasonal weather or delivery route change. Another example is the tendency consumers have, according to marketing specialists, to change colour preferences during the year. Therefore, specific characteristics of such products also need to be predominantly assessed by experts before they undergo DWV3 evaluation.

Following the literature analysis, the design of a market-oriented supply chain will be explored through the following questions:

- What framework might be developed to design a supply chain network based on different decision levels?
- How might product market-specific characteristics be incorporated in supply chain design and aligned with multiple channels and concepts?
- How would the application of product market-specific characteristics affect the performance of a supply chain in terms of efficiency, responsiveness and service.

The conceptual model of the research presented in Figure 2.3 will be used to guide the proposed research. As mentioned by Melnyk et al. (2014), SC architecture includes the interaction of several design factors. According to research findings, it could be recommended that a robust SC network will exploit SC concepts that integrate all three interrelated parts (shown in Figure 2.3) to be able to respond to market changes and satisfy customers in the best possible way without sacrificing company objectives. Due to the increasing role of uncertainty and risk the proposed model, designed with appropriate metrics, needs to deal with a high level of randomness of variables.

A positive result can be achieved through the integration of different modelling technics. At the macro level the proposed model is shaped by SC optimisation concepts that allow for improved profitability and/or customer service level depending on the SC objectives, as well creating a core layout for further market-specific analysis and allocation of flows and strategies.

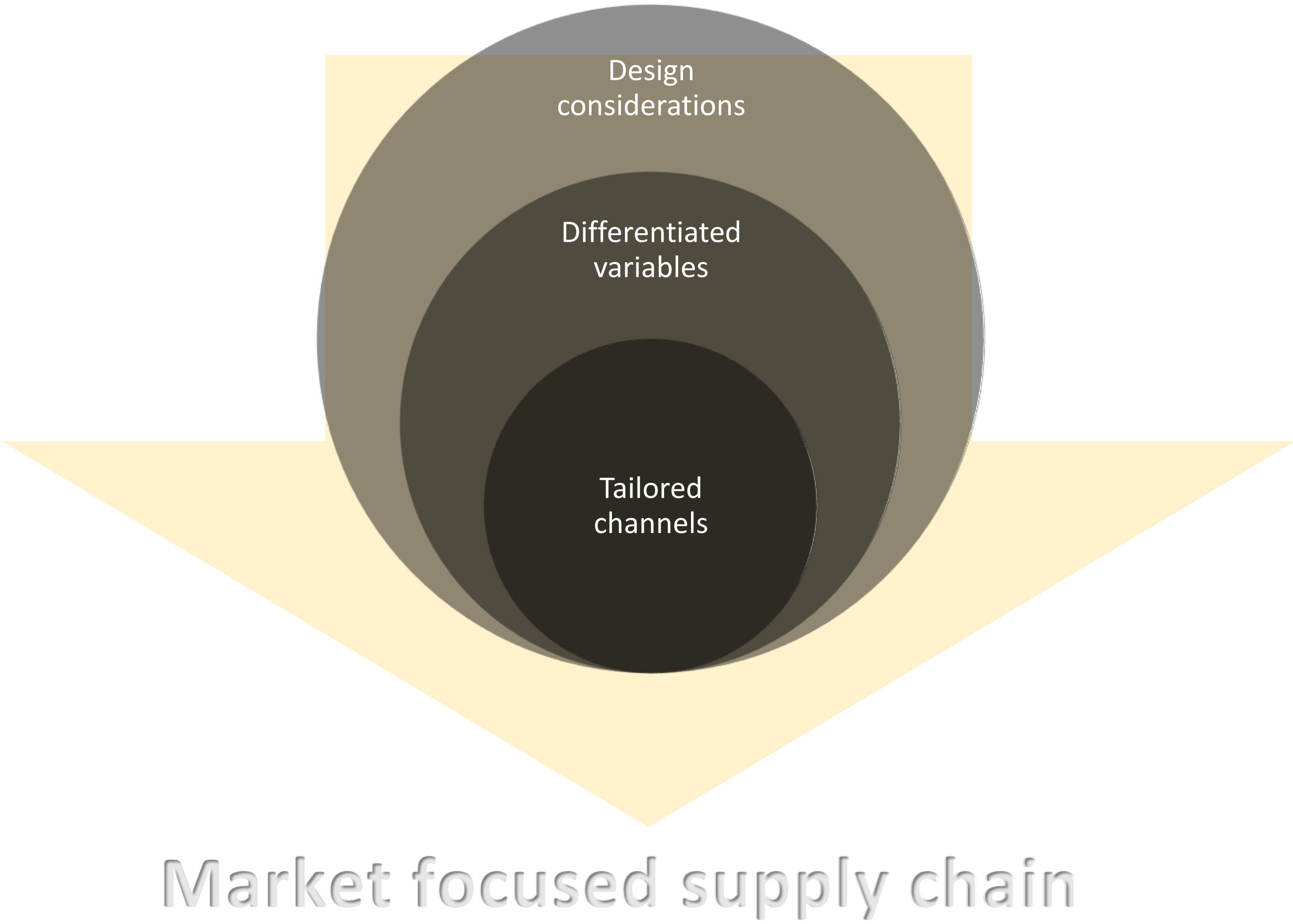

Figure 2.3 Supply chain design framework

2.7 Research gap

The existing literature provides different approaches to building efficient and effective supply chains. All models have their own advantages and limitations. The literature revealed that some research has already been done on the combination of different concepts and techniques aimed to enhance positive outcomes and minimise tension points. For instance, a combination of the Lean and Six Sigma concepts achieved better performance, using the ideas of pragmatic and value-centred Lean and data-driven Six Sigma. Christopher and Towill (2001) developed a framework for merging Agile and Lean concepts that were initially pronounced mutually exclusive. The concept looks promising for application to the design of market-driven supply chains. However, existing studies mostly encompass manufacturing and assembly systems. Aitken et al. (2003) contend that currently the classification "is rather logical rather than "ad hoc". Hence, there is a need for other industry case studies to test the theory in different business environments. This study may shed light on how a synthesis of different concepts works in the commercial sector.

Despite attempts to study opportunities created by combining the benefits of different models and strategies, there is still a considerable research gap; that is, in the integration of several systems. Further research is recommended on combinations of design concepts and their alignment with market needs by identifying integration frameworks. This study will investigate how multiple strategies fit into network pipelines and align with actual market needs.

As mentioned earlier, SC design is context-sensitive and therefore it is crucial to consider SC model architecture in the context of decision levels and interrelated factors. It can be concluded that the relationship and mutual influence of these factors and their influence on the supply chain is an area for future research. The strengths and drawbacks inherent in different modelling approaches will be studied with the aim of developing a framework to overcome the weaknesses and enhance the positive aspects. The current study intends to cover the above gaps and present a tool to address the development of market-focused channels.

Chapter III: Research methodology

3.1 Introduction

Building a robust supply chain encompasses many aspects, which include supply chain strategies, network, assets, capacities, procedures, product characteristics, contracts and information flows shaped by business goals and the overall environment. “One size does not fit all”, hence diversity in products, supply and demand, market volatility and risks complicate design decisions to be made and requires close attention to specific characteristics relevant to achieving the SC goal.

This research will study the design of market-focused SC channels by examining specific characteristics and applying them in a New Zealand-based, commercial industry case. The objective of the research is to develop a theoretical decision support framework to assist with the allocation of strategies and products to multiple market-oriented pipelines, as well as to assess the application of market needs-based DWV3 methodology. It is hoped that New Zealand case-shaping factors will make the study applicable for practitioners planning to design or reengineer commercial supply chains in the New Zealand context.

The primary questions of the research relate to:

- balanced efficiency/effectiveness design approach able to work with different decision levels
- market-oriented strategies tied with multiple supply chain channels
- allocation of strategies and products to multiple channels.

The study will explore a three-step network design where linear optimisation and simulation are chosen for modelling and testing SC levels. The linear programme will be applied to optimise the network based on supply chain influencers. Products will then be assessed in terms of DWV3 methodology and multiple market-specific channels framed by optimal networks. The networks will be tested in detail by a continuous simulation programme.

The chapter begins with the ontological and epistemological perspectives of the research. Different research methodologies will then be appraised and selected along with the data collection method. The chapter ends with ethical considerations of the research followed by a conclusion.

3.2 Ontology and epistemology

Ontology is a philosophical study of existence with a long history. Even though it is well known it still creates controversy. According to Angeles (1981), ontology deals with the structure and order of reality in the widest possible sense. Bateman (1995) claims that "the general programme of ontology relies on it being possible to uncover properties that could not fail to be as they are for the world to exist." (p. 931). Others consider ontology more specific and define it as the study of nature and organisation independent of people's knowledge about it (Guarino, 1995). This description is more suitable for the research provided as it separates ontology from epistemological perspectives.

Objectivism and constructivism are two ontological positions that, according to Byrman and Bell (2015), could define a research strategy. In other words, these are materialistic and idealistic points of view. Objectivism studies reality as a static and tangible concept independent of social factors such as ideas, feelings and opinions. Objectivists believe that existing reality creates boundaries and rules that constrain individuals. Alternatively, constructivists (idealists) believe that reality is dependent on social factors and shaped by individuals. In other words, knowledge does not simply reflect the existing reality but continuously serves the organisation of an inner world of the subject.

In the context of the current research, the tangibility of supply chain network is particularly important. Besides that, the structure is significantly affected by the pre-set of regional and international rules, procedures, regulations and requirements. The supply chain is not static, but a continually evolving, dynamic process. It is constantly affected by stakeholder interaction. Personally, I believe there are no unsolvable controversies between objectivism and constructivism concepts. Conceptualisation paradigm mostly depends on the level of materialistic/idealistic mutual influence similarly to the Chinese yin and yang philosophy (Figure 3.1).

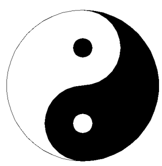

Figure 3.1 Yin & yang philosophy in objectivism/constructivism context

In contrast to ontology, epistemology deals with knowledge and its nature. Mertens (2010) defines it as a relationship between a person (knower) and that which would be known. Epistemology studies the rationality of beliefs and methods of acquiring knowledge. Bryman and Bell (2015) define interpretivism and positivism as two main views on how things can be known. These criteria relate to the status of scientific methods and human subjectivity. Positivism is an objective approach concerned with the testing of theories and based on natural science principles. It studies objects by applying predetermined guidelines and aims to determine cause-and-effect relationships. Bryman and Bell (2015) define interpretivism as opposed to positivism. They outline that due to its nature, the social world requires principles that significantly differ from those suggested by positivists. The doctrine of interpretivism is based on the assumption that human subjectivity and reaction play a key role in the construction of social phenomena. Interpretivism aims at determining and interpreting the behaviour of individuals or social groups.

<table>
<tr><th>Ontology</th><th>Positivist</th><th>Interpretivist</th></tr>
<tr><td>Nature of ‘being’/ nature of the world</td><td>Direct connection to real world</td><td>No direct connection to the real world</td></tr>
<tr><td>Reality</td><td>Single external reality</td><td>No single external reality</td></tr>
<tr><th>Epistemology</th><th></th><th></th></tr>
<tr><td rowspan="3">Base of knowledge/ connection between research and reality</td><td>Possible to acquire hard, secure objective knowledge</td><td>Acquired through ‘perceived’ knowledge</td></tr>
<tr><td>Study concentrates on generalisation and abstraction</td><td>Study focuses on the specific and concrete</td></tr>
<tr><td>Thought ruled by hypotheses and stated concepts</td><td>Seeking to understand and interpret specific context</td></tr>
</table>

Table 3.1 Differences between positivism and interpretivism in the context of ontology and epistemology (Adopted from Carson et al. 2001)

I agree that the positivist approach is emotionally unbiased, has better generalisability and is more reliable. However, the interpretivist approach gives the opportunity to understand meanings, motives, reasons and other personal experiences that are time and context-sensitive. Furthermore, Hudson and Ozanne (1988) state that interpretivists are open to innovations and new knowledge. The context of supply chain design involves much social interaction between SC participants. Moreover, the reaction of individuals significantly affects dynamic changes in SC. For example, Goldratt (1984) argues that people inertia changes the system and impedes optimisation. Pragmatism as a problem-oriented philosophy can absorb the strengths of both concepts. Due to the duality of many dilemmas analysed, applying the strengths of different concepts enables research questions to be answered more effectively (Feilzer, 2010).

Therefore, even though positivists methods will be widely used in the current research, the interpretivism perspective will be applied where the reaction of individuals affects the research dilemma.

3.3 Appraisal of alternative research methodologies

Scholars generally divide scientific research methods onto two base categories that come from different paradigms - quantitative and qualitative. Edmonds and Kennedy (2016) suggest this categorisation is based on process and techniques rather than on formula. Both paradigms possess strengths and weaknesses, and Brannen (2017) claims that the consolidation of the positive aspects of both methodologies leads to a robust approach that gains depth and breadth of understanding and justification while counteracting the weaknesses inherent in utilising each method by itself.

Quantitative methodology

Quantitative methods implicate a statistical approach to data analysis. They could be characterised as 'formalised', where the methodology is aimed at a structured, fixed set of variables and their quantitative measurement.

The main characteristics of quantitative research are: (Lewin, 2005)

- data collected using structured exploration instruments
- methods allow greater accuracy and objectivity of results
- the study is reliable as can be replicated with a similar result
- the questions are clearly defined
- the structure of questions is carefully designed prior to data collection
- the data is usually arranged as non-textual document forms (tables, figure, charts)
- the approach allows wide generalisation and future results prediction.

The quantitative approach has received much criticism. According to Bryman and Bell (2015), advocates of the qualitative concept argue that quantitative methods do not distinguish between the social and natural world, the research is separated from the reality of everyday life, and the methods provide a static view that does not investigate social dynamics.

I believe quantitative data analysis will be a valuable contributor to this research goal as supply chain design implies an analysis of constant and measurable data, such as distance, time, inventory turnover, product lines quantity and financial outcome. Also, the ability to generalise data provides the opportunity to apply research results to different types of supply chain.

Qualitative methodology

The qualitative method emphasises the quality of meanings and processes rather than experimental measures (such as quantity, frequency or intensity). This methodology focuses on the relationship between the researcher and the entities studied. Unlike the quantitative method, qualitative methodology uses an inductive approach and evaluates casual relationships between variables rather than processes. The data is collected through the engagement of researchers and their personal experiences. The method focuses on words, not numbers. Bryman and Bell (2015) define the concept as “observing through the people eyes”.

The main characteristics of qualitative research are (Bryman and Bell, 2015):

- a realistic view of the social world
- allows researchers to describe current phenomena and present situations
- flexible data collection and further analysis and interpretation
- outcomes are supportive of new ways of understanding
- responds to dynamic changes and local situations and conditions
- liaises with subjects on their own terms.

Qualitative methods have been criticised in a similar way to quantitative methods. Bryman and Bell (2015) stress that the methodology of qualitative research is extremely subjective and lacks transparency. Another issue is with the generalisation of findings; however some scholars argue this problem might be solved by using a broader set of identifiable features for the enquiry focus (moderate generalisation). Also, as the social situation is dynamic not static, replication of the study is another challenge to overcome.

The proposed research deals with different SC segments, where individuals might have different opinions on internal and external processes. As mentioned above, the social interaction and reaction of individuals, as well as social factors, have a significant impact on SC performance. In this instance, the qualitative approach could provide valuable insight into the designed network and the evaluation of classification, so current qualitative research methods will be applied alongside the most common quantitative methods.

Mixed research methods

Mixed methods is an approach introduced by Jick (1979) that utilises both qualitative and quantitative concepts. Tashakkori and Creswell (2007) describe this as integration of findings where both numerical and qualitative approaches are used. There is much debate regarding the combination of approaches. Morgan (2007) states the contrast of pure ontological and epistemological paradigms impedes the merging of the two concepts, although a combination of quantitative and qualitative methodologies has been widely used in research, simultaneously exploring both the social and material worlds, and can enhance the strengths of both methods. Ostlund et al. (2011), for example, highly appraise the integration of quantitative and qualitative methods in healthcare research.

The strength of merging both concepts can be defined as follows:

- easy to report and describe
- useful when unexpected results arise
- qualitative data can be generalised
- transformative framework is possible.

The weaknesses of this method relate largely to discrepancies between different types, the time required to carry it out and difficulties with framework design. Creswell (2013) suggests the following mixed strategies could be used, as shown in Table 3.2

Mixed strategy	**Strategy description**
Sequential Explanatory	Qualitative findings assist in the interpretation of quantitative results. Gathering and examination of quantitative data followed by analysis of qualitative information.
Sequential Exploratory	Useful in phenomenon exploration and new instrument development. A primary stage of qualitative data analysis followed by a phase of quantitative data collection and analysis.
Sequential Transformative	Engages methods that best assist the theoretical perspective. Either quantitative or qualitative data is collected first and results are integrated.
Concurrent Triangulation	Increases strengths and minimises weaknesses of each method. The concurrent data collection of both methods is used to cross-validate or corroborate findings.
Concurrent Nested	Useful in addressing questions different from the dominant. One methodology is used to guide the research while another is "nested" (embedded).

Table 3.2 Mixed research strategies (Adopted from Creswell, 2013)

This research uses a *sequential exploratory* method with the aim of defining a SC network, and a *concurrent triangulation* concept that will not only increase the reliability of findings but also help resolve the subjectivity problem inherent in the qualitative approach.

3.4 Selection of research methodology and research process

It is important the research methodology is designed to clarify and apply the theoretical background to the questions of the study. It needs to be well aligned with the main aspects of the exploration. In other words, it will represent a framework that ensures the efficiency of the research.

This section will describe the methodology, approaches, techniques and measurements to be used to address the problems, objectives and questions of the study.

Generally, the design comprises the following tasks and components (Sreejesh et al., 2014):

- selection of the design type: exploratory or formal design
- identification of the problem and information required

- designing a data collection mode and form
- defining the measures and ranking for the information selected
- defining a suitable sample size and sampling process
- selection of an information analysis process.

The reviewed literature revealed existing design models have advantages and drawbacks, where the negative effects could be alleviated and model strengths enhanced by the marrying of different supply chain paradigms. An analytical tool for this research will be linear optimisation followed by creating and applying tailored strategies and further detailed simulation of processes. The proposed flow of research steps is shown in Figure 3.2.

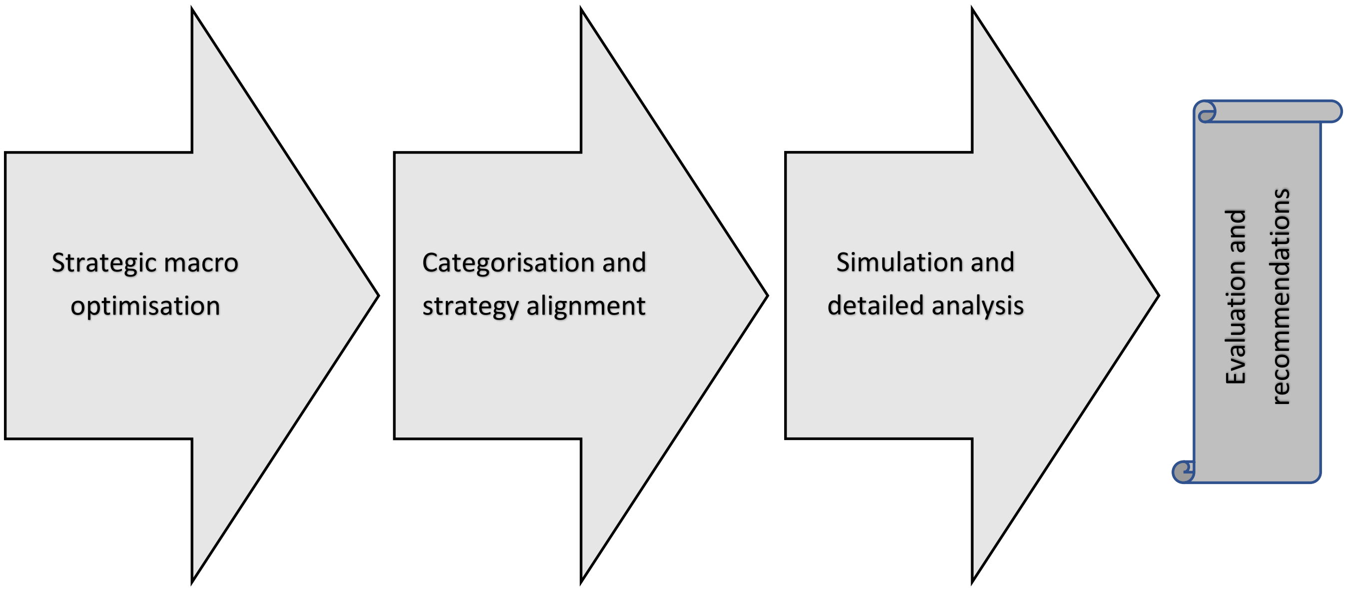

Figure 3.2 Integrated research process

The first step is to explore strategic optimisation by creating a linear programme with a target to form core settings on which the chain will operate. This step provides a holistic view of the supply chain structure and identifies strategic level design decisions to be made. The objective function of the model will be aimed at shaping a supply chain network in accordance with strategic level influencers. Tactical and operational level variables will be ignored at this stage.

In the next stage, the research will categorise characteristics that reflect market needs, create product groups, assess them in terms of order winners and market qualifiers, and tailor market-oriented strategies for multiple pipelines. DWV3 classification was identified as a prominent approach to cluster products and services in accordance with market and customer needs. This concept will be used to differentiate innovative and functional products and provide insights into delivery time, volume, variety and demand variability. Integration of this methodology will allow the alignment of product flows and fulcrum points with actual market needs without overlapping strategic decisions made earlier.

Stage three will focus on detailed simulation and assessment of designed networks, taking into account multiple, interrelated variables. This detailed analysis will be executed using Arena computer simulation, which examines how supply chain processes work over time. The aim here is to evaluate the application of the previously selected DWV3 classifications, and assess risks and continuous performance at lower levels.

Question crystallisation	Exploratory	New insight supported by formal testing
Data source	External/internal	Internal and external quantitative secondary data triangulated with qualitative primary data
Data collection	Monitoring/communication	Mainly data monitoring with some communication interactions for gathering qualitative data
Control of variables	Experiment	Manipulating of variables
Purpose	Descriptive	Exploring 'what' questions rather than 'why'
Time	Cross-sectional/ longitudinal	Data collected at a single point of time/data collected to represent activities over the period of time
Scope	Case/statistical	In-depth case study supported by statistical data examination
Environment	Field/simulation	Field data collection with later simulation of scenarios
Participant perception	Routine/modified	Mostly routine

Table 3.3 Research design considerations

Considerations of design for the proposed research are presented in Table 3.2 The research can be either exploratory or formal. An exploratory study is usually carried out to assess critical issues, evaluate alternatives, discover new ideas and make the problem suitable for detailed investigation. It is not used in cases where a certain result is wanted. Exploratory research gains the necessary information to develop a base for further, detailed research. In contrast, formal research tests a preformulated hypothesis. The proposed research will investigate questions that may later create a hypothesis, therefore an exploratory approach will be mostly used. Some concepts of formal research design will also be adopted however, as findings will be tested with existing cases.

In terms of information required the source of data can be either primary or secondary. Primary data is collected by researchers for specific purposes and tailored to a specific study. However, obtaining this data is expensive and time-consuming. In contrast, secondary data is information already collected by others for a different purpose; for instance, it may be routinely collected as a part of day-to-day company processes and operations. Obtaining this type of data is less costly and time-consuming. Also, many studies require historical data that may be available from secondary sources only. The disadvantage of secondary data is that information collected for a different purpose may be biased, inaccurate or unreliable in terms of the new research. Also, definitions of measures can differ. Sreejesh et al. (2014) define syndicated data as information gathered by research firms, and suggest separating it from primary and secondary data. However, this data should be attributed to one of the types previously mentioned, depending on the method under which it was produced. In this study, secondary data will be widely used at all stages of research while primary purposively collected data will be received at the simulation stage. The disadvantages of secondary and primary data will be resolved using the triangulation techniques mentioned in the previous section and multiple replications respectively.

The source of data can be internal or external. Internal sources are available within a company or organisation, such as financial statements and reports, production summaries, sales records and department reports. External sources are those obtained from outside a firm or organisation. The most common forms of external data are retrievable databases, associations, periodicals, external experts and governmental sources. In the current case study, external data sources will be used alongside internal sources to facilitate generalisation and help avoid subjectivity.

The research is aimed at the exploration of market-oriented design concepts through the analysis of supply chain processes of the case company. Therefore, most of the data will be collected by acquiring historical quantitative data from company ERP and external sources. However, as the reaction of individuals has a noticeable impact on SC performance, some interrogation and communication data collection will be included. As mentioned earlier, qualitative data will be used in cases where quantitative data is not available, or the experience of specialists is required for preliminary analysis and the concurrent triangulation of findings. In the current study, data received via communication will triangulate the monitored data of product segregation and help with facilities location analysis.

Variables of contemporary supply chains are continuously affected by aspects such as actors' mutual influence, unpredictability of demand and failure and disruption risks. To overcome challenges caused by dynamic changes in a supply chain, a simulation model will be used alongside the experimental approach to variables control.

In terms of time dimension, the research can be either cross-sectional or longitudinal. Sreejesh et al. (2014) state that statistically most existing studies need to be attributed to the cross-sectional category. These are surveys that collect data at a single point in time, and are more representative of the population, but cannot be used when objectives need to be defined over a time period. In contrast, longitudinal research looks at behavioural changes over time. The current research will be cross-sectional for data sets represented by rates and costs, but retrospective in terms of collecting sales performance.

The scope of examination relates to the breadth and depth of the study. This research will be based on a case study with a statistical examination of information gathered from relevant sources to provide in-depth research on the drivers and triggers of market-focused supply chain design in the New Zealand context.

The research will observe operations and subjects in their routine environment; although in some cases, actors will be modified in a simulation model to trigger a projected response. A field environment will therefore be chosen for the first stage, followed by the simulation of scenarios.

3.5 Data collection

The allocation of inventory and configuration of the SC network encompass large data sets, so the collection and analysis of relevant information is a vital component of the study. SC design data will be collected on each of the research stages, as shown on Figure 3.3

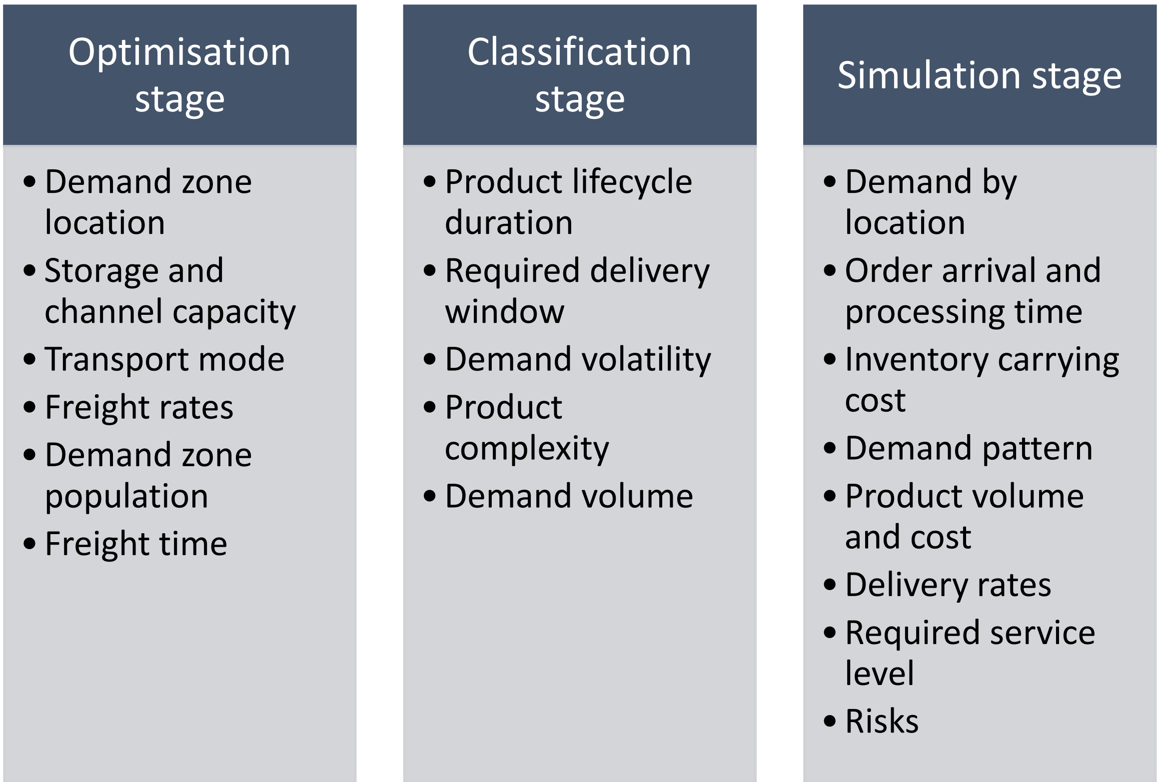

Figure 3.3 Data collection stages

As mentioned above the study will mainly use quantitative data. The information will be collected from a purposively selected New Zealand importer whose supply chain encompasses different product types. David and Sutton (2001) define four types of data that influence the analysis stage. *Nominal* data represent variables with identifiable differences and which cannot be ranked. In *ordinal* data, the differences between categories can be judged in order of importance. For instance, the scale can be developed as highly desirable, desirable, neutral, undesirable and highly undesirable. *Interval* and *ratio* data can be ranked on the importance and distance between observations. However, interval variables have no true zero point. For instance, volume can be named as ratio data when time is an interval. Table 3.3 presents variables relevant to SC design.

Supply chain design and optimisation include a large amount of data. For example, a typical supply chain may have many supplier or customer accounts and product lines. Simchi-Levi and Kaminsky (2008) suggest aggregation of data facilitates the analysis. In this research, the clustering technique will be used for customer and supplier aggregation; for example, classification can be done depending on location or population density. As mentioned above various classification systems are suggested by academics and supply chain experts, where products can be classified according to distribution pattern, contribution to margin, product type and many other variables. The study will use the DWV3 system, and products will be aggregated in different clusters depending on their market-specific characteristics.

Transportation rates	Ratio	Internal fleet rates External fleet rates Class rates Exception rates Commodity rates
Mileage estimation	Ratio	Distances to sourcing points Distances to customer Distances between subsidiaries
Warehouse cost	Interval	Handling costs (labour and utility) Fixed costs Storage costs
Warehouse capacities	Interval	Storage space Operational space
Potential facilities location	Ordinal	Labour and resources and availability Governmental regulations Geographical and infrastructure conditions Public interest Possibility of facilities expansion
Service level requirements	Ratio/Ordinal	Order fulfilment time Order cycle time DIFOT Fill rates
Demand	Ratio/Ordinal	Demand pattern Cost changes Planning horizons Demand changes

Table 3.4 Supply chain design data variables

It is important the data is collected accurately and reflects the design problem. Neuman (2006) defines data reliability as the ability to be repeatable under similar circumstances. To increase reliability, collected data will be conceptualised to avoid “noise”, and validated with case company experts. Preciseness will be improved by increasing the level of measurement. Also, multiple replications will be performed at simulation stage to ensure data reliability.

The valid output of data collected is another key aspect of research. According to Neuman (2006), valid data should reflect the nature and characteristics of events being studied. Collected data will be validated through following questions:

- Do measures make sense?
- Are they consistent?
- Can the result be fully explained?

For supply chain design Simchi-Levi and Kaminsky (2008) recommend techniques where the existing network can be reconstructed using a model and gathered information, and the model's output compared to existing accounting information. In the existing research the empirically collected data of the case company will be compared with the outcome of the simulation model.

3.6 Ethical considerations

It is important the research does not harm participants. According to Cooper and Shindler (2008), all research participants must be protected from emotional discomfort, distress, physical harm and confidentiality issues. This research will be conducted in accordance with Massey University research ethics (Massey University, 2017).

The main principles to be used are:

- respect for individuals and their gender, culture, age and religion
- harm minimisation for contributors, researchers, organisations and institutions
- participants shall be informed, protected and voluntary consent received
- confidentiality and privacy
- conflict of interest shall be avoided.

Most data in this study will be collected from secondary sources. Where interaction with participants is required, individuals will be informed about research aims, goals and processes, and voluntary consent will be obtained. Participants will have the right to withdraw from participation at any time and at any stage of the research. All questions and interviews will be designed with respect for participants' beliefs, age and gender.

Even though the research does not indicate any potential harm to participants, including the researcher, all safety considerations will be applied. The confidentiality of information obtained purposively or accidentally will be respected and all risks of disclosure will be mitigated. No unnecessary deception issues are expected.

As the researcher is a part of the firm to be studied there is a potential conflict of interest. The issue will be resolved by obtaining the freedom of researcher consent. The data will be collected from a New Zealand company. As received case company data will be market, personnel and financially sensitive, and required to be protected, company name and details will not be disclosed.

3.7 Conclusion

The main limitations of this study are those of quantitative approach, and time and resource constraints. Concurrent triangulation will be used to overcome the drawbacks of quantitative research. Also, the synthesis of the objectivist and constructivist approaches and selected epistemological perspectives, quantitative methods enhanced with qualitative techniques, and the proposed framework of the research process, show explicit potential for resolving the market-oriented supply chain design dilemma, ensuring reliability of findings and the meeting of research objectives.

Chapter IV: Stage 1 linear model development and analysis

4.1 Introduction

All supply chains are shaped by multiple factors that vary from global, such as the international market situation, to local such as national or regional regulations. In the New Zealand context these influencers are a wide range of political, economic and social aspects, geographical constraints, sources, product and demand characteristics, service requirements, governmental regulations and cultural traditions.

The population density in New Zealand exhibits considerable geographical variation (Figure 4.1). More than 30 percent of the population resides in one city (Auckland). The population of the North Island is four times higher than of the South Island. Additionally, most South Island residents live in the greater Christchurch area (New Zealand, 2013). Normally the demand pattern for consumer goods follows the population and needs to be considered in supply chain architecture as an important shaping factor.

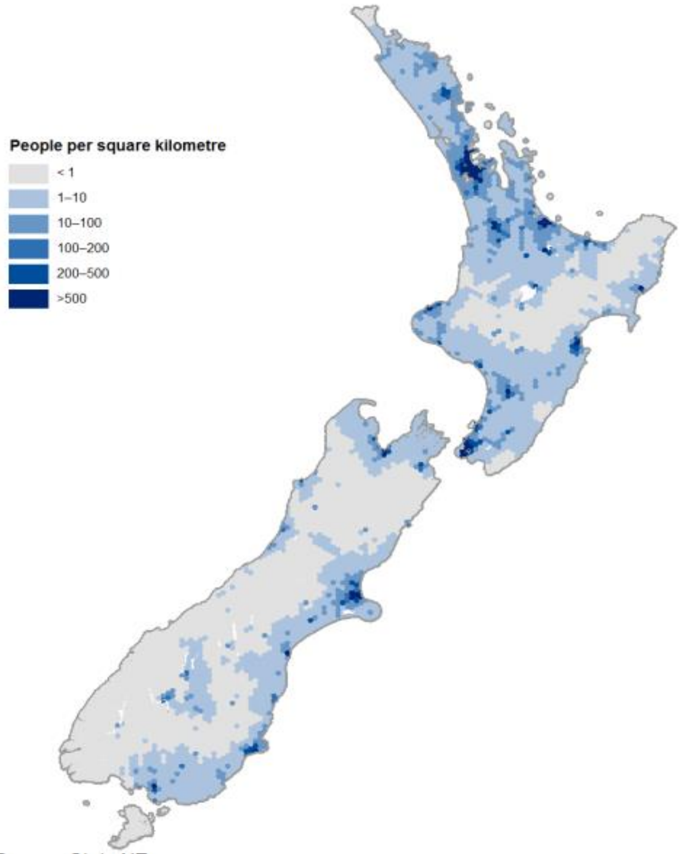

Figure 4.1 Population density of New Zealand (New Zealand statistics, 2017)

Freight transport in the country is notably influenced by landscape, climate, island character, historical settlement and natural resources distribution patterns. In addition, privatisation in the transport sector has enabled companies to create integrated, multi-modal freight solutions (Cavana et al., 1997), which has added unique characteristics to the transport network.

Even though the New Zealand road system is approximately 100,000 km, most highways are two-lane roads that inhibit total speeds and affect delivery schedules. At the same time, this has allowed the railway to capture (even short-haul) forestry freight from road transport despite deregulation in the mid-1980s (Gil, 1996). At the same time, freight rates are subject to fierce competition. Grant (1997) cites a senior executive of one of the largest NZ freight operators, Mainfreight, that he did not know how many operators could survive with the existing rates. Adding value alongside price reduction is therefore a significant task for the local logistics market.

The island character of the country underlines the importance of seaports. According to the Ministry of Transport (2017), container turnover in New Zealand grew from 1,572,385 in 2012 to 1,832,899 TEU (twenty-foot equivalent unit) in 2016. Noticeably, seaports are heavily engaged in not only import/export operations but also in local transit. The 1995 coastal shipping deregulation allowed foreign-flagged ships to be involved in local cabotage, which has significantly changed coastal shipping patterns and affected shipping rates (Kennedy, 1998).

Other factors affect the strategical positioning of supply chain hubs in the New Zealand context. Distribution facilities, leasehold rates and availability of workforce vary considerably depending on region and population density.

Sankaran (2000) suggests that SC construction factors may be grouped into three categories; structural (population and geography), regulatory (governmental regulations), and developmental (ongoing development). In New Zealand the structural factors are Cook Strait, the dominance of Auckland, non-linear and thin market density, facilities and resource costs and availability, freight rates and geographical isolation. Regulatory factors are tracking restrictions, coastal shipping deregulation, MPI requirements and international agreements. New Zealand development factors include innovations in freight for perishable goods (e.g., cold chain) and inland hub development.

The company used in this case study is a New Zealand importer and supplier of hospitality products. The company has been on the market for more than 30 years, which has allowed it to build a strong customer base and gain a solid history of demand. Its current strategy determines the physical flow of goods from a company distribution centre to customers all around New Zealand. The key element of company strategy, as highlighted by the senior leadership team, is a high level of customer service (HSL). However, fierce competition on the market requires the company to maintain HSL and meet customer expectation without sacrificing the cost of business. The senior leadership team emphasises that a robust, first-class supply chain be an integral part of its HSL strategy. The company exploits reorder point planning (ROP) for stock replenishment. The stock holding policy aims for 98 percent availability, with a KPI level of not less than 95 percent. Most suppliers are located overseas which affects order replenishment time and requires batching orders to meet MOQ. The company applies margin-based ABC product classification and has no differentiation in terms of other product characteristics, such as volume or demand regularity.

According to Daskin et al. (2005), facility location is the most critical decision for SC architecture. Inefficient sites result in excessive costs that may be carried through the lifetime of the facility, affecting company revenue and decreasing competitiveness. Decisions about the inventory holding policy, information interchange, capacities and facilities layout are relatively flexible and can be altered to respond to changes, whereas site/facility locations are immobile or bound for a long period and thus cannot be easily moved for the reason of demand fluctuations.

The problem to be addressed in the first stage of this research is to determine the quantity and location of distribution facilities (DC) required to optimise supply chain performance and cost. Supply chain facilities allocation generally requires significant investment; thus, it might be considered one of the most important decisions in creating a base for further SC design. This involves higher level strategic decisions that shape a designed supply chain. As defined in the literature review, it is important the development embraces the main aspects of designed supply chain without being distorted by lower level influencers. Linear programming is a simple but powerful tool to evaluate trade-offs among strategically important factors and processes by applying a ‘what if’ scenario to strategic processes (Bowersox et al., 2012). A mathematical optimisation approach via integer linear programming with binary variables will be used to find the best SC outcome and optimise locations for decoupling points. This will later be exploited as the basis for a more detailed review.

4.2 Developing an LP model

The objective of the first step is to determine the number and location of facilities to satisfy regional demand based on population density alongside freight and operation cost parameters (Bowersox et al., 2012). Since fast service has become one of the most important market winners, a delivery period also needs to be studied to ensure the system provides the lowest response time.

The first step in Figure 4.2 represents the task being addressed. The aim is to determine an optimal location and number of distribution facilities. Demand zones will be allocated to preliminary chosen locations as possible distribution sites.

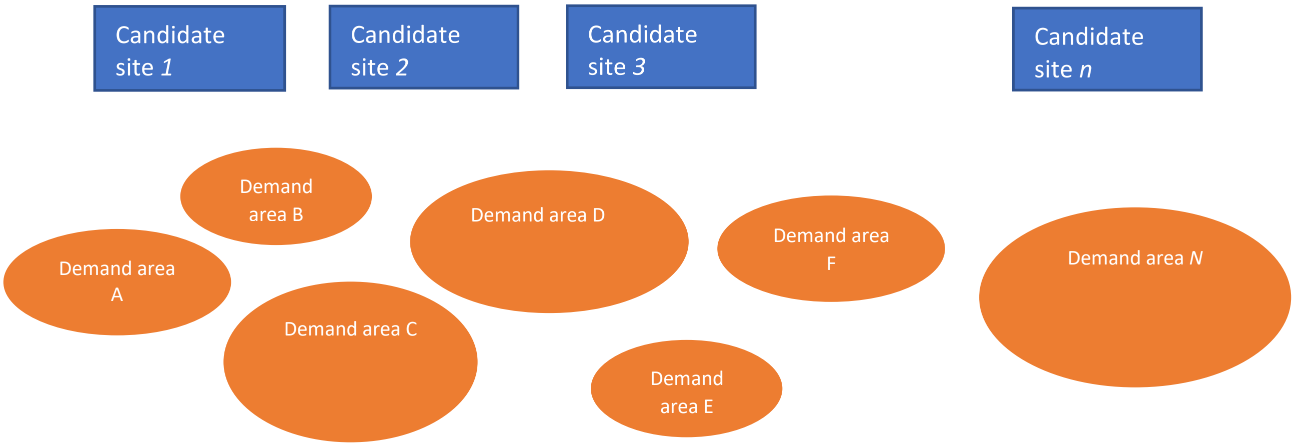

Figure 4.2 Linear optimisation objective task

Some researchers suggest building an LP model based on the distance between candidate sites and customers (Ogryczak & Olender, 2012; Zhou & Chen, 2010), while others recommend applying unit freight cost between each possible distribution centre (DC) and each customer location (Daskin et al., 2005). In New Zealand freight rates are not linear, and due to multimodal transport the delivery cost depends not only on distance but also on location and direction. Therefore, local freight rates (Appendix 2) and delivery time (Appendix 3) are applied to solve the location problem.

A demand pattern for consumer goods has a tendency to follow population density. In this case study, a preliminary demand analysis conducted to determine historical demand tendencies followed pro rata the Census survey population pattern. Based on this fact the aggregated yearly demand from each customer area is used in the analysis.

Facilities availability and cost were studied through open sources (Appendix 4), revealing that annual cost also depends on the geographic location of a candidate site, where percentage cost deviation may vary up to seven percent. Annual rates are estimated by applying average rates in the each of the candidate site regions. For generalisation purposes it can be assumed there are no restrictions, and the maximum quantity of decoupling points is equal to the regions in which they are positioned.

The following symbols used in the model are defined below:

x_{ij} – quantity shipped from regional DC

$y_i - binary = 1$ if opening DC and *0* otherwise

$C_{(ij)}$ – cost for shipping of one unit from DC *i* to retailer location *j*

$d_{(ij)}$ – freight rate between DC *i* and customer zone *j*

$t_{(ij)}$ – delivery time between DC *i* and customer zone *j*

q_{ij} – simple order shipped from regional DC

$B_{(1)}$ – DC *i* operating cost

$D_{(j)}$ – aggregated demand at customer zone *j*

$P_{(i)}$ – capacity of DC *i*

$A_{(i)}$ – demand areas

k – prespecified max number of DC

N – number of facilities restricted by function 1

The objective for function (1) is targeted to minimise SC expenses that include delivery rates, facilities lease and operating costs. The model allocates demand through candidate sites, weighting costs of facilities and freight rates. As an outcome, the model provides the optimal number and location of opened DC as well as quantities supplied to each customer area.

Function (1) is subject to the following constraints:

- sum of shipment x_{ij} is more or equal than 0
- demand requirements for each customer location must be satisfied
- demand satisfied from opened DC cannot be higher than DC capacity
- opening DC - binary
- quantity of SC facilities to be opened cannot exceed the number of predetermined areas k.

The objective for function (2) is a second linear optimisation stage aimed at minimising service time based on delivery time for a simple order between SC nodes and customer areas and tests function (1) result. As an outcome, it allocates demand between the number of decoupling points recommended by function (1) but is not restricted by locations defined in function (1) outcome.

Function (2) is subject to the following constraints:

- total amount of orders delivered from any location is not negative
- orders for all the customer areas are shipped
- total quantity of orders is equal or less than the number of demand areas
- allocating to DC - binary
- quantity of SC sites to be opened cannot exceed the number of facilities predetermined by function 1.

$$min \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}\, C(ij) d(ij) + \sum_{i=1}^{m} y_i\, B_1 \qquad (1)$$

Constraints:

$x_{ij} \geq 0 \qquad \forall\, i, j$

$\sum_{i=1}^{m} x_{ij} \geq D_{(j)} \qquad \forall\, j$

$\sum_{j=1}^{n} x_{ij} \leq P_{(i)} y_i \qquad \forall\, i, j$

Unmet demand = 0

$y_i \in \{\, 0,1\} \qquad \forall\, i$

$\sum_{i=1}^{n} y_i \leq k$

$$min \sum_{i=1}^{m} \quad \sum_{j=1}^{n} q_{ij} t_{ij} \tag{2}$$

Constraints:

$xq_{ij} \geq 0 \qquad \forall\ i, j$

Unshipped orders = 0

$\sum_{j=1}^{n} q_{ij} \leq A_{(i)} y_i \qquad \forall\ i, j$

$y_i \in \{ 0,1\} \qquad \forall\ i$

$\sum_{i=1}^{n} y_i \leq N | y_i$

In this study, the Simplex LP algorithm is used to solve the location problem. At the first step, 11 candidate sites were chosen across New Zealand. All sites are located in cities with available facilities and high population density. A delivery cost matrix based on local freight rates (Appendix 2) was applied for the optimisation model. Considering required response time and New Zealand logistics constraints, DC capacity has been limited by 10,000, which satisfies existing demand in each of the islands and maintains a required response level for remote sites.

Demand areas were initially connected with the nearest candidate site. Running the model reallocated existing demand for only two candidate sites #2 North Island (NI) and #8 South Island (SI) (Table 4.1 and Table 4.2), which are Tauranga and Christchurch.

DC No	Northland	Auckland	Bay of Plenty	Waikato region	Gisborne region	Hawkes bay region	Taranaki region	Wanganui region	Wellington region	Tasman region	Nelson region	Marlborough region	Canterbury region	Otago region	Southland region	West Coast region	WH opening (1=open)
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2	403	3751	710	1070	117	400	291	591	1248	0	0	0	0	0	0	0	**1**
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
8	0	0	0	0	0	0	0	0	0	124	122	114	1428	535	246	87	**1**
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
																	2

Table 4.1 Demand allocation matrix

Objective cell (min.)						
	Cell	Name	Original value	Final value		
	$C$55	COST= excess capacity	9323062.091	2512778.327		
Variable cells						
	Cell	Name	Original value	Final value	Integer	
	$C$24:$S$34					
Constraints						
	Cell	Name	Cell value	Formula	Status	Slack
	$C$39:$C$49 >= 0					
	$C$52:$R$52 = 0					
	$S$35	WH opening (1=open)	2	$S$35<=11	Not binding	9
	$C$24:$S$34 >= 0					
	$S$24:$S$34=Binary					

Table 4.2 Simplex LP cost optimisation result

At the second step Simplex LP optimisation was run to ensure the chosen candidate locations have the best response time. The delivery time matrix (Appendix 3) was used in response optimisation. For generalisation purposes, a simple order was used. The maximum quantity of candidate DCs was restricted to the number suggested by the cost optimisation model.

Customer zones were initially connected with sites located in areas with the lowest average response time (Candidate site #6 and #7). The running of the optimisation function reallocated simple orders against two other candidate sites ## 2 (NI) and 8 (SI) (Table 4.3 and Table 4.4), which are the same candidate sites previously determined by function 1.

No	Northland	Auckland	Bay of Plenty	Waikato region	Gisborne region	Hawkes Bay region	Taranaki region	Wanganui region	Wellington region	Tasman region	Nelson region	Marlborough region	Canterbury region	Otago region	Southland region	West Coast region	WH opening (1=open)
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.3 Response allocation matrix

Objective cell (min.)						
	Cell	Name	Original value	Final value		
	$C$55	COST= excess capacity	32	29		
Variable cells						
	Cell	Name	Original value	Final value	Integer	
	$C$24:$S$34					
Constraints						
	Cell	Name	Cell value	Formula	Status	Slack
	$C$39:$C$49 >= 0					
	$C$52:$R$52 = 0					
	$S$35	WH opening (1=open)	2	$S$35<=2	Binding	0
	$C$24:$S$34 >= 0					
	$S$24:$S$34=Binary					

Table 4.4 Simplex LP response optimisation result

4.3 Sensitivity analysis

As specified in chapter 4.2, model objectives rely on customer zone demand, freight rates, operational cost, delivery time and facilities capacity. Some models may suggest several warehouses be opened, which in real life might be restricted by SC design influencers such as governmental regulation and environmental factors. This problem does not affect the current study. However, if required it might be solved by constraining the number of facilities in linear optimisation algorithm after primary analysis of possible network variants. In the current study, the number of nominees has not been limited and is equal to the number of preliminary chosen locations.

For generalisation purposes, and with the aim of not constraining or prioritising any of the sites, distribution centre capacities are set regardless of site location. If the DC capacity is not able to satisfy demand the linear algorithm will reallocate outstanding demand to facilities with capacity excess.

In some cases, non-consumer goods demand might not follow density of population; for instance, if delivery points are tied to specific customers such as factories, mines, military camps or others located in a particular area. For such occasions, demand location-allocation analysis shall be preliminarily conducted based on specific demand characteristics.

No	**Northland**	**Auckland**	**Bay of Plenty**	**Waikato region**	**Gisborne region**	**Hawkes Bay region**	**Taranaki region**	**Wanganui region**	**Wellington region**	**Tasman region**	**Nelson region**	**Marlborough region**	**Canterbury region**	**Otago region**	**Southland region**	**West Coast region**	**WH opening (1=open)**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	343	3188	604	910	99	340	247	502	1061	105	104	97	1214	455	209	74	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																	1

Table 4.5 15 percent demand decrease allocation matrix

Often the demand for consumer goods changes in all locations simultaneously (e.g., seasonal demand decrease or increase). Even if global changes proportionally affect demand in all delivery locations to the same extent, the function may reroute connections between candidate sites and customer zones. Table 4.5 presents the delivery pattern matrix as impacted by a demand decrease of 15 percent. As a result of the test, all demand is reallocated to one candidate

#6 (Wellington). However, demand increase does not have such a strong effect, and starts changing DC location from a 40 percent demand drop.

Variation in operational cost is another area subject to routing change. It is clear that sufficient change in one of the site's costs redirects customer zone demand from one candidate to another; for example, routing changes from site 2 to site 1 if the operational cost of site 1 is equal to that for site 2.

Balancing delivery and operational cost also affects network layout when operational costs change for all sites. The model suggests moving the decoupling point from site 2 in favour of site 5 in the case of a simultaneous 15 percent lease cost increase (Table 4.6). With regard to decreases in demand change, reallocation does not start until there is a 30 percent facilities rate drop.

No	Northland	Auckland	Bay of Plenty	Waikato region	Gisborne region	Hawkes bay region	Taranaki region	Wanganui region	Wellington region	Tasman region	Nelson region	Marlborough region	Canterbury region	Otago region	Southland region	West Coast region	Operational cost
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1144250
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	933800
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1040750
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	759000
5	403	3751	710	1070	117	400	291	591	1248	0	0	0	0	0	0	0	782000
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	823400
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	811900
8	0	0	0	0	0	0	0	0	0	124	122	114	1428	535	246	87	934950
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	925750
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	941850
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	940700
																	1144250

Table 4.6 15 percent operation cost increase allocation matrix

Differences in freight rates between nodes play their own role in the optimisation model. In the current study a proportional 15 percent rate increase does not affect the designed network as rates overweigh the impact of operational cost. The function starts changing the network layout from a 40 percent freight increase. However, if tariffs drop the operational cost increases its influence on the network. For instance, with a 15 percent freight decrease, operational expenses start competing and change preferences to candidate site #5 and #6 (Table 4.7).

Substantial changes in the country's freight pattern, such as creating new multi-modal routes and launching new transport modes, may lead to non-proportional rates change that reshuffles the network layout.

No	Northland	Auckland	Bay of Plenty	Waikato region	Gisborne region	Hawkes Bay region	Taranaki region	Wanganui region	Wellington region	Tasman region	Nelson region	Marlborough region	Canterbury region	Otago region	Southland region	West Coast region	WH opening (1=open)
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	403	3751	710	1070	117	400	291	591	1248	0	0	0	0	0	0	0	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	124	122	114	1428	535	246	87	1
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																	2

Table 4.7 15 percent rates reduction allocation matrix

The analysis above reveals that alterations in variables affect the optimal solution. Table 4.8 shows the impact of a 15 percent increase/decrease of system variables on the SC outcome. Supply chain cost is most sensitive to a rise in operational charges, resulting in an additional 9.55 percent increase to the forecast SC total cost. On the other hand, a 15 percent shortfall would result in a 27 percent total SC cost decrease. However, this significant cost reduction will not increase company profit because the lower cost is purely the result of fewer products or materials supplied. On the other hand, delivery charges have the smallest impact on SC cost, resulting in 5.3 percent and -6 percent in the case of increase and decrease respectively, and do not have a major impact on the system. Thus, operational cost might be identified as the most significant variable for the system, which corelates with the findings of Cohen and Moon's (1990) model mentioned in the literature review. It determines that this variable requires closer attention to mitigating supply chain risks.

	Original		**Increase 15%**			**Decrease 15%**		
	Candidate site #	**SC cost**	**Candidate site #**	**SC cost**	**SC cost % change**	**Candidate site #**	**SC cost**	**SC cost % change**
Demand	2,8	$ 2,512,778.33	2,8	$ 2,645,945.08	5.30%	6	$ 1,833,461.58	-27%
Operational cost	2,8	$ 2,512,778.33	5,8	$ 2,752,648.01	9.55%	2,8	$ 2,269,028.33	-10%
Freight rates	2,8	$ 2,512,778.33	2,8	$ 2,645,945.08	5.30%	5,8	$ 2,373,343.30	-6%

Table 4.8 Effect of changing variables on facilities allocation and cost

Today, value enhancement and service level have become leading requirements. Thus, the agility paradigm becomes a critical SC dimension where service level is a market-winning criterion (Christopher & Towill, 2001). Normally for large scale models, such as multinational or intercontinental, transfer time follows the distance between decoupling points and consumers. In such cases, delivery time optimisation might be omitted or used to triangulate findings. On a smaller scale, local chain supply influencers, such as multimodal freight and historical logistics network, often break the linear relationship between delivery cost and time. Therefore, the outcomes of both functions need to be studied and aligned with market winners to provide the best balance between Lean and Agile paradigms.

The time optimisation function (2) tends to allocate facilities to the nearest candidate site. Therefore, in the current study the number of despatch locations was limited by the number prescribed by function (1) to balance lead time against supply cost. Function (2) optimisation resulted in the same network pattern that enhanced the outcome of cost optimisation (1).

Due to specific characteristics, some products might be subject to regulation, restrictions or special requirements. For example, dangerous and perishable goods have special requirements for transport and delivery time respectively. These goods need to be withdrawn from aggregated demand and studied separately by applying constraints and variables in accordance with a product distinctive characteristic.

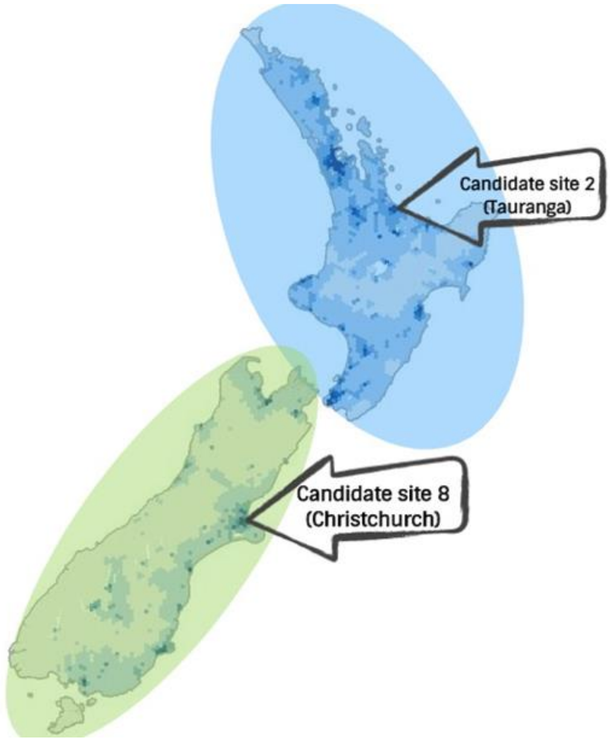

Figure 4.3 Linear model DC allocation

The key outcome of LP optimisation is a macro Lean-Agile model that balances the effects of delivery cost with distribution centre expenses and their capacity. The model recognises the effects of external SC influencers and provides insight into the shape of a planned supply chain. For example, the model reveals that natural constraints, such as Cook Strait, impact on the New Zealand SC outline (Figure 4.3). Furthermore, the actual location of distribution centres positioned by linear optimisation allows the proposed SC to benefit from two large international ports located in the same area. The results of the linear optimisation model have been compared to the case company's DC locations intuitively chosen by management. In contrast with the linear model the case company had three regional distribution centres, Tauranga, Christchurch and Auckland. Discussion with the senior leadership team revealed plans, however, to reduce the number of facilities to two only, in Tauranga and Christchurch. This confirms the validity of findings provided by the linear optimisation model. The outcome of stage 1 will be used as a base for more detailed supply chain analysis in the following chapters.

Chapter V: Stage 2 product classification and clustering

5.1 Introduction

Today's companies face serious challenges created by various business environment factors. Mendes (2001) states that shortened product lifecycle, amplified demand variability, product variety and uncertainty in supply enhanced by low forecast accuracy, are major contributors to a decrease in operational efficiency and sources for many supply chain risks. The solution for the dilemma may lie with achieving both effectiveness and efficiency through building supply chain, market-specific strategies on the basis of differing customer needs (Christopher, 2000; Childerhouse et al., 2002).

The aim of this chapter is to integrate market-specific classification in the supply chain network shaped by linear optimisation and align it with relevant supply chain strategies. Following the literature review, the DWV3 classification proposed by Childerhouse et al. (2002) seemed to be able to cluster company product ranges into groups with similar characteristics that reflected market requirements and aligned with specific strategies. This chapter will attempt to differentiate products by applying the five DWV3 variables: *life cycle duration* (LC), *delivery time window* (DW), *variability*, *variety* and *volume*, to create market-reflective product clusters. The relevant SC paradigm will apply to each of these product groups in accordance with their market characteristics.

5.2 Classifying product portfolio

The case company portfolio represents a diversity of functional, innovative and customised products that may require different supply chain strategies and stock policy. Therefore, the aim of this chapter is to cluster company X products to enable them to be tied to different supply chain strategies.

Historically, the company product range is codified into 15 groups in accordance with company retail product hierarchy (RPH): accommodation (*P1*), chemicals (*P 2*), crockery (*P3*), cutlery (*P 4*), disposables (*P5*), equipment (*P6*), furniture (*P7*), glassware (*P8*), hardware (*P9*), laundry (*P10*), refrigeration (*P11*), shelving (*P12*), non-inventory (*P13*), stainless steel (*P14*), uniform (*P15*).

Non-inventory (P13) RPH was later regarded as irrelevant and excluded from the research as it mostly defines specific processes and jobs, such as installation, repair, warranty and so on. All other goods have similar market characteristics and will be used as a base for the portfolio classification process.

5.2.1 Duration of the life cycle (LC)

Differentiating a short and long life cycle requires setting a level against which to measure product life duration. The duration of life cycle for each of the products is defined in Appendix 6. The average lifecycle for products was between four and six years. It is noticeable that products with electric components (P6/P10/P11) had a relatively shorter LC. However, there is a clear difference between P14 and the others. The highly customised P14 had a deactivation maximum of two years; 2.5 times less than the shortest LC for the other RPH groups (Figure 5.1). Based on this, two years has been set as the limit for short life cycle products.

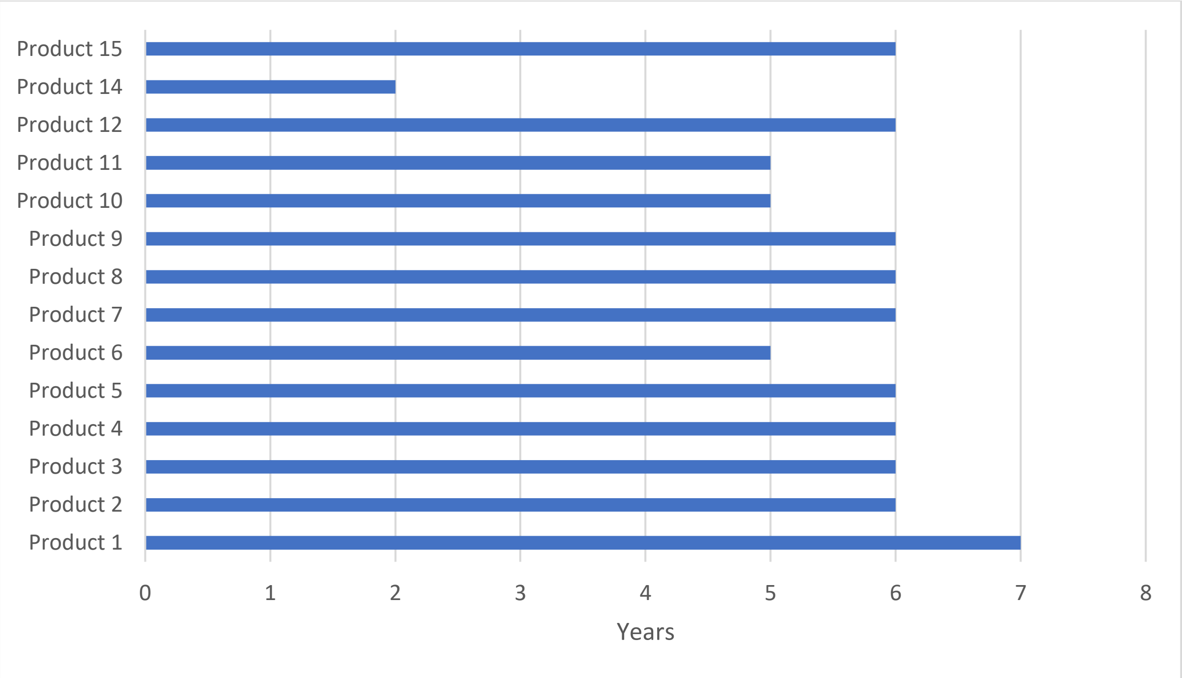

Figure 5.1 Product life cycle

5.2.2 Time window for delivery

The window for delivery reflects the supply responsiveness of a designed supply chain. A short delivery window determines products where rapid response is a market winner. Often there is a link between the level of customisation and acceptable lead time. Generally, customers are ready to wait longer for products with a higher level of customisation. Following this, P14 can be defined as a product with a low response time. However, even though other products are functional, the desired delivery period in these groups is different and needs to be studied to determine the group DW threshold.

Sales representatives were questioned to define the desired DW level for all RPH groups (Appendices 5 and 6). There is a noticeable difference in the expected time (Figure 5.2). Some products require immediate replenishment or delivery. Fast-wearable, fragile or disposable products P2, P3, P4, P5, P8, P9 and P15, represented by chemicals, crockery, disposables, glassware, uniform and hardware, require a maximum DW of up to two days, while the anticipated delivery time for long-serving equipment and furniture (P1, P6, P7, P10, P11 and P12) starts from five days. Based on this information, a two-day lead time was set, as DW qualifying products required rapid supply.

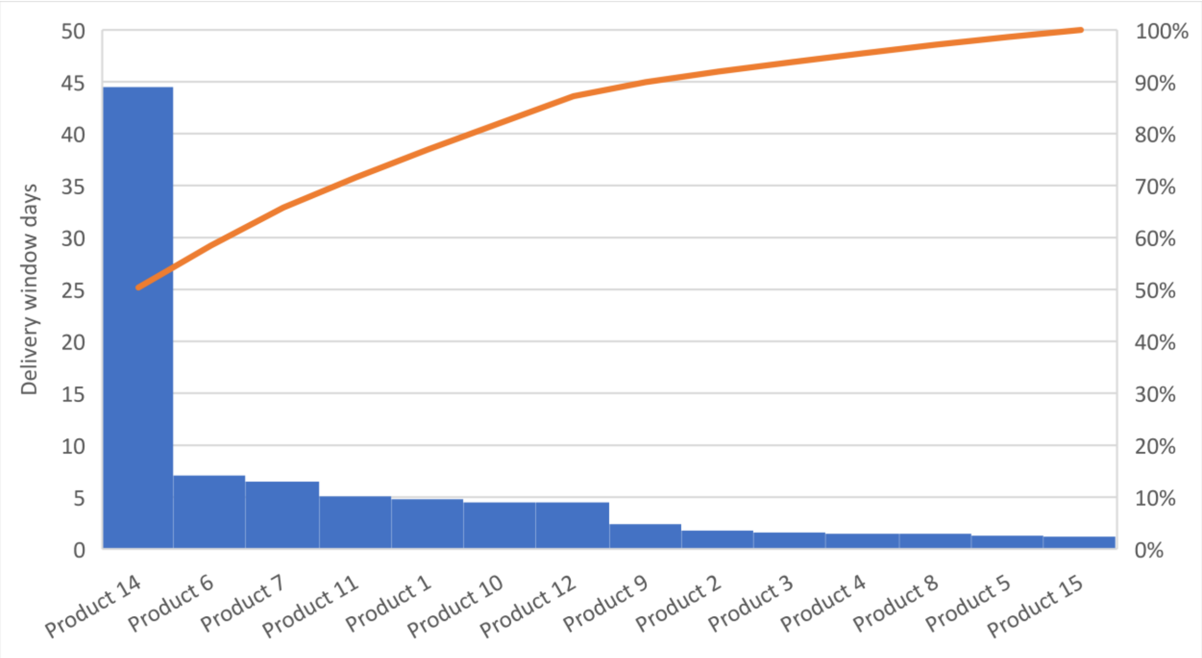

Figure 5.2 Product delivery window

5.2.3 Volume

Childerhouse et al. (2002) highlight the importance of the volume as a market-specific measure, based on Fuller et al.'s (1993) statement that key products critical to a company are generally both high volume and significant margin contributors. Besides, high-volume (HV) products in many cases benefit from a Lean paradigm while low-volume (LV) products are often aligned with a flexible, agile concept. Therefore, volume is an important defining aspect when it comes to choosing a planning and control method.

Annual sales have been chosen to estimate volume for all the products. The annual volume throughput is shown in Appendix 6. Figure 5.3 represents the Pareto principle applied where 20 percent of the products are responsible for 80 percent of the total volume of goods sold over the period.

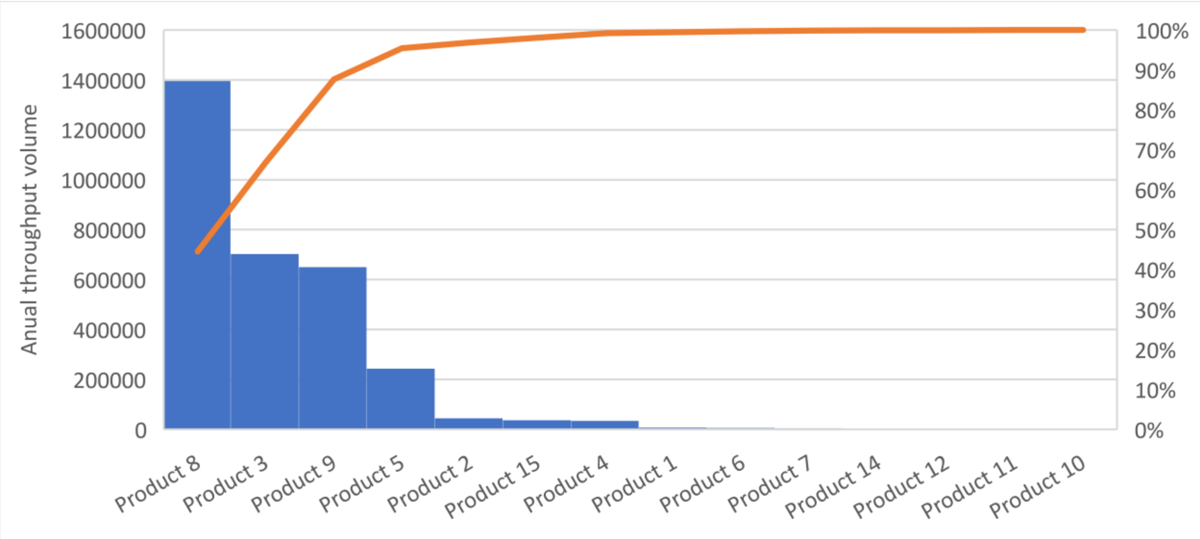

Figure 5.3 Accumulated annual volume of each RPH as a share of total annual demand

According to the Pareto principle, the limit of 650,000 each per year is chosen to divide high- and low-volume products. There is a distinct difference between these two groups. Products 8, 3 and 9 represent most of the annual sales. Meanwhile, product 5, with the largest number in the LV product group, has 2.6 times lower volume than the product with the lowest sales in the other group.

5.2.4 Demand variability

In the opinion of Childerhouse et al. (2002), who designed the DWV3 classification, the variability of demand is the most significant of the five proposed characteristics. Authors cite Fisher (1997) and Harrison (1997) to highlight the impact that demand unpredictability might have on running out of stock or alternatively on excessive stock and system capacity.

Annual sales orders of the case company have been assessed on order line (OL) level to define demand standard deviation and mean for the numbers of all products to evaluate the demand inconsistency level through a coefficient of variation (CV). Existing sample sizes allow estimating CV as a ratio of the standard deviation σ for each product to the mean μ where n is the number of RPH represented in Appendix 6.

$$CV_{Pn} = \frac{\sigma_{Pn}}{\mu_{Pn}}$$

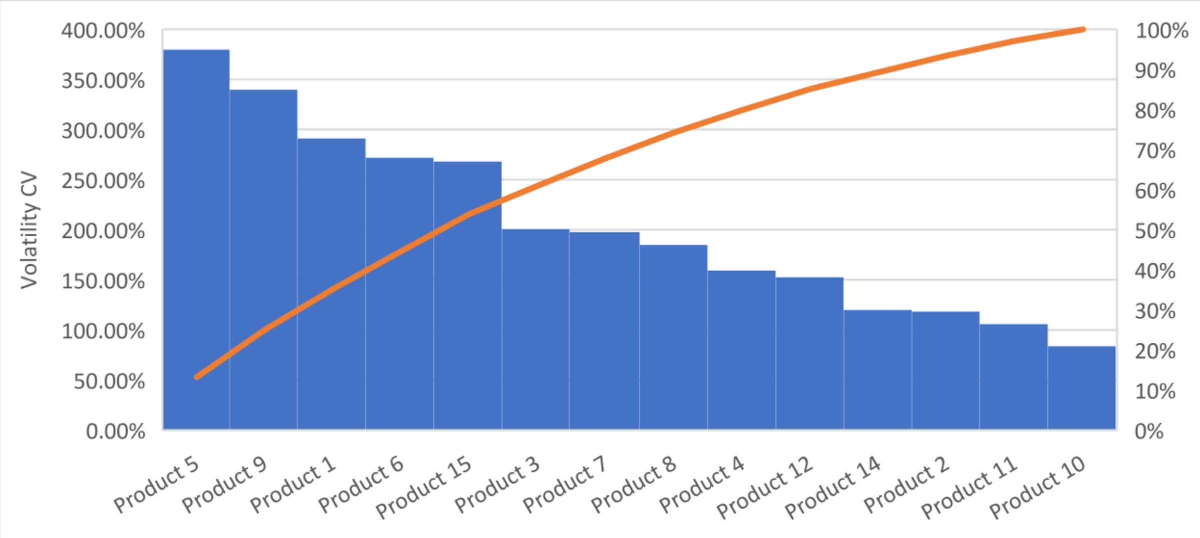

Figure 5.4 CV_{Pn} Demand volatility Pareto law distribution

Figure 5.4 shows the Pareto principle applied to a coefficient of demand variation for all RPH. There is no clear difference in order line demand volatility. To triangulate Pareto chart findings and define low and high variable demand group demand, the planning manager was interviewed. As a result of the interview and applying Pareto law the following product groups with a CV higher than 185 percent have been set as products with high-demand variability (P1, P2, P5, P6, P7, P8, P9, P15).

5.2.5 Product variety

The last DWV3 classification metrics is variety, which articulates the number of variants of a product and adds value by providing options in relation to specific product characteristics, such as shape, colour, function etc.

In manufacturing or assembly product variety is a vital measure to define the necessity of the postponement concept; it therefore often requires deep assessment. Company X is an importer where production postponement does not play a significant role in company business processes. However, product variety might affect stock holding. Due to the variety, the SKU level is not substantial in relation to the case company's total product range, and for generalisation purposes it is proposed that this case study variety index *(IV)* as defined in Appendix 6 should not investigate inside groups, but on an RPH level, and defined as a ratio of types a product *(T)* to units sold *(S)*.

$$IV_{P_n} = \frac{T_{P_n}}{S_{P_n}}$$

The distribution of product variety is shown in Figure 5.5. Applying the Pareto principle, it is agreed that products P6, P10, P11, P12 and P14, with an index higher than 0.15, will be considered as high IV.

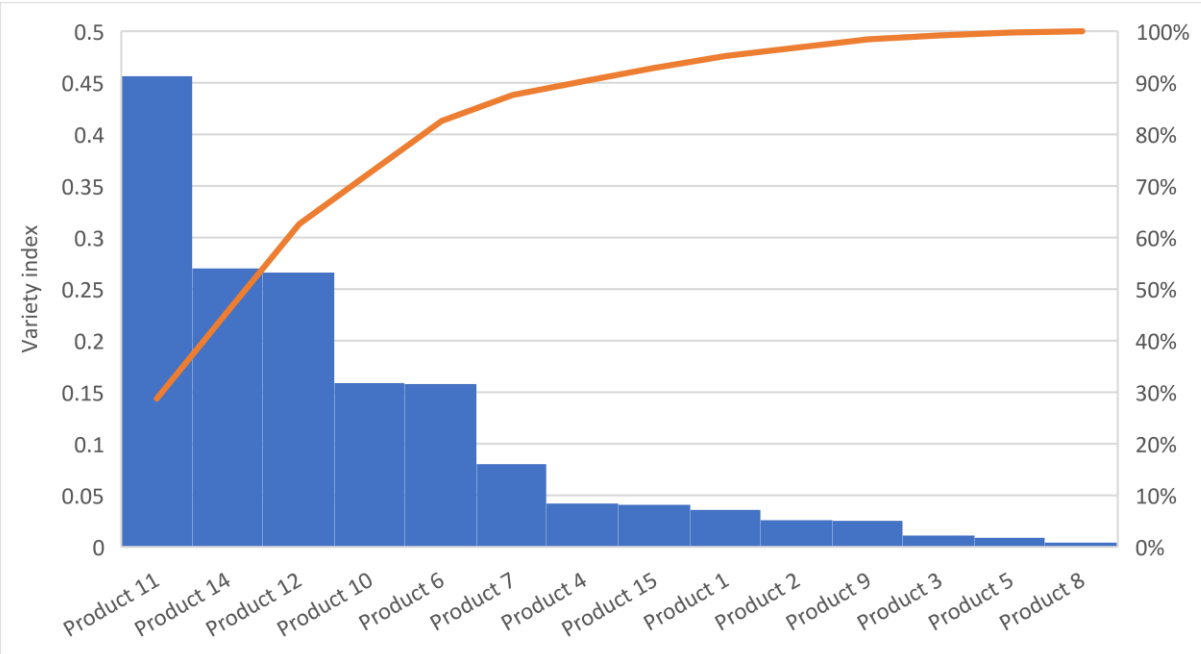

Figure 5.5 Variety index distribution

5.3 Product clustering and analysis

In section 5.2, market-specific variables have been assessed and products have been binary evaluated in terms of DWV3 classification (Table 5.1). Products with a short life cycle require rapid end-to-end SC channels and continuous replenishment without building up high stock levels. In this research, for generalisation purposes, products on the RPH level have been studied as this will not affect research outcomes. However, practitioners might find some life-cycle differences within groups. In such cases, they might want to study on a SKU or even component level.

As mentioned above, different supply chain concepts rely on different product characteristics. Goods that require a high service level are also highly sensitive to delivery time window that forces businesses to compete on the basis of response time and moving decoupling points closer to customers. Applying Lean principles and gaining benefits from increased product level is mostly inherent to products with high sales volume. Besides, high volume increases the accuracy of demand planning that often results in make/buy to forecast strategy. In contrast to volume, an upsurge of demand variability increases the unpredictability of the system and is responsible for both out-of-stock and overstock risks, resulting in lost sales or increased expenses, ROI drop and stock obsolescence. Singular spikes in demand might represent bulk orders. However, if such orders are rare and unusual for the business, they might be filtered to achieve better data clarity at the planning stage. Due to the choice of alternatives, high product variety enhances SC unpredictability and complexity in terms of planning, stock holding or manufacturing costs that at first sight appears similar to demand volatility. However, often differences between variants are relatively small from a customer point of view, which sees them competing for the same demands inside the system. The production or assembly postponement concept is widely used as a powerful solution to overcome this problem.

	Duration of the life cycle	**Volume**	**Variability (demand volatility)**	**Response (delivery window)**	**Variations**
	High > 2 year > Low	**High > 650000 > Low**	**High >185%>Low**	**High <=2 < Low**	**High>0.15>Low**
P1	Long > 2 years	Low	High	Low	Low
P2	Long > 2 years	Low	Low	High	Low
P3	Long > 2 years	High	High	High	Low
P4	Long > 2 years	Low	Low	High	Low
P5	Long > 2 years	Low	High	High	Low
P6	Long > 2 years	Low	High	Low	High
P7	Long > 2 years	Low	High	Low	Low
P8	Long > 2 years	High	High	High	Low
P9	Long > 2 years	High	High	High	Low
P10	Long > 2 years	Low	Low	Low	High
P11	Long > 2 years	Low	Low	Low	High
P12	Long > 2 years	Low	Low	Low	High
P14	Short < 2 years	Low	Low	Low	High
P15	Long > 2 years	Low	High	High	Low

Table 5.1 DWV3 classification of the product range

Theoretically, a product portfolio might consist of 32 different clusters (Figure 5.6). DWV3 authors do not provide detailed sequencing of cluster analysis because the weight of each of the metrics is not equal for different industries and it may be an area for future research. In the current study the priority sequence has been chosen as follows:

(1) *Duration of life cycle*

This variable has been chosen as a primary differentiator to segregate innovative, customised products that represent new opportunities for the company from others which are more or less standard for the business. Each category represents a basis for fundamentally different supply chain strategies (Fisher, 1997).

(2) *Delivery window*

This characteristic defines decoupling points required to balance cost and lead time. The characteristic is also important for customer satisfaction and might be linked with the trend of "having the customer in the driving seat". Thus, it has been assigned as second in importance for the case company supply chain.

(3) Volume

This defines stock replenishment strategy in decoupling points. Usually high-volume products are significant margin contributors (Fuller et al. (1993). Besides volume represents an indicator to separate SC paradigms. High-volume products benefit from lean practises while low-volume products benefit from an agile concept. For this reason, this parameter has been ranked as third in importance.

(4) *Variability*

Unpredictability defined by this characteristic affects stock holding and system capacity. For the case company it is more aligned with operational expenses and was prioritised down in favour of volume.

(5) *Variety*

In some cases the characteristic might have a significant impact on production postponement. However, this has been down-prioritised in favour of the other four metrics due to the nature of the case company business.

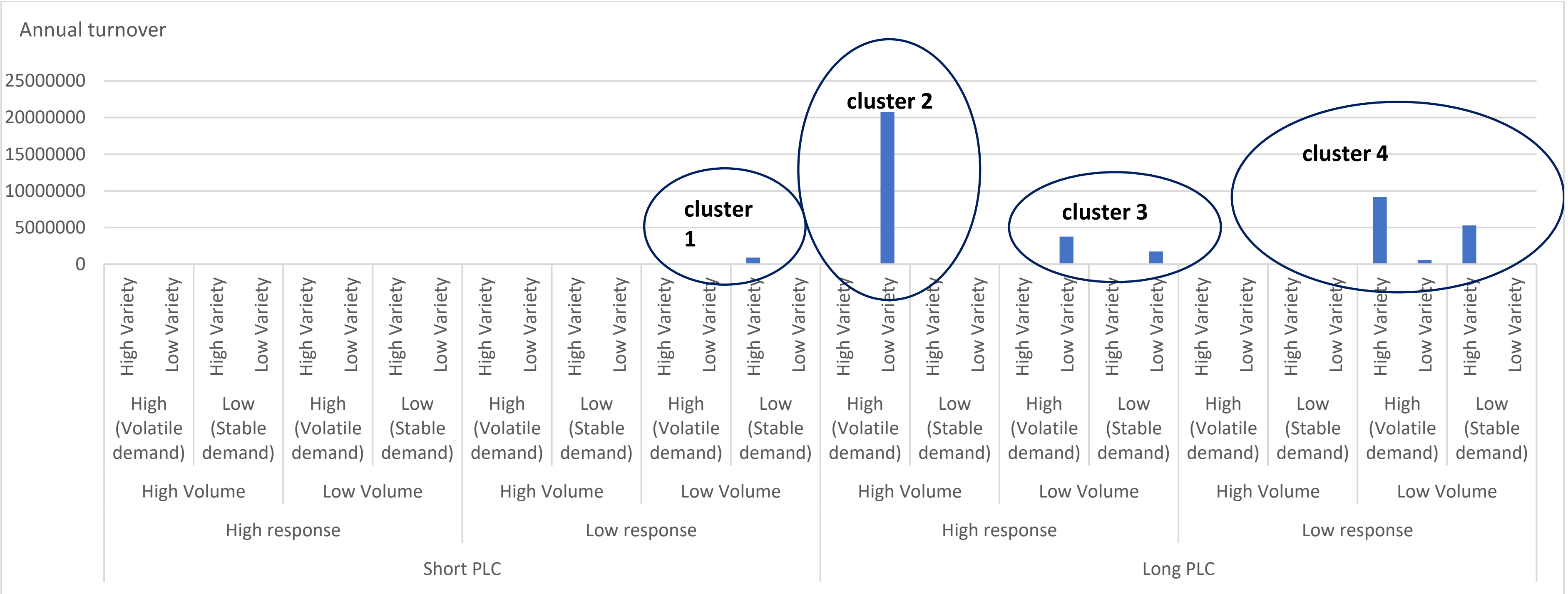

Figure 5.6 Products DWV3 clustering

After the analysis of market-specific characteristics, products have been consolidated in four clusters and studied according to the order winner (OW)/market qualifier (MQ) matrix proposed by Mason-Jones et al. (2000). Table 5.2 demonstrates all four cluster characteristics with respect to the OW/MQ concept.

	Key cluster characteristics	**OW**	**MQ**	**DC allocation**	**Replenishment strategy**
Cluster 1 Strangers	Short life cycle	Custom design	Quality Lead time Cost	1 DC	Design and build to order
Cluster 2 Runners	High response High volume	Cost	Service level Lead time Quality	2 DC	Kanban
Cluster 3 Repeaters	High response Low volume	Service level	Lead time Quality Cost	2 DC	ROP
Cluster 4 Repeaters	Low response Low volume	Cost	Quality Lead time Service level	1 DC	ROP

Table 5.2 Order winner and market qualifier characteristics application to decoupling and sourcing strategy

Identification of product clusters allows the choice of an appropriate supply chain paradigm for each of them and the building of separate pipelines based on cluster-specific characteristics and needs. The DC locations defined at stage 1 of the SC design have been assigned to demand for products in each of the clusters.

Cluster 1 is mostly aligned with the opportunity to provide a high level of customisation. Products included in this cluster can be identified as *strangers* in accordance with the Lean RSS concept and might require “process-control” rather than “system-control”. The cluster is not very lead-time or cost sensitive; however, some products are required for projects with strict deadlines, and therefore need to be well planned. Due to these requirements the *design and build to order* strategy was selected for the category. Even though cost is not the most critical parameter for products in the cluster, the JIT strategy and cross-docking might considerably reduce expenses and improve the bottom line.

Products in cluster 2 are both high volume and require rapid response. In RSS terminology they might be aligned with *runners*. These are functional goods that compete on a cost basis that might be aligned with lean practices. However, requirements for fast response (delivery in up to two days) create an additional challenge. To deal with this dilemma the Kanban system has been chosen to increase efficiency alongside 2DC locations to relieve pressure on lead time and increase service level.

Next, two low-volume clusters can be associated with *repeaters* according to the Lean concept. Cluster 3 consists of low-volume products that require a high response. These products can be theoretically aligned with the Agile strategy. Service level is a key order winner criterion for the group, and fast delivery and availability are important contributors to group success. It was decided that the existing reorder point replenishment strategy, based on a forecast (ROP) would be the most appropriate for products in this cluster. By reason of required short customer-service time, the forecast demand has been allocated against two decoupling points determined at stage 1.

Products in cluster 4 are required to be cost-effective rather than compete on service level and delivery time bases. The existing ROP system has been applied to stock policy because splitting stock between two locations (North Island and South Island) in a case with low-volume products increases demand unpredictability and supply uncertainty. Therefore, to hedge these risks, the inventory for products in cluster 4 has been assigned to one DC only. Due to its geographical position the North Island site needs to be considered as the most appropriate location able to serve the majority of customers in the fastest and least costly way.

As mentioned earlier many authors, including Porter (1985), Kotler and Keller (2001), and Aitken et al. (2003), argue that product characteristics are not static. As products are constantly evolving through the life cycle, order winners and market qualifiers migrate inside the OW/MQ matrix replacing each other. For example, at earlier life stages cost is down-prioritised in favour of specific customer needs (ability to customise or high-service level). This phenomenon is not critical for current research; however, for practitioners it is essential the life cycle stage be monitored and channels revised once a product progresses to the next life cycle phase.

The main contribution to SC design proposed at stage 2 grouping of products and aligning them with SC concepts are tailored to the market SC solutions that might be applied to different products within a company ("one size does not fit all"). These pipelines combat certain challenges in selected groups with the aim to deliver a better result. Addressing the averaging problem through segregating products might also assist to identify weak areas that were initially hidden. The findings of stages 1 and 2 are will be tested and evaluated in simulation models in the next chapter.

Chapter VI: Stage 3 supply chain simulation and analysis

6.1 Introduction

The linear optimisation provided a foundation for the modelled supply chain. However, supply chains traditionally consist of multiple actors, such as suppliers, processors, distributors, customers and others connected by supply chain channels where each supply chain participant and channel experiences its own level of uncertainty. Besides, stakeholders might have a complex internal structure within which all layers undergo their own risks: this makes a system even more complex. These network risks might need to be analysed in depth, which overcomplicates LP models due to the interdependency of variables. Furthermore, the outcome of the linear model is static, delivering a result at a moment in time, whereas it could be valuable to analyse system ups and downs dynamically over a period of time.

Modern computer simulation is a powerful tool that contests challenges inherent in linear models and monitors the dynamics of supply chain performance. Simulation may be described as an experiment that emulates the behaviour of a real system with the aim of evaluating strategies and providing support in decision making (Hollocks, 1992; Pegden et al., 1995). Another benefit of computer simulation is that it executes long-time processes in a short period of time. These aspects increase the reliability of output results and ensure a confidence interval by proceeding with a large number of repetitive runs.

In this research Arena simulation software is utilised to address the supply chain network design problem. Application of Arena allows for the imitation of real-world, supply-chain activities over time and encompasses many variables. The software allows for the setting of risks of SC process failure and disruptions, and analyses their effect on the supply chain. Furthermore, it improves the statistical reliability of findings by running multiple replications for each scenario. In the existing study it is used to analyse multiple factors affecting supply chain performance with the aim to confirm or disprove the model developed on the basis of the findings of stages 1 and 2.

Three models will be built, evaluated and compared with the aim to exam findings in chapters IV and V. Examination starts with a 1DC model, which is the most common in New Zealand. It might be used as a benchmark for both succeeding models to evaluate their strengths and weaknesses. After interviewing case company SC specialists and taking into account facilities availability, rates, workforce and proximity to ports, Tauranga has been chosen as a primary distribution point for the 1DC network. The second is a 2DC model with facilities locations defined by the linear optimisation conducted in stage 1, those the case company actually plans to employ. The model focuses on optimal outcome, so continuous simulation will help to study optimised activities in detail without an averaging effect. Finally, in the third model supply chain paradigms and decoupling points will be revised in accordance with market-specific characteristics (DWV3) developed at stage 2 and assigned to designed channels. The third model simulation will study the effect purposefully chosen strategies have on tailored channels. Each model will be run for a year with 100 repetitions. Data collected from the case company along with existing freight rates will be used as input for all three simulation model variables to keep the model aligned with real life.

6.2 Building of 1DC model (model 6.2)

The proposed Arena simulation of the 1DC model is constructed to present the structure and function of SC processes in the most common type of New Zealand trade supply chain network. The model consists of two segments, *demand* and *replenishment*. The first segment controls company inventory on hand and simulates customer order flow from the moment an order is received until it is delivered. The inventory management segment deals with external sources and is responsible for the inventory replenishment process.

6.2.1 1DC demand management segment

The designed network needs to be tested in relation to product characteristics. To support this, incoming customer orders are split into RPH groups, similar to what was carried out in chapter V. Appendix 7 shows the Arena demand management segment simulation flow.

Create module named *Product$_n$ order arrives* (Appendix 13, Figure 1) where *n* is a product number, simulates arrival entity (order) with assigned time arrival pattern specific for P_n. Some researchers suggest using uniform probability inter-arrival time distribution built into the module (Vieira, 2004; Altiok & Melamed, 2010). However, orders which normally do not come in at night, and peaks at some hours might affect the consistency of total order time output. For this reason Poisson probability distribution is loaded as a schedule for arrival time in each of **Create** modules. The arrival time matrix, based on case company order arrival statistics, is represented in Appendix 16.

Assign module with the name *Product$_n$ Direction ID* (Appendix 13, Figure 2) assigns product code, demand quantity distribution, and records the actual order arrival time and customer zone. The case company's demand fluctuations have been preliminary assessed in *input* *analyser* and distributions with the least square error are applied as quantity distribution input (Appendix 17). Each order is assigned to one of preliminary customer zones chosen in chapter IV; therefore, order direction ID is a discrete function of the cumulative probabilities associated with a particular product in the studied company (1) (2) (Appendix 17).

$$p_{ID_n} = (x_n - x_{n-1}) \quad (1)$$

where $x_0=0$

$$DISC(x_1, ID_1, x_2, ID_2, \ldots, x_n, ID_n) \quad (2)$$

Demand quantity probability distribution chosen for a product in module *Product$_n$ direction ID*, results in fractions. Due to the order, the quantity might be represented by a natural number only. **Assign** module *P_n quantity rounded* is required to change it to integer (3).

$$a\_sales\ demand\ quantity\ rounded_n = ANINT(a\_sales\ demand\ quantity)_n \quad (3)$$

Next **Assign** module named *P_n order volume* allocates the order net cost (4), and order volume (5) by multiplying the order quantity by SKU volume (Appendix 17). Products in RPH groups have similar characteristics. For generalisation purposes, they have been averaged in each group. Also, this assign module deals with global variables and estimates total demand and number of Product$_n$ entering the system at any given moment (Appendix 13, Figure 6.4). The succeeding **Assign** module, called *Variable P_n volume,* assesses the total volume entering the system. If the system starts with 0 inventory all of the orders will be missed at the early stage until the stock is not delivered. For this reason, the initial inventory with a quantity higher than ROP needs to be loaded as a system global variable *v_p$_n$ NI inventory* (Appendix 17).

$$a\_order\ net\ cost_n = a\_sales\ demand\ quantity\ rounded_n \times v\_product\ net\ cost(a\_product\ code)_n \quad (4)$$

$$a\_order\ volume_n = a\_sales\ demand\ quantity\ rounded_n \times V_n \quad (5)$$

Model evaluation requires statistics to be collected. Normally, a real company does not start with 0, and already has inventory and orders in the system. However, final statistics based on variables show 0 as a minimum and thus affect the reliability of results. Because of this issue **Record** modules are more suitable for the collection of statistics. Backorders were excluded from the simulation to keep track of service level. Logically *Record P_n* modules need to be built before stock is assessed, and some of the entities are disposed of due to lack of inventory. If further model evaluation requires statistics to be split into periods depending on the time it has been collected, *Record into sets* might be selected as an option. In the current study, sets are monthly based, so time sets have been determined as *time now/30.417* (Appendix 13, Figure 4).

Afterwards the entered entity is assessed in the **Decide** logic *Check P_n inventory* module to determine order quantity, *a_sales demand quantity rounded$_n$* less or equal to the existing variable *v_p_n NI inventory*. Lack of inventory disposes of unsatisfied demand by recording a missed opportunity cost, missed orders and missed demand quantity in *P_n NI missed orders* **Record** module.

If the value of inventory on hand, variable *v_p_n NI inventory*, is greater or equal to the order demand attribute, the system is able to fulfil the entered order, and a **Decide** module directs the flow to the next **Assign** module, called *Reduce P_n NI inventory* (Appendix 13, Figure 5). The mission of this module is to reduce global inventory variable by the order quantity (6). Also, it estimates and evaluates delivery and inventory-related costs as a set of variables as follows: *delivery cost* depending on delivery area (7), annual *obsolescence cost* (two percent for short and eight percent for long life cycle products) (8), six percent annual *damage risk cost* (9), 10 percent annual *capital cost* (10) and *storage cost* including storage and inventory-related DC operations (11). If operational costs depend on product type (for example, some products such as heavy equipment or bulky goods require special operations), practitioners might apply storage and operational rates as a set of variables dependent on a product type and physical characteristics. Inventory obsolescence, damage risk, capital and storage costs are dynamic and influenced by current inventory turnover, and inventory days are reflected in value assignments for their variables.

v_p_n NI inventory= v_p_n NI inventory - a_sales demand quantity rounded$_n$ (6)

v_p_n NI delivery cost= v_p_n NI delivery cost + a_order volume$_n$ x v_NI freight rates(a_direction ID) (7)

v_p_n NI obsolescence cost=v_p_n NI obsolescence cost+ v_p_n NI inventory/v_daily consumption NI(a_product code) x a_order net cost$_n$ x v_osolescence rate(a_direction ID) (8)

v_p_n NI damage risk cost= v_p_n NI damage risk cost + v_p_n NI inventory / v_daily consumption NI(a_product code) x a_order net cost$_n$ x 0.016438% (9)

v_p_n NI capital cost =v_p_n NI capital cost+ v_p_n NI inventory/v_daily consumption NI(a_product code) x a_order net cost$_n$ x 0.0273973% (10)

v_p_n NI storage cost =v_p_n NI storage cost + ((v_p_n NI inventory/v_daily consumption NI(a_product code) x a_order volume$_n$ x v_storage rates+a_order volume$_n$ x v_pick and dispatch rate) (11)

Next, **Decide** *Restart P_n production* and **Assign** *P_n replenishment status* modules are responsible for inventory replenishment. These two modules are designed to check if the inventory level is less than P_n reorder point (*v_p_n NI min*) (Appendix 18), and changes the supply status to 1 (12) that releases the replenishment process in the supply segment. Reorder point is calculated as a sum of a lead time demand and safety stock for each product. Lead time demand (*LTD*) is stock required to fulfil average daily orders during the replenishment cycle (performance cycle) (13). Safety stock (*SS*) is aimed to prevent stockouts in cases of fluctuations in both demand or lead time; its calculation (14) takes in account the length of the replenishment cycle and standard deviations of demand and lead time. Company stock policy requires min 95 percent availability rate. To prevent stockouts and follow the policy, 95 percent confidence level factor (*Z-score*) is applied.

If v_p_n *NI inventory <= * v_p_n *NI min then* v_p_n *NI supply status=1* (12)

$LTD_n = AD_n\, PC_n$ (13)

AD – average daily demand

PC – performance cycle (days)

$$SS_n = Z\sqrt{\left(\frac{PC}{T_1}\,\sigma D_n^2\right) + (Z\,\sigma LT\,Davg_n\,)^2} \quad (14)$$

Z (Z-score) = 1.65 (for 95% service level)

PC (performance cycle) = 30 days

T1 (year observation standard deviation time increment time)

σD = standard deviation of demand

σLT=standard deviation of lead time

Davg= average demand

Appendix 13 Figure 6 depicts the *seize delay releas*e **Process** module for warehouse operation activities for all the products. The module has a *queue* where entities are delayed during the time they are being processed by *R_NI warehouse team* **Resource** unit. The resource itself has two constraints. Firstly, the availability of the resource is based on a working schedule *NI schedule*; secondly, the resource is seized by the entity (order) being processed. If a more detailed assessment of warehouse operation is required **Process** modules might be built for each operation or DC processes or developed and simulated as a *sub-model*.

In real life, orders are not able to be despatched straight after being processed by the DC team. Often orders are waiting to be collected by a delivery company at a certain time (for example 4 pm pick-up). Orders released later can be collected only in the next collection cycle that affects customer service time. The effect of a preassigned 4 pm collection time might be simulated by applying release condition *CalHour(TNOW) == 16* for *NI Waiting to be collected queue* in a **Hold** module.

Next, once the entities are collected the system splits the flow in accordance with the area an order is intended for. **Decide** *NI order direction* module creates several flows based on *a_direction ID* attribute assigned at the early stage. Each of the flows is seized by the time *t* uniformly distributed (15) in *Delivery to location L* **Process** module where *L* represents direction ID code. Figure 7 in Appendix 13 depicts a dialogue box for D*elivery to location L* process with time limits for each of locations L.

$$f(t) = \begin{cases} \frac{1}{t_b - t_a}, \; for\ t_a \leq t(x) \leq t_b \\ 0, \text{otherwise} \end{cases} \qquad (15)$$

Before the order is virtually delivered and the entity is disposed of in the final **Dispose** module it is necessary to estimate an order delivery cost. This could be assessed in two subsequent **Assign** modules *Delivery to L cost* and *Delivery to L amount*. The first module assigns delivery cost based on order volume and delivery freight rates defined in Appendix 19 to the order being delivered (16), the second estimates and collects statistics for freight cost as a global variable (17). Afterwards leaving these two modules the entity archives throughputs statistics in *Order lead time estimation* **Record** module and then is disposed of.

$$a\_delivery\ cost_L = a\_order\ volume_n\ x\ v\_NI\ freight\ rates(a\_direction\ ID) \qquad (16)$$

$$v\_delivery\ location\ cost_L = v\_delivery\ location\ cost_L + a\_delivery\ cost_L \qquad (17)$$

6.2.2 1DC supply management segment

The *supply management* segment (Appendix 8) keeps track of inventory replenishment and represents a virtual supplier. In many real-life cases, one supplier makes and/or sells goods associated with a particular RPH group. The case company procurement specialists confirm clear distinctions between most of the vendors in terms of product RPH; for example, companies who supply fridges do not sell glassware, or firms producing chemicals do not manufacture uniform. Cases where one supplier dispatches a mix of products are minor. Besides, the portions of products that belong to different RPH groups compared to the major RPH in such consignments are not noteworthy. Due to this insignificance, such cases are disregarded in actual research. Thus, similarly to *demand management* described in the previous section, the *supply management segment* consists of a number of simulation flows equal to the number of products in the *demand management* section.

The **Create** module generates only one entity, *e_p_n raw material*, at 0.0 moment of time (*Entities per Arrival=1, Max Arrival=1, First Creation=0.0).* Since the replenishment management process has no **Dispose** module, a created entity does not leave the system and is constantly circulating to control replenishment processes. It activates other modules and starts and stops replenishment operations.

After creation, the entity proceeds to the **Hold** module, shown in Appendix 13, Figure 8, that exams the replenishment status. Once the inventory level drops below reorder point (Appendix 18) the *demand management* segment activates the replenishment process by changing the status to 1 (v_p_n *NI supply status = 1*) (12) and the *supply management* segment simultaneously releases the entity from the *shall we order* P_n *NI* module.

After the entity is released the system imitates the production/replenishment cycle. In the **Assign** module the entity receives a specific attribute that reflects a quantity being produced/supplied, that is the difference between the maximum inventory point and the current inventory level (16). In the subsequent **Process** *Supply* P_n *NI* module the entity queues for the time required to manufacture and supply. Global market segmentation and the New Zealand geographical position make the Asian market a preferable sourcing point. Following this trend, 30 days have been nominated as a time for the replenishment process. Transhipments, port congestion, weather conditions and other external factors often affect delivery time. To reflect these disruptions and delays, uniform probability distribution with the range of [25, 35] has been applied to the P_n *Supply NI* process.

$$a\_replenishment\ quantity_n = v\_p_n\ NI\ max - v\_p_n\ NI\ inventory \quad (16)$$

After the replenishment order is released the **Assign** module called *Increase* P_n *NI inventory* (Appendix 13 Figure 9) adjusts the stock-holding global variable by incrementing it in the assigned replenishment quantity (17). If the released quantity builds stock higher than ROP the entity proceeds to the *Stop* P_n *NI Supply* module, which changes production status to 0 and returns entity to the *Shall we order* P_n *NI* queue where it waits till demand changes the status to 0 to repeat the process. If the released order does not meet ROP in the inventory variable there is no need to put the replenishment on hold. In this situation, the **Decide** module returns the entity to **Assign** p_n *NI order quantity* to restart production with no delays (18)

$$v\_p_n\ NI\ inventory = v\_p_n\ NI\ inventory + a\_replenishment\ quantity \quad (17)$$

$$\begin{aligned} &IF\ v\_p1\ NI\ inventory >= v\_p1\ NI\ min\ then\ Shall\ we\ order\ P1\ NI.Queue \\ &otherwise\ a\_replenishment\ quantity = v\_p1\ NI\ max - v\_p1\ NI\ inventory \end{aligned} \quad (18)$$

6.3 Building of LP-based 2DC model (Model 6.3)

The simulation for the LP-based 2DC model is aimed to depict supply chain processes in the 2DC network with locations predefined by linear optimisation. Technically this model can be described as an extended 1DC simulation model. Similarly to 1DC, it comprises d*emand* and *replenishment* segments responsible for demand and replenishment control. the objective of the model is to compare it to the model 6.2 with the aim of examining and evaluating findings of linear optimisation.

6.3.1 LP-based model demand management segment

Appendix 9 depicts 2DC *demand management* network layout. Demand pattern and volatility remain unchanged; therefore, at the first stage simulation flows exploit the same modules and probability distributions set for 1DC model 6.2. The arrived entity (order) appears in the **Create** modules with the same time interval as in 1DC simulation 6.2 and proceeds through the **Assign** modules to receive the following order attributes: demand quantity ($a\_sales\ demand\ quantity\ rounded_n$), arrival time (*TNOW*), allocation to demand zone ($a\_direction\ ID_n$), volume ($a\_order\ volume_n$) and cost ($a\_order\ net\ cost_n$).

However, before stock holding is evaluated and orders are processed in DC, entities for all products need to be assessed in the Decide module (Appendix 14, Figure 1) in accordance with the optimal facilities location defined by stage 1 LP modelling. **Decide** module logic separates entities and creates two parallel flows. Orders with the ID that represent demand locations from 1 to 7 (flow 1) are being allocated to Tauranga (NI) while others marked from 8 to 12 (flow 2) need to be distributed from Christchurch (SI).

Both created flows assess inventory in appointed facilities, and activate or deactivate the replenishment process depending on the ROP based on demand deviation, cycle time and average demand for each product in each of facilities (19) (20). Flows then proceed to the queue for DC processing and dispatch. Attributable to different product ID, simulation model 6.3 releases entities from different facilities. Consequently, variables designed to estimate delivery cost ($v\_delivery\ location\ cost_L$) apply delivery rates specific for each DC location.

$$LTD_{(DC)n}=AD_{(DC)n}\ PC_{(DC)n} \quad (19)$$

$$SS_{(DC)n} = Z\sqrt{(\frac{PC}{T_1}\ \sigma D^2_{(DC)n}) + (Z\ \sigma LT\ Davg_{(DC)n})^2} \quad (20)$$

6.3.2 LP-based model supply management segment

Two decoupling points determined by the linear model require replenishment processes to be deployed for each of the distribution facilities. In New Zealand sea freight is accountable for 99 percent of total imports (Ministry of Transport, 2017). Both of the predetermined DC are located in areas with easy access to seaports, so the replenishment process does not require cross-docking to be performed in one of the facilities for further sub delivery unless the minimum order quantity (MOQ) or the economic order value (EOV) entails batching. The current model does not imply batching, therefore separate replenishment flows are simulated for each of the sites. The *replenishment management* segment (Appendix 10) duplicates replenishment flows for each product but intended for different distribution facilities. In other words, each of the supply flows is activated/deactivated by a corresponding supply status variable ($v\_p_{(DC)n}$ *supply status*) and increases inventory for a congruent distribution centre (21).

$$v\_p_{(DC)n}\ inventory = v\_p_{(DC)n}\ inventory + a\_replenishment\ quantity \tag{21}$$

6.4 Building of DWV3 simulation model (model 6.4)

DWV3 classification has been employed to improve system performance by applying market-specific characteristics and related supply chain concepts aimed to tailor supply chain channels to the market. Simulation flow is based on the model 6.3 network. However, it exploits fulcrum and SC concepts in accordance with strategies determined at stage 2 cluster analysis. Every cluster is assigned to a corresponding decoupling point and material flow control strategy developed in chapter 5.3.

6.4.1 DWV3 simulation model demand management segment

Parameters assigned to entities at the first stage of the simulation are replicated in all three models to avoid output to be affected by input dissimilarities. Entities (orders) in DWV3 simulation (Appendix 11) come with the same time-interval distribution as in both previous models and receive identical order quantity, direction, volume and net cost at the first phase of the imitation process. Once orders are formed the cluster approach needs to be deployed to direct flows of demand in accordance with product characteristics.

As defined in chapter V, innovative, highly customised short life cycle cluster 1, represented by P14, takes advantage of the *design and build* concept with a possible cross-docking. The cluster does not utilise the replenishment status variable because there is no inventory level predefined and production is to be executed once the order is entered into the system. As soon as the entity is assigned to one of the facilities, manufacturing activity starts in a **Process** module with a *UNIF(25;35)* time delay. The subsequent **Hold** module (Appendix 15, Figure 1) releases the entity once condition *CalDayOfWeek(TNOW) = 1* is met. It imitates batching required to meet shipping MOQ/EOV as well as a depart schedule. Once cluster 1 goods are released, they undergo cross-docking and delivery from the DC to which they were allocated.

High response cluster 2 (P3, P8 and P9) and cluster 3 (P2, P4, P5 and P15) require immediate reaction on the order placed and therefore fulcrum is moved closer to a customer. For this reason, their stock is allocated to both distribution facilities. All demand simulation flows for these two clusters are similar to flows designed for model 6.4. Even though demand flows for these two clusters are identical, the disparity in product volume exploits different replenishment methods Kanban and ROP, which will be detailed in the following section.

Low-response, cost-sensitive cluster 4, which includes P1, P6, P7, P10, P11, P12 aggregates, all demand one decoupling point. The North Island DC is surrounded by areas with the highest population (demand) that in turn results in lower freight rates and shorter lead time for most of the orders. For this reason, the North Island is the most appropriate location for cluster 4 inventory able to serve a bigger number of clients in the fastest and least costly way. Demand allocation for this cluster is similar to the most common method many companies in New Zealand apply. Therefore, simulation flows for the cluster entirely replicates flows for products in model 6.2.

6.4.2 Cluster-based supply management simulation segment

Four clusters in the DWV3-based model apply three different strategies (Design and Build, Kanban and Min-Max ROP) that require different simulation flows to be created in the *replenishment management* segment of the model (Appendix 12).

As already mentioned in section 6.4.1, sourcing for cluster 4 is based on Design and Build strategy. Order fulfilment control modules were fully incorporated in the flow for P14 in the *demand management* segment.

The Kanban strategy developed for products in cluster 2 aims at more efficient replenishment. It emphasises continual delivery that helps to limit the build-up of excess inventory. Replenishment flows for P3, P8 and P9 likewise have the only arrived entity to control the cycle. However, once the entity is released to production the system assigns attribute that in contrast with ROP is a fixed Kanban bin size defined for each location (21), (22).

$$a\_replenishment\ quantity_n = v\_p_{(DC)n}\ Kanban\ bin \quad (21)$$

$$Number\ of\ Kanban\ K_{(DC)n} = ((AD_{(DC)n}\, RT) + (Z\, SD_{(DC)n}))/SCQ_{(DC)n} \quad (22)$$

AD: Average period demand

RT: Replenishment time

Z: The Z factor

SD: Demand standard deviation

SCQ: The standard container quantity

To evade the replenishment order to be seized and the next Kanban bin delayed during the process for an antecedent bin, a **Separate** module (Appendix 16, Figure 2) duplicates entered entity. One of them proceeds through a **Process** module and increases inventory in a designated facility before being disposed of. At the same time, another duplicated entity checks inventory level, stops the replenishment process if required and returns to the beginning of the replenishment cycle simulation flow.

Replenishment simulation for clusters 3 and 4 are identical to the sourcing processes in models 6.2 and 6.1 respectively. With the aim to shorten order service time, the cluster 3 inventory is moved closer to a customer and allocated against both sites. Hence, sourcing management simulation for this cluster products consists of two replenishment flows, North and South islands. In contrast, cluster 4 goods are stored in the North Island only; consequently the NI supply management only is applicable for these products.

6.5 Simulation models output and analysis

Statistical analysis of the simulation gives the idea of the precision of results. As mentioned before the Arena simulation can be run for an almost endless length of time and a number of replications that improves the reliability and precision of the output. To achieve the required data consistency all three models have been run for 100 replications with the length of 365 base units (days) for each replication.

The following parameters are initialised in the statistics report to provide the data required for further analysis:

- missed order quantity and missed opportunity dollar
- order throughput time
- distribution centre queue (days and orders)

- supply chain cost including
  - delivery cost
  - DC storage and processing cost
  - damage risk cost
  - obsolescence cost
  - capital cost
- Inventory turnover and days of supply.

6.5.1 Missed opportunity

The *missed opportunity report* (Appendices 20, 21 and 22) and *stock level model charts* (Appendices 23, 24 and 25) list statistical output for lost orders along with missed opportunity cost.

In benchmarking 1DC model output, most of the extremely rare products come to the point where stock is not able to satisfy existing demand. Out-of-stock products might be fragmented into three groups. Products in group 1 (P2, P3, P5, P8, P9) never run to zero and always have stock to satisfy all coming orders. The largest group, group 2, consists of products that with 95 percent confidence miss no more than two orders per annum (P1, P4, P6, P10, P11, P12, P14). This group does not affect performance. However, practitioners might want to study group performance in more detail if a company aims for a higher service level for any of the groups. Group 3 includes the only product (P7) that has a service level resulting in 7.08 mean of missed orders with 1.84 half-widths (95 percent confidence interval). The stock holding dropped to zero two times over the simulation period, which might be described as a trend rather than a random failure. Closer investigation revealed that product 7 (furniture) inventory level is affected by discrete demand. Chairs in this group are usually bought in bunches of different sizes required for newly opened cafés and restaurants. The current service level for the product is still higher than that predetermined in case company policy, so no further action needs to be taken.

Table 6.1 consolidates and compares missed orders for all three models studied. It shows a decrease in service level for all products. High volume P9 was the only product in this simulation that avoided running out of stock. All other KPIs significantly decreased. If for the 1DC model only P7 was associated with Group 3, in the optimised model 6.3 products that missed more than two orders over the period were P1, P4, P7, P10, and P11. It is noticeable that almost all of these products are low volume, thus splitting decoupling points enhanced unpredictability of demand that resulted in the service level drop.

	1DC missed orders	1DC Average % of missed orders	Max % of missed order	LP missed orders	LP Average % of NI&SI orders shipped	Max Average % of NI&SI orders shipped	DWV3 missed orders	DWV3 Average % of NI&SI orders shipped	Max Averag e % of NI&SI orders shipped
Product 1	0.62	0.064	1.220	1.83	0.188	2.486	0.36	0.037	0.845
Product 2	0	0.000	0.000	0.09	0.001	0.053	0	0.000	0.000
Product 3	0	0.000	0.000	1.3	0.006	0.290	1.15	0.006	0.176
Product 4	0.14	0.002	0.113	1.18	0.020	0.775	1.41	0.023	0.680
Product 5	0	0.000	0.000	0.22	0.001	0.035	0.24	0.001	0.080
Product 6	0.06	0.001	0.126	0.65	0.014	0.531	0.07	0.002	0.147
Product 7	7.08	1.004	5.512	7.47	1.058	6.130	5.35	0.759	6.069
Product 8	0	0.000	0.000	0.61	0.002	0.211	0.19	0.001	0.052
Product 9	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000
Product 10	1.76	0.480	3.440	6.1	1.669	9.832	2.1	0.575	3.922
Product 11	1.07	0.107	1.855	2.63	0.264	2.974	0.64	0.065	1.283
Product 12	0.39	0.065	2.102	0.99	0.166	3.916	0.45	0.075	1.703
Product 14	0.34	0.023	0.641	1.11	0.076	1.610	0	0.000	0.000
Product 15	0	0.000	0.000	0.07	0.001	0.038	0.56	0.004	0.144

Table 6.1 Missed orders

In contrast with the optimised model, the DWV3-based simulation shows substantial improvement in customer service level. The total number of lost orders plunged from 25 to 12, equal to the less cost-effective model 6.2. Products with 95 percent probability (mean + half-width) that missed more than two orders were P3, P7 and P10. It should be underlined that none of the missed orders related to products where service level was an order winner (OW).

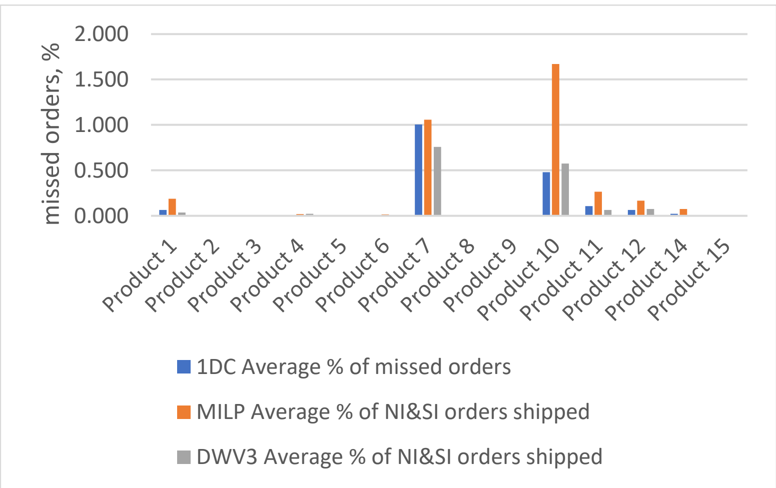

Figure 6.1 Missed orders percentage to received

Identifier	*Average*	*Standard deviation*	*0.950 C.I. half-width*	*Minimum value*	*Maximum value*	*Number of OBS.*
s_DWV3 model total missed opportunity dollar	*9.95e+003*	*1.22e+004*	*2.42e+003*	*0*	*5.68e+004*	*100*
s_LP model total missed opportunity dollar	*2.35e+004*	*1.81e+004*	*3.59e+003*	*1.15e+003*	*8.47e+004*	*100*
s_NI only Total missed opportunity dollar	*6.75e+003*	*7.75e+003*	*1.54e+003*	*0*	*3.49e+004*	*100*

Table 6.2 Statistical outcome of 100 replication for missed opportunity cost parameter

Figure 6.2 Missed opportunity cost, $

Figure 6.2 and Table 6.2 represent missed order quantity and statistical analysis for missed opportunity cost. They show that models 6.2 and 6.4 provide the best service level with almost identically low negative performance indicators. According to the statistical analysis for the 100 replications performed in the Arena output analyser shown on figure 6.2, model 6.3 provides the highest lost business opportunity while confidence interval limits for model 6.2 and 6.4 are almost similar where 1DC model is leading due to the aggregation of all stock in one location.

6.5.2 Order throughput time

Order throughput time is an ability to serve demand in the shortest possible time. It is a crucial metric that defines the time required for an order to move across the supply chain. In other words, it embraces the period from when the order is received until the products are delivered to a customer, and encompasses all the subprocesses, such as order processing time, queue time and move time. The concept of throughput time is objected at time reduction, thus following

Lean practices: analysing all processes involved in order throughput and eliminating waste might not only improve service time but also reduce expenses. Current simulation estimates the total throughput time, comprised of order value-added time and wait time. (Appendices 26, 27 and 28).

Non-value-added time is a parameter that might be studied to asses capacity and reduce waste. Table 6.3 depicts the DC queue for orders being processed. It is clear that DC resources in all models perform tasks with no significant delays and therefore do not affect throughput time. On the other hand, excessive capacity might be subject to further cost reduction. The 1DC model has two orders waiting in a processing queue. It does not affect performance on a large scale. However, this might be a trigger for capability assessment. In contrast, 2DC LP has only 0.2 and 0.03 orders waiting for NI and SI locations respectively; this signals that both facilities have excess capacity that might need to be reduced. At the same time the NI DC in the DWV3 simulation has 0.7 order waiting, which means there is no idle time and resources have almost perfect capacity balance. Conversely, the SI location shows excessive capacity that might be reduced to save business expenses.

An inspection of total throughput time (Table 6.4) revealed that some of the product flows simulated on model 6.2 do not meet required service time which affects customer satisfaction. These are products P2, P3, P4, P5, P8 and P15. It should be noted that of these, P2, P4, P5 and P15 require high service level and delivery time is ranked as the most important market qualifier (MQ) for them. Due to locating fulcrum points closer to demand areas, all products in the optimised model fit into the required delivery window that shows the best throughput performance in all three models. Even though throughput time for some products in DWV3 simulation is slightly higher than the optimised 2DC model, it not only meets but exceeds required delivery time limitations.

	1 DC model						2DC model						DWV3 model					
DC queue (days)																		
	Average	**Half-Width**	**Min average**	**Max Average**	**Min Value**	**Max Value**	**Average**	**Half-Width**	**Min average**	**Max Average**	**Min Value**	**Max Value**	**Average**	**Half-Width**	**Min average**	**Max Average**	**Min Value**	**Max Value**
NI DC picking and dispatch queue	0.00333	0	0.00308	0.00366	0	0.25	0.00054	0	0.00051	0.00056	0	0.25	0.0019	0	0.00176	0.00206	0	0.2702
SI DC picking and dispatch queue							0.00017	0	0.00014	0.00021	0	0.2499	0.00164	0	0.00139	0.00183	0	0.2614
NI waiting to be collected	0.1769	0	0.1753	0.178	0	0.9583	0.173	0	0.1717	0.1742	0	0.9583	0.1746	0	0.1735	0.1755	0	0.9583
SI waiting to be collected							0.173	0	0.1712	0.1753	0	0.9583	0.1745	0	0.1728	0.1764	0	0.9583
DC queue (orders)																		
NI DC picking and dispatch	1.8533	0.01	1.7085	2.0471	0	71	0.2026	0	0.1931	0.2135	0	21	0.7313	0	0.673	0.7911	0	33
SI DC picking and dispatch							0.03056	0	0.025	0.03748	0	7	0.2829	0	0.2385	0.3152	0	21
NI waiting to be collected	98.4397	0.09	97.3961	99.43	0	587	65.3311	0.05	64.7927	65.9248	0	424	67.049	0.05	66.2198	67.671	0	429
SI waiting to be collected							30.9708	0.04	30.5339	31.4412	0	226	30.0854	0.03	29.6693	30.4584	0	214

Table 6.3 Distribution centre processing parameters

	1 DC model						**LP model**						**DWV3 model**						
Total Time Days																			**Delivery window**
	1 DC Average	**Half Width**	**Min Average**	**Max Average**	**Min Value**	**Max Value**	**LP Average**	**Half Width**	**Min Average**	**Max Average**	**Min Value**	**Max Value**	**DWV3 Average**	**Half Width**	**Min Average**	**Max Average**	**Min Value**	**Max Value**	
e_product 1	1.8627	0.01	1.7177	1.9756	0	4.9595	1.197	0	1.1705	1.2244	0	2.4565	1.8664	0.01	1.7639	1.9534	0	4.9518	4.8
e_product 2	1.9162	0	1.8943	1.9383	0.5006	4.9698	1.1627	0	1.1556	1.1699	0	2.4594	1.1626	0	1.1557	1.1673	0.5006	2.4595	1.8
e_product 3	1.9558	0	1.9379	1.974	0.5005	4.9767	1.1441	0	1.1377	1.1496	0	2.4588	1.1441	0	1.1378	1.1496	0	2.4587	1.6
e_product 4	1.9468	0	1.9127	1.993	0	4.9769	1.1313	0	1.1197	1.1406	0	2.4584	1.1307	0	1.1176	1.1429	0	2.4591	1.5
e_product 5	1.9606	0	1.9416	1.9768	0.5006	4.9799	1.1504	0	1.1457	1.1542	0	2.4593	1.1507	0	1.1468	1.1546	0	2.4586	1.3
e_product 6	1.8269	0	1.7907	1.8638	0	4.961	1.1323	0	1.1219	1.1457	0	2.4588	1.8213	0	1.7706	1.8721	0	4.9496	7.1
e_product 7	2.3041	0.01	2.1562	2.4423	0	4.9554	1.2562	0	1.1871	1.3042	0	2.455	2.2963	0.01	2.1439	2.4435	0	4.9485	6.5
e_product 8	1.8493	0	1.8302	1.8699	0.5005	4.9816	1.1433	0	1.1389	1.1485	0	2.4589	1.1433	0	1.1374	1.1489	0	2.4585	1.5
e_product 9	1.8404	0	1.8286	1.8508	0.5005	4.9839	1.1334	0	1.1309	1.1361	0.5005	2.4618	1.1334	0	1.1309	1.1376	0.5004	2.4592	2.4
e_product 10	1.6037	0.01	1.4804	1.7707	0	4.9507	1.1139	0.01	1.028	1.1738	0	2.4569	1.6032	0.01	1.49	1.7332	0	4.9584	4.5
e_product 11	1.4355	0.01	1.3713	1.5204	0	4.9418	1.0618	0	1.0339	1.0925	0	2.4568	1.4337	0.01	1.3561	1.5434	0	4.9487	5.1
e_product 12	1.9647	0.01	1.8499	2.0626	0	4.9546	1.1647	0	1.1164	1.1979	0	2.4523	1.9698	0.01	1.8412	2.0892	0	4.9471	4.5
e_product 14	1.8771	0.01	1.8004	1.9589	0	4.9698	1.1487	0	1.1243	1.1765	0	2.4582	34.1481	0.02	33.8763	34.473	25.5343	42.7971	44.5
e_product 15	1.8659	0	1.8399	1.8998	0.501	4.9729	1.1819	0	1.1759	1.1888	0	2.459	1.1815	0	1.1742	1.189	0	2.4588	1.2

Table 6.4 Throughput time

6.5.3 Supply chain cost

Cost is probably the most popular business-related topic. Many practitioners consider cost reduction as the main competitive advantage. Even though these days businesses start looking for other competitive advantages such as quality, service or ability to react to changes, cost still remains one of the top-ranked performance indicators in company agendas. Supply chain cost compounds a substantial part of total business cost. SC cost is the sum of costs and expenses accompanying supply chain related processes. This study collected cost statistics for transportation, DC storage and processing, capital, and damage and obsolescence risks for all three simulation models (Appendices 29, 30 and 31). Similar to the delivery time metric, setting inventories closer to demand areas creates advantages for the LP-optimised SC model. The chart in Figure 6.3 shows that 1DC model 6.2 has the highest delivery spends and runs to $1,500,000, the highest of the three models. Delivery expenses for 2DC model 6.3 total $900,000, while freight charges for DWV3 model 6.4 are 16 percent higher (approximately $1,050,000).

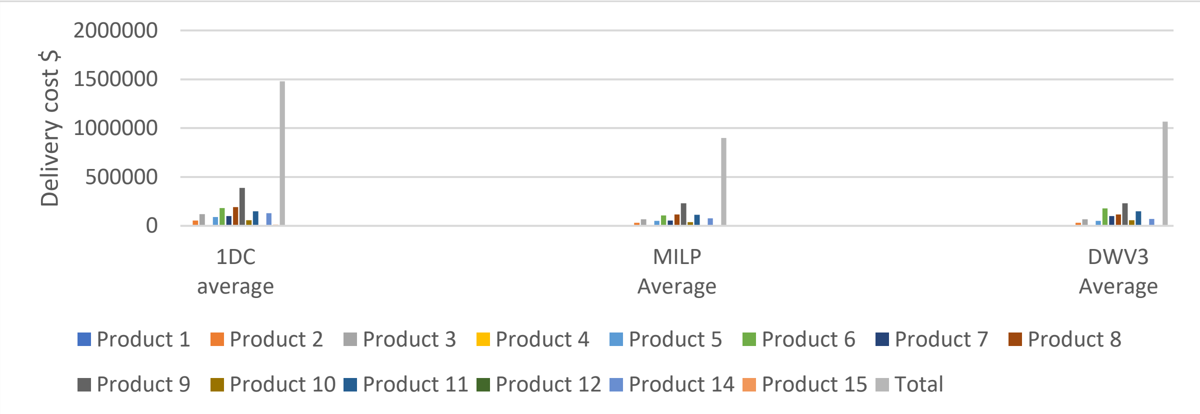

Figure 6.3 Delivery cost

However, as mentioned above, delivery is not the only cost that builds supply chain total expenses. Chart 6.4 displays the statistics breakdown for model inventory-related costs (DC operations, obsolescence, damage and capital). In all inventory-related areas, the DWV3 model demonstrates the most cost-effective outcome. It seems that the Kanban replenishment solution established for high volume P3, P8 and P9 is a weighty contributor to model success. It is worth noting that these products are cost-sensitive, and practitioners might obtain an additional competitive advantage by applying the ABC costing method to these products.

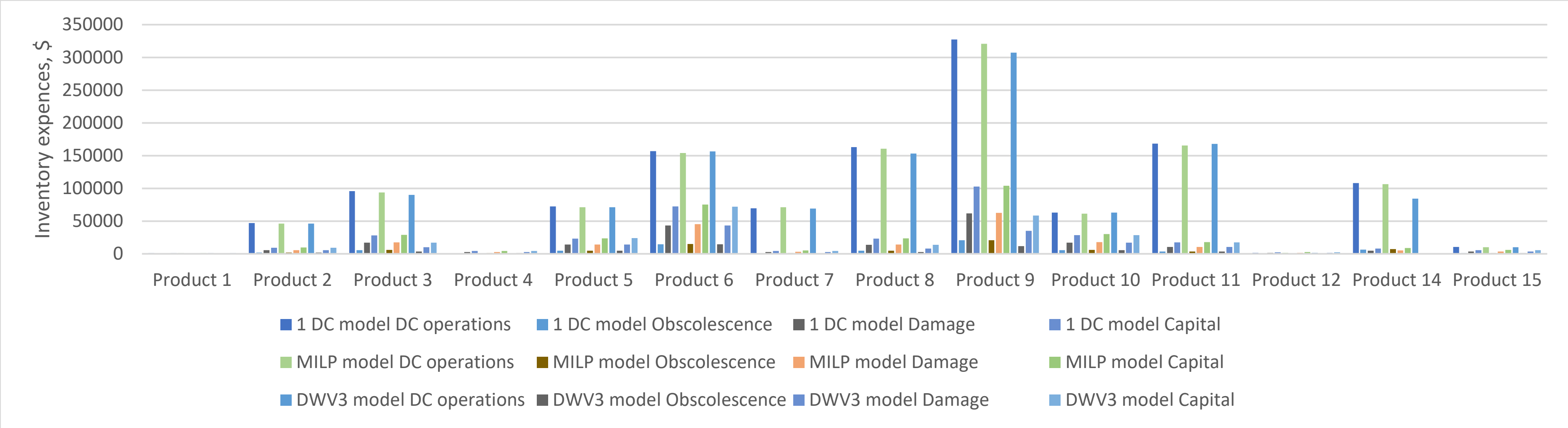

Figure 6.4 Inventory related expenses

Statistics shown in Table 6.5 and Figure 6.5 shows statistical analysis performed by Arena for 100 observations of total SC cost (inventory-related expenses + freight charges) defined within a 95 percent confidence interval. The 1DC model has the highest spends in both delivery and inventory areas, which totals the highest overall SC cost. The range of values inside the confidence interval has no significant variation, which increases the reliability of the received simulation outcome. There is no doubt the clustered model provides the most cost-effective supply chain solution. Even though the site optimisation model has a lower delivery cost, the simulation based on the clustered approach absorbs the delivery cost difference and brings a better overall result.

Identifier	***Average***	***Standard deviation***	***0.950 C.I. half-width***	***Minimum value***	***Maximum value***	***Number of OBS.***
s_DWV3 model Total SC cost	*2.76e+006*	*2.57e+004*	*5.1e+003*	*2.69e+006*	*2.83e+006*	*100*
s_LP model total SC cost	*2.78e+006*	*2.18e+004*	*4.33e+003*	*2.72e+006*	*2.84e+006*	*100*
s_NI only Total SC cost	*3.43e+006*	*2.51e+004*	*4.99e+003*	*3.38e+006*	*3.49e+006*	*100*

Table 6.5 Statistical outcome of 100 replication for total supply chain cost

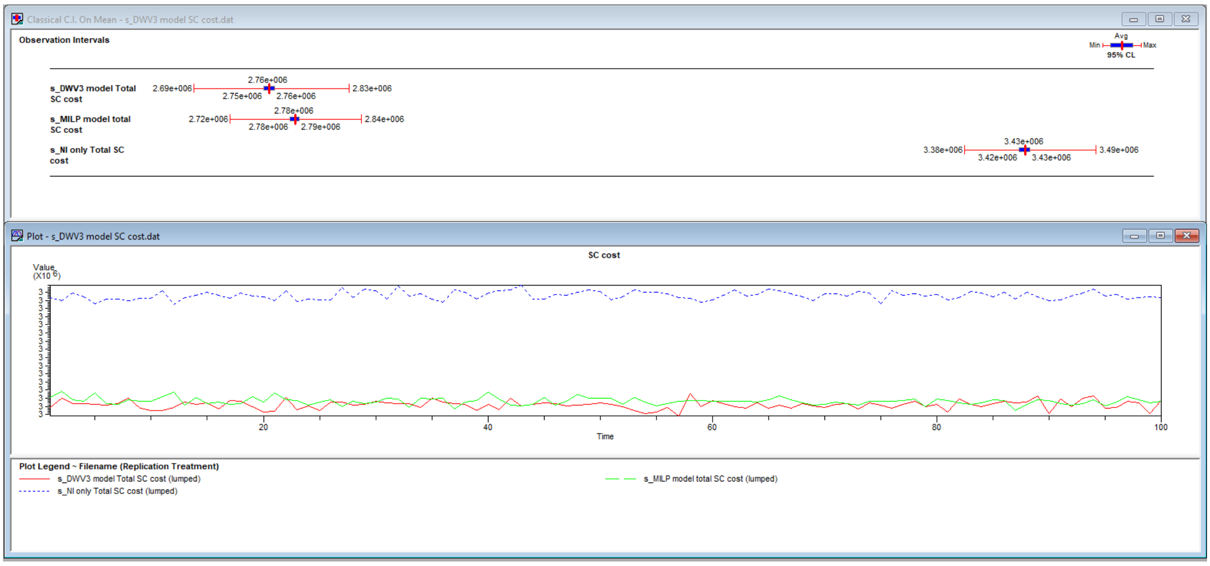

Figure 6.5 Supply chain cost statistics observation

6.5.4 Inventory turnover

Inventory turnover ratio and days of supply are other important KPIs that estimate opportunities to profit from capital invested in stock, as well as assesses risks of excessive and obsolete inventory. The rates shown in Table 6.6 demonstrate that the DWV3 model provides the best opportunity to earn profit for a dollar spent as well as keep the lowest stock on hand (SOH). This simulation output shows the highest turnover rate for DWV3 model 6.4 is enhanced by the JIT strategy employed for high-volume products. Increased inventory turnover and low SOH in the DWV3 model mitigate risks, contribute to better asset efficiency (ROI) and cash-to-cash cycle and consequently improve a company's economic bottom line.

	Inventory turnover			Days of supply		
	1 DC model	LP model	DWV3 model	1 DC model	LP model	DWV3 model
P01	9.28	8.38	8.78	39.34	43.53	41.58
P02	12.15	11.55	11.67	30.03	31.61	31.27
P03	11.95	12.93	25.45	30.53	28.22	14.34
P04	12.85	12.51	12.65	28.41	29.17	28.86
P05	11.44	12.07	11.33	31.91	30.23	32.22
P06	13.89	12.65	13.44	26.27	28.86	27.16
P07	12.82	10.06	12.49	28.47	36.27	29.22
P08	11.75	12.22	26.51	31.07	29.86	13.77
P09	11.33	11.59	29.94	32.2	31.5	12.19
P10	11.14	9.78	11.74	32.75	37.32	31.09
P11	11.52	12.22	11.27	31.67	29.87	32.39
P12	9.19	7.23	8.81	39.7	50.47	41.42
P14	11.62	10.76	0	31.42	33.92	0
P15	14.58	13.53	15.12	25.04	26.98	24.13

Table 6.6 Inventory turnover and supply days

6.5.5 Analysis summary

Many supply chain experts focus on cost or time reduction to achieve the best results and improve competitiveness. However, a significant challenge is that the parts of a supply chain are interconnected and can conflict with each other, so achieving improvement in one area often affects other supply chain KPIs. For example, getting a cost reduction in inventory often affects service level or delivery time. It is therefore necessary to understand all the processes involved to ensure proposed improvement leads to a balanced result. Supply chain metrics can be consolidated into groups: cost (total cost, operational cost, missed opportunity cost); responsiveness (inventory turnover, inventory days of supply); service (order fill rate, order lead time, order accuracy); asset efficiency (gross margin return on investment (ROI), cash-to-cash cycle), and information (information availability, information accuracy and information exchange). Asset efficiency correlates to inventory turnover but embraces other business areas such as sales, accounting and trade agreements not studied in this research. Three supply chain KPIs are defined in Table 6.7 below.

	Cost		Inventory management & responsiveness		Service	
	Total annual SC cost, $	Missed opportunity cost, $	Annual inventory turnover	Inventory days of supply	Missed orders per year	Order lead time, days
1 DC model	3364941	7860	11.82	31.34	11.46	1.87
LP optimised model	2781816	23476	11.25	33.42	24.25	1.15
DWV3 model	2753484	8165	14.23	25.69	12.52	3.8

Table 6.7 Supply chain KPIs

The chart in Figure 6.6 demonstrates that the DWV3 simulation model can be the most cost-efficient solution. This is due largely to the sound balance the system builds between operational, delivery and inventory expenses. At the same time the model misses only one percent more opportunity than the least cost-effective but stable 1DC model.

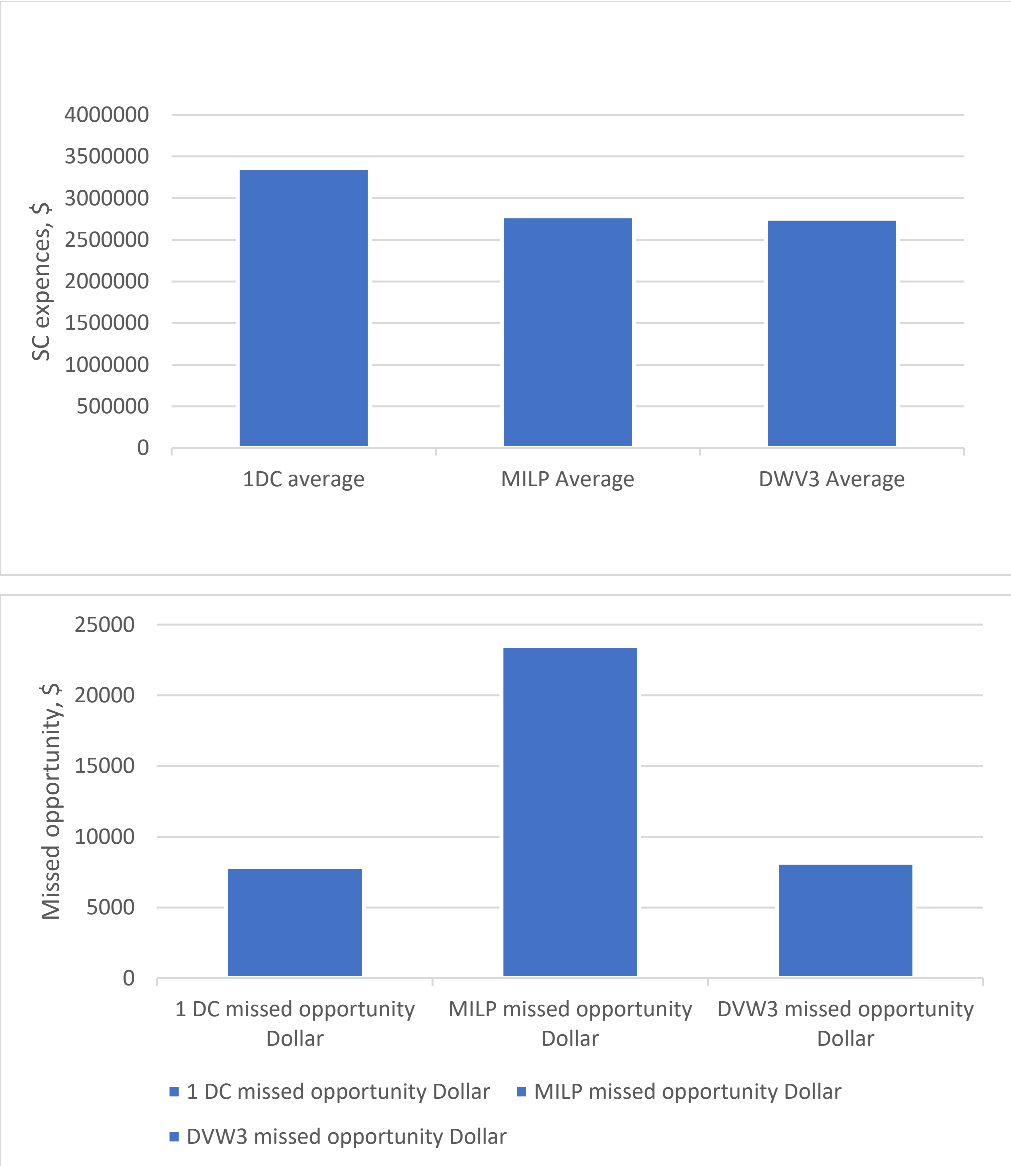

Figure 6.6 Total SC cost and missed opportunity

In contrast with cost efficiency, inventory management related metrics are serious diagnostic tools that define system efficiency. Inventory, one of the highest investments, is directly linked to company asset efficiency, thus high inventory performance with minimum days of supply provides a better return per dollar spent.

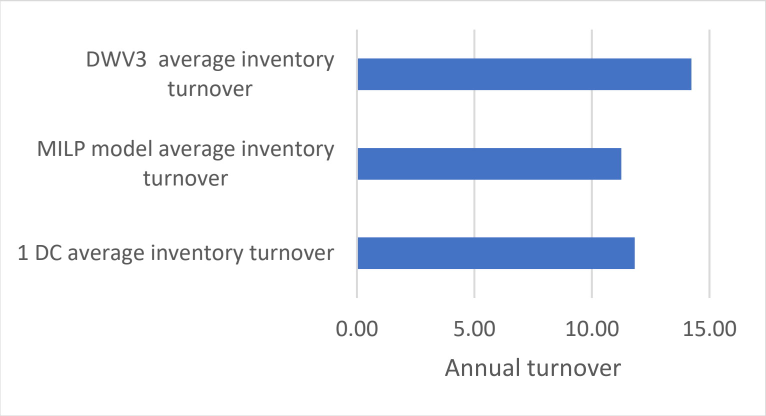

Figure 6.7 Inventory turnover

Figure 6.7 represents how many times inventory could be sold over a given period. While the DC and optimised models show similar turnover ratio, the market-focused DWV3 model demonstrates a 20 percent better result. These metrics are also responsible for the system's ability to purposefully respond to market requests and changes. In other words, they define the capability of the SC to be innovative and flexible. Having ability to quickly replace stock with pioneering products significantly improves competitiveness in volatile markets. Analogously to cost KPI, applying several supply chain concepts in one model and aligning them with product characteristics result in best inventory KPIs, as confirmed by model 6.4 output.

Standards or objectives that need to be achieved and properly managed to meet customer expectations often oppose system efficiency. The global market situation pushes service level popularity as an order winner. However, fierce competition calls for the careful balancing of inventory holding versus stockouts. The current study reveals that the most costly and bulky 1DC simulation model shows the best order fulfilment rate, with more than two times fewer stockouts than the cost optimised model. In contrast, the optimised model provides the shortest lead time. This phenomenon is furnished by the concept of moving the fulcrum towards the customer. It is noticeable that cluster-based model 6.4 has almost the same rate for orders delivered in full as 1DC model 6.2. Surprisingly, simulation of the market-oriented DWV3 model shows the longest order fulfilment time. However, a detailed analysis of simulation output reveals that total lead time for products in a specific design and build segment is a key contributor to this phenomenon. Despite the long lead time, this category is still within the desired delivery window due to the high level of customisation. If the category is excluded, the average delivery time drops to 1.46.

Performance area	Model with the best overall KPI result
Cost effectiveness	*DWV3 model*
Inventory performance	*DWV3 model*
DIFOT balance	*DWV3 model*

Table 6.8 Model outcome in terms of KPI groups

The model with channels aligned with market needs based on DWV3 classification is a winner over the others with which it was compared in the study. It provides the best financial outcome, stock-related KPI and service level (Table 6.8). In summary, simulation of the three models demonstrated that the supply chain network is a complex balance of interrelated and interconnected blocks affected by internal and external influencers and shaped by supply chain strategies. These multiple factors can enhance or absorb each other, and their effect on SCs depends on their combination. With the aim of facilitating the complexity of SC influencers, constructing a supply chain can be performed in three steps, from large scale to more detailed analysis. First is the macro optimisation of external factors and constraints conducted by linear programming that provides an optimal shape for the SC network. The second step involves segregating products and building SC strategies aligned with product market-specific characteristics that enhance the positive aspects of the optimised model and mitigate the negative effects. The third step is exploring designed model strengths and weaknesses through detailed simulation of supply chain processes and risks to assess the interaction of factors in depth over time and rebalance them as required. The simulation revealed a hierarchical combination of macro and operational modelling, where the integration of market-specific analysis provided the best outcome in terms of cost, performance and service.

Chapter VII: Discussion

Previous chapters propose an approach to the design of a market-focused supply chain, dependent on unique market-specific characteristics and testing the numerical outcome of proposed models. The current chapter debates the contribution to the existing literature and the implication of findings for supply chain practitioners.

7.1 Theoretical implication

The literature analysis revealed that architecting of a robust supply chain is affected by many interrelated factors, not least the growing importance of customer and market-focused aspects. Some of these aspects contradict each other and these negative effects need to be considered in supply chain design. For instance, being market-oriented often conflicts with cost-effective concepts. On the other hand, the appropriate integration of different approaches to SC design might not only alleviate challenges formed by theoretically opposed agendas but also amplify their positive effects. Based on this, the proposed modelling method aims to overcome weaknesses of standard SC design tools and provide a framework for a supply chain that aligns the pipelines with market requirements and objectives. The proposed approach depicted in Figure 7.1 represents a framework for building a market-focused supply chain. The strategy has three stages; macro optimisation, product segregation and analysis, and detailed simulation. These are described below.

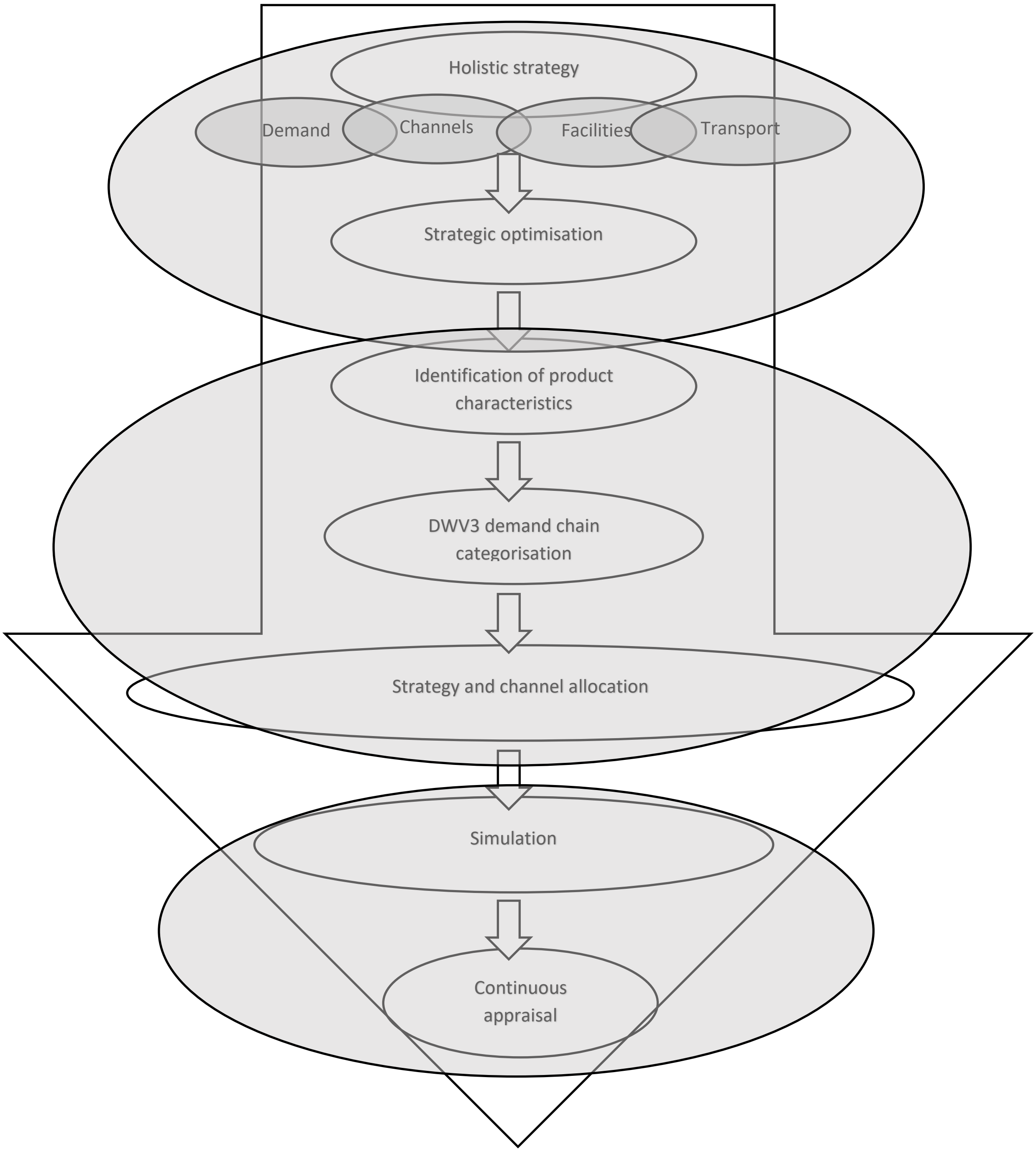

Figure 7.1 Framework for market-oriented supply chain design

Macro optimisation

Based on the existing literature, linear programming is a useful tool for defining a high-level strategy that provides a holistic view on supply chain processes. This is the reason this analytical tool was used to define the frame for a supply chain. A similar approach has been described in the existing literature. For example, models presented by Arntzen et al. (1995) and Ma and Suo (2006) described heuristic models aimed to configure an optimal network. However, even though these models explored certain levels of detail, such as multiple echelons in the GSCM model and a two-stage LP design that included batch size and cycle time for each hub in the LP framework, the total outcome still represented a high-level, strategic view of the proposed supply chain. Also, these models focused largely on optimisation and efficiency and were not aligned with the real market and customer needs. For this reason, the optimisation programme applied in this research has been simplified to provide total efficiency and time optimisation on an aggregate level, to cope with major constraints and set minimum business goals that will be later augmented by aligning strategies with market requirements. As pointed out in the literature review, linear programmes have already been widely used in the modelling of supply chains. Thus, the model itself does not have much novelty for supply chain design, although in the context of the research framework it represents a methodological step that separates different decision levels and frames a network for further market-specific analysis.

Clustering

Current supply chain trends constantly move the fulcrum from efficient "supply-centric" towards effective "customer-focused" supply chain concepts. Fuller et al. (1993) claim that in today's markets customers take control of a steering wheel and so tailored logistics solutions are becoming a key component of business success. Dealing with multiple products and satisfying different customer requirements constrained by multiple factors show that companies need to employ not one, but many supply chain solutions to acquire competitive advantage.

As noted by many researchers, "One size does not fit all". The unlimited increase in product variety and life cycle differences noted by Shewchuk (1989), necessitate the application of differentiated approaches for different products and services. Alternative products in one supply chain can often be aligned with different order winners and market qualifiers. Therefore, market-focused segmentation provides an opportunity for multiple strategies to be incorporated into one supply chain. In contrast with the widely used but not market-specific CPA or ABC classification methods, the DWV3 approach used in the current study is a tool that categorises products and chosen strategies in accordance with actual market requirements.

The key challenge for the application of multiple strategies is to find a well-balanced "mix and match" approach, where integrated strategies have synergy (Childerhouse et al., 2002). Across the various clustering concepts described in the existing literature, the DWV3 codification defined by Christopher and Towill (2001) has been adopted by this research as it provides a simple but powerful tool for binding product characteristics with market-specific strategies. The research revealed that the application of DWV3 segmentation to SC design not only enhances overall SC performance but also improves a focusing KPI for a particular product. For instance, the high-volume “runners” consolidated in cluster 2 are cost sensitive and the approach builds the channel in accordance with this specific requirement.

It worth noting that the DWV3 approach incorporates the opportunity to not only follow customer-focused trends but change channels in accordance with new requirements. As pointed out by Childerhouse et al. (2002), a product’s characteristics migrate through a product lifecycle from service level-oriented to cost-sensitive and back. The DWV3 approach can capture these changes and provide an opportunity to adjust supply chain channels in accordance with new characteristics.

Different industries require the application of different channels and strategies. The preliminary literature provided insight into DWV3 application for production/assembly companies but did not deal with commercial cases. This research tested DWV3 methodology with a trading company case study. The study revealed that application of the focused approach greatly enhanced the competitive advantages of the case company, reduced total costs and helped to avoid the averaging problem, which signalled the applicability of DWV3 methodology to other industries.

Authors of the DWV3 framework highlight that the selection and sequence of binary variables are subjective and imply the utilisation of knowledge by a leadership team. Even though this quandary can be resolved by practitioners it creates problems with the generalisation for SC theory. As Aitken et al. (2005) claimed, the approach is not suitable for “learning-by-doing”. Thus, the application of the DWV3 methodology requires solid analysis before any practical change is made. Therefore, creating a framework for the prioritisation of variables may be a potential for future research.

Simulation

Linear optimisation designed at stage 1 provides a “bird’s eye” view of the designed supply chain, and deals with high-level strategic decisions shaping the network. This implies a low level of detail. However, further design involves lower tactical and operational levels of design decision and amplifies the volume of variables to be analysed. Furthermore, tailored strategies constructed and applied at stage 2 increase the complexity of the designed supply chain by adding variables based on specific characteristics.

Studying a supply chain in depth requires a tool that can deal with layered constraints, uncertainties, multiple characteristics and collaboration of supply chain participants and processes. In doing so, simulation models are suggested as an instrument able to imitate supply chain processes with the required level of detail. A similar approach was applied by Zhou and Chen (2010) for a telecom products network design. The model they developed aimed to study in depth an earlier proposed strategic framework. Even though the two-tiered methodology the researchers proposed indicated a positive outcome, it focused on efficiency and resource utilisation rather than customer satisfaction and market needs as key business goals.

The Arena simulation software employed by the current study provided insight into the interaction of multiple constraints (influencers), flows (design decisions) and structural components (building blocks). The ability to imitate uncertainties inherent in a real-life supply chain helped to identify, examine and hedge supply chain risks. The integrated output analysis module made the Arena simulation an effective instrument for the detailed and reliable statistical examination of multiple pipelines in accordance with different business goals. It helped to compare and evaluate different scenarios as well as explore how DWV3 classification and tailored strategies act in terms of efficiency by analysing costs, responsiveness via inventory management metrics and customer satisfaction through service level characteristics. Even though the simulation approach can be traced back to 1960 (Kleijnen, 2005), constantly expanding IT technology allows modern simulation to embrace a large number of variables and processes and study them dynamically. In contrast with discrete simulations, the programme applied to the existing research provided dynamic information on how a designed supply chain would act over a defined period. The study revealed that the Arena software can emulate specific supply chain characteristics and evaluate their effect on a designed network. In other words, Arena could be a useful modelling tool, which provides a comprehensive analysis of complex processes in a designed network and assesses long-time performance of the model in terms of its alignment to specific requirements. It can be used not only for newly designed or re-engineered supply chains but also for further continuous improvement programmes (CIP).

The sequence of steps in the proposed methodology is intended to enhance the positive effects of actions taken at a previous stage. The comparable two-tier approach used by Zhou and Chen (2010) provided downstream detail but captured strategic design decisions only. Although the current study method exploited macro- and micro-analysis comparable to one suggested by Zhou and Chen (2010), it, in contrast, embraced design decisions at strategic, tactical and operational levels.

The macro optimisation taken in stage 1 helps with the strategic positioning of the network, with the objective of supporting maximum general efficiency of the system. Because of the level of variables involved in optimisation the designed network is not obstructed by lower level influencers but shapes the network in accordance with an overall supply chain goal.

The necessity to satisfy customer needs in the best possible way requires the supply chain to set this as a goal. However, modern supply chains are usually complex systems that ensure the flow of multiple products, so diverse characteristics inherent in different products require multiple pipelines and strategies to be designed in accordance with specific product characteristics. Incorporation of the

DWV3 analysis of market-specific characteristics and strategy alignment performed in stage 2 examines supply chain attributes responsible for subordinate decisions. Evaluation of this tailored approach reveals a substantial positive effect on designed pipelines. Aligning these characteristics with market needs and implementing multiple pipelines offers the opportunity to gain competitive advantage through an increase in responsiveness without sacrificing overall efficiency.

The micro-level analysis and continuous appraisal performed at stage 3 aims to examine findings of step 2 in-depth and analyse activities in designed channels in dynamic. Hierarchically, the analysis is performed at the lower levels, so while it does not affect high-level decisions it provides a comprehensive detailed analysis of strategies chosen.

7.2 Practical implication

McRae (2001) and Aitken et al. (2003) cite Irish economics expert Garrett Fitzgerald, who said ‘‘I can see how it will work in practice, but I am still trying to figure out how it works in theory!’’. This statement shows that practitioners often intuitively understand the nature of processes, however still require a theoretical methodology as a base they can rely on.

Existing research recommended the framework for gaining competitive advantage through a three-stage methodology based on identifying and building multiple market-focused channels. Two-tier optimisation is already covered in the literature, and there are many proven cases in multiple business sectors demonstrating that strategic macro optimisation followed by more detailed analysis has a positive effect on supply chain design. However, as discussed earlier, there is a need for managing a supply chain in accordance with market requirements rather than merely increasing efficiency or mitigating overall risk. The proposed methodology suggests integrating DWV3 assessment at the macro and operational analysis stages. This step adds complexity to the design process that some small business may want to avoid. However, many smaller businesses, similarly to large enterprises, operate with a range of products that have different characteristics where the application of market-specific analysis is vital. For instance, many individuals who sell goods using web platforms such as “eBay” or “trade me”, are able to gain advantages by aligning their products to market needs regardless of the size of their business. There are still potential opportunities to move the fulcrum towards demand points using 3PL operators or aggregating inventory with the aim of confronting volatility and hedging risk. Application of the method, therefore, lies not with the size of a company but with its alignment to the market.

The preceding literature described manufacturing and assembly cases to which the DWV3 classification has successfully been applied. This paper is based on an importer trade company case and demonstrates that the approach can also be applied to this type of business. Many companies do not deal with products or materials but provide services which, unlike commodities are intangible. Despite having different nature, being a demand-driven for service industry is even more important. Service market-specific characteristics can be evaluated and affiliated with customer needs analogously to commodities. Thus, application of the proposed method may also be explored by practitioners in service areas; for example, recruiting businesses might benefit from applying various market-focused strategies to different online, offline and hybrid channels.

As was earlier noted by Hill (1995) and Aitken et al. (2003), order winners and market qualifiers are not static, and product characteristics migrate as a product proceeds through its life cycle. For example, in the computer market or fashion industry such changes are rapid, and practitioners in these areas need to place special emphasis on the effect of product life cycle and revise policies in accordance with new trends and innovations.

This research is based on a case company operating in the New Zealand import and distribution environment. On the practical side, studying supply chain strategic influencers in the New Zealand context revealed that the positioning of distribution facilities in Tauranga and Christchurch provides the best results in terms of both cost optimisation and lead time effectiveness. The network suggested by the strategic optimisation tool covers both islands and avoids the additional geographical constraint of Cook Strait. The positioning of facilities at these two points additionally benefits from proximity to large ports that directly operate with overseas lines that in turn evade cabotage transhipments for inbound products.

The proposed market-tailored DWV3 approach presented recommendations that improve responsiveness and mitigate supply chain risks in product clusters without sacrificing the overall supply chain goal. It was recommended that short life-cycle, highly customised products be allocated against only one DC with a postponement of assembly and possible cross-docking. Choosing the Kanban pull strategy and moving the fulcrum towards customers are supported "runners" and enhances quick response, while ROP strategy is suggested for products sold in smaller volumes where aggregating low-response products in one of the most cost-effective location hedges risks created by demand volatility.

7.3 Limitation and direction for further research

The research has revealed some limitations but also opened promising vistas for further study.

The combination of methods has enabled the capture and evaluation of many supply chain characteristics on different levels of the supply chain. Furthermore, the application of the detailed computer simulation has provided an opportunity to incorporate and study key supply chain variables in dynamics. However, due to time constraints, the complexity of a real supply chain was not fully replicated, and the conducted study is based on the statistics data of one case company. Even though collected data has been generalised to avoid selection bias, triangulating it against data of a comparable company could potentially improve the generalisation of research findings.

Another limitation of the study is that this model did not investigate the backwards flow of materials. The reverse logistics concept has been growing in popularity over the past decade, and many companies now consider it a tool aimed at not only providing better service but also an opportunity to increase profit through the reuse of materials. Although reverse logistics can use the same channels as traditional logistics, the nature of the processes is different from forward logistics activities, mostly applying a “push” approach initiated by customers, so special strategies need to be designed. Therefore, studying reverse activities in the model as well may add additional value to the concept.

The application of DWV3 classification employed to reflect market dependant characteristics for supply chain products provided a sound outcome for the design of market-focused supply chains. However, other classification systems might also impact the design of SC channels. For instance, the CPA classification, based on physical characteristics, shapes logistics processes while ABC methodology assists with inventory control. Due to time limitations this research does not examine the interaction of these classifications and is a field that calls for further exploration.

Lastly, this study mostly employed a quantitative approach. The applied methodology meant that cultural, behavioural and social aspects were omitted. In real life, these aspects have a significant impact on supply chain decisions and need to be considered in the supply chain design process.

Requirements for supply chain process automation are noted by many scholars. Enterprise Resource Planning (ERP) software provides countless options for integrating processes across business functions in a cooperative way that is highly praised by many companies. In the 1990s ERP systems were employed mainly by large establishments (O’Leary, 2000); however, Seethamraju (2015) argues that ERP is now also in high demand for small and medium-sized enterprises (SMEs). Gartner (2018) reports that ERP market experiences 10 percent annual growth and reached $35 billion in 2018. O’Leary (2000) mentions that the integration of company activities, enhancing of “best practices”, standardisation of processes, real-time information and visibility, external and internal communication and collaboration are the main value-adding aspects. Researchers describe the potential impact of ERP applications on process improvement, but most focus on system and cost efficiency (Maiga et al., 2013) and decision reliability and speed (Holsapple & Sena, 2005); market alignment is not widely covered. Karabek et al. (2011) highlight the willingness of ERP to adopt new approaches and innovations to provide users with up-to-date solutions to increase company competitiveness. This study verified that aligning supply chain processes with market requirements provides a weighty outcome. Hence, incorporating the market-driven methodology proposed by the conducted study into ERP systems and linking them with ERP value-adding processes creates a perspective for further research.

Chapter VIII: Conclusion

To conclude 21st century challenging environment has a substantial impact on supply chains. Increased competition requires companies to boost capabilities to meet current trends, which dictate moving from a supply-centric to a customer-centric perspective. In such an environment being market specific is a serious competitive advantage for supply chains regardless of their size. Existing research revealed that the products supply chains operate with are not homogeneous. As noted by Shewchuk (1989), “one size does not fit all”. Different supply chain actors are affected by influencers that entails different design decisions and building blocks, which in turn suggest that the diversity of products in a supply chain calls for multiple, tailored, pipelines determined by the market-specific characteristics of the products. Maximisation of benefits for some products is associated with the efficiency of processes, cost and waste reduction and hedging risk, while others gain from agility and reactiveness. Efficiency and effectiveness are no longer opposite concepts and can be successfully married in one supply chain. The tools explored in the existing research help to amplify the positive effects of the various strategies incorporated in one supply chain and reduce their drawbacks.

Incorporation of DWV3 analysis into the design method helps with the careful, market-specific assessment of processes and opportunities and the creation of multiple market-faced channels customised for each particular product group. In each channel, a decoupling point and sourcing strategy need to balance capacity and cost with customer requirements. The outcome of DWV3 analysis and strategy allocation reveals a substantial positive impact on overall supply chain performance and helps to avoid the averaging effect. The approach represents a core concept of the proposed design framework. It offers an opportunity to assess and segregate products based on market-specific characteristics, define a strategy and design multiple, tailored channels.

It is important the structure of design helps maximise the benefits of the proposed SC architecture method and ensures it covers different decision levels. The use of the three-stage analytical approach provides a wider view on supply chain processes compared to studies at either strategic or operational levels. Scholars planning to apply similar methods need to ensure decisions made at different stages do not overlap, to avoid distortion of the results. The proposed framework starts with strategic analysis and optimises the network in accordance with existing constraints. It is followed by an integrated, market-specific analysis and detailed simulation of operations that embrace lower level decisions and augment the outcomes of the previous design stage. This method creates a base for market-specific analysis alongside the separation of decision level and elimination of distortion.

The proposed system is not an ultimate decision-making tool that will suit all supply chain policymakers. However, it provides a framework supportive of achieving competitive advantage through the construction of tailored, market-driven supply chain channels. Future academics and practitioners are encouraged to use the methods and findings of this study to develop new approaches to supply chain design.

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Appendices

Appendix 1 Specifications of SC models in terms of a model type

	Model				Performance Metrics					Decision variables					
Author	Deterministic	Stochastic	OS & Economic	Simulation	Cost	Customer responsiveness	Activity time	Elasticity	Risk	Distribution/ manufacturing scheduling	Batch size & inventory Level	Stages	DC-customer assignment	Manufacture-product assignment	Relationships
1	X				X		X			X	X	X	X	X	
2		X			X		X		X		X				
3			X		X	X									X
4	X				X						X				
5	X				X					X					
6	X				X	X				X	X				
7		X				X					X				
8		X			X	X					X				
9	X				X					X	X		X		
10		X			X		X				X				X
11		X			X						X				
12				X	X	X					X	X			
13	X							X		X	X				
14				X	X	X					X	X			
15	X				X					X					

No	Reference
1	Arntzen, et al. (1995)
2	Azaron, et al. (2008)
3	Cachon & Zipkin (1997)
4	Cohen & Lee (1988)
5	Cohen & Moon (1990)
6	Ishii, et al. (1988)
7	Lee & Billington (1993)
8	Lee, et al. (1993)

Appendix 2 New Zealand local freight rates

Delivery area	**DC candidate location**										
	Auckland	**Tauranga**	**Hamilton**	**Hastings**	**Palmerston North**	**Wellington**	**Nelson**	**Christchurch**	**Dunedin**	**Invercargill**	**Greymouth**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Northland	57.0029	228.8051	182.1411	215.9478	205.8738	237.5606	430.4479	264.569	342.6751	625.5238	519.7172
Auckland	48.1585	61.3468	57.0029	89.7177	81.4789	84.4236	175.5718	157.267	195.1297	231.7602	229.9955
Bay of Plenty	67.97	53.4004	63.35	102.575	94.2073	154.4097	213.7504	191.8613	328.3905	373.3737	414.2899
Waikato region	57.0029	51.9176	48.1585	129.5652	142.5261	57.431	327.5109	180.3856	214.1759	411.7305	416.7803
Gisborne region	125.7624	94.39	148.9978	100.7825	133.1846	125.7634	328.2175	267.4196	370.3569	444.1066	440.5131
Hawkes bay region	89.7177	94.38	129.5652	48.1585	79.1869	150.4542	328.2175	177.9839	185.6274	444.1066	440.5131
Taranaki region	98.4681	94.39	142.5261	100.7825	87.1064	182.1411	339.024	194.263	224.9938	444.1066	440.5131
Wanganui region	81.4789	84.95	142.5261	79.1869	48.1585	95.026	256.2608	152.6307	190.3785	372.15	368.5564
Wellington region	84.4236	110.1512	158.3738	150.4542	95.026	53.4004	224.5826	134.6809	180.8554	356.2936	331.113
Tasman region	175.5718	212.3694	327.5109	339.024	256.2608	81.4476	53.4004	81.3327	230.1939	441.2543	259.0788
Nelson region	175.5718	212.3694	327.5109	339.024	256.2608	81.4476	53.4004	81.3327	230.1939	441.2543	259.0788
Marlborough region	155.8155	249.2923	308.8108	292.963	237.5606	78.315	71.9653	67.2778	218.9374	419.65	223.1435
Canterbury region	164.1691	249.2923	308.8108	292.963	237.5606	146.188	133.9085	53.4004	95.1997	213.802	107.9695
Otago region	231.7602	291.029	407.7836	444.1066	372.15	281.934	441.2543	124.8863	63.7693	151.1437	241.1197
Southland region	231.7602	276.8696	411.7305	444.1066	372.15	292.376	441.2543	124.8863	63.7693	53.4004	285.7587
West coast region	229.9955	231.2485	416.7803	440.5131	368.5564	229.724	259.0788	75.6836	160.0863	285.7587	53.4004

source Mainfreight and Flyway, 2019

Appendix 3 Local freight delivery time matrix

Delivery area	DC candidate location										
	AK	Tauranga	Hamilton	Hastings	Palmerston North	Wellington	Nelson	Christchurch	Dunedin	Invercargill	Greymouth
	1	2	3	4	5	6	7	8	9	10	11
Northland	2	2	2	3	3	3	5	5	6	6	6
Auckland	1	2	2	2	2	2	3	4	5	5	5
Bay of Plenty	2	1	2	2	2	2	3	5	5	5	5
Waikato region	2	1	1	2	2	2	3	5	5	5	5
Gisborne region	2	2	2	1	2	2	3	5	5	5	5
Hawkes bay region	2	2	2	1	2	2	3	5	5	5	5
Taranaki region	2	2	2	2	1	2	3	5	5	5	5
Wanganui region	2	2	2	2	1	2	3	5	5	5	5
Wellington region	2	2	2	2	2	1	2	3	5	5	5
Tasman region	3	3	3	3	3	2	1	2	3	3	2
Nelson region	3	3	3	3	3	2	1	2	3	3	2
Marlborough region	3	3	3	3	3	3	2	2	3	3	2
Canterbury region	4	5	5	5	4	3	2	1	2	2	2
Otago region	4	5	5	5	4	3	3	2	1	1	3
Southland region	4	5	5	5	4	4	3	2	1	1	3
West coast region	4	5	5	5	4	4	2	2	3	3	1

Appendix 4 Supply chain DC lease cost

	Annual operation cost $											Average $
Northland	160.95	138.25	95.12	130.52	125.12	112.00	142.35	130.47	107.86	109.25	137.89	**126.34**
Auckland	78.82	153.75	160.03	183.20	169.48	100.46	149.24	108.25	136.27	168.79	155.97	**142.21**
Bay of Plenty	124.51	125.20	117.02	107.22	115.15	115.20	110.00	97.47	125.00	138.74	101.87	**116.12**
Waikato region	115.56	137.58	142.42	109.32	130.25	156.68	111.94	127.89	144.15	106.83	139.98	**129.33**
Gisborne region	105.28	95.24	93.57	70.57	92.12	90.12	105.50	85.49	101.27	94.25	101.74	**94.10**
Hawkes bay region	111.12	95.33	86.24	75.26	115.20	90.02	87.96	70.12	96.60	101.80	107.71	**94.30**
Taranaki region	104.41	78.62	80.26	90.24	107.54	108.26	105.33	86.27	115.57	111.00	80.93	**97.13**
Manawatu-Wanganui region	77.64	63.49	95.12	90.48	120.26	107.25	125.63	80.49	74.82	114.86	115.68	**96.88**
Wellington region	108.27	120.45	109.72	90.46	85.46	111.23	90.12	125.78	101.03	94.20	89.45	**102.38**
Nelson/Tasman region	100.65	86.37	134.23	78.46	105.23	115.78	89.12	73.28	85.02	112.42	130.08	**100.97**
Marlborough region	85.19	98.12	85.95	105.79	108.48	93.79	83.79	72.85	91.07	109.13	105.87	**94.55**
Canterbury region	137.14	70.95	117.00	116.51	130.43	114.29	126.47	97.08	101.33	129.71	137.54	**116.22**
Southland region	101.48	145.23	99.13	95.40	135.89	112.28	128.93	99.77	108.21	132.12	128.06	**116.95**
Otago region	85.86	76.28	185.19	112.50	124.25	101.95	120.25	92.67	118.01	99.80	147.15	**114.90**
West coast region	132.19	120.10	138.85	97.74	108.74	97.76	137.69	101.23	95.02	139.54	117.02	**116.90**

sources https://www.realestate.co.nz, https://www.trademe.co.nz/property/commercial-property, https://www.bayleys.co.nz/commercial

Appendix 5 Acceptable delivery window questionnaire

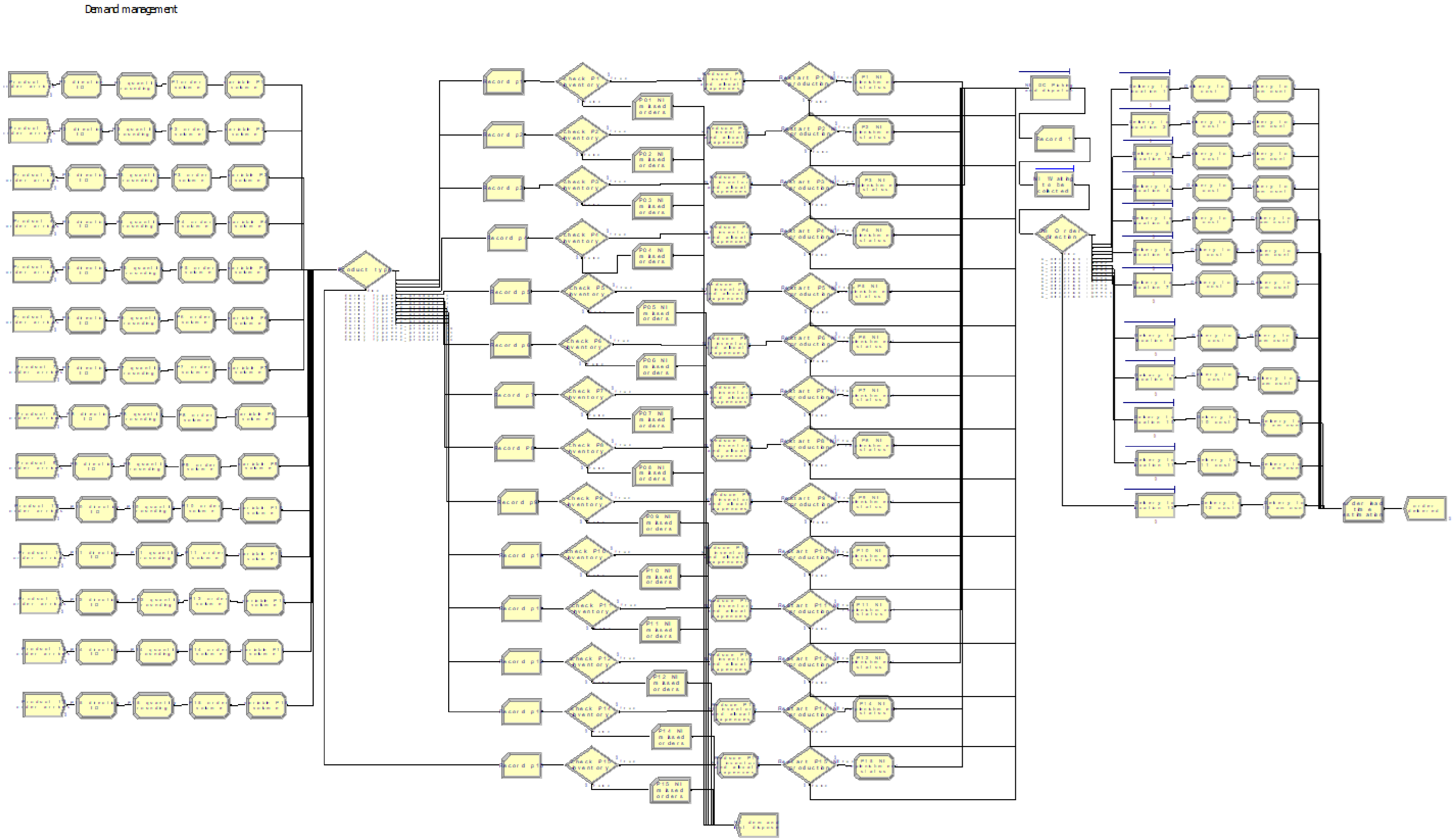
	Acceptable Delivery window										
	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Rep 5**	**Rep 6**	**Rep 7**	**Rep 8**	**Rep 9**	**Rep 10**	**Average**
Product 1	14	4	3	1	4	7	5	5	1	4	4.8
Product 2	1	1	1	1	2	5	2	2	1	2	1.8
Product 3	3	1	1	1	1	2	1	2	3	1	1.6
Product 4	2	1	1	1	1	2	1	2	3	1	1.5
Product 5	1	1	1	1	1	2	1	2	1	2	1.3
Product 6	21	4	3	3	4	5	5	10	10	6	7.1
Product 7	14	5	3	3	4	5	7	5	10	9	6.5
Product 8	1	1	1	1	1	2	1	2	3	2	1.5
Product 9	2	1	1	1	1	2	2	2	10	2	2.4
Product 10	1	10	2	2	4	2	5	10	4	5	4.5
Product 11	2	3	2	3	4	3	5	10	14	5	5.1
Product 12	3	3	2	2	4	3	4	5	14	5	4.5
Product 14	40	55	65	30	25	40	50	60	40	40	44.5
Product 15	1	1	1	1	1	2	1	2	1	1	1.2

Appendix 6 DWV3 parameters

	RPH name	Life cycle	Delivery window	Volume	Demand variability			Product variety		
	RPH name	Duration (year)	Acceptable delivery window (days)	Annual throughput	std deviation	mean (average)	CV (coefficient of variety)	Product types	Units sold	Viriety index
Product 1	Accommodation	7	5	663	24.13	8.29	291.15%	24	663	0.04
Product 2	Chemicals	6	2	3930	3.38	2.86	118.34%	103	3930	0.03
Product 3	Crockery	6	2	51347	60.70	30.24	200.71%	580	51347	0.01
Product 4	Cutlery	6	2	2836	9.14	5.74	159.29%	120	2836	0.04
Product 5	Disposables	6	1	20147	32.87	8.65	379.79%	185	20147	0.01
Product 6	Equipment	5	7	651	4.72	1.74	271.84%	103	651	0.16
Product 7	Furniture	6	7	448	15.27	7.72	197.71%	36	448	0.08
Product 8	Glasware	6	2	108424	91.59	49.51	185.00%	464	108424	0.00
Product 9	Hardware	6	2	59846	30.11	8.86	339.86%	1521	59846	0.03
Product 10	Laundry	5	5	88	2.46	2.93	83.95%	14	88	0.16
Product 11	Refrigeration	5	5	103	1.33	1.26	106.01%	47	103	0.46
Product 12	Shelving	6	5	124	3.86	2.53	152.64%	33	124	0.27
Product 14	Stainless Steel	2	45	222	2.20	1.83	120.11%	60	222	0.27
Product 15	Uniform	6	1	3243	8.17	3.05	268.18%	133	3243	0.04

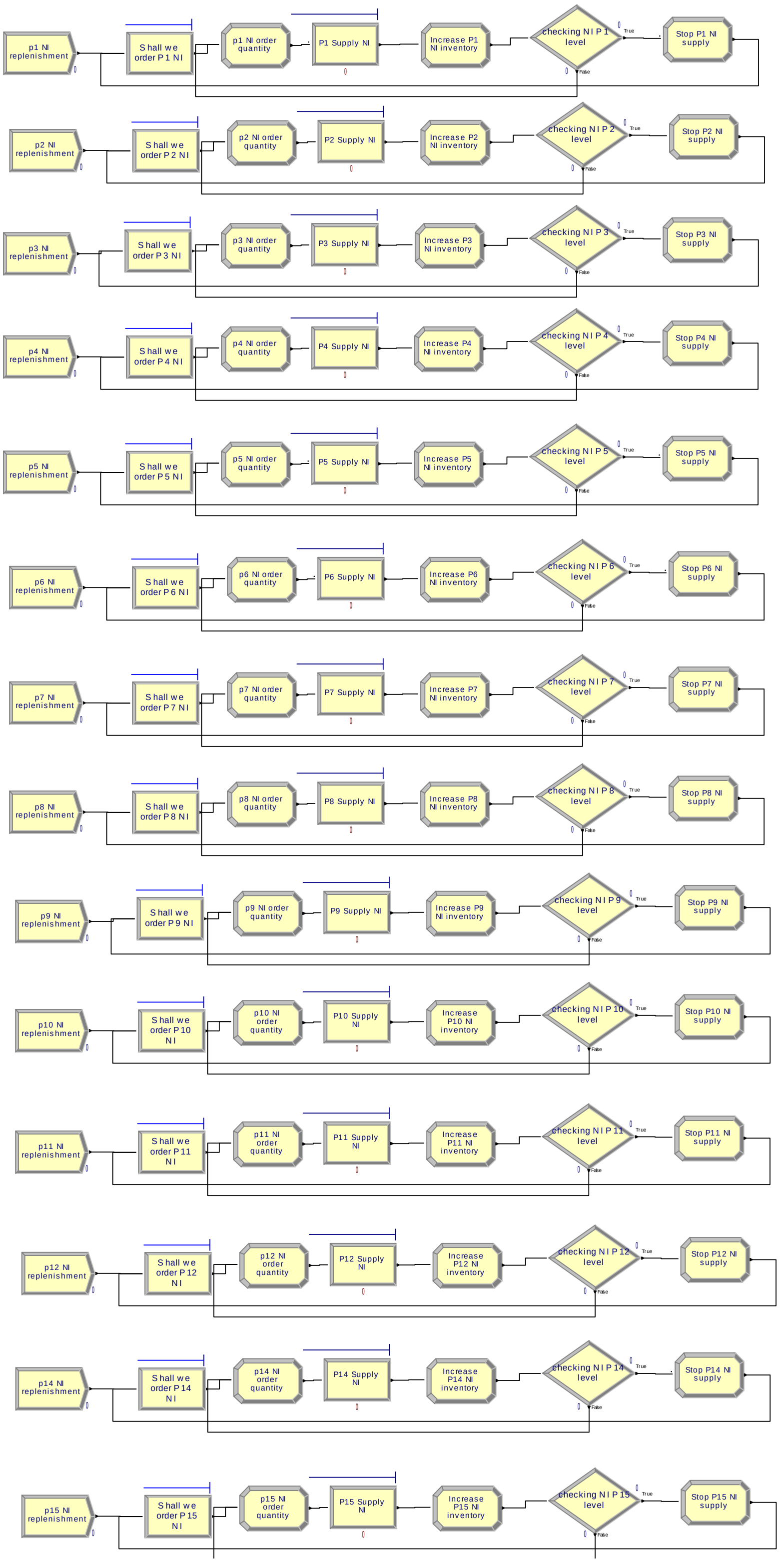
DWV3 parameters

Appendix 7 Demand management segment for 1DC model

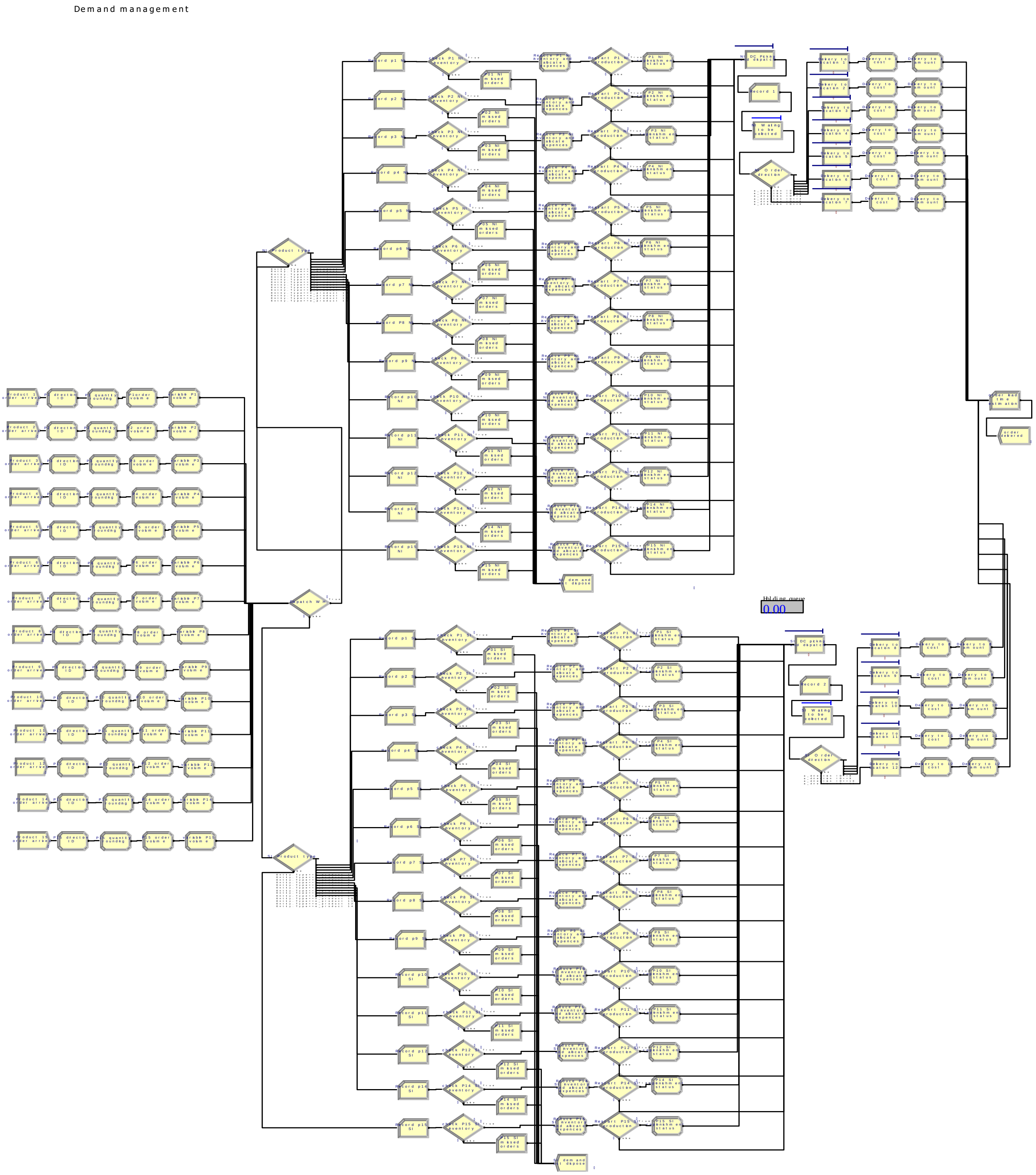


Appendix 8 Supply management segment for 1DCmodel

NI Supply management

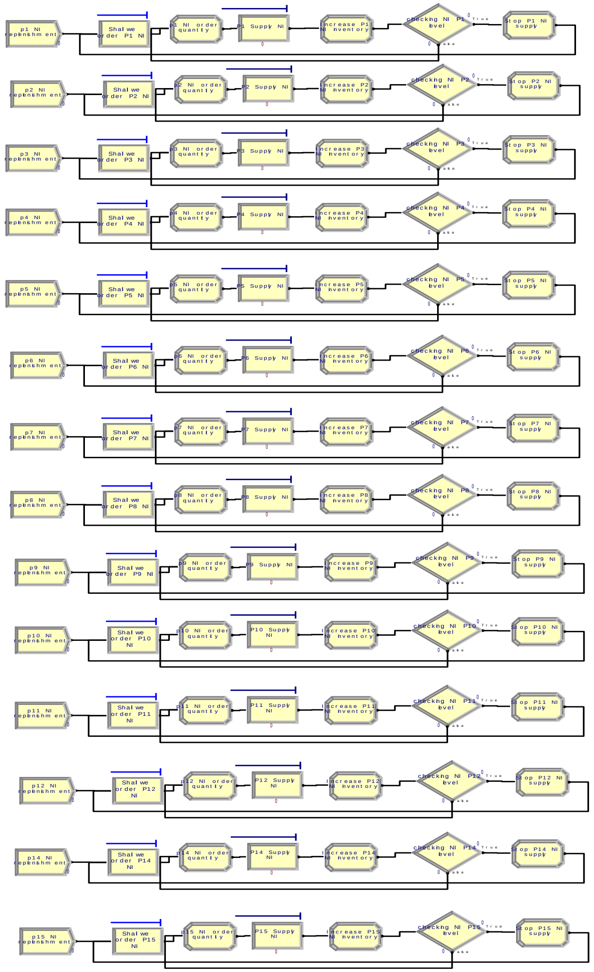


Appendix 9 Demand management segment for linear optimised model

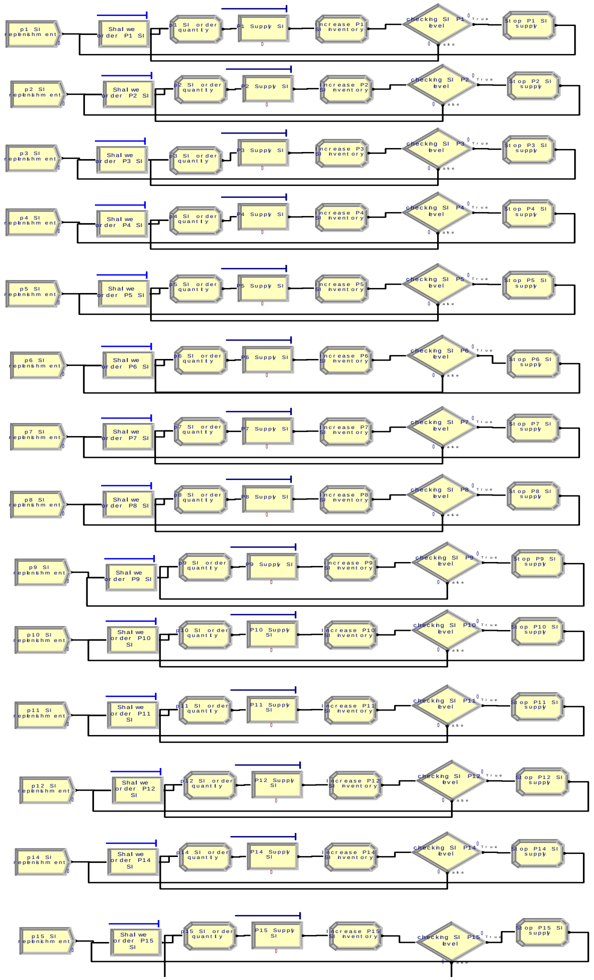


Appendix 10 Supply management segment for linear optimised model

NI Supply management



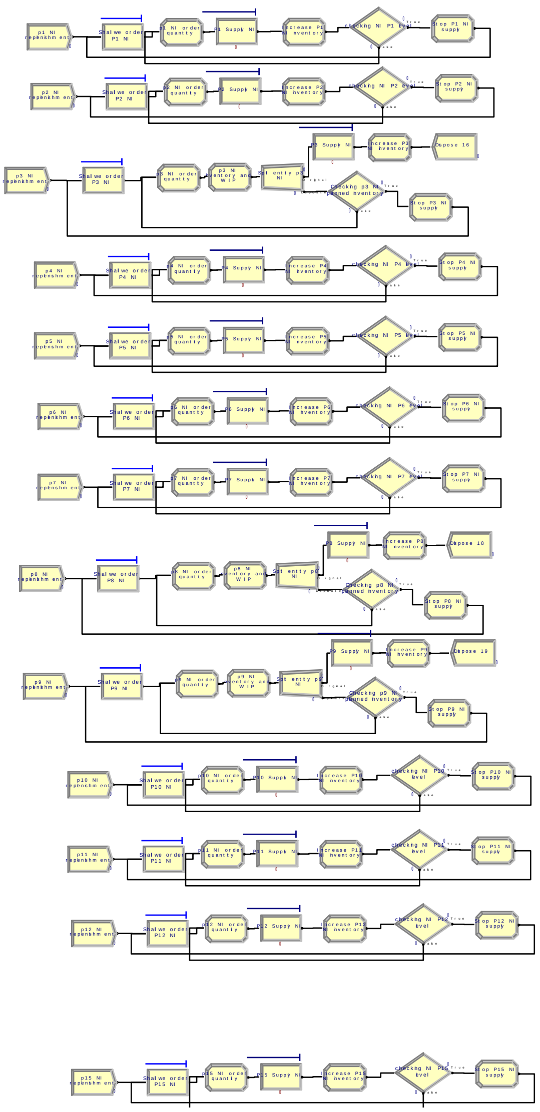
SI Supply management



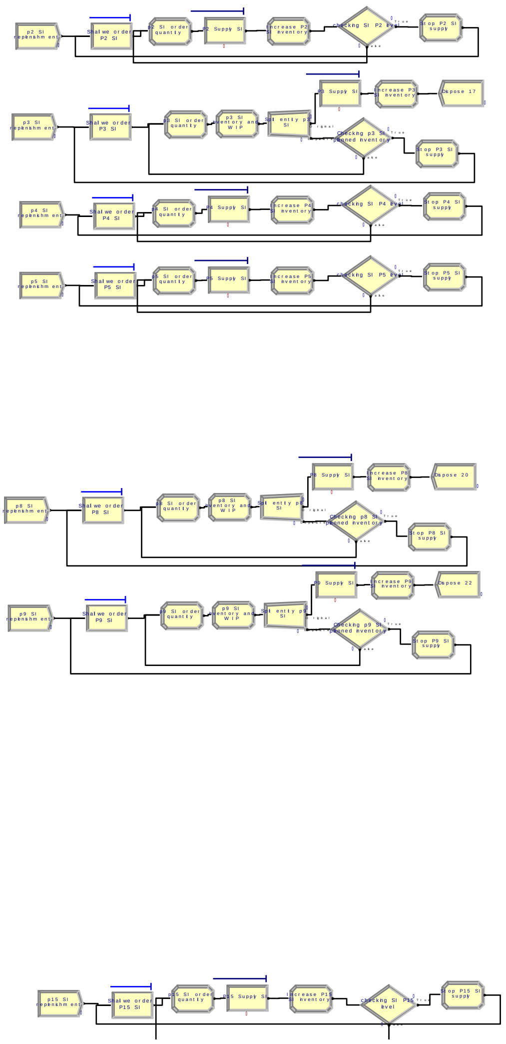
Appendix 11 Demand management segment for DWV3 model

Appendix 12 Supply management segment for DWV3 model

NI Supply management



SI Supply management



Appendix 13 *Arena* dialog boxes for 1DC model

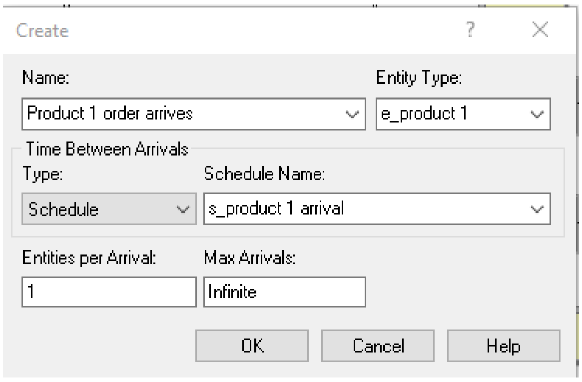


Figure 1 Create module for P_n orders

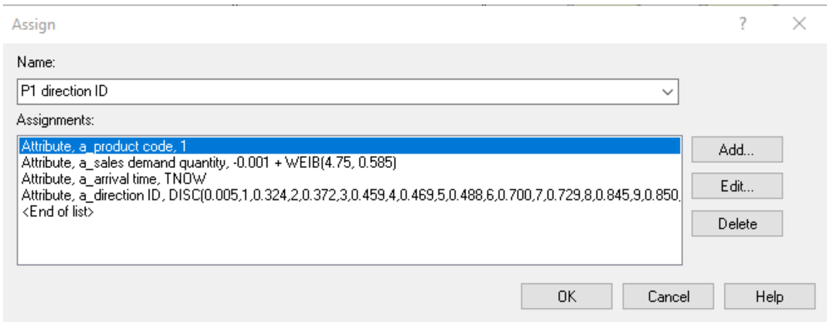


Figure 2 Direction ID Assign module for P_n

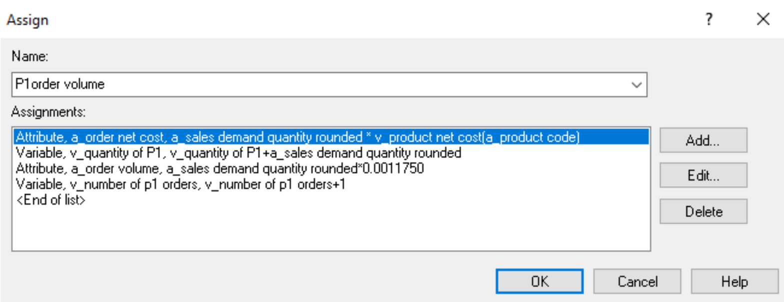


Figure 3 P_n volume module dialogue box

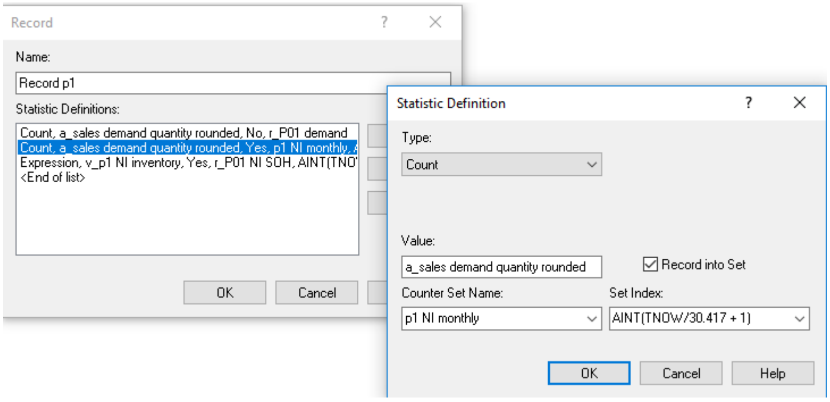


Figure 4 Record P_n module and record statistic definition dialog boxes

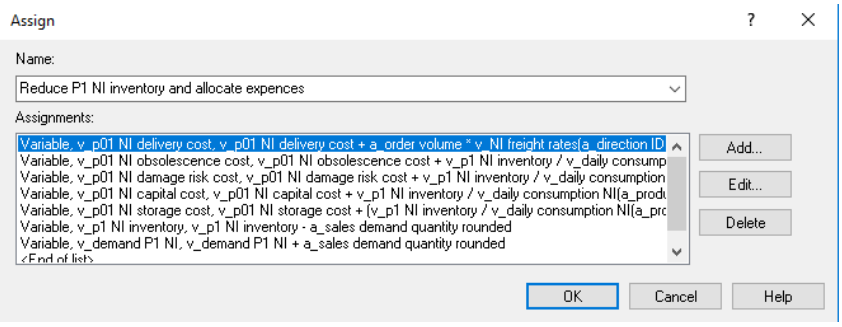


Figure 5 Dialogue box of the Reduce P_n Inventory and allocate expenses module

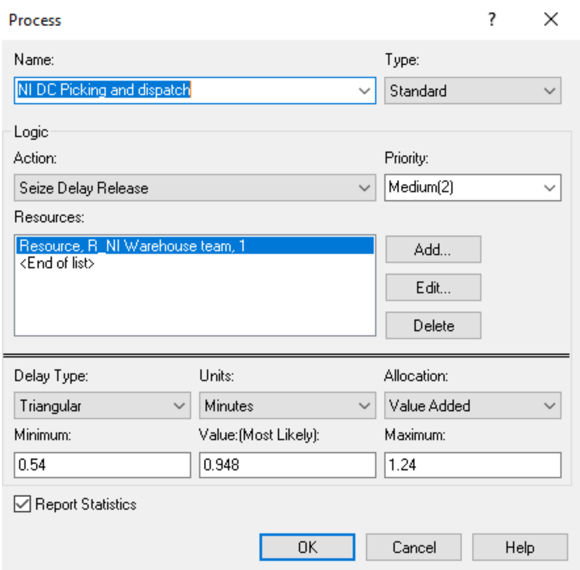


Figure 6 Warehouse operation Seize Delay Release module dialogue box

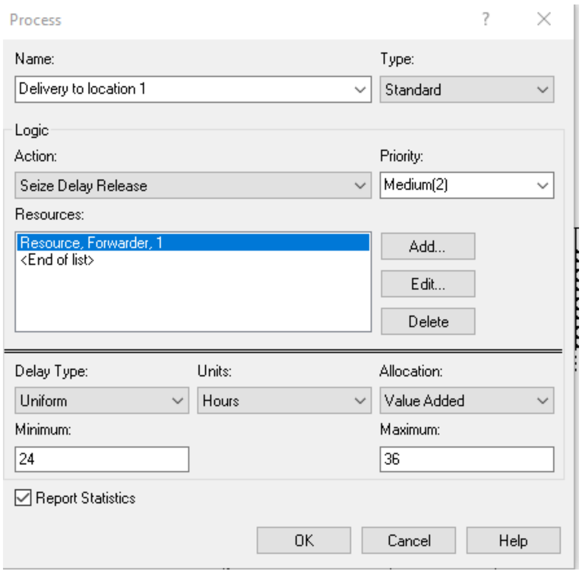


Figure 7 Dialog box of the Delivery to location L process module

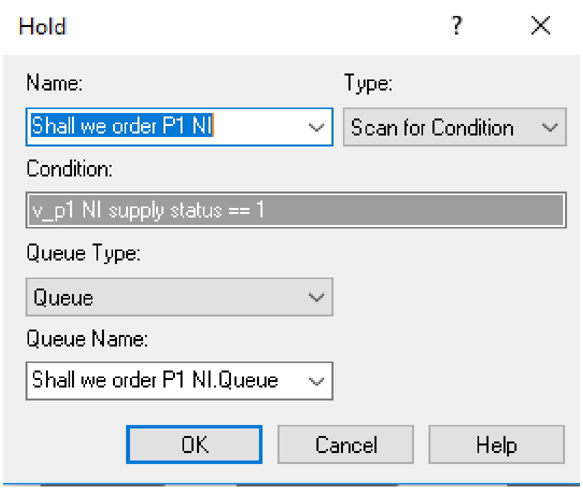


Figure 8 Reorder Dialogue box

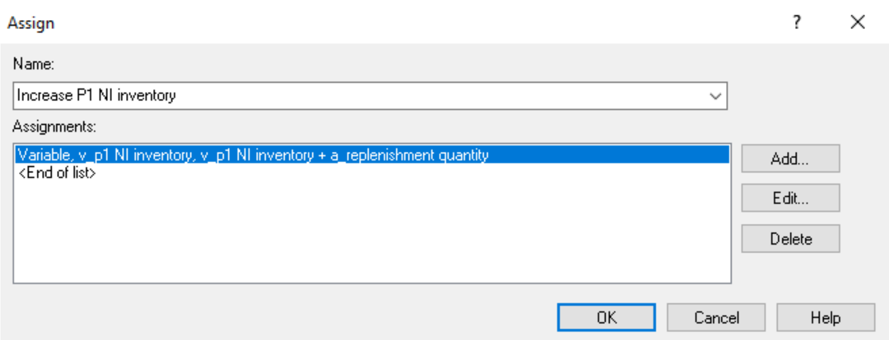


Figure 9 Increase global inventory dialogue box

Appendix 14 *Arena* dialog boxes for linear optimised model

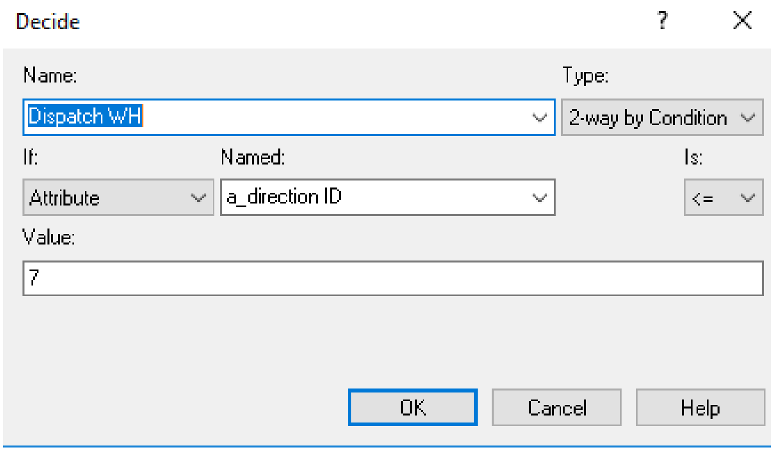


Figure 1 Site allocation logic dialog box

Appendix 15 *Arena* dialog boxes for DWV3 model

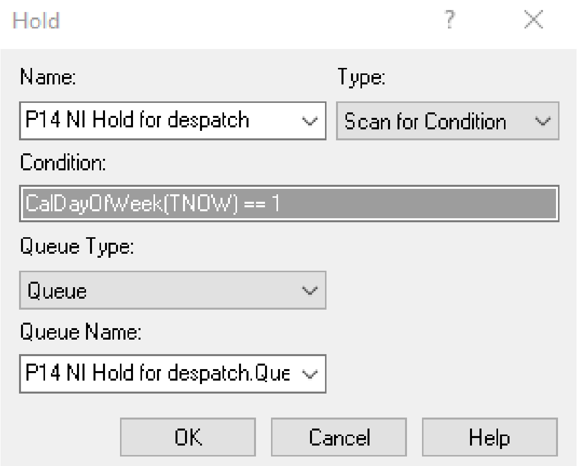


Figure 1 Cluster 4 scan for release condition dialogue box

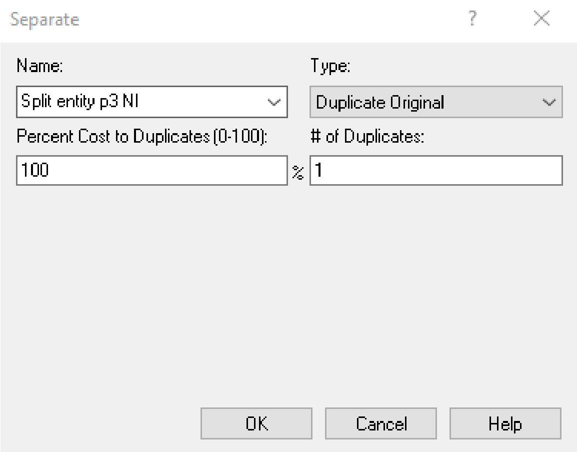


Figure 2 Separate module for Kanban replenishment simulation

Appendix 16 Order arrival times matrix

Time	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P14	P15
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.033	0.033	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000
7	0.000	0.067	0.133	0.033	0.200	0.000	0.000	0.367	0.467	0.000	0.000	0.000	0.033	0.067
8	0.067	1.433	1.200	0.333	2.233	0.300	0.000	1.967	4.700	0.033	0.100	0.033	0.033	0.333
9	0.233	5.000	5.200	1.767	7.900	1.367	0.233	7.233	16.467	0.033	0.300	0.133	0.300	2.567
10	0.400	5.000	5.200	1.700	8.167	1.167	0.333	6.267	19.933	0.167	0.200	0.200	0.400	3.233
11	0.133	4.200	6.100	1.800	7.533	1.533	0.100	6.733	21.333	0.067	0.267	0.033	0.333	3.867
12	0.100	5.100	6.033	1.067	8.267	1.400	0.167	7.633	26.133	0.100	0.333	0.133	0.400	3.833
13	0.233	4.733	5.733	1.967	8.400	0.933	0.100	7.500	26.333	0.167	0.433	0.167	0.567	3.900
14	0.400	5.100	6.633	2.033	7.800	1.167	0.333	7.733	26.800	0.100	0.167	0.200	0.600	4.067
15	0.267	5.133	7.000	2.067	9.500	1.933	0.267	9.167	28.800	0.267	0.433	0.300	0.600	4.900
16	0.433	4.367	5.333	1.567	8.433	1.300	0.133	8.567	24.567	0.000	0.200	0.200	0.267	4.567
17	0.233	3.833	5.633	1.567	6.833	0.967	0.133	7.267	22.200	0.033	0.233	0.200	0.333	3.533
18	0.133	0.767	0.933	0.300	1.233	0.133	0.100	1.067	3.233	0.033	0.067	0.033	0.033	0.233
19	0.000	0.167	0.267	0.100	0.167	0.033	0.000	0.433	0.733	0.000	0.000	0.000	0.033	0.133
20	0.000	0.300	0.467	0.067	0.267	0.100	0.033	0.400	0.900	0.000	0.000	0.000	0.000	0.133
21	0.033	0.333	0.533	0.033	0.200	0.067	0.000	0.333	0.933	0.000	0.000	0.000	0.067	0.067
22	0.000	0.200	0.033	0.067	0.267	0.000	0.000	0.200	0.967	0.000	0.000	0.000	0.033	0.000
23	0.000	0.067	0.167	0.000	0.067	0.067	0.000	0.033	0.400	0.000	0.000	0.000	0.000	0.000
24	0.000	0.033	0.000	0.000	0.067	0.000	0.000	0.100	0.167	0.000	0.000	0.000	0.000	0.033

Appendix 17 Arrival assign module distributions and inventory related variables

	Quantity distribution	Direction ID distribution	SKU net cost	SKU volume m3	Initial inventory
P1	-0.001 + WEIB(4.75, 0.585)	DISC(0.005,1, 0.324,2, 0.372,3, 0.459,4, 0.469,5, 0.488,6, 0.700,7, 0.729,8, 0.845,9, 0.850,10, 0.995,11, 1,12)	$15.00	0.001175	1372
P2	-0.5 + LOGN(3.23, 2.5)	DISC(0.034,1, 0.384,2, 0.406,3, 0.538,4, 0.559,5, 0.591,6, 0.691,7, 0.707,8, 0.875,9, 0.889,10, 0.994,11, 1.000,12)	$26.65	0.00902575	7100
P3	-0.001 + WEIB(18, 0.514)	DISC(0.029,1, 0.354,2, 0.419,3, 0.484,4, 0.506,5, 0.545,6, 0.651,7, 0.682,8, 0.847,9, 0.868,10, 0.993,11, 1,12)	$5.10	0.001186495	111089
P4	-0.001 + WEIB(4.62, 0.699)	DISC(0.015,1, 0.356,2, 0.409,3, 0.48,4, 0.496,5, 0.546,6, 0.642,7, 0.684,8, 0.877,9, 0.887,10, 0.999,11, 1,12)	$15.25	0.00004485	5574
P5	-0.001 + WEIB(6.05, 0.622)	DISC(0.021,1, 0.356,2, 0.385,3, 0.455,4, 0.48,5, 0.525,6, 0.65,7, 0.684,8, 0.849,9, 0.875,10, 0.998,11, 1,12)	$12.50	0.002586516	38170
P6	-0.5 + LOGN(1.91, 1.28)	DISC(0.014,1, 0.41,2, 0.465,3, 0.533,4, 0.564,5, 0.602,6, 0.701,7, 0.725,8, 0.848,9, 0.867,10, 0.998,11, 1,12)	$1,438.00	0.2145243	1013
P7	-0.001 + WEIB(4.99, 0.572)	DISC(0.005,1, 0.278,2, 0.291,3, 0.33,4, 0.382, 5, 0.408,6, 0.551,7, 0.555,8, 0.645,9, 0.658,10, 0.996,11, 1,12)	$83.00	0.107777778	914
P8	-0.001 + WEIB(37.7, 0.639)	DISC(0.017,1, 0.405,2, 0.451,3, 0.516,4, 0.531,5, 0.566,6, 0.686,7, 0.717,8, 0.833,9, 0.847,10, 0.994,11, 1,12)	$2.20	0.001025233	216683
P9	-0.001 + WEIB(5.91, 0.658)	DISC(0.022,1, 0.39,2, 0.441,3, 0.515,4, 0.537,5, 0.589,6, 0.688,7, 0.721,8, 0.847,9, 0.873,10, 0.996,11, 1,12)	$21.60	0.004423048	99390
P10	-0.5 + LOGN(3.52, 3.13)	DISC(0.009,1, 0.294,2, 0.466,3, 0.637,4, 0.646,5, 0.674,6, 0.809,7, 0.817,8, 0.954,9, 0.963,10, 0.991,11, 1,12)	$2,763.00	0.491878571	191
P11	-0.5 + ERLA(0.585, 3)	DISC(0.038,1, 0.618,2, 0.637,3, 0.703,4, 0.75,5, 0.788,6, 0.854,7, 0.863, 8, 0.92,9, 0.925,10, 0.991,10, 1,12)	$1,623.00	1.172506	203
P12	-0.5 + LOGN(2.87, 3.32)	DISC(0.022,1, 0.314,2, 0.336,3, 0.34,4, 0.362,5, 0.57,6, 0.669,7, 0.68,8, 0.829,9, 0.832,10, 0.997,11, 1,12)	$153.00	0.009	275
P14	-0.5 + LOGN(2.28, 1.83)	DISC(0.012,1, 0.435,2, 0.476,3, 0.51,4, 0.551,5, 0.609,6, 0.662,7, 0.697,8, 0.772,9, 0.79,10, 0.999,11, 1,12)	$352.00	0.357294667	437
P15	-0.001 + WEIB(2.71, 0.871)	DISC(0.039,1, 0.288,2, 0.338,3, 0.426,4, 0.482,5, 0.54,6, 0.691,7, 0.729,8, 0.838,9, 0.872,10, 0.999,11, 1,12)	$19.25	0.002449905	5915

Appendix 18 Inventory for 1 DC, linear optimisation and DWV3 *Arena* simulation models

	1 DC simulation model				LP optimisation 2 DC model								DWV3 model									
	Initial inventory	**Safety stock**	**Min inventory (reorder point)**	**Max inventory (target stock)**	**NI initial inventory**	**NI Safety stock**	**NI Min inventory (reorder point)**	**NI Max inventory (target stock)**	**SI initial inventory**	**SI Safety stock**	**SI Min inventory (reorder point)**	**SI Max inventory (target stock)**	**NI initial inventory**	**NI safety stock**	**NI Kanban bin size**	**NI Min (reorder point)**	**NI Max (target stock)**	**SI initial inventory**	**SI safety stock**	**SI Kanban bin size**	**SI Min (reorder point)**	**SI Max (target stock)**
P1	1372	369	1002	1741	970	264	710	1230	462	164	352	572	1372	369		1002	1741					
P2	7100	1178	4919	9282	4867	787	3364	6371	2301	459	1622	2979	4867	787		3364	6371	2301	459		1622	2979
P3	111089	19640	77397	144781	73508	13151	51271	95745	39169	8077	27714	50624	73508	13151	10000			39169	8077	5000		
P4	5574	1015	3894	7254	3561	656	2491	4632	2141	487	1531	2750	3561	656		2491	4632	2141	487		1531	2750
P5	38170	6358	26450	49891	25045	4346	17419	32671	13515	2402	9420	17609	25045	4346		17419	32671	13515	2402		9420	17609
P6	1013	174	704	1322	707	128	494	920	328	68	232	424	1013	174		704	1322					
P7	914	245	667	1161	538	201	414	662	486	154	364	608	914	245		667	1161					
P8	216683	35109	149787	283579	148612	25350	103200	194024	70521	12209	49038	92005	148612	25350	20000			70521	12209	10000		
P9	99390	14673	68179	130602	68568	10118	47034	90102	31293	5025	21615	40970	68568	10118	10000			31293	5025	5000		
P10	191	47	138	244	146	40	107	185	53	15	39	67	191	47		138	244					
P11	203	45	145	261	172	38	122	221	33	10	25	42	203	45		145	261					
P12	275	71	200	351	197	63	148	246	109	39	83	135	275	71		200	351					
P14	437	101	314	561	290	71	209	370	168	51	125	211										
P15	5915	1002	4105	7725	4151	733	2892	5411	1844	350	1294	2395	4151	733		2892	5411	1844	350		1294	2395

Appendix 19 Delivery time distribution and freight rates

		Delivery time distribution			Delivery rates	
Region ID	**Region name**	**From Auckland**	**From Tauranga**	**From Christchurch**	**From NI**	**From SI**
1	Northland	UNIF(12,24)	UNIF(24-36)	UNIF(72-96)	228.8051	264.569
2	Auckland	UNIF(12,24)	UNIF(12,24)	UNIF(72-96)	61.3468	157.267
3	Bay of Plenty	UNIF(12,24)	UNIF(12,24)	UNIF(72-96)	53.4004	191.8613
4	Waikato region	UNIF(12,24)	UNIF(24-36)	UNIF(72-96)	51.9176	180.3856
5	Hawks bay region	UNIF(12,24)	UNIF(24-36)	UNIF(72-96)	94.3852	177.9839
6	Taranaki region	UNIF(12,24)	UNIF(24-36)	UNIF(72-96)	94.3852	152.6307
7	Wellington region	UNIF(12,24)	UNIF(24-36)	UNIF(72-96)	110.1512	134.6809
8	Nelson region	UNIF(24-36)	UNIF(24-36)	UNIF(24-36)	212.3694	81.3327
9	Canterbury region	UNIF(72,84)	UNIF(72-96)	UNIF(12,24)	249.2923	53.4004
10	Southland region	UNIF(72,84)	UNIF(72-96)	UNIF(12,24)	276.8696	124.8863
11	Otago region	UNIF(72,84)	UNIF(72-96)	UNIF(24-36)	291.029	124.8863
12	South Island west coast region	UNIF(72,84)	UNIF(72-96)	UNIF(24-36)	231.2485	76.6836

Appendix 20 Missed opportunity cost and missed orders for 1DC model based simulation

User Specified

Count	Average	Half Width	Minimum Average	Maximum Average
r_P01 demand	7271.02	100.28	6016.00	8501.00
r_P01 NI missed opportunity dollar	46.0500	27.85	0.00	897.00
r_p01 NI missed orders	0.6200	0.40	0.00	13.0000
r_p01 NI missed quantity	15.3500	9.28	0.00	299.00
r_P02 demand	45642.61	104.74	44310.00	47072.00
r_P02 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p02 NI missed orders	0.00	0.00	0.00	0.00
r_p02 NI missed quantity	0.00	0.00	0.00	0.00
r_P03 demand	706289.18	2,305.01	683114.00	735498.00
r_P03 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p03 NI missed orders	0.00	0.00	0.00	0.00
r_p03 NI missed quantity	0.00	0.00	0.00	0.00
r_P04 demand	35102.67	164.61	32959.00	36875.00
r_P04 NI missed opportunity dollar	5.8700	7.06	0.00	272.00
r_p04 NI missed orders	0.1400	0.19	0.00	7.0000
r_p04 NI missed quantity	1.9400	2.34	0.00	90.0000
r_P05 demand	245864.05	607.17	238616.00	254452.00
r_P05 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p05 NI missed orders	0.00	0.00	0.00	0.00
r_p05 NI missed quantity	0.00	0.00	0.00	0.00
r_P06 demand	6401.24	20.46	6177.00	6669.00
r_P06 NI missed opportunity dollar	20.1000	40.40	0.00	2010.00
r_p06 NI missed orders	0.06000000	0.12	0.00	6.0000
r_p06 NI missed quantity	0.07000000	0.14	0.00	7.0000
r_P07 demand	5653.35	99.11	4656.00	7127.00
r_P07 NI missed opportunity dollar	2385.85	578.56	0.00	14502.00
r_p07 NI missed orders	7.0800	1.84	0.00	42.0000
r_p07 NI missed quantity	143.91	34.89	0.00	875.00
r_P08 demand	1397756.42	3,063.73	1359652.00	1435693
r_P08 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p08 NI missed orders	0.00	0.00	0.00	0.00
r_p08 NI missed quantity	0.00	0.00	0.00	0.00
r_P09 demand	653317.07	827.88	644239.00	662698.00
r_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p09 NI missed orders	0.00	0.00	0.00	0.00
r_p09 NI missed quantity	0.00	0.00	0.00	0.00
r_P10 demand	1100.65	16.22	890.00	1327.00
r_P10 NI missed opportunity dollar	4668.72	1,442.40	0.00	27071.00
r_p10 NI missed orders	1.7600	0.61	0.00	14.0000
r_p10 NI missed quantity	8.4500	2.61	0.00	49.0000
r_P11 demand	1243.75	10.56	1088.00	1371.00
r_P11 NI missed opportunity dollar	606.55	332.77	0.00	10053.00
r_p11 NI missed orders	1.0700	0.61	0.00	20.0000
r_p11 NI missed quantity	1.8700	1.03	0.00	31.0000
r_P12 demand	1416.51	22.07	1135.00	1789.00
r_P12 NI missed opportunity dollar	83.0700	67.82	0.00	2295.00
r_p12 NI missed orders	0.3900	0.36	0.00	14.0000
r_p12 NI missed quantity	2.7200	2.22	0.00	75.0000
r_P14 demand	2605.54	20.88	2401.00	2927.00
r_P14 NI missed opportunity dollar	43.5000	46.01	0.00	1615.00
r_p14 NI missed orders	0.3400	0.35	0.00	10.0000
r_p14 NI missed quantity	0.6200	0.66	0.00	23.0000
r_P15 demand	37415.97	102.39	36219.00	39019.00
r_P15 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p15 NI missed orders	0.00	0.00	0.00	0.00
r_p15 NI missed quantity	0.00	0.00	0.00	0.00

Appendix 21 Missed opportunity cost and missed orders for linear optimised model based simulation

User Specified

Count	Average	Half Width	Minimum Average	Maximum Average
r_P01 NI demand	5061.81	81.08	3966.00	5829.00
r_P01 NI missed opportunity dollar	67.5600	33.58	0.00	765.00
r_p01 NI missed orders	0.8000	0.42	0.00	14.0000
r_p01 NI missed quantity	22.5200	11.19	0.00	255.00
r_P01 SI demand	2121.77	50.07	1551.00	2789.00
r_P01 SI missed opportunity dollar	77.5500	28.51	0.00	606.00
r_p01 SI missed orders	1.0300	0.46	0.00	12.0000
r_p01 SI missed quantity	25.8500	9.50	0.00	202.00
r_P02 NI demand	31550.74	73.67	30780.00	32543.00
r_P02 NI missed opportunity dollar	1.6000	3.22	0.00	160.00
r_p02 NI missed orders	0.0900	0.18	0.00	9.0000
r_p02 NI missed quantity	0.3100	0.62	0.00	31.0000
r_P02 SI demand	14078.04	53.90	13539.00	15044.00
r_P02 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p02 SI missed orders	0.00	0.00	0.00	0.00
r_p02 SI missed quantity	0.00	0.00	0.00	0.00
r_P03 NI demand	458691.68	1,640.16	435237.00	477408.00
r_P03 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p03 NI missed orders	0.00	0.00	0.00	0.00
r_p03 NI missed quantity	0.00	0.00	0.00	0.00
r_P03 SI demand	245282.41	1,441.30	227900.00	263182.00
r_P03 SI missed opportunity dollar	73.2400	90.82	0.00	4328.00
r_p03 SI missed orders	1.3000	1.45	0.00	61.0000
r_p03 SI missed quantity	72.1900	89.48	0.00	4263.00
r_P04 NI demand	22489.29	136.48	21007.00	24382.00
r_P04 NI missed opportunity dollar	36.4500	28.64	0.00	912.00
r_p04 NI missed orders	1.1100	1.00	0.00	42.0000
r_p04 NI missed quantity	12.0600	9.48	0.00	303.00
r_P04 SI demand	12589.75	90.46	11460.00	13770.00
r_P04 SI missed opportunity dollar	1.1400	2.23	0.00	111.00
r_p04 SI missed orders	0.07000000	0.12	0.00	6.0000
r_p04 SI missed quantity	0.3800	0.74	0.00	37.0000
r_P05 NI demand	159576.65	552.29	153101.00	167146.00
r_P05 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p05 NI missed orders	0.00	0.00	0.00	0.00
r_p05 NI missed quantity	0.00	0.00	0.00	0.00
r_P05 SI demand	86051.22	320.10	82322.00	90022.00
r_P05 SI missed opportunity dollar	12.1400	16.30	0.00	742.00
r_p05 SI missed orders	0.2200	0.27	0.00	10.0000
r_p05 SI missed quantity	4.8700	6.53	0.00	297.00
r_P06 NI demand	4479.96	23.51	4233.00	4747.00
r_P06 NI missed opportunity dollar	117.79	161.69	0.00	7469.00
r_p06 NI missed orders	0.2400	0.33	0.00	15.0000
r_p06 NI missed quantity	0.4100	0.56	0.00	26.0000
r_P06 SI demand	1902.19	14.86	1714.00	2086.00
r_P06 SI missed opportunity dollar	229.87	212.80	0.00	6896.00
r_p06 SI missed orders	0.4100	0.37	0.00	10.0000
r_p06 SI missed quantity	0.8000	0.74	0.00	24.0000
r_P07 NI demand	3161.96	70.69	2397.00	4035.00
r_P07 NI missed opportunity dollar	2391.95	454.33	0.00	10622.00
r_p07 NI missed orders	5.4700	1.23	0.00	32.0000
r_p07 NI missed quantity	144.23	27.39	0.00	640.00
r_P07 SI demand	2513.22	57.12	1947.00	3346.00
r_P07 SI missed opportunity dollar	1053.30	282.00	0.00	5442.00
r_p07 SI missed orders	2.0000	0.62	0.00	16.0000
r_p07 SI missed quantity	63.5000	17.00	0.00	328.00
r_P08 NI demand	960361.05	2,496.89	931673.00	987930.00
r_P08 NI missed opportunity	9.1000	18.29	0.00	910.00

dollar				
r_p08 NI missed orders	0.3100	0.62	0.00	31.0000
r_p08 NI missed quantity	21.1100	42.43	0.00	2111.00
r_P08 SI demand	440096.45	2,073.97	405887.00	464976.00
r_P08 SI missed opportunity dollar	8.7500	13.44	0.00	651.00
r_p08 SI missed orders	0.3000	0.53	0.00	26.0000
r_p08 SI missed quantity	20.1800	31.04	0.00	1503.00
r_P09 NI demand	448683.05	741.70	440543.00	456575.00
r_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p09 NI missed orders	0.00	0.00	0.00	0.00
r_p09 NI missed quantity	0.00	0.00	0.00	0.00
r_P09 SI demand	203655.86	492.36	198212.00	210250.00
r_P09 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p09 SI missed orders	0.00	0.00	0.00	0.00
r_p09 SI missed quantity	0.00	0.00	0.00	0.00
r_P10 NI demand	896.23	18.12	722.00	1137.00
r_P10 NI missed opportunity dollar	13652.47	3,270.45	0.00	76248.00
r_p10 NI missed orders	5.2800	1.36	0.00	30.0000
r_p10 NI missed quantity	24.7100	5.92	0.00	138.00
r_P10 SI demand	211.65	7.99	121.00	358.00
r_P10 SI missed opportunity dollar	3536.29	1,527.98	0.00	46966.00
r_p10 SI missed orders	0.8200	0.35	0.00	11.0000
r_p10 SI missed quantity	6.4000	2.77	0.00	85.0000
r_P11 NI demand	1063.55	9.81	953.00	1184.00
r_P11 NI missed opportunity dollar	791.47	417.31	0.00	11353.00
r_p11 NI missed orders	1.2600	0.72	0.00	23.0000
r_p11 NI missed quantity	2.4400	1.29	0.00	35.0000
r_P11 SI demand	182.43	3.72	125.00	225.00
r_P11 SI missed opportunity dollar	969.89	285.42	0.00	7786.00
r_p11 SI missed orders	1.3700	0.40	0.00	9.0000
r_p11 SI missed quantity	2.9900	0.88	0.00	24.0000
r_P12 NI demand	946.40	17.63	756.00	1154.00
r_P12 NI missed opportunity dollar	102.27	87.01	0.00	3366.00
r_p12 NI missed orders	0.4900	0.36	0.00	12.0000
r_p12 NI missed quantity	3.3500	2.85	0.00	110.00
r_P12 SI demand	464.41	13.53	333.00	674.00
r_P12 SI missed opportunity dollar	102.91	82.36	0.00	2845.00
r_p12 SI missed orders	0.5000	0.37	0.00	14.0000
r_p12 SI missed quantity	3.3700	2.69	0.00	93.0000
r_P14 NI demand	1727.15	14.88	1554.00	1916.00
r_P14 NI missed opportunity dollar	182.62	102.91	0.00	2877.00
r_p14 NI missed orders	0.8300	0.52	0.00	18.0000
r_p14 NI missed quantity	2.6000	1.47	0.00	41.0000
r_P14 SI demand	879.82	11.82	765.00	1015.00
r_P14 SI missed opportunity dollar	54.7900	38.57	0.00	983.00
r_p14 SI missed orders	0.2800	0.21	0.00	7.0000
r_p14 SI missed quantity	0.7800	0.55	0.00	14.0000
r_P15 NI demand	25817.74	74.20	24938.00	26703.00
r_P15 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p15 NI missed orders	0.00	0.00	0.00	0.00
r_p15 NI missed quantity	0.00	0.00	0.00	0.00
r_P15 SI demand	11551.96	54.60	10955.00	12353.00
r_P15 SI missed opportunity dollar	2.6600	3.56	0.00	159.00
r_p15 SI missed orders	0.07000000	0.10	0.00	5.0000
r_p15 SI missed quantity	0.7000	0.94	0.00	42.0000

Missed opportunity cost and missed orders for LP based simulation

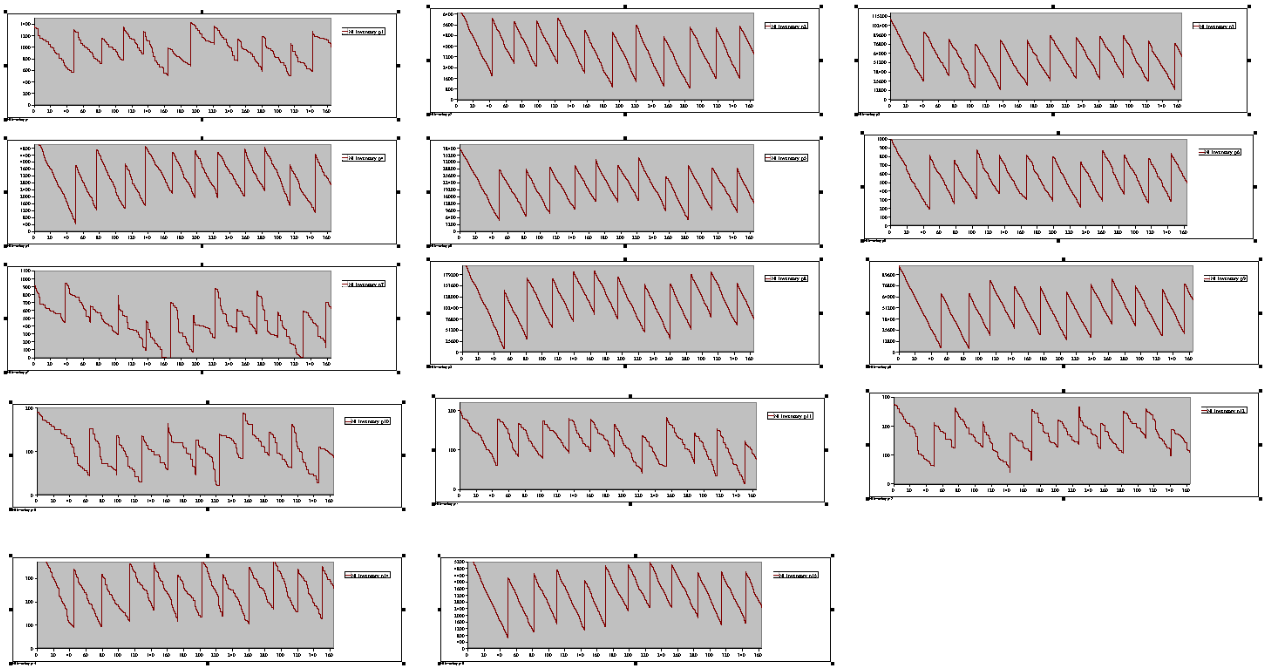
Appendix 22 Missed opportunity cost and missed orders for DWV3 optimised model-based simulation

User Specified

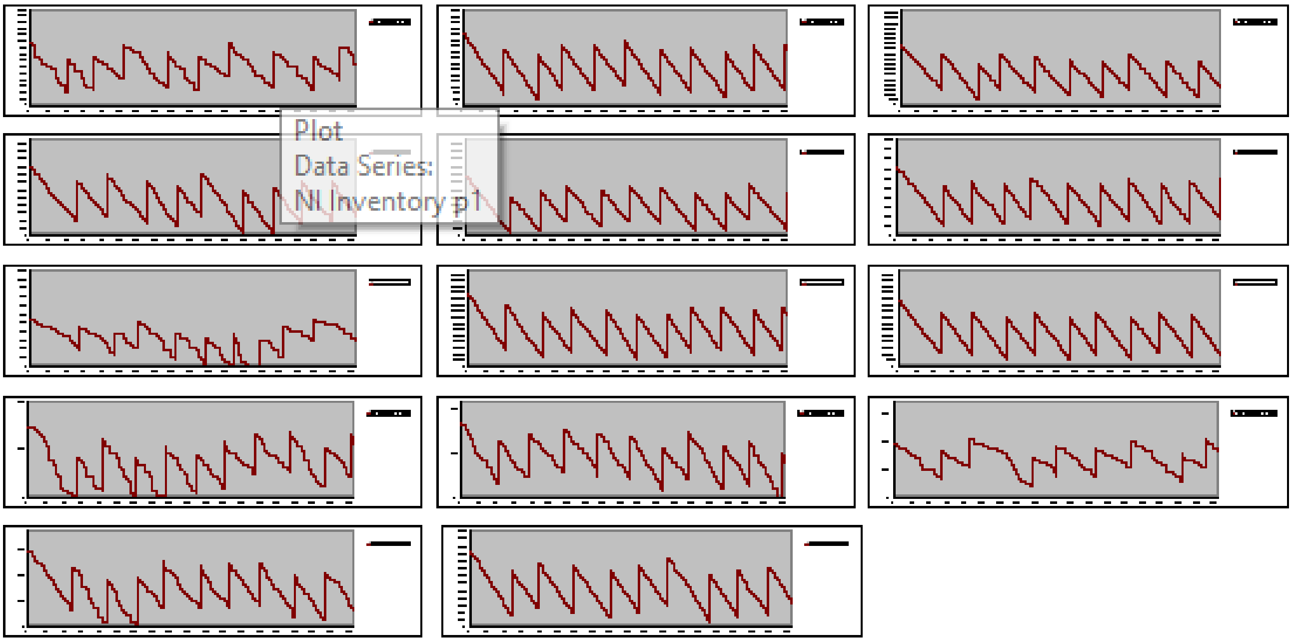
Count	Average	Half Width	Minimum Average	Maximum Average
r_P01 NI missed opportunity dollar	22.2000	21.68	0.00	894.00
r_p01 NI missed orders	0.4300	0.42	0.00	16.0000
r_p01 NI missed quantity	7.4000	7.23	0.00	298.00
r_P01 SI demand	0.00	0.00	0.00	0.00
r_P01 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p01 SI missed orders	0.00	0.00	0.00	0.00
r_p01 SI missed quantity	0.00	0.00	0.00	0.00
r_P02 NI demand	31520.21	85.45	30474.00	32698.00
r_P02 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p02 NI missed orders	0.00	0.00	0.00	0.00
r_p02 NI missed quantity	0.00	0.00	0.00	0.00
r_P02 SI demand	14075.54	55.40	13395.00	14805.00
r_P02 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p02 SI missed orders	0.00	0.00	0.00	0.00
r_p02 SI missed quantity	0.00	0.00	0.00	0.00
r_P03 NI demand	459044.05	1,878.09	432031.00	479277.00
r_P03 NI missed opportunity dollar	8.7600	17.61	0.00	876.00
r_p03 NI missed orders	0.1200	0.24	0.00	12.0000
r_p03 NI missed quantity	8.6200	17.33	0.00	862.00
r_P03 SI demand	247522.56	1,248.54	232800.00	262170.00
r_P03 SI missed opportunity dollar	221.35	138.17	0.00	3739.00
r_p03 SI missed orders	3.2300	2.15	0.00	61.0000
r_p03 SI missed quantity	217.96	135.97	0.00	3667.00
r_P04 NI demand	22545.51	124.34	20548.00	23793.00
r_P04 NI missed opportunity dollar	15.5900	12.66	0.00	357.00
r_p04 NI missed orders	0.6400	0.54	0.00	20.0000
r_p04 NI missed quantity	5.1700	4.20	0.00	118.00
r_P04 SI demand	12597.43	99.39	11449.00	14049.00
r_P04 SI missed opportunity dollar	11.2500	8.82	0.00	244.00
r_p04 SI missed orders	0.5100	0.46	0.00	16.0000
r_p04 SI missed quantity	3.7300	2.93	0.00	81.0000
r_P05 NI demand	159970.78	479.04	154186.00	165566.00
r_P05 NI missed opportunity dollar	18.9200	38.03	0.00	1892.00
r_p05 NI missed orders	0.8600	1.73	0.00	86.0000
r_p05 NI missed quantity	7.6600	15.40	0.00	766.00
r_P05 SI demand	85946.55	364.52	81300.00	91587.00
r_P05 SI missed opportunity dollar	0.9000	1.81	0.00	90.0000
r_p05 SI missed orders	0.01000000	0.02	0.00	1.0000
r_p05 SI missed quantity	0.3600	0.72	0.00	36.0000
r_P06 NI demand	6425.61	27.10	6110.00	6750.00
r_P06 NI missed opportunity dollar	160.95	254.85	0.00	12359.00
r_p06 NI missed orders	0.2500	0.39	0.00	19.0000
r_p06 NI missed quantity	0.5600	0.89	0.00	43.0000
r_P06 SI demand	0.00	0.00	0.00	0.00
r_P06 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p06 SI missed orders	0.00	0.00	0.00	0.00
r_p06 SI missed quantity	0.00	0.00	0.00	0.00
r_P07 NI demand	5660.56	100.06	4520.00	6739.00
r_P07 NI missed opportunity dollar	2187.38	619.49	0.00	14831.00
r_p07 NI missed orders	5.6800	1.84	0.00	49.0000
r_p07 NI missed quantity	131.92	37.36	0.00	894.00
r_P07 SI demand	0.00	0.00	0.00	0.00
r_P07 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p07 SI missed orders	0.00	0.00	0.00	0.00
r_p07 SI missed quantity	0.00	0.00	0.00	0.00
r_P08 NI demand	960014.95	2,698.85	918872.00	984282.00
r_P08 NI missed opportunity	24.3800	30.12	0.00	1124.00

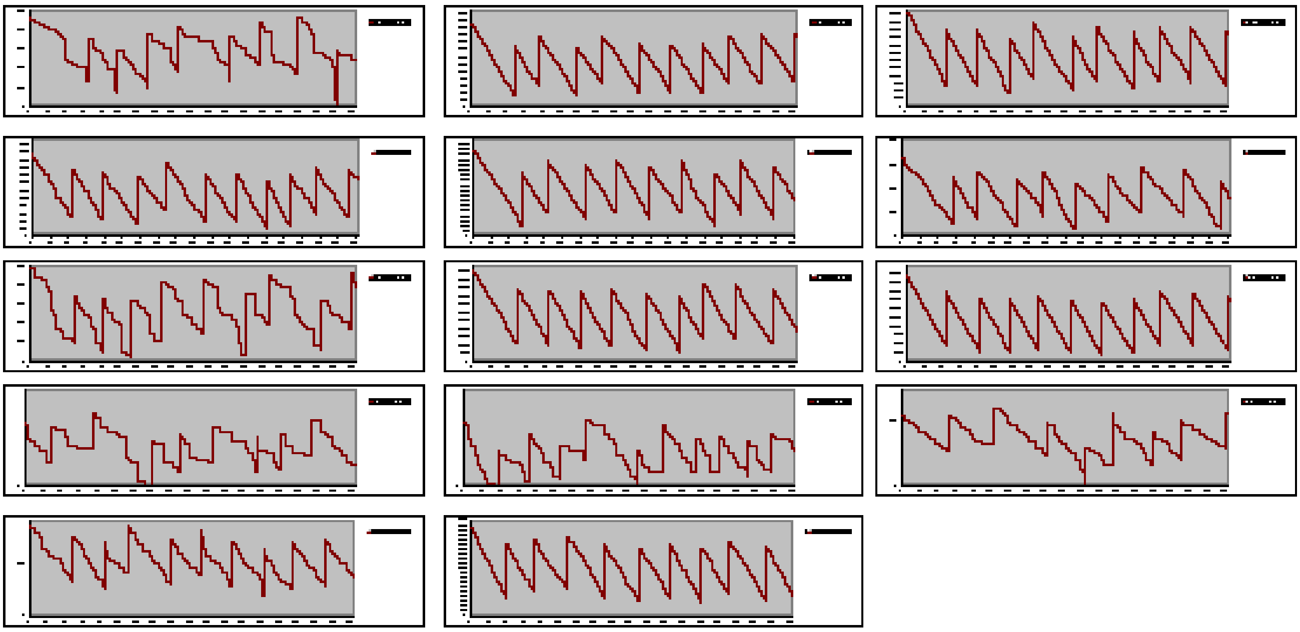
dollar				
r_p08 NI missed orders	0.9500	1.17	0.00	49.0000
r_p08 NI missed quantity	56.3900	69.64	0.00	2609.00
r_P08 SI demand	439296.54	1,887.13	416256.00	460374.00
r_P08 SI missed opportunity dollar	0.9300	1.87	0.00	93.0000
r_p08 SI missed orders	0.01000000	0.02	0.00	1.0000
r_p08 SI missed quantity	2.1300	4.28	0.00	213.00
r_P09 NI demand	449348.08	685.87	440122.00	457807.00
r_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p09 NI missed orders	0.00	0.00	0.00	0.00
r_p09 NI missed quantity	0.00	0.00	0.00	0.00
r_P09 SI demand	203898.48	418.98	199649.00	207902.00
r_P09 SI missed opportunity dollar	1.9000	3.82	0.00	190.00
r_p09 SI missed orders	0.07000000	0.14	0.00	7.0000
r_p09 SI missed quantity	0.4500	0.90	0.00	45.0000
r_P10 NI demand	1100.53	16.66	895.00	1290.00
r_P10 NI missed opportunity dollar	5171.51	1,766.11	0.00	43649.00
r_p10 NI missed orders	1.9600	0.66	0.00	17.0000
r_p10 NI missed quantity	9.3600	3.20	0.00	79.0000
r_P10 SI demand	0.00	0.00	0.00	0.00
r_P10 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p10 SI missed orders	0.00	0.00	0.00	0.00
r_p10 SI missed quantity	0.00	0.00	0.00	0.00
r_P11 NI demand	1233.73	10.03	1128.00	1376.00
r_P11 NI missed opportunity dollar	236.80	176.77	0.00	6163.00
r_p11 NI missed orders	0.4300	0.32	0.00	11.0000
r_p11 NI missed quantity	0.7300	0.54	0.00	19.0000
r_P11 SI demand	0.00	0.00	0.00	0.00
r_P11 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p11 SI missed orders	0.00	0.00	0.00	0.00
r_p11 SI missed quantity	0.00	0.00	0.00	0.00
r_P12 NI demand	1420.95	21.47	1160.00	1743.00
r_P12 NI missed opportunity dollar	67.1100	47.72	0.00	1282.00
r_p12 NI missed orders	0.4700	0.35	0.00	9.0000
r_p12 NI missed quantity	2.2000	1.56	0.00	42.0000
r_P12 SI demand	0.00	0.00	0.00	0.00
r_P12 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p12 SI missed orders	0.00	0.00	0.00	0.00
r_p12 SI missed quantity	0.00	0.00	0.00	0.00
r_P14 NI demand	1742.82	17.23	1568.00	1955.00
r_P14 NI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p14 NI missed orders	0.00	0.00	0.00	0.00
r_p14 NI missed quantity	0.00	0.00	0.00	0.00
r_P14 SI demand	878.80	11.78	716.00	1082.00
r_P14 SI missed opportunity dollar	0.00	0.00	0.00	0.00
r_p14 SI missed orders	0.00	0.00	0.00	0.00
r_p14 SI missed quantity	0.00	0.00	0.00	0.00
r_P15 NI demand	25803.68	77.42	24849.00	26880.00
r_P15 NI missed opportunity dollar	0.2300	0.46	0.00	23.0000
r_p15 NI missed orders	0.01000000	0.02	0.00	1.0000
r_p15 NI missed quantity	0.06000000	0.12	0.00	6.0000
r_P15 SI demand	11563.08	56.79	10899.00	12197.00
r_P15 SI missed opportunity dollar	4.4800	6.30	0.00	286.00
r_p15 SI missed orders	0.3600	0.58	0.00	28.0000
r_p15 SI missed quantity	1.2200	1.73	0.00	79.0000

Appendix 23 1DC model stock dynamics

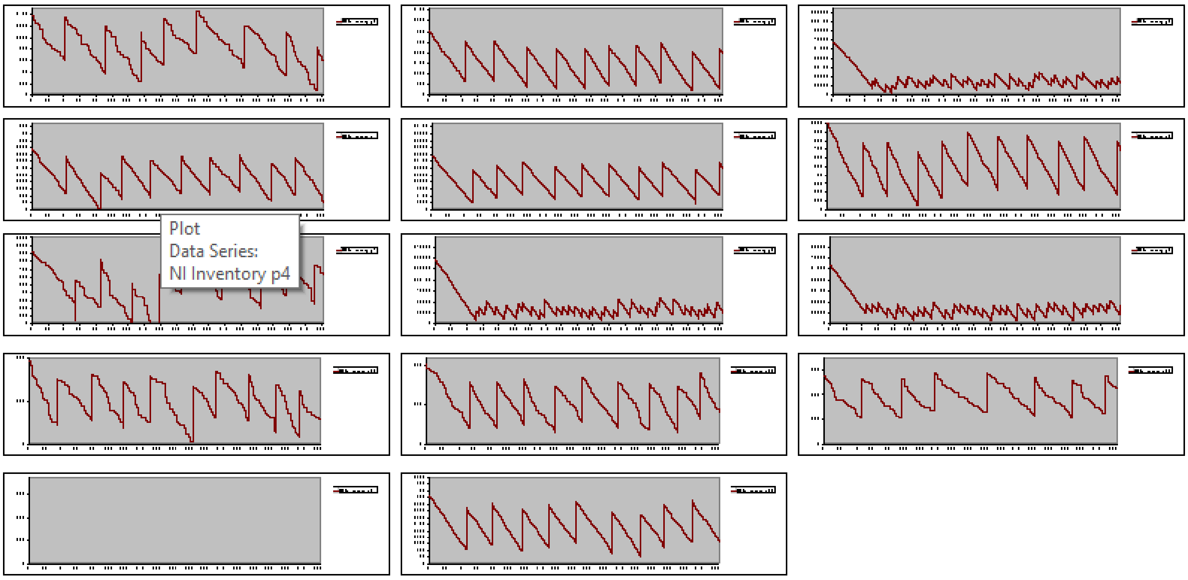


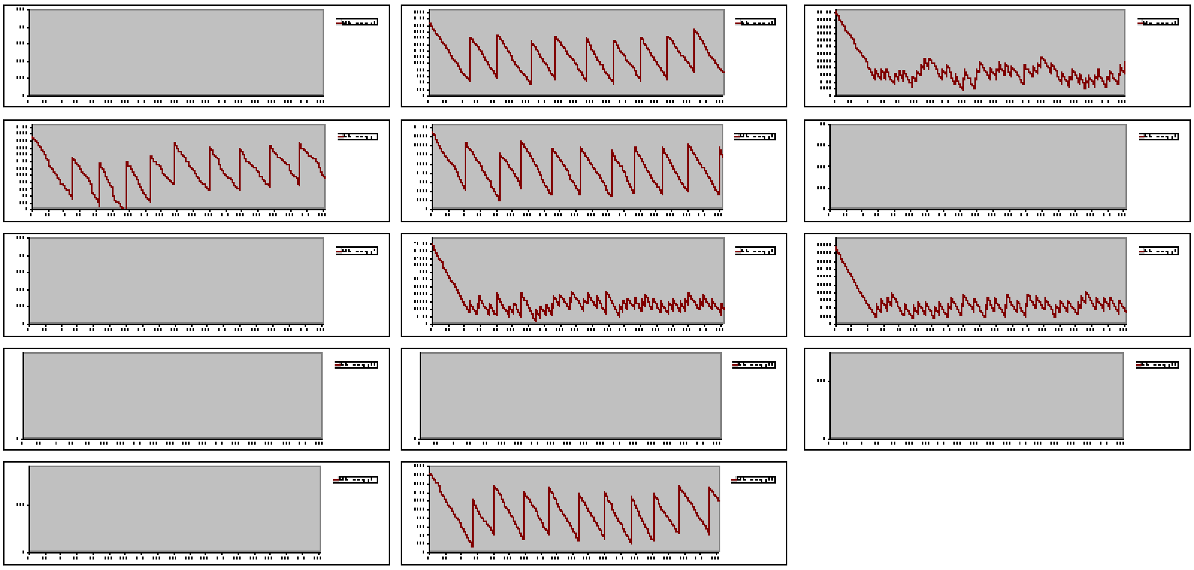
Appendix 24 Linear optimised model stock dynamics





Appendix 25 DWV3 optimised model stock dynamics





Appendix 26 1DC model throughput time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.6648	0.01	1.5330	1.7793	0.00	4.0006
e_product 2	1.7211	0.00	1.7010	1.7440	0.5005	4.0008
e_product 3	1.7670	0.00	1.7505	1.7841	0.5004	4.0009
e_product 4	1.7616	0.00	1.7268	1.8077	0.00	4.0008
e_product 5	1.7769	0.00	1.7567	1.7933	0.5004	4.0008
e_product 6	1.6423	0.00	1.6078	1.6797	0.00	4.0006
e_product 7	2.0885	0.01	1.9530	2.2325	0.00	4.0006
e_product 8	1.6671	0.00	1.6481	1.6843	0.5004	4.0008
e_product 9	1.6651	0.00	1.6530	1.6759	0.5004	4.0008
e_product 10	1.4187	0.01	1.2880	1.5998	0.00	4.0006
e_product 11	1.2520	0.01	1.1821	1.3398	0.00	4.0005
e_product 12	1.8071	0.01	1.6930	1.9055	0.00	4.0006
e_product 14	1.6949	0.01	1.6112	1.7825	0.00	4.0007
e_product 15	1.7066	0.00	1.6825	1.7402	0.5005	4.0008

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	0.1980	0.00	0.1816	0.2149	0.00	0.9833
e_product 2	0.1951	0.00	0.1909	0.1989	0.00	1.0010
e_product 3	0.1888	0.00	0.1856	0.1928	0.00	1.0002
e_product 4	0.1852	0.00	0.1794	0.1910	0.00	0.9968
e_product 5	0.1837	0.00	0.1797	0.1863	0.00	0.9969
e_product 6	0.1846	0.00	0.1788	0.1908	0.00	0.9933
e_product 7	0.2156	0.00	0.1833	0.2489	0.00	0.9880
e_product 8	0.1822	0.00	0.1795	0.1855	0.00	1.0000
e_product 9	0.1754	0.00	0.1737	0.1774	0.00	1.0007
e_product 10	0.1851	0.00	0.1614	0.2073	0.00	0.9860
e_product 11	0.1835	0.00	0.1748	0.1990	0.00	0.9950
e_product 12	0.1575	0.00	0.1395	0.1805	0.00	0.9878
e_product 14	0.1822	0.00	0.1703	0.1945	0.00	0.9902
e_product 15	0.1592	0.00	0.1562	0.1638	0.00	0.9973

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.8627	0.01	1.7177	1.9756	0.00	4.9595
e_product 2	1.9162	0.00	1.8943	1.9383	0.5006	4.9698
e_product 3	1.9558	0.00	1.9379	1.9740	0.5005	4.9767
e_product 4	1.9468	0.00	1.9127	1.9930	0.00	4.9769
e_product 5	1.9606	0.00	1.9416	1.9768	0.5006	4.9799
e_product 6	1.8269	0.00	1.7907	1.8638	0.00	4.9610
e_product 7	2.3041	0.01	2.1562	2.4423	0.00	4.9554
e_product 8	1.8493	0.00	1.8302	1.8699	0.5005	4.9816

e_product 9	1.8404	0.00	1.8286	1.8508	0.5005	4.9839
e_product 10	1.6037	0.01	1.4804	1.7707	0.00	4.9507
e_product 11	1.4355	0.01	1.3713	1.5204	0.00	4.9418
e_product 12	1.9647	0.01	1.8499	2.0626	0.00	4.9546
e_product 14	1.8771	0.01	1.8004	1.9589	0.00	4.9698
e_product 15	1.8659	0.00	1.8399	1.8998	0.5010	4.9729

Appendix 27 Linear optimised model throughput time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.0052	0.00	0.9818	1.0288	0.00	1.5008
e_product 10	0.9333	0.00	0.8657	0.9804	0.00	1.5007
e_product 11	0.8847	0.00	0.8628	0.9083	0.00	1.5008
e_product 12	1.0169	0.00	0.9785	1.0463	0.00	1.5006
e_product 14	0.9724	0.00	0.9539	1.0008	0.00	1.5008
e_product 15	1.0294	0.00	1.0241	1.0345	0.00	1.5008
e_product 2	0.9735	0.00	0.9680	0.9782	0.00	1.5008
e_product 3	0.9622	0.00	0.9578	0.9672	0.00	1.5008
e_product 4	0.9524	0.00	0.9422	0.9607	0.00	1.5007
e_product 5	0.9731	0.00	0.9682	0.9772	0.00	1.5008
e_product 6	0.9535	0.00	0.9427	0.9643	0.00	1.5008
e_product 7	1.0461	0.00	0.9881	1.0815	0.00	1.5007
e_product 8	0.9683	0.00	0.9638	0.9716	0.00	1.5008
e_product 9	0.9650	0.00	0.9628	0.9672	0.5004	1.5008

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	0.1918	0.00	0.1699	0.2038	0.00	0.9601
e_product 10	0.1806	0.00	0.1582	0.2226	0.00	0.9585
e_product 11	0.1770	0.00	0.1614	0.1920	0.00	0.9608
e_product 12	0.1478	0.00	0.1320	0.1607	0.00	0.9625
e_product 14	0.1764	0.00	0.1654	0.1930	0.00	0.9608
e_product 15	0.1525	0.00	0.1494	0.1561	0.00	0.9634
e_product 2	0.1892	0.00	0.1854	0.1921	0.00	0.9630
e_product 3	0.1818	0.00	0.1788	0.1853	0.00	0.9619
e_product 4	0.1789	0.00	0.1738	0.1839	0.00	0.9610
e_product 5	0.1774	0.00	0.1755	0.1794	0.00	0.9622
e_product 6	0.1787	0.00	0.1732	0.1856	0.00	0.9611
e_product 7	0.2101	0.00	0.1893	0.2375	0.00	0.9608
e_product 8	0.1750	0.00	0.1725	0.1779	0.00	0.9635
e_product 9	0.1684	0.00	0.1670	0.1701	0.00	0.9654

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.1970	0.00	1.1705	1.2244	0.00	2.4565
e_product 10	1.1139	0.01	1.0280	1.1738	0.00	2.4569
e_product 11	1.0618	0.00	1.0339	1.0925	0.00	2.4568
e_product 12	1.1647	0.00	1.1164	1.1979	0.00	2.4523
e_product 14	1.1487	0.00	1.1243	1.1765	0.00	2.4582
e_product 15	1.1819	0.00	1.1759	1.1888	0.00	2.4590
e_product 2	1.1627	0.00	1.1556	1.1699	0.00	2.4594
e_product 3	1.1441	0.00	1.1377	1.1496	0.00	2.4588

e_product 4	1.1313	0.00	1.1197	1.1406	0.00	2.4584
e_product 5	1.1504	0.00	1.1457	1.1542	0.00	2.4593
e_product 6	1.1323	0.00	1.1219	1.1457	0.00	2.4588
e_product 7	1.2562	0.00	1.1871	1.3042	0.00	2.4550
e_product 8	1.1433	0.00	1.1389	1.1485	0.00	2.4589
e_product 9	1.1334	0.00	1.1309	1.1361	0.5005	2.4618

Appendix 28 DWV3 optimised model throughput time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.6677	0.01	1.5923	1.7409	0.00	4.0006
e_product 10	1.4259	0.01	1.3039	1.5567	0.00	4.0006
e_product 11	1.2598	0.01	1.1981	1.3261	0.00	4.0005
e_product 12	1.8078	0.01	1.7086	1.9369	0.00	4.0006
e_product 14	30.9454	0.02	30.7323	31.1182	25.5068	36.4961
e_product 15	1.0294	0.00	1.0228	1.0345	0.00	1.5008
e_product 2	0.9735	0.00	0.9683	0.9792	0.5004	1.5008
e_product 3	0.9626	0.00	0.9569	0.9671	0.00	1.5008
e_product 4	0.9516	0.00	0.9396	0.9617	0.00	1.5008
e_product 5	0.9730	0.00	0.9671	0.9784	0.00	1.5008
e_product 6	1.6382	0.00	1.5886	1.6876	0.00	4.0008
e_product 7	2.0821	0.01	1.9363	2.2054	0.00	4.0007
e_product 8	0.9684	0.00	0.9643	0.9722	0.00	1.5008
e_product 9	0.9650	0.00	0.9627	0.9681	0.00	1.5008

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	0.1915	0.00	0.1736	0.2075	0.00	0.9614
e_product 10	0.1836	0.00	0.1613	0.2104	0.00	0.9600
e_product 11	0.1777	0.00	0.1671	0.1891	0.00	0.9611
e_product 12	0.1478	0.00	0.1265	0.1652	0.00	0.9604
e_product 14	3.2002	0.01	3.0854	3.3433	0.00	6.6661
e_product 15	0.1524	0.00	0.1497	0.1551	0.00	0.9631
e_product 2	0.1893	0.00	0.1859	0.1930	0.00	0.9630
e_product 3	0.1820	0.00	0.1795	0.1855	0.00	0.9631
e_product 4	0.1789	0.00	0.1736	0.1849	0.00	0.9613
e_product 5	0.1774	0.00	0.1745	0.1803	0.00	0.9638
e_product 6	0.1794	0.00	0.1733	0.1854	0.00	0.9622
e_product 7	0.2109	0.00	0.1898	0.2287	0.00	0.9628
e_product 8	0.1749	0.00	0.1713	0.1776	0.00	0.9657
e_product 9	0.1684	0.00	0.1672	0.1698	0.00	0.9661

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
e_product 1	1.8591	0.01	1.7772	1.9300	0.00	4.9564
e_product 10	1.6095	0.01	1.4895	1.7502	0.00	4.9368
e_product 11	1.4375	0.01	1.3796	1.4999	0.00	4.9477
e_product 12	1.9556	0.01	1.8487	2.0796	0.00	4.9471
e_product 14	34.1456	0.02	33.8509	34.3503	25.5968	42.8123
e_product 15	1.1818	0.00	1.1747	1.1885	0.00	2.4587
e_product 2	1.1628	0.00	1.1576	1.1689	0.5006	2.4587
e_product 3	1.1446	0.00	1.1388	1.1497	0.00	2.4587

e_product 4	1.1305	0.00	1.1184	1.1418	0.00	2.4591
e_product 5	1.1503	0.00	1.1442	1.1568	0.00	2.4578
e_product 6	1.8176	0.00	1.7686	1.8648	0.00	4.9559
e_product 7	2.2930	0.01	2.1353	2.4173	0.00	4.9563
e_product 8	1.1433	0.00	1.1376	1.1485	0.00	2.4594
e_product 9	1.1335	0.00	1.1315	1.1371	0.00	2.4591

Appendix 29 1DC model cost statistics

Output	Average	Half Width	Minimum Average	Maximum Average
s_P01 demand	7271.02	100.28	6016.00	8501.00
s_p01 NI and SI capital cost	1117.16	9.23	1014.17	1264.95
s_p01 NI and SI damage risk cost	670.28	5.54	608.49	758.95
s_p01 NI and SI obsolescence cost	224.27	1.85	203.60	253.94
s_P01 NI delivery cost	1141.59	19.28	902.97	1377.96
s_P01 NI inventory	783.58	57.56	84.0000	1436.00
s_P01 NI inventory expenses	3023.97	23.98	2716.66	3280.71
s_P01 NI missed opportunity dollar	46.0500	27.85	0.00	897.00
s_P01 NI storage cost	1012.25	11.93	859.13	1141.90
s_P02 demand	45642.61	104.74	44310.00	47072.00
s_p02 NI and SI capital cost	9301.95	63.38	8611.60	9999.35
s_p02 NI and SI damage risk cost	5581.04	38.03	5166.84	5999.47
s_p02 NI and SI obsolescence cost	1867.36	12.72	1728.78	2007.37
s_P02 NI delivery cost	55414.40	148.59	53602.97	57793.22
s_P02 NI inventory	3755.13	379.16	296.00	6016.00
s_P02 NI inventory expenses	63695.90	174.16	62014.59	66021.60
s_P02 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P02 NI storage cost	46945.54	99.66	45910.52	48204.28
s_P03 demand	706289.18	2,305.01	683114.00	735498.00
s_p03 NI and SI capital cost	28253.07	177.39	26244.44	30070.78
s_p03 NI and SI damage risk cost	16951.45	106.43	15746.30	18042.05
s_p03 NI and SI obsolescence cost	5671.80	35.61	5268.56	6036.70
s_P03 NI delivery cost	119424.90	445.61	113560.79	124176.76
s_P03 NI inventory	59084.95	5,606.69	7409.00	94441.00
s_P03 NI inventory expenses	146673.23	515.74	140062.06	152081.50
s_P03 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P03 NI storage cost	95796.91	295.32	92576.19	99401.86
s_P04 demand	35102.67	164.61	32959.00	36875.00
s_p04 NI and SI capital cost	4227.87	30.68	3903.16	4658.75
s_p04 NI and SI damage risk cost	2536.66	18.41	2341.84	2795.18
s_p04 NI and SI obsolescence cost	848.74	6.16	783.56	935.24
s_P04 NI delivery cost	221.31	1.23	209.20	236.35
s_P04 NI inventory	2732.43	246.57	644.00	4892.00
s_P04 NI inventory expenses	7793.59	55.37	7213.18	8577.98
s_P04 NI missed opportunity dollar	5.8700	7.06	0.00	272.00
s_P04 NI storage cost	180.32	0.75	169.66	188.81
s_P05 demand	245864.05	607.17	238616.00	254452.00
s_p05 NI and SI capital cost	23371.72	155.89	21589.91	25396.48
s_p05 NI and SI damage risk cost	14022.71	93.53	12953.65	15237.53
s_p05 NI and SI obsolescence cost	4691.87	31.30	4334.17	5098.34
s_P05 NI delivery cost	90865.71	274.81	87606.24	94250.05
s_P05 NI inventory	21493.72	1,793.60	2474.00	31443.00
s_P05 NI inventory expenses	114504.85	384.52	109752.54	118970.08
s_P05 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P05 NI storage cost	72418.56	171.73	70311.79	74801.83
s_P06 demand	6401.24	20.46	6177.00	6669.00
s_p06 NI and SI capital cost	72299.84	466.14	66099.40	79306.02
s_p06 NI and SI damage risk cost	43378.90	279.68	39658.72	47582.51
s_p06 NI and SI obsolescence cost	14514.17	93.58	13269.43	15920.66
s_P06 NI delivery cost	180308.42	735.23	171460.94	189494.83
s_P06 NI inventory	460.73	49.37	104.00	873.00
s_P06 NI inventory expenses	287197.74	1,040.52	276199.35	301353.16
s_P06 NI missed opportunity dollar	20.1000	40.40	0.00	2010.00
s_P06 NI storage cost	157004.83	450.32	152022.80	163428.01

s_P07 demand	5653.35	99.11	4656.00	7127.00
s_p07 NI and SI capital cost	4248.72	39.31	3776.76	4716.40
s_p07 NI and SI damage risk cost	2549.18	23.58	2266.00	2829.77
s_p07 NI and SI obsolescence cost	852.93	7.89	758.18	946.82
s_P07 NI delivery cost	100737.71	1,806.72	80658.28	132228.51
s_P07 NI inventory	441.02	39.42	14.0000	929.00
s_P07 NI inventory expenses	77099.03	888.17	66053.25	90567.45
s_P07 NI missed opportunity dollar	2385.85	578.56	0.00	14502.00
s_P07 NI storage cost	69448.20	868.30	59200.16	82776.61
s_P08 demand	1397756.42	3,063.73	1359652.00	1435693.00
s_p08 NI and SI capital cost	23297.49	158.82	21367.75	24960.92
s_p08 NI and SI damage risk cost	13978.17	95.29	12820.36	14976.21
s_p08 NI and SI obsolescence cost	4676.96	31.88	4289.57	5010.90
s_P08 NI delivery cost	193314.59	578.96	186327.51	202064.88
s_P08 NI inventory	118990.00	10,924.42	18464.00	185152.00
s_P08 NI inventory expenses	205063.93	520.88	199176.48	210308.26
s_P08 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P08 NI storage cost	163111.31	339.72	158761.50	167293.22
s_P09 demand	653317.07	827.88	644239.00	662698.00
s_p09 NI and SI capital cost	102753.87	729.55	93722.92	112595.09
s_p09 NI and SI damage risk cost	61650.89	437.72	56232.45	67555.49
s_p09 NI and SI obsolescence cost	20627.81	146.46	18814.85	22603.43
s_P09 NI delivery cost	388331.29	650.78	381453.29	396448.91
s_P09 NI inventory	57644.03	4,900.89	5694.00	81363.00
s_P09 NI inventory expenses	512394.03	1,604.40	492639.56	534555.65
s_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P09 NI storage cost	327361.47	441.88	322510.29	331801.64
s_P10 demand	1100.65	16.22	890.00	1327.00
s_p10 NI and SI capital cost	28716.35	254.23	25085.42	31452.33
s_p10 NI and SI damage risk cost	17229.41	152.53	15050.90	18870.96
s_p10 NI and SI obsolescence cost	5764.80	51.04	5035.89	6314.05
s_P10 NI delivery cost	56102.81	1,039.23	43929.25	67525.46
s_P10 NI inventory	98.7600	7.30	4.0000	176.00
s_P10 NI inventory expenses	114763.26	1,019.15	100106.24	126182.82
s_P10 NI missed opportunity dollar	4668.72	1,442.40	0.00	27071.00
s_P10 NI storage cost	63052.70	770.58	52507.64	71556.12
s_P11 demand	1243.75	10.56	1088.00	1371.00
s_p11 NI and SI capital cost	17352.86	123.58	15811.21	18991.73
s_p11 NI and SI damage risk cost	10411.47	74.15	9486.51	11394.77
s_p11 NI and SI obsolescence cost	3483.58	24.81	3174.10	3812.58
s_P11 NI delivery cost	147972.15	1,393.67	131976.74	166212.52
s_P11 NI inventory	107.93	7.75	22.0000	189.00
s_P11 NI inventory expenses	199737.70	1,345.87	179393.52	217265.08
s_P11 NI missed opportunity dollar	606.55	332.77	0.00	10053.00
s_P11 NI storage cost	168489.79	1,260.29	149474.38	184503.18
s_P12 demand	1416.51	22.07	1135.00	1789.00
s_p12 NI and SI capital cost	2254.89	21.03	1983.07	2507.21
s_p12 NI and SI damage risk cost	1352.90	12.62	1189.81	1504.29
s_p12 NI and SI obsolescence cost	452.67	4.22	398.10	503.32
s_P12 NI delivery cost	1839.99	32.71	1528.66	2248.61
s_P12 NI inventory	154.07	11.43	36.0000	281.00
s_P12 NI inventory expenses	5574.94	53.84	4818.18	6246.84
s_P12 NI missed opportunity dollar	83.0700	67.82	0.00	2295.00
s_P12 NI storage cost	1514.48	20.65	1235.11	1795.85
s_P14 demand	2605.54	20.88	2401.00	2927.00
s_p14 NI and SI capital cost	8167.20	53.80	7528.03	8905.80
s_p14 NI and SI damage risk cost	4900.21	32.28	4516.72	5343.35
s_p14 NI and SI obsolescence cost	6528.44	43.00	6017.52	7118.84

s_P14 NI delivery cost	130417.43	1,216.91	116562.48	149080.85
s_P14 NI inventory	224.31	16.54	0.00	366.00
s_P14 NI inventory expenses	127797.57	793.77	120162.88	139543.80
s_P14 NI missed opportunity dollar	43.5000	46.01	0.00	1615.00
s_P14 NI storage cost	108201.72	757.09	101257.87	119813.38
s_P15 demand	37415.97	102.39	36219.00	39019.00
s_p15 NI and SI capital cost	5641.32	33.74	5233.12	5998.51
s_p15 NI and SI damage risk cost	3384.72	20.25	3139.80	3599.02
s_p15 NI and SI obsolescence cost	1132.49	6.77	1050.55	1204.20
s_P15 NI delivery cost	12893.72	44.04	12457.20	13395.51
s_P15 NI inventory	2566.71	309.31	532.00	5200.00
s_P15 NI inventory expenses	20635.34	68.78	19828.76	21413.12
s_P15 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P15 NI storage cost	10476.81	24.93	10196.73	10806.53

Appendix 30 Linear optimised model cost statistics

Output	Average	Half Width	Minimum Average	Maximum Average
s_P01 delivery cost	682.87	8.93	520.94	788.86
s_P01 demand	7183.58	92.50	5566.00	8200.00
s_P01 inventory	856.79	48.37	334.00	1306.00
s_P01 inventory expenses	3143.79	24.29	2773.01	3469.32
s_P01 missed opportunity dollar	145.11	48.98	0.00	1146.00
s_p01 NI and SI capital cost	1203.36	9.08	1100.85	1350.59
s_p01 NI and SI damage risk cost	722.00	5.45	660.49	810.34
s_p01 NI and SI obsolescence cost	241.57	1.82	220.99	271.13
s_P01 NI and SI storage cost	976.85	10.73	782.18	1062.08
s_P01 NI delivery cost	457.28	7.66	356.45	533.46
s_P01 NI inventory	566.26	40.56	101.00	936.00
s_P01 NI inventory expenses	2141.07	19.52	1877.86	2392.93
s_P01 NI missed opportunity dollar	67.5600	33.58	0.00	765.00
s_P01 NI storage cost	706.04	9.81	572.35	800.21
s_P01 SI delivery cost	225.59	5.61	161.08	295.39
s_P01 SI inventory	290.53	23.03	10.0000	517.00
s_P01 SI inventory expenses	1002.72	15.34	812.40	1212.19
s_P01 SI missed opportunity dollar	77.5500	28.51	0.00	606.00
s_P01 SI storage cost	270.80	5.67	202.68	334.65
s_P02 delivery cost	32493.02	74.07	31643.02	33463.38
s_P02 demand	45628.78	92.83	44544.00	46833.00
s_P02 inventory	3951.14	246.23	725.00	5754.00
s_P02 inventory expenses	63061.30	146.01	61169.24	64836.07
s_P02 missed opportunity dollar	1.6000	3.22	0.00	160.00
s_p02 NI and SI capital cost	9485.97	46.07	8918.31	9986.00
s_p02 NI and SI damage risk cost	5691.45	27.64	5350.86	5991.46
s_p02 NI and SI obsolescence cost	1904.31	9.25	1790.35	2004.69
s_P02 NI and SI storage cost	45979.57	91.15	44752.00	47190.38
s_P02 NI delivery cost	21980.13	62.02	21330.03	22862.54
s_P02 NI inventory	2815.88	219.23	230.00	4142.00
s_P02 NI inventory expenses	43812.29	133.56	42101.30	45590.17
s_P02 NI missed opportunity dollar	1.6000	3.22	0.00	160.00
s_P02 NI storage cost	32395.51	76.15	31458.75	33420.68
s_P02 SI delivery cost	10512.89	43.38	10126.20	11340.39
s_P02 SI inventory	1135.26	110.54	231.00	1952.00
s_P02 SI inventory expenses	19249.01	63.78	18707.96	20141.93
s_P02 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P02 SI storage cost	13584.06	49.03	13097.77	14434.12
s_P03 delivery cost	67603.84	217.01	64961.84	70540.88
s_P03 demand	703974.09	2,221.35	680122.00	736170.00
s_P03 inventory	54435.58	3,666.20	14163.00	90893.00
s_P03 inventory expenses	146015.92	409.20	141318.16	150908.63
s_P03 missed opportunity dollar	73.2400	90.82	0.00	4328.00
s_p03 NI and SI capital cost	29039.48	151.45	27175.01	30949.33
s_p03 NI and SI damage risk cost	17423.29	90.87	16304.63	18569.17
s_p03 NI and SI obsolescence cost	5829.67	30.40	5455.38	6213.07
s_P03 NI and SI storage cost	93723.48	264.95	91068.04	97781.02
s_P03 NI delivery cost	42502.17	159.47	39866.46	44176.24
s_P03 NI inventory	33290.05	3,492.51	7935.00	62325.00
s_P03 NI inventory expenses	96084.88	337.84	92148.51	99919.06
s_P03 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P03 NI storage cost	62372.52	200.18	59538.05	64856.14
s_P03 SI delivery cost	25101.66	154.94	23430.61	26882.36
s_P03 SI inventory	21145.53	1,448.76	0.00	35804.00
s_P03 SI inventory expenses	49931.04	210.07	47008.94	52241.25
s_P03 SI missed opportunity dollar	73.2400	90.82	0.00	4328.00
s_P03 SI storage cost	31350.96	167.86	29255.95	33384.38
s_P04 delivery cost	121.14	0.60	115.05	127.72
s_P04 demand	35079.04	169.28	33074.00	36807.00
s_P04 inventory	2803.32	177.79	1126.00	4992.00

s_P04 inventory expenses	8199.75	40.47	7784.99	8816.57
s_P04 missed opportunity dollar	37.5900	28.67	0.00	912.00
s_p04 NI and SI capital cost	4455.05	22.33	4225.49	4795.26
s_p04 NI and SI damage risk cost	2672.97	13.40	2535.24	2877.09
s_p04 NI and SI obsolescence cost	894.35	4.48	848.27	962.65
s_P04 NI and SI storage cost	177.38	0.78	168.60	185.18
s_P04 NI delivery cost	75.1322	0.46	69.9753	80.3834
s_P04 NI inventory	1755.90	156.47	372.00	3235.00
s_P04 NI inventory expenses	5023.16	34.07	4719.22	5521.68
s_P04 NI missed opportunity dollar	36.4500	28.64	0.00	912.00
s_P04 NI storage cost	115.57	0.62	108.59	122.76
s_P04 SI delivery cost	46.0074	0.33	41.4184	49.9098
s_P04 SI inventory	1047.42	87.25	182.00	2061.00
s_P04 SI inventory expenses	3176.59	20.49	2934.46	3463.89
s_P04 SI missed opportunity dollar	1.1400	2.23	0.00	111.00
s_P04 SI storage cost	61.8154	0.41	56.5306	67.1061
s_P05 delivery cost	51631.76	136.32	50012.36	52984.88
s_P05 demand	245627.87	598.00	238399.00	252435.00
s_P05 inventory	20344.74	1,396.93	4637.00	31959.00
s_P05 inventory expenses	113889.74	286.11	110178.27	117969.49
s_P05 missed opportunity dollar	12.1400	16.30	0.00	742.00
s_p05 NI and SI capital cost	23795.46	111.21	22509.56	25027.29
s_p05 NI and SI damage risk cost	14276.94	66.73	13505.43	15016.03
s_p05 NI and SI obsolescence cost	4776.93	22.33	4518.79	5024.22
s_P05 NI and SI storage cost	71040.41	158.83	69029.21	73023.10
s_P05 NI delivery cost	32325.03	119.05	30838.96	33933.48
s_P05 NI inventory	13280.27	1,175.78	2485.00	21868.00
s_P05 NI inventory expenses	74727.23	239.68	71937.74	78229.91
s_P05 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P05 NI storage cost	47073.67	144.51	45371.34	49224.24
s_P05 SI delivery cost	19306.73	76.31	18515.10	20245.74
s_P05 SI inventory	7064.47	640.15	937.00	11729.00
s_P05 SI inventory expenses	39162.50	134.15	37587.23	40962.55
s_P05 SI missed opportunity dollar	12.1400	16.30	0.00	742.00
s_P05 SI storage cost	23966.74	83.67	23063.74	24940.33
s_P06 delivery cost	107755.83	470.06	102054.22	112983.45
s_P06 demand	6382.15	25.99	6127.00	6677.00
s_P06 inventory	504.65	34.37	147.00	928.00
s_P06 inventory expenses	289555.62	998.20	277426.35	301369.11
s_P06 missed opportunity dollar	347.66	263.09	0.00	7469.00
s_p06 NI and SI capital cost	75398.90	393.45	69981.11	79669.61
s_p06 NI and SI damage risk cost	45238.29	236.06	41987.69	47800.66
s_p06 NI and SI obsolescence cost	15136.31	78.98	14048.69	15993.65
s_P06 NI and SI storage cost	153782.13	568.93	148466.57	160277.12
s_P06 NI delivery cost	70396.86	383.50	65549.14	74453.39
s_P06 NI inventory	332.52	31.30	61.0000	652.00
s_P06 NI inventory expenses	202009.99	905.70	192272.49	213258.31
s_P06 NI missed opportunity dollar	117.79	161.69	0.00	7469.00
s_P06 NI storage cost	110007.33	515.35	104475.80	115781.87
s_P06 SI delivery cost	37358.97	296.43	33625.81	40260.99
s_P06 SI inventory	172.13	11.86	58.0000	316.00
s_P06 SI inventory expenses	87545.63	450.51	81467.44	92100.18
s_P06 SI missed opportunity dollar	229.87	212.80	0.00	6896.00
s_P06 SI storage cost	43774.79	318.16	39669.39	47460.29
s_P07 delivery cost	54742.96	794.08	45195.86	65623.04
s_P07 demand	5675.18	95.92	4596.00	7381.00
s_P07 inventory	563.97	34.54	0.00	977.00
s_P07 inventory expenses	80560.36	983.02	68731.61	95660.55
s_P07 missed opportunity dollar	3445.25	507.80	0.00	10971.00
s_p07 NI and SI capital cost	5208.02	46.83	4637.06	5734.34
s_p07 NI and SI damage risk cost	3124.74	28.10	2782.17	3440.53
s_p07 NI and SI obsolescence cost	1045.51	9.40	930.89	1151.17
s_P07 NI and SI storage cost	71182.10	923.10	59852.31	85584.48
s_P07 NI delivery cost	25668.85	484.88	20486.59	31591.63

s_P07 NI inventory	274.84	27.32	0.00	547.00
s_P07 NI inventory expenses	44375.91	680.03	36510.45	52780.80
s_P07 NI missed opportunity dollar	2391.95	454.33	0.00	10622.00
s_P07 NI storage cost	39258.74	640.69	32005.52	47204.95
s_P07 SI delivery cost	29074.11	601.43	22987.77	37703.21
s_P07 SI inventory	289.13	20.30	0.00	539.00
s_P07 SI inventory expenses	36184.45	627.15	29419.89	44048.31
s_P07 SI missed opportunity dollar	1053.30	282.00	0.00	5442.00
s_P07 SI storage cost	31923.36	585.77	25745.29	39470.99
s_P08 delivery cost	115834.17	318.61	111616.57	119836.47
s_P08 demand	1400457.50	3,535.19	1355291.00	1440607.00
s_P08 inventory	114576.21	6,785.65	25791.00	169547.00
s_P08 inventory expenses	203154.57	472.28	196940.68	208801.74
s_P08 missed opportunity dollar	17.8500	22.56	0.00	910.00
s_p08 NI and SI capital cost	23768.12	120.81	22365.14	25010.41
s_p08 NI and SI damage risk cost	14260.54	72.48	13418.78	15005.90
s_p08 NI and SI obsolescence cost	4771.44	24.25	4489.80	5020.83
s_P08 NI and SI storage cost	160354.46	370.76	155401.58	164264.06
s_P08 NI delivery cost	73757.34	205.45	71430.68	75600.08
s_P08 NI inventory	85999.50	5,730.56	5525.00	118203.00
s_P08 NI inventory expenses	141176.56	380.39	136642.79	145170.60
s_P08 NI missed opportunity dollar	9.1000	18.29	0.00	910.00
s_P08 NI storage cost	112158.61	272.41	108708.08	114933.43
s_P08 SI delivery cost	42076.83	213.00	38567.89	44714.43
s_P08 SI inventory	28576.71	2,844.14	7308.00	60715.00
s_P08 SI inventory expenses	61978.01	252.27	57150.97	65192.76
s_P08 SI missed opportunity dollar	8.7500	13.44	0.00	651.00
s_P08 SI storage cost	48195.86	215.48	44449.36	50869.48
s_P09 delivery cost	231999.04	314.40	228079.40	236415.59
s_P09 demand	652338.91	855.04	642956.00	662817.00
s_P09 inventory	56299.43	3,974.83	13106.00	78139.00
s_P09 inventory expenses	507769.15	1,366.70	491646.45	520987.71
s_P09 missed opportunity dollar	0.00	0.00	0.00	0.00
s_p09 NI and SI capital cost	103931.36	622.80	95122.48	109416.07
s_p09 NI and SI damage risk cost	62357.37	373.67	57072.17	65648.12
s_p09 NI and SI obsolescence cost	20864.19	125.03	19095.81	21965.24
s_P09 NI and SI storage cost	320616.23	425.10	316346.10	326492.47
s_P09 NI delivery cost	150188.43	240.10	146919.86	153083.82
s_P09 NI inventory	38402.16	3,604.81	6612.00	56803.00
s_P09 NI inventory expenses	353083.85	1,209.14	337644.63	365726.44
s_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P09 NI storage cost	225027.68	372.13	221120.30	229655.71
s_P09 SI delivery cost	81810.61	212.25	79304.41	84762.63
s_P09 SI inventory	17897.27	1,328.71	2812.00	26258.00
s_P09 SI inventory expenses	154685.30	454.56	150365.89	161785.20
s_P09 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P09 SI storage cost	95588.56	223.96	93086.17	98659.16
s_P10 delivery cost	36700.75	561.35	31706.00	44364.51
s_P10 demand	1107.88	19.16	948.00	1350.00
s_P10 inventory	113.28	6.82	44.0000	207.00
s_P10 inventory expenses	115302.83	1,081.80	102647.89	131121.27
s_P10 missed opportunity dollar	17188.76	3,579.74	0.00	76248.00
s_p10 NI and SI capital cost	30054.15	265.26	26767.75	34298.15
s_p10 NI and SI damage risk cost	18032.07	159.16	16060.28	20578.42
s_p10 NI and SI obsolescence cost	6033.36	53.25	5373.62	6885.34
s_P10 NI and SI storage cost	61183.25	772.20	54446.24	71472.60
s_P10 NI delivery cost	29711.61	509.57	24830.91	35964.62
s_P10 NI inventory	75.4000	6.13	1.0000	144.00
s_P10 NI inventory expenses	91026.91	946.96	80353.64	102367.46
s_P10 NI missed opportunity dollar	13652.47	3,270.45	0.00	76248.00
s_P10 NI storage cost	50229.03	734.69	42404.55	60441.34
s_P10 SI delivery cost	6989.14	242.64	4360.71	9740.28
s_P10 SI inventory	37.8800	2.57	6.0000	63.0000
s_P10 SI inventory expenses	24275.92	642.19	14935.05	31587.17
s_P10 SI missed opportunity	3536.29	1,527.98	0.00	46966.00

dollar				
s_P10 SI storage cost	10954.21	339.37	6495.54	14727.70
s_P11 delivery cost	112910.49	1,002.27	102915.69	125707.64
s_P11 demand	1245.98	11.10	1134.00	1392.00
s_P11 inventory	101.96	7.35	27.0000	167.00
s_P11 inventory expenses	197306.22	1,319.42	178904.04	211840.27
s_P11 missed opportunity dollar	1761.36	502.23	0.00	12004.00
s_p11 NI and SI capital cost	17706.28	130.95	16061.57	18918.61
s_p11 NI and SI damage risk cost	10623.52	78.57	9636.72	11350.90
s_p11 NI and SI obsolescence cost	3554.53	26.29	3224.36	3797.91
s_P11 NI and SI storage cost	165421.88	1,258.97	149981.40	180598.98
s_P11 NI delivery cost	93646.51	890.47	85010.54	107349.88
s_P11 NI inventory	83.5000	7.36	11.0000	150.00
s_P11 NI inventory expenses	169930.82	1,151.92	153754.51	182641.99
s_P11 NI missed opportunity dollar	791.47	417.31	0.00	11353.00
s_P11 NI storage cost	143654.43	1,109.55	130175.82	157007.28
s_P11 SI delivery cost	19263.98	380.05	13494.35	24391.98
s_P11 SI inventory	18.4600	1.56	0.00	35.0000
s_P11 SI inventory expenses	27375.40	433.12	20064.37	32171.09
s_P11 SI missed opportunity dollar	969.89	285.42	0.00	7786.00
s_P11 SI storage cost	21767.45	397.57	15277.71	26293.45
s_P12 delivery cost	1100.99	19.48	867.28	1317.75
s_P12 demand	1410.81	24.00	1153.00	1732.00
s_P12 inventory	195.06	8.99	71.0000	300.00
s_P12 inventory expenses	6330.87	63.20	5525.68	6999.63
s_P12 missed opportunity dollar	205.18	125.82	0.00	3662.00
s_p12 NI and SI capital cost	2681.26	25.22	2373.29	2937.93
s_p12 NI and SI damage risk cost	1608.72	15.13	1423.94	1762.72
s_p12 NI and SI obsolescence cost	538.26	5.06	476.44	589.79
s_P12 NI and SI storage cost	1502.63	21.94	1248.90	1770.88
s_P12 NI delivery cost	724.70	14.98	557.76	907.64
s_P12 NI inventory	122.28	7.52	20.0000	203.00
s_P12 NI inventory expenses	4136.13	46.23	3606.69	4632.56
s_P12 NI missed opportunity dollar	102.27	87.01	0.00	3366.00
s_P12 NI storage cost	1033.70	16.83	849.50	1235.34
s_P12 SI delivery cost	376.29	11.11	267.33	530.93
s_P12 SI inventory	72.7800	4.87	0.00	125.00
s_P12 SI inventory expenses	2194.74	38.76	1784.59	2617.17
s_P12 SI missed opportunity dollar	102.91	82.36	0.00	2845.00
s_P12 SI storage cost	468.93	11.83	344.75	628.28
s_P14 delivery cost	77339.78	622.38	69749.08	84112.97
s_P14 demand	2606.97	19.32	2378.00	2780.00
s_P14 inventory	242.30	12.12	78.0000	380.00
s_P14 inventory expenses	127845.48	708.08	118643.64	134392.53
s_P14 missed opportunity dollar	237.41	107.17	0.00	2877.00
s_p14 NI and SI capital cost	8874.29	51.29	8198.10	9550.31
s_p14 NI and SI damage risk cost	5324.45	30.77	4918.75	5730.05
s_p14 NI and SI obsolescence cost	7093.66	41.00	6553.14	7634.03
s_P14 NI and SI storage cost	106553.08	676.54	98274.95	112626.15
s_P14 NI delivery cost	44543.51	401.33	40365.86	49206.63
s_P14 NI inventory	151.75	10.57	29.0000	264.00
s_P14 NI inventory expenses	84955.81	522.01	79693.32	91234.91
s_P14 NI missed opportunity dollar	182.62	102.91	0.00	2877.00
s_P14 NI storage cost	71785.57	507.70	66238.17	77398.63
s_P14 SI delivery cost	32796.27	444.46	28234.99	37717.68
s_P14 SI inventory	90.5500	6.83	5.0000	160.00
s_P14 SI inventory expenses	42889.67	466.71	37991.03	48541.29
s_P14 SI missed opportunity dollar	54.7900	38.57	0.00	983.00
s_P14 SI storage cost	34767.51	429.35	30524.28	39857.58
s_P15 delivery cost	8051.34	21.25	7769.42	8296.88
s_P15 demand	37369.70	85.67	36069.00	38448.00
s_P15 inventory	2762.56	211.58	951.00	4997.00
s_P15 inventory expenses	20712.37	55.85	20079.42	21474.49
s_P15 missed opportunity dollar	2.6600	3.56	0.00	159.00
s_p15 NI and SI capital cost	5800.18	25.82	5535.51	6114.61
s_p15 NI and SI damage risk	3480.03	15.49	3321.23	3668.68

cost				
s_p15 NI and SI obsolescence cost	1164.38	5.18	1111.25	1227.51
s_P15 NI and SI storage cost	10267.77	21.78	9986.51	10494.68
s_P15 NI delivery cost	5385.65	17.64	5177.19	5551.29
s_P15 NI inventory	1819.17	200.97	390.00	3748.00
s_P15 NI inventory expenses	14470.50	52.40	13773.74	15151.75
s_P15 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P15 NI storage cost	7255.67	19.22	7003.61	7481.91
s_P15 SI delivery cost	2665.69	13.78	2514.29	2857.99
s_P15 SI inventory	943.39	82.93	123.00	1536.00
s_P15 SI inventory expenses	6241.87	26.62	5882.49	6593.55
s_P15 SI missed opportunity dollar	2.6600	3.56	0.00	159.00
s_P15 SI storage cost	3012.10	13.38	2872.94	3208.94

Appendix 31 DWV3 optimised model cost statistics

Output	Average	Half Width	Minimum Average	Maximum Average
s_P01 delivery cost	1124.40	16.77	933.79	1304.88
s_P01 demand	7118.48	97.62	5808.00	8752.00
s_P01 inventory	811.01	57.38	174.00	1414.00
s_P01 inventory expenses	3013.43	26.38	2716.10	3454.93
s_P01 missed opportunity dollar	26.1000	25.09	0.00	990.00
s_p01 NI and SI capital cost	1120.56	9.73	1009.60	1287.50
s_p01 NI and SI damage risk cost	672.32	5.84	605.75	772.48
s_p01 NI and SI obsolescence cost	224.95	1.95	202.68	258.47
s_P01 NI and SI storage cost	995.59	12.11	832.01	1201.39
s_P01 NI delivery cost	1124.40	16.77	933.79	1304.88
s_P01 NI inventory	811.01	57.38	174.00	1414.00
s_P01 NI inventory expenses	3013.43	26.38	2716.10	3454.93
s_P01 NI missed opportunity dollar	26.1000	25.09	0.00	990.00
s_P01 NI storage cost	995.59	12.11	832.01	1201.39
s_P01 SI delivery cost	0.00	0.00	0.00	0.00
s_P01 SI inventory	0.00	0.00	0.00	0.00
s_P01 SI inventory expenses	0.00	0.00	0.00	0.00
s_P01 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P01 SI storage cost	0.00	0.00	0.00	0.00
s_P02 delivery cost	32533.47	83.53	31472.71	33835.34
s_P02 demand	45661.75	108.49	44251.00	47355.00
s_P02 inventory	3911.74	246.82	826.00	5997.00
s_P02 inventory expenses	63076.15	154.93	61070.30	64793.25
s_P02 missed opportunity dollar	0.00	0.00	0.00	0.00
s_p02 NI and SI capital cost	9478.99	49.60	8941.19	10198.55
s_p02 NI and SI damage risk cost	5687.26	29.76	5364.59	6118.99
s_p02 NI and SI obsolescence cost	1902.90	9.96	1794.94	2047.36
s_P02 NI and SI storage cost	46006.99	102.59	44694.77	47537.35
s_P02 NI delivery cost	21984.61	62.13	21127.18	22736.98
s_P02 NI inventory	2783.94	217.03	342.00	4087.00
s_P02 NI inventory expenses	43820.13	129.70	42303.25	45072.94
s_P02 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P02 NI storage cost	32406.88	81.45	31496.47	33567.08
s_P02 SI delivery cost	10548.87	48.21	10064.49	11239.62
s_P02 SI inventory	1127.80	110.38	234.00	1994.00
s_P02 SI inventory expenses	19256.02	72.93	18388.03	20418.61
s_P02 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P02 SI storage cost	13600.12	54.38	13016.05	14466.71
s_P03 delivery cost	68059.02	247.39	64115.87	71546.36
s_P03 demand	708578.98	2,291.16	676909.00	743816.00
s_P03 inventory	27839.47	1,113.30	11924.00	44014.00
s_P03 inventory expenses	120942.33	252.90	117595.45	124456.48
s_P03 missed opportunity dollar	92.8400	69.77	0.00	1870.00
s_p03 NI and SI capital cost	17140.25	79.01	16042.68	18214.46
s_p03 NI and SI damage risk cost	10283.91	47.41	9625.39	10928.42
s_p03 NI and SI obsolescence cost	3440.90	15.86	3220.56	3656.55
s_P03 NI and SI storage cost	90077.27	260.35	86375.12	93867.46
s_P03 NI delivery cost	42758.79	195.72	40013.80	45028.41
s_P03 NI inventory	18108.25	920.58	9176.00	30680.00
s_P03 NI inventory expenses	79243.50	208.51	76341.15	81246.46
s_P03 NI missed opportunity dollar	6.3300	12.72	0.00	633.00
s_P03 NI storage cost	59419.27	207.03	56503.93	61807.14
s_P03 SI delivery cost	25300.23	165.71	23446.12	27722.65
s_P03 SI inventory	9731.22	558.22	2166.00	15389.00
s_P03 SI inventory expenses	41698.83	150.25	39771.77	43331.24
s_P03 SI missed opportunity dollar	86.5100	68.93	0.00	1870.00
s_P03 SI storage cost	30658.00	173.28	28459.54	32926.62
s_P04 delivery cost	120.99	0.63	111.49	131.67
s_P04 demand	35202.38	173.19	33214.00	38512.00
s_P04 inventory	2782.98	172.45	1006.00	4624.00

s_P04 inventory expenses	8205.78	36.16	7782.27	8658.54
s_P04 missed opportunity dollar	46.2800	27.08	0.00	732.00
s_p04 NI and SI capital cost	4458.10	20.04	4224.61	4707.75
s_p04 NI and SI damage risk cost	2674.80	12.02	2534.71	2824.59
s_p04 NI and SI obsolescence cost	894.96	4.02	848.09	945.08
s_P04 NI and SI storage cost	177.93	0.77	169.51	191.99
s_P04 NI delivery cost	75.0345	0.50	68.2569	81.0308
s_P04 NI inventory	1713.47	145.63	281.00	3153.00
s_P04 NI inventory expenses	5019.03	33.87	4597.54	5409.90
s_P04 NI missed opportunity dollar	28.7400	24.09	0.00	732.00
s_P04 NI storage cost	115.91	0.65	108.87	124.35
s_P04 SI delivery cost	45.9544	0.39	41.6832	50.6418
s_P04 SI inventory	1069.51	82.01	104.00	1906.00
s_P04 SI inventory expenses	3186.75	22.42	2865.62	3499.23
s_P04 SI missed opportunity dollar	17.5400	13.93	0.00	368.00
s_P04 SI storage cost	62.0178	0.44	56.2395	67.6380
s_P05 delivery cost	51704.68	132.62	49944.97	53015.36
s_P05 demand	245956.10	567.28	239449.00	252649.00
s_P05 inventory	21711.50	1,355.23	6451.00	31939.00
s_P05 inventory expenses	114434.26	298.04	110100.17	117657.09
s_P05 missed opportunity dollar	7.3600	11.06	0.00	527.00
s_p05 NI and SI capital cost	24001.78	113.55	22466.67	25100.32
s_p05 NI and SI damage risk cost	14400.73	68.13	13479.69	15059.85
s_p05 NI and SI obsolescence cost	4818.35	22.80	4510.18	5038.88
s_P05 NI and SI storage cost	71213.40	155.48	69290.88	73062.24
s_P05 NI delivery cost	32346.28	104.54	30951.74	33375.52
s_P05 NI inventory	13968.80	1,185.37	2048.00	21828.00
s_P05 NI inventory expenses	75335.62	254.12	71617.24	77953.23
s_P05 NI missed opportunity dollar	1.5700	3.16	0.00	157.00
s_P05 NI storage cost	47210.68	126.76	45412.63	48644.52
s_P05 SI delivery cost	19358.41	83.38	18256.74	20473.48
s_P05 SI inventory	7742.70	548.56	1602.00	11464.00
s_P05 SI inventory expenses	39098.65	153.09	37415.03	40772.28
s_P05 SI missed opportunity dollar	5.7900	10.63	0.00	527.00
s_P05 SI storage cost	24002.72	87.45	22804.85	25202.31
s_P06 delivery cost	179576.36	934.91	170284.00	191905.82
s_P06 demand	6381.19	24.68	6098.00	6705.00
s_P06 inventory	474.82	48.89	117.00	922.00
s_P06 inventory expenses	286453.06	1,063.78	276064.54	299566.37
s_P06 missed opportunity dollar	25.8500	51.96	0.00	2585.00
s_p06 NI and SI capital cost	72148.31	461.91	67755.60	77430.43
s_p06 NI and SI damage risk cost	43287.98	277.14	40652.42	46457.18
s_p06 NI and SI obsolescence cost	14483.75	92.73	13601.92	15544.14
s_P06 NI and SI storage cost	156533.02	535.78	150225.71	162855.05
s_P06 NI delivery cost	179576.36	934.91	170284.00	191905.82
s_P06 NI inventory	474.82	48.89	117.00	922.00
s_P06 NI inventory expenses	286453.06	1,063.78	276064.54	299566.37
s_P06 NI missed opportunity dollar	25.8500	51.96	0.00	2585.00
s_P06 NI storage cost	156533.02	535.78	150225.71	162855.05
s_P06 SI delivery cost	0.00	0.00	0.00	0.00
s_P06 SI inventory	0.00	0.00	0.00	0.00
s_P06 SI inventory expenses	0.00	0.00	0.00	0.00
s_P06 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P06 SI storage cost	0.00	0.00	0.00	0.00
s_P07 delivery cost	100875.36	1,554.56	80537.09	122591.61
s_P07 demand	5617.23	81.02	4777.00	6779.00
s_P07 inventory	449.74	36.80	4.0000	878.00
s_P07 inventory expenses	76784.13	792.29	68438.50	88978.66
s_P07 missed opportunity dollar	2076.55	570.09	0.00	15289.00
s_p07 NI and SI capital cost	4218.29	40.18	3678.94	4865.74
s_p07 NI and SI damage risk cost	2530.91	24.11	2207.31	2919.38
s_p07 NI and SI obsolescence cost	846.82	8.07	738.55	976.80
s_P07 NI and SI storage cost	69188.11	763.38	61118.60	81101.33
s_P07 NI delivery cost	100875.36	1,554.56	80537.09	122591.61

s_P07 NI inventory	449.74	36.80	4.0000	878.00
s_P07 NI inventory expenses	76784.13	792.29	68438.50	88978.66
s_P07 NI missed opportunity dollar	2076.55	570.09	0.00	15289.00
s_P07 NI storage cost	69188.11	763.38	61118.60	81101.33
s_P07 SI delivery cost	0.00	0.00	0.00	0.00
s_P07 SI inventory	0.00	0.00	0.00	0.00
s_P07 SI inventory expenses	0.00	0.00	0.00	0.00
s_P07 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P07 SI storage cost	0.00	0.00	0.00	0.00
s_P08 delivery cost	115887.23	330.03	112212.04	119766.13
s_P08 demand	1400127.73	3,407.79	1360395.00	1444908.00
s_P08 inventory	52820.44	2,075.03	25145.00	74801.00
s_P08 inventory expenses	177856.67	326.33	173859.74	181368.38
s_P08 missed opportunity dollar	6.5600	7.62	0.00	282.00
s_p08 NI and SI capital cost	13711.05	56.46	13096.75	14310.25
s_p08 NI and SI damage risk cost	8226.44	33.88	7857.87	8585.95
s_p08 NI and SI obsolescence cost	2752.49	11.33	2629.17	2872.78
s_P08 NI and SI storage cost	153166.69	338.17	149090.64	157448.77
s_P08 NI delivery cost	73829.41	235.38	71077.25	76650.17
s_P08 NI inventory	34915.85	1,917.80	12683.00	54837.00
s_P08 NI inventory expenses	122790.67	267.89	118842.55	125953.69
s_P08 NI missed opportunity dollar	0.9400	1.89	0.00	94.0000
s_P08 NI storage cost	106271.64	263.25	102509.35	109456.19
s_P08 SI delivery cost	42057.82	192.17	39747.29	44598.97
s_P08 SI inventory	17904.59	992.92	7140.00	29593.00
s_P08 SI inventory expenses	55066.00	165.67	53242.51	57227.46
s_P08 SI missed opportunity dollar	5.6200	7.42	0.00	282.00
s_P08 SI storage cost	46895.05	184.83	44873.65	49153.23
s_P09 delivery cost	232472.01	331.07	229161.63	236173.52
s_P09 demand	653678.88	898.66	643114.00	663180.00
s_P09 inventory	21832.12	959.86	11075.00	35551.00
s_P09 inventory expenses	412566.09	530.26	405030.42	419832.92
s_P09 missed opportunity dollar	0.00	0.00	0.00	0.00
s_p09 NI and SI capital cost	58582.81	236.57	55504.55	61540.30
s_p09 NI and SI damage risk cost	35148.87	141.94	33301.96	36923.32
s_p09 NI and SI obsolescence cost	11760.48	47.49	11142.52	12354.20
s_P09 NI and SI storage cost	307073.92	380.42	302903.18	311200.41
s_P09 NI delivery cost	150454.69	250.65	146433.89	153170.18
s_P09 NI inventory	14580.75	831.00	3281.00	24092.00
s_P09 NI inventory expenses	284547.39	478.68	278990.73	291032.96
s_P09 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P09 NI storage cost	213543.47	296.77	209266.52	216893.61
s_P09 SI delivery cost	82017.32	193.47	79559.39	84326.50
s_P09 SI inventory	7251.37	409.27	2639.00	13212.00
s_P09 SI inventory expenses	128018.70	255.12	124901.25	131258.81
s_P09 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P09 SI storage cost	93530.45	205.03	90855.30	95955.74
s_P10 delivery cost	55862.22	924.73	45107.30	67407.70
s_P10 demand	1100.58	18.26	848.00	1319.00
s_P10 inventory	93.7400	8.40	1.0000	175.00
s_P10 inventory expenses	114069.97	1,196.49	95911.98	126323.36
s_P10 missed opportunity dollar	5420.11	1,775.88	0.00	48620.00
s_p10 NI and SI capital cost	28423.28	275.63	25683.79	31968.03
s_p10 NI and SI damage risk cost	17053.58	165.37	15409.92	19180.37
s_p10 NI and SI obsolescence cost	5705.97	55.33	5156.01	6417.57
s_P10 NI and SI storage cost	62887.15	866.17	49662.26	72270.15
s_P10 NI delivery cost	55862.22	924.73	45107.30	67407.70
s_P10 NI inventory	93.7400	8.40	1.0000	175.00
s_P10 NI inventory expenses	114069.97	1,196.49	95911.98	126323.36
s_P10 NI missed opportunity dollar	5420.11	1,775.88	0.00	48620.00
s_P10 NI storage cost	62887.15	866.17	49662.26	72270.15
s_P10 SI delivery cost	0.00	0.00	0.00	0.00
s_P10 SI inventory	0.00	0.00	0.00	0.00
s_P10 SI inventory expenses	0.00	0.00	0.00	0.00
s_P10 SI missed opportunity	0.00	0.00	0.00	0.00

dollar				
s_P10 SI storage cost	0.00	0.00	0.00	0.00
s_P11 delivery cost	148228.01	1,398.10	132319.87	168416.11
s_P11 demand	1238.44	9.79	1085.00	1378.00
s_P11 inventory	109.90	7.63	6.0000	199.00
s_P11 inventory expenses	199323.68	1,298.05	179462.03	216655.84
s_P11 missed opportunity dollar	379.47	234.23	0.00	6163.00
s_p11 NI and SI capital cost	17393.41	120.39	15918.90	18744.08
s_p11 NI and SI damage risk cost	10435.81	72.23	9551.12	11246.19
s_p11 NI and SI obsolescence cost	3491.72	24.17	3195.71	3762.87
s_P11 NI and SI storage cost	168002.74	1,194.37	149300.27	184516.42
s_P11 NI delivery cost	148228.01	1,398.10	132319.87	168416.11
s_P11 NI inventory	109.90	7.63	6.0000	199.00
s_P11 NI inventory expenses	199323.68	1,298.05	179462.03	216655.84
s_P11 NI missed opportunity dollar	379.47	234.23	0.00	6163.00
s_P11 NI storage cost	168002.74	1,194.37	149300.27	184516.42
s_P11 SI delivery cost	0.00	0.00	0.00	0.00
s_P11 SI inventory	0.00	0.00	0.00	0.00
s_P11 SI inventory expenses	0.00	0.00	0.00	0.00
s_P11 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P11 SI storage cost	0.00	0.00	0.00	0.00
s_P12 delivery cost	1879.20	34.89	1460.82	2431.44
s_P12 demand	1425.06	21.51	1168.00	1724.00
s_P12 inventory	161.71	10.79	61.0000	286.00
s_P12 inventory expenses	5571.25	47.07	4795.87	6316.21
s_P12 missed opportunity dollar	73.8800	43.23	0.00	1162.00
s_p12 NI and SI capital cost	2248.78	19.05	1929.51	2542.34
s_p12 NI and SI damage risk cost	1349.24	11.43	1157.68	1525.37
s_p12 NI and SI obsolescence cost	451.44	3.82	387.35	510.37
s_P12 NI and SI storage cost	1521.79	19.76	1267.01	1814.42
s_P12 NI delivery cost	1879.20	34.89	1460.82	2431.44
s_P12 NI inventory	161.71	10.79	61.0000	286.00
s_P12 NI inventory expenses	5571.25	47.07	4795.87	6316.21
s_P12 NI missed opportunity dollar	73.8800	43.23	0.00	1162.00
s_P12 NI storage cost	1521.79	19.76	1267.01	1814.42
s_P12 SI delivery cost	0.00	0.00	0.00	0.00
s_P12 SI inventory	0.00	0.00	0.00	0.00
s_P12 SI inventory expenses	0.00	0.00	0.00	0.00
s_P12 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P12 SI storage cost	0.00	0.00	0.00	0.00
s_P14 delivery cost	70015.89	623.29	62709.08	77117.08
s_P14 demand	2606.52	20.40	2332.00	2844.00
s_P14 inventory	0.00	0.00	0.00	0.00
s_P14 inventory expenses	84141.83	700.08	74281.57	91717.55
s_P14 missed opportunity dollar	0.00	0.00	0.00	0.00
s_p14 NI and SI capital cost	0.00	0.00	0.00	0.00
s_p14 NI and SI damage risk cost	0.00	0.00	0.00	0.00
s_p14 NI and SI obsolescence cost	0.00	0.00	0.00	0.00
s_P14 NI and SI storage cost	84141.83	700.08	74281.57	91717.55
s_P14 NI delivery cost	39983.37	419.71	35635.27	45825.67
s_P14 NI inventory	0.00	0.00	0.00	0.00
s_P14 NI inventory expenses	55401.76	547.55	49449.59	61025.93
s_P14 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P14 NI storage cost	55401.76	547.55	49449.59	61025.93
s_P14 SI delivery cost	30032.51	409.38	23835.96	35180.88
s_P14 SI inventory	0.00	0.00	0.00	0.00
s_P14 SI inventory expenses	28740.07	382.74	23116.97	33049.76
s_P14 SI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P14 SI storage cost	28740.07	382.74	23116.97	33049.76
s_P15 delivery cost	8058.34	27.47	7772.87	8488.07
s_P15 demand	37370.45	114.63	36115.00	39048.00
s_P15 inventory	2470.84	176.39	1037.00	4935.00
s_P15 inventory expenses	20648.62	60.50	20128.15	21485.97
s_P15 missed opportunity dollar	9.6000	8.67	0.00	273.00
s_p15 NI and SI capital cost	5769.39	27.09	5488.56	6151.75
s_p15 NI and SI damage risk	3461.55	16.25	3293.06	3690.96

cost				
s_p15 NI and SI obsolescence cost	1158.20	5.44	1101.83	1234.96
s_P15 NI and SI storage cost	10259.48	28.28	9928.54	10692.09
s_P15 NI delivery cost	5384.48	23.71	5141.41	5766.16
s_P15 NI inventory	1524.60	153.87	583.00	3563.00
s_P15 NI inventory expenses	14384.62	54.71	13763.67	15146.36
s_P15 NI missed opportunity dollar	0.00	0.00	0.00	0.00
s_P15 NI storage cost	7237.21	25.04	6959.28	7613.98
s_P15 SI delivery cost	2673.85	14.42	2496.77	2854.02
s_P15 SI inventory	946.24	79.92	211.00	1611.00
s_P15 SI inventory expenses	6263.99	26.50	5976.56	6749.74
s_P15 SI missed opportunity dollar	9.6000	8.67	0.00	273.00
s_P15 SI storage cost	3022.27	14.43	2872.02	3218.05