Domestic supply chain for UK apparel manufacturing as a digital business: A computer simulation approach

(*Equitable order allocation among SMEs to ensure manufacturers' survival*)

A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Science and Engineering

2020

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Word Count: **79,990** (*excluding references, appendices, acknowledgements, declaration, copyright statements, publications, and achievements*).

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List of Acronyms and Abbreviations

UK	United Kingdom
EU27	The European Union with 27 countries (2007–2013)
CSDCs	Critical success decision criteria
SSEP	SMEs selection and evaluation process
MRP II	Manufacturing Resource Planning systems
DSC	Domestic Supply Chain
SC	Supply Chain
T&A	Textiles and apparel
UKFT	UK Fashion & Textile Association
EE	Extended Enterprise
VF	Virtual factory
SMEs	Small and medium-sized enterprises
RFID	Radio-Frequency Identification
IoT	Internet of Things
ICT	Information and Communications Technology
EDI	Electronic Data Interchange
POS	Point of sale
SRSM	Single retailer to a single manufacturer
SRMM	Single retailer to multiple manufacturers
MRSM	Multiple retailers to a single manufacturer
MRMM	Multiple retailers to multiple manufacturers
KPIs	Key Performance Indicators
CSPI	Cumulative Sourcing Performance Index
CMS	Computer Modelling and Simulation
DACE	Design and Analysis of Computer Experiments
MM	Mathematical Modelling
RLE	Real-life experimentation
SAM/SMV	Standard Allowed Minutes/Standard Minute Values
ANOVA	Analysis of variance
NORM	Normal distribution
EXPO	Exponential distribution
POIS	Poisson distribution
USD ($)	The United States dollar
PAN	Process Analyser
µ	Mean (average)
δ (STD)	Standard Deviation
HW	Half-Width
WUP	Warm-up period
MRP	Materials Resource Planning system
ERP	Enterprise Resource Planning
et al.	And others
etc.	*et cetera*, to imply that further there are other related items.
e.g.	*exempli gratia*, which means for example
i.e.	*id est*, which means *that is* (to say), in other words

Abstract

Bulk order allocation or distribution to a cluster of SMEs (manufacturers) working collaboratively as a single virtual entity can be performed traditionally. However, the traditional techniques are insufficient to meet Industry 4.0-related advancement technologies and conceptual frameworks which necessitate working digitally. Theoretical underpinnings show that the UK SMEs have not fully digitalised their equitable order distribution (sharing) systems as a necessity towards Industry 4.0. To bridge the gap, a research background indicated the computer simulation approach as one of the best methods to enable digitalisation of the domestic supply chain for UK apparel manufacturing. The digitalisation is about enabling SMEs to secure orders from the British apparel retailers that on their own would not secure orders through an extended enterprise conceptual framework. The distribution is on enabling an equitable order allocation, dividing, or sharing among the SMEs to ensure long term manufacturers' survival.

This is mixed-methods research: qualitative and quantitative approaches. The research was conducted as follows. Firstly, exploring an extended enterprise (EE) within the Industry 4.0 perspective. Considering that it is an Industry 4.0 era, it was thus crucial exploring the meaning of an EE, and how does it exist. The benefits of developing the concept of an EE on simplifying order placement by retailers were also determined. Secondly, establishing suitable decision criteria in digitalising equitable order allocation systems. Thirdly, assessing potential software needed in transforming equitable order allocating systems. Fourth, the computer simulation approach by the Arena® version 16.00.00 simulation software developed the discrete-event simulation models. Models were simulated for 50,000 minutes (~ 834 hours) as a warm-up period and ~ 4,992 hours (299,560 minutes) as the steady-state period: making a total simulation runtime of 349,560 minutes for 69 replications per year. Fifth, simulating for several scenarios. Finally, verifying, validating, and applying the design and analysis of computer experiments to show the feasibility of allocating bulk order sizes given multiple orders and multiple scenarios.

The developed SRSM, SRMM, MRSM and MRMM digitalisation models indicate how distribution, sharing or dividing of bulk orders can be digitally managed. The order sharing processes between multiple manufacturers were executed equitably by considering the developed pertinent critical success decision criteria. The findings thus show the significance of enabling a smooth retailing between retailers and manufacturers (SMEs). The developed models are also expected to be a vital support in creating an alignment of the multi-sites production processes to enable a virtual factory. The virtual factory will thus be established with sufficient capacity to service the retail demands in an agile manner.

The research contributions are mainly in threefold. First, the blueprint systems (models) were developed to enhance digital order distribution equitably amongst multiple manufacturers (SMEs). Second, coming up with models which can allow the small-scale production units to fill in the gaps in their existing production schedules and ultimately to ensure the full asset utilisation over time. Third, the conducted design and analysis of computer experiments (DACE) to show the feasibility of allocating bulk order sizes given multiple orders and multiple scenarios is a contribution to methodology.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institutes of learning.

Copyright Statement

Acknowledgements

Primarily, I would like to extend my sincere appreciations to the Almighty God, Whom I am always living in His purposes. Indeed, nothing I can successfully achieve without asking for God's grace in Trinity, unconditional loving-kindness, and compassion. Thank You, LORD!

Secondly, several people big-heartedly supported this PhD research. Amongst those, the special mention goes to my enthusiastic and passionate supervisors: Dr Steven George Hayes and Dr Iain Duncan Stalker supported me wholeheartedly throughout. I also acknowledge the support received from Dr Amy Benstead, who joined my supervisory team lately. They inspired me to know much that pursuing PhD studies with enthusiasm is truthfully life-changing and a fantastic experience. The fruition of this research could not be realised without the support and continued engagement of the three brilliant supervisors. I am indeed immensely grateful for having them for the entire PhD duration. Thank you all!

Profound gratitude likewise goes to The University of Manchester for offering me a PhD admission and other related opportunities, and the University of Dar es Salaam who allowed me to conduct this incredible research work. I also appreciate the support and cooperation received from Madam Kerry Beckwith (Manufacturing and Quality Manager) at Matalan Ltd and Madam Ruth Crawshaw-Sykes (Sales Manager) at Joseph H. Clissold & Son Ltd.

I hereby also acknowledge the UK Government for funding my PhD research by awarding me the Commonwealth Scholarship [TZCS-2017-720]. There could be no easy way I could have managed to sponsor myself to carry out the PhD research in the UK without the full support received from the UK government. Thank you all!

Moreover, other special deepest gratitude goes to Madam Gillian Kilburn, '*my English Mum*.' She is certainly such a helpful and extraordinary person to work with. I am not sure how I would have managed to get through several complicated logistics for this research without her enthusiastic support. May God shower you with blessings always!

Other thankfulness goes to all my incredible friends who prayed, encouraged, supported, helped and/or motivated me to keep working so hard. Their invaluable prayers, encouragement, assistance, and motivation were monumental towards the success of this PhD. Thank you all!

Finally, but by no means least, I am equally appreciative to my lovely Mum and Dad, Sisters and Brothers, for their great love and incredible support. They are the most significant people in my world. May the Almighty God shower you with blessings always!

Publications and Achievements

Publications (journal and conferences)

- **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Computer modelling and simulation of an equitable order distribution in manufacturing through the Industry 4.0 framework*", 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE), IEEE, 12-13 June 2020, Istanbul, Turkey (https://doi.org/10.1109/ICECCE49384.2020.9179275)

- **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Towards a digital revolution in the UK apparel manufacturing: An Industry 4.0 perspective*", Industry 4.0 – Shaping the Future of the Digital World, in Bartolo, P., Silva, F., Jaradat, S. and Bartolo, H. (Eds.), Taylor & Francis, 2nd International Conference on Sustainable Smart Manufacturing (S2M 2019), Manchester, UK, pp. 3-8.

- **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Development of the critical success decision criteria for an equitable order sharing for an extended enterprise*", The TQM Journal, Emerald Vol. 32 No. 6, pp. 1715–1742. (https://doi.org/10.1108/TQM-05-2019-0138).

- **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (Accepted/In press June 2020), "*Enabling manufacturer selection and an equitable order allocation amongst textiles and apparel manufacturers*", International Journal of Management and Decision Making, Inderscience. (https://doi.org/10.1504/IJMDM.2021.10032107).

Conferences/presentations/workshop/award/prize

- Attended Connected Everything II Online Conference 2020, "Accelerating Digital Manufacturing Research Collaboration and Innovation", on Tuesday 21st July – Wednesday 22nd July 2020.

- Presented a poster entitled "*Domestic supply chain for UK Apparel manufacturing as a digital business: A simulation approach*" at the School of Materials PGR 2019 Conference held on 09th-10th May 2019 at the University of Manchester, Manchester, UK. Awarded a **2nd Prize** in the Poster Competition for Management and Marketing/Textiles and Apparel category.

- Attended a Three Days CSC Workshop on "Maximising your impact: training for development" held on 16th-18th March 2018 at Cumberland Lodge, The Great Park, Windsor, UK. Presented a poster titled '*Domestic supply chain for UK apparel manufacturing: a digital business approach.*'

- Attended a one-day CSC Workshop on "Researcher Excellence: Improve your research project management skills" held on 29th January 2019 at the CSC offices, Woburn House, London, UK.

- Presented during the "2nd International Conference on Sustainable Smart Manufacturing (S2M 2019) part of the Industry 4.0 Academia Summit 2019" held on 9th-11th April 2019, Manchester Central Convention Complex, Manchester, UK.

- Taifa, I.W.R., Hayes, S.G. & Stalker, I.D., "*UK apparel as a digital business: a simulation approach*", at the School of Materials PGR 2018 Conference held on 10th-11th April 2018 at The University of Manchester, Manchester, UK.

- Co-chaired/moderated during the School of Materials PGR 2019 Conference held on 10th May 2019 at The University of Manchester, Manchester, UK.

Chapter 1 Introduction

1.1 Introduction

Globally, textiles and apparel (T&A) industries are gradually transforming compared to other manufacturing industries. To this date, there are four industrial revolutions: the first (18th Century) to the fourth (21st Century) industrial revolution (Wee *et al.*, 2015; Küsters *et al.*, 2017). The subset of the fourth one is Industry 4.0. The textiles sector (now known as the T&A sector) is diverse and heterogeneous (Froud *et al.*, 2017). The sector contributed massively in the first industrial revolution (Bertola and Teunissen, 2018), specifically during the first mechanical weaving loom invention in 1784 which was firstly built-in 1785 (Gökalp *et al*., 2018). The sector has enterprises from small and medium-sized enterprises (SMEs) to large enterprises (Brill *et al.*, 2019). SMEs and many other traditional sectors are lagging to the new industrial revolution (EU, 2018). In Europe, the T&A sector contributes a turnover of EUR 166 billion and employs 1.7 million people as per data of 2013 (EU, 2017).

The T&A sector has several segments requiring transformation. The supply chain (SC) is one of the critical competitive areas that require Industry 4.0-enabled transformation (Kazantsev *et al.*, 2019). The required transformation can be through digitalisation and collaboration increase (Arnold *et al.*, 2016). However, for the transformation to occur with the necessary agility, flexibility, speed and efficiency, the supporting decision tools and systems are highly needed to facilitate an extended enterprise which can enhance collaborative innovation advantages (Owen *et al.*, 2008). Successful deployment of such tools can thus help SMEs to share their capabilities, extra capacities and organise their activities systematically in securing and processing orders (Kazantsev *et al.*, 2019). Collaborative innovation can be for the entire supply chain or to one of the vital segments. Both within the UK and elsewhere, the digital transformation should not be enhanced through a fragmented approach, i.e. by focusing on digitising isolated functions or processes (Lay, 2018): it should be for the whole system.

The UK is one of the five most populated European Union (EU) countries that produce around three-quarters of the total T&A sector's products: other countries include Germany, France, Italy and Spain (EU, 2017). In Europe, the sector is dominated by SMEs; for instance, over 90% of the total employees are from firms with less than 50 workers (EU, 2017). This thus drives a need to focus on SMEs because they produce circa 60% of the total value-added output (EU, 2017). The UKFT (2017) supports the dominance of SMEs and micro-businesses, and 85% of companies have less than ten employees. The T&A industry comprises four main phases: design, manufacturing, distribution and sales (Tyler e*t al.*, 2006; Weinswig, 2017).

The manufacturing phases cannot be executed successfully if manufacturers (SMEs) fail to secure orders from either British retailers or elsewhere over an extended period. Anecdotal evidence is that apparel SMEs in the UK struggle to utilise their capacities, probably due to lack of enough secured orders from retailers to be sustainable over a long time. So, this makes an argument on how SMEs should be enabled to work collectively as a single virtual entity that assists distributing or sharing the received orders amongst several SMEs to ensure manufacturers' survival for a longer period. To bridge the gap, one of the strategies is for the SMEs to collaborate so that to equitably be allocated the received apparel orders corresponding to their capacities and capabilities. In this study, the other terms for allocating orders include sharing, distributing, or dividing. The apparel orders can be placed from either a single retailer to a single manufacturer (SME), a single retailer to multiple SMEs, many retailers to a single SME, or from many retailers to many SMEs. The latter category is much challenging on allocating orders equitably across several SMEs working collaboratively, that is, working in an extended enterprise framework.

Through the digitalised technology, it is possible to connect and integrate the T&A's stakeholders, including the manufacturers and the retailers (Weinswig, 2017). Enabling integration requires advanced technology and digitalisation models, as the crucial factors in creating new business models (Leminen *et al.*, 2020). Applying digitalised techniques and tools can support SMEs to share capabilities and capacity information on electronic databases or other electronic marketplaces such as the computing cloud (Cisneros-cabrera *et al.*, 2017). Success to this needs the continuous practice of sharing pertinent information through digitalised networks. SMEs can thus benefit from the fourth industrial revolution by securing opportunities by searching and bidding for apparel orders and ultimately filling their capacities and capabilities. Also, committed SMEs should develop a collaborative culture (Owen *et al.*, 2008; Kane *et al.*, 2015). So, it is crucial to integrate SMEs and retailers in the T&A's retail supply chain through collaboration and close interactions.

Furthermore, lots of contextual information is available concerning digital transformation (digitalisation). Many researchers call Industry 4.0 as digitalisation (Kazantsev *et al.*, 2018). Concerning the T&A sector, it is crucial to analyse the importance of digitalising equitable order allocation amongst SMEs. By contrast, there is a tendency to prescribe the normative view that digital transformation is fundamentally an excellent and vital concept. Foremost, digitalisation has many definitions. For this study, *digitalisation* refers to the continuous process of changing or improving the current traditional business approach(es), systems or business models through an integration of the internet-connected digital technologies, networked systems and data, and sophisticated information technology infrastructure (Schumacher *et al*., 2016; Srai and Lorentz, 2019), specifically for handling the apparel orders from the retailers to the manufacturers working as an extended enterprise. *Digital transformation* can accordingly be described "as changes in ways of working, roles, and business offering caused by the adoption of digital technologies in an organisation, or in the operating environment of the organisation" (Parviainen *et al.*, 2017, p.64). Digital transformation is not concerned with changing the current operations into digital versions: it reconsiders existing processes from new perspectives aided by digital technology (Parviainen *et al.*, 2017). Further discussion of the differences between digitisation, digitalisation and digital transformation is in Section 2.4.

Digital transformation has been reported to be crucial to several organisations; for example, MIT Sloan Management Review and Deloitte involved 4800 business analysts, managers and executives from organisations worldwide during the 2015 Digital Business Global Executive Study and Research Project: they researched how organisations view digitalisation (Kane *et al.*, 2015). The results indicated that 92% of the respondents (4416) thought to accrue benefits after three years and 76% (3648) felt that digital transformations are crucial to their organisations (Kane *et al.*, 2015). Kane *et al.* (2015) also found that digitalisation success is not all about technology: appropriate strategies should be prioritised by companies that need to achieve benefits of digitalisation. Despite the benefits due to digitalisation, it requires an initial investment in the beginning. Companies that rely on short term goals would value digitalisation as a loss; however, it is advised for the organisation to take a proactive approach to anticipate future benefits. Firms should also execute their supply chain phases in a synergy way to maximise the digitalisation benefits.

1.2 Research context

The UK T&A sector has a long history since the first industrial revolution era. Between the 1970s and the mid-2000s, the sector was faced with the decline of employment opportunities, products exportation and the domestic production which resulted in a huge volume of apparels importation (Jones and Hayes, 2004; Froud *et al.*, 2017). The sector declined by 69% from 1995 to 2012 (CSWEF, 2015). Over the last two decades, the average size of this sector decreased by 60%, and in 2013, 82% of the garment firms had less than ten workers (CSWEF, 2015). In 2012, the EU27 received more than 42% of the clothing from China, Turkey (13%) and Bangladesh (13%) (Turker and Altuntas, 2014): this massive importation implies that the apparel market for the British manufactured products was in great danger. But there have been signs of revival since the early 2010s (Froud *et al.*, 2018).

In efforts to revitalise the sector, the UK government has renewed an Industrial Policy for textiles and apparel (Froud *et al.*, 2017). All initiatives towards reviving this sector should be performed on all the critical indicators of the entire sector without ignoring supply chain aspects. For instance, at the bottom end of the UK apparel sector, there is currently an increase in online fashion retailers and fast fashion (Taplin, 2014; Tupikovskaja-Omovie and Tyler, 2018). In 2016, around a quarter of all the UK apparel sales were through the online (e-commerce) business (Weinswig, 2016) whereas in 2017 the online sales accounted for 24% of total fashion spend (Tupikovskaja-Omovie and Tyler, 2020). There is also a demand increase of Made in Britain luxury and heritage products at the top end of the T&A sector, mostly from the Middle East and Asian markets (Froud *et al.*, 2018). Made in Britain can be successful if SMEs can also utilise well their capacities and capabilities by working jointly. SMEs need to secure enough orders from British retailers to sustain their survival.

The UK T&A sector comprises more than 15% of SMEs and 84% of micro-size (TAP, 2017). The country has less than 1% large firms with more than 250 employees (TAP, 2017). The sector still contributes significantly to the UK economy (Froud *et al.*, 2017).

Contributions are directly related to employment, economic output and a provision of substantial support to the UK Exchequer: the sector is ranked 15th position in the world (The Alliance Project, 2015). Fashion retailing is a great business in the UK and elsewhere, and thus forming a crucial part of textiles (McCormick *et al.*, 2014; EAC, 2019). The EAC (2019) confirms that the UK purchase rate of apparel per person is more than any other EU countries. In 2017, the sector was worth thirty-two billion pounds to the UK economy (EAC, 2019): this is thus a competitive sector to digitalise to obtain further benefits.

SMEs require well-digitalised networks to enable indigenous SMEs to secure orders within the UK for utilising their resources. It is a digital era which requires the distribution networks to be digitalised as well. Digitalisation can also enable the UK T&A sector to compete successfully with the foreign importers who have the advantages of lower labour costs, low price of the raw materials and the highly automated containerised distribution networks. SMEs require digitalised supply chains to develop a strong ability to respond to the volatile demands from retailers, ability to change volume, change colour or ability to shift production of new production lines in actual time (Fung *et al.*, 2008).

There is also a need for having proper coordination and collaboration to achieve an intrinsic satisfaction of the volatile demands of the apparel. Such a quick response cannot be fulfilled without having strong networks, both internally and externally of the sector. A quick response cannot also be satisfied if the lead time is too long (The Alliance Project, 2015). Lead-times are traditionally long in the T&A industry (Al-Zubaidi and Tyler, 2004), whereas retailers need short lead times (Tyler, 2008). The T&A sector needs transformation (Taifa et al., 2020a); otherwise, retailers might completely shift to the imports where they can quickly source at their convenient time while taking advantage of the low prices opportunities for some apparel products (Bruce and Daly, 2011).

The apparel manufacturing firms have also continuously been with a distinctive nature in relationships to its complexity of the whole production system, dynamism and ultimately the volatile nature about consumers (Fung *et al.*, 2008). Fulfilment of the quick response through digitalised supply chains can be achieved if virtual integration, process alignment and networked logistical, and market sensitivity can all be successfully met (Christopher *et al.*, 2004). However, one of the influential factors for winning the market is the issue of time management: time to serve, time to market and time to react to retailers' demands. For the UK SMEs to work efficiently and effectively, they should develop robust digitalised distribution networks, specifically for the received bulk orders from retailers.

Christopher *et al.* (2004) argue that it is vital to integrate the virtual supply chains by networking various discrete production units through the virtual factory. Virtual factory is "an integrated simulation model of major subsystems in a factory that considers the factory as a whole and provides an advanced decision support capability" (Jain *et al.*, 2001, p.595). Such a factory can be fully accountable for delivering values by aligning various production processes across the whole apparel industry's network. A virtual factory should be developed beyond the general modelling of one subsystem at once, e.g., the business process model, the manufacturing model, together with the communication network model established separately (Jain *et al.*, 2001). Integration of the virtual supply chain is highly needed for an entire sector rather than on an individual process if the aim is to gain the maximum advantages from it (Ngai *et al.*, 2014).

Today's retailing should not be as an individual silo: it should work holistically (McCormick *et al.*, 2014). Revitalising the sector thus necessitates that all the participating apparel manufacturers, i.e. SMEs, must share their information regarding the available capacities and capabilities. They should then bid for the work via the private computing cloud service, which must be accessed through the digitalised systems. It is also important to have optimised scheduling services through an advanced combinatorial optimisation engine to enable factories to plan production activities more efficiently. An engine should allocate orders to the selected factory's units.

Ideally, the engine must be able to satisfy the multi-criteria decision factors in ensuring proper coordination of the production. A factory could either represent a workstation in longer production processes which pull in the services of other factories in the network or provide the completed garments as part of larger orders supplied by other factories in the scheme. The model should generate and schedule the suitable production plans that consider the spare capacities in a factory's production schedule, lead-time constraints, quality, and other needs from retailers. The model should also maximise sustainable workload for all factories to ensure the guaranteed effective cash flow. A scheme needs the full participation of the logistic service providers for apparel order consolidation and delivery of the partial products between the factories, and the final deliveries of the finished products to retailers.

1.3 Problem statement

Supply chain management (SCM) is a broad research area to which the competition can be experienced at any phase. Brun and Castelli (2008) observed the fiercest competition for SCM at the retail side. The T&A sector has been dynamic and complex to the issue of retailing and distribution. UK T&A retailers mostly source their products from overseas factories because of the cost benefits and quick response (Bruce *et al.*, 2004; Abramovsky *et al.*, 2004). Shao and Stalker (2016, p.97) also stated that “it is obvious that more and more firms are purchasing goods from overseas, such as South East Asia, the Far East and even moving to manufacture to the neighbouring countries with lower labour costs.” Offshoring the business services for the apparel sector creates a big problem for the UK SMEs who could secure apparel orders from British retailers.

Even for the few retailers who source within the UK SMEs, they still cannot utilise the SMEs’ capacities and capabilities (CSWEF, 2015): this brings in an extended enterprise concept (collaborative innovation) that dictates several SMEs to work collectively. SMEs can probably work effectively through a virtual factory, whereby such a factory works as a decision-supporting tool. The virtual factory’s functions involve allocating, dividing, or distributing received orders from British retailers equitably: this involves bulk orders, multiple retailers, multiple SMEs, and dependent performance criteria from SMEs.

The UK apparel sector has large firms who have enough capacity and capabilities (Taplin, 2014; TAP, 2017) to handle bulk orders while the SMEs probably have low capabilities and capacities in processing bulk orders. For the SMEs, they should probably work jointly in executing bulk order distribution amongst themselves. All the participatory factories must show up their commitment, time available to handle orders, capacities for their factories, etc. Until recently, an equitable order allocation process through a virtual factory for the SMEs was not available. Probably this is due to the non-existence of well-optimised digital approaches (Christopher *et al.*, 2004; Shao and Stalker, 2016). SMEs are also limited in size: they can work as bigger factories only through an extended enterprise (EE) setup. Working as an EE is possible through the digital business approach, which is not yet fully embraced by the SMEs. Therefore, hardly any approach enabled bulk order distribution (sharing) processes from the apparel retailers in an extended enterprise framework.

Furthermore, manual interventions dominate the T&A sector (Berg *et al.*, 2017). Nayak and Padhye (2015, p.14) argue that "although there is some automation, the apparel industries are still far behind the other sectors and rely on manual intervention." It is not only SMEs within the T&A sector that are lagging as the EU (2018) also argues that within the EU, many SMEs are not fully digitalised. Additionally, several UK SMEs lack elementary digital skills, while other SMEs have fewer capacities to utilise new digital technologies (Reeves *et al.*, 2018). The traditional and semi-traditional processes are implemented continuously within the sector. If there can be an integrated factory, such a factory can probably allow the small-scale production units to fill in the gaps in their existing production schedules to ensure full asset utilisation over time. The factory can also optimise order distribution (sharing) process(es) of the received apparel orders.

To this date, the sector has embraced some technological innovations when compared to past decades: those technological innovations and systems are such as barcode, EDI, POS, RFID, MRP system, ERP system, sensors, and MRP II systems. There are also innovations in developing apparel (Tyler, 2008; Tyler *et al.*, 2012). Tools and systems are vital but not satisfactory: "when sophisticated software systems are acquired, users often only employ a small part of the functionality—not because this is all they need, but because they have not been trained beyond the basics and because the way the company is organised effectively restricts the full exploitation of the software systems" (Tyler, 2008, p.170). Despite the present ICT systems, it is still easy to process orders from a single retailer who places orders to a single manufacturer (SME). When multiple retailers place bulk orders to multiple SMEs, it becomes sophisticated in sharing (allocating) orders (Di Pasquale *et al.*, 2020). So, this becomes a typical Industry 4.0 concept. Since industrialisation is gradually shifting from Industry 3.0 to Industry 4.0, this thus necessitates implementing Industry 4.0-

related approaches which can handle the allocation process(es) of the received bulk orders. The success of such a transformation can create a positive impact (ILO, 2019) and can be a good starting point of shifting the T&A sector to Apparel 4.0 (Gökalp *et al.*, 2018), Fashion 4.0 (Bertola and Teunissen, 2018) and Textile 4.0 (Chen and Xing, 2015).

So, continuing having the domestic supply chain systems which operate in traditional or semi-traditional based approaches (Castelli and Brun, 2010) which do not entirely fulfil retailers' orders could lead to huge importation. As far as this author knows, it is at this moment concluded that the apparel sector has probably not been transformed enough, enabling manufacturers (SMEs) to distribute or allocate enough bulk orders digitally. Collectively this thus forms a base of this research. Figure 1.1 depicts some concepts on how the extended enterprise framework can enable collaboration between retailers and manufacturers to retail effectively using Industry 4.0-enabled technologies or mechanisms. An illustration of the problem on the need for an equitable allocation of apparel orders is as follows: suppose bulk orders, e.g. 10,000 jackets, 30,000 trousers, etc., are required by UK retailers. Such orders are placed to manufacturers (SMEs). Due to the small size of SMEs, most of them generally do not have enough capabilities and capacities to process bulk orders. The question yet to be answered is how the SMEs can be supported with a digitalised mechanism(s) to work collectively and allocate or distribute orders equitably amongst them.

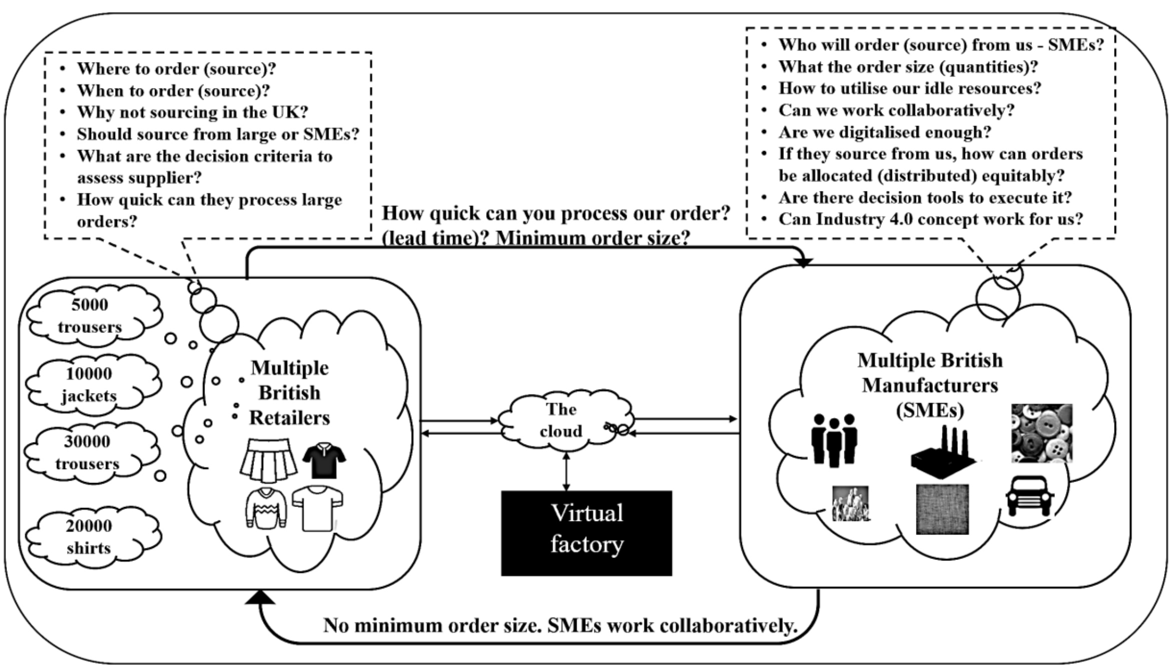


Figure 1.1: A summary of the problem statement.

1.4 Research questions (RQs)

The UK SMEs are not yet digitally competent enough for each one to work alone. They also probably do not have the digitalised approaches for allocating orders using an extended enterprise concept equitably. The broader contextual question is: *how can an equitable order distribution, sharing, dividing or allocation system be digitalised for UK apparel manufacturing—SMEs*? Nevertheless, the driving research question is: *is it feasible for a group of UK apparel manufacturing (SMEs) to work together by equitably allocated or distributed multiple orders?* So, achieving the illustration of the feasibility of equitable order allocation answers whether it is feasible to have digitalised infrastructure (systems) that would support a cluster of SMEs to work together. Four questions were raised to answer the main question as follows:

RQ1. What is an extended enterprise within the Industry 4.0 perspective? It is an Industry 4.0 era whereby numerous sectors are slowly transforming. This question thus explores the meaning of an extended enterprise (EE), and how it exists. What are the benefits of developing the concept of an EE on simplifying order placement by retailers?

RQ2. What are the key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing? In transforming the T&A sector, it requires decision criteria which are crucial in creating integration and collaboration amongst apparel retailers and SMEs. This question helped to deepen the sourcing criteria, which are significant in driving the feasibility of digitalising the distribution process(es).

RQ3. What are the potential techniques, tools, and management software required in transforming the apparel sector and how to evaluate those techniques, tools, and software? The decision supporting tools and techniques are required to digitalise the distribution processes. Which software packages are highly recommended? Can the computer simulation approach drive the digitalisation of the equitable order allocation processes?

RQ4. How to develop, verify, validate and illustrate the feasibility models for the UK apparel manufacturing (SMEs) regarding the processes of distributing (allocating) orders *equitably?* What worth this question is: does the T&A sector need the digitalised models? What are the criteria and evidence to prove the practicability of the developed models? How can the developed models be validated to be worth an implementation in the UK and elsewhere?

In concluding on the four research questions, it was thus essential researching to answer the above questions. The required research was entitled 'Domestic supply chain for UK apparel manufacturing as a digital business: A computer simulation approach.' This title covers the SCM field in general. The subtitle covers the main objective: equitable order allocation among SMEs to ensure manufacturers' survival.

1.5 Research objectives (ROs)

1.5.1 The main objective or original aim

This research mainly digitalises the DSC for the UK apparel manufacturing in enabling the SMEs to secure enough orders from the British apparel retailers that on their own could not be able to secure orders. Digitalisation is about enabling an equitable order allocation, distribution, or sharing across several SMEs (manufacturers) as a single virtual entity to ensure their long-term survival. The ultimate intention was to come up with validated feasibility models to allocate orders equitably. Models would enable smooth retailing between the retailers and SMEs. Such models are expected to be vital support in creating an alignment of the multi-sites production processes to enable a virtual factory. The virtual factory should be established with sufficient capacity to service the retail demands in an agile manner. Results are also expected to help firms get the proper approaches, techniques, tools, and validated solutions for integrating the small-scale production units in filling up the gaps of their existing production schedules to ensure full asset utilisation over time.

1.5.2 Specific objectives (SOs)

To attain the principal research aim, the following specific objectives were considered and accomplished pragmatically:

SO1: To explore an extended enterprise within the Industry 4.0 perspective.

- To define an EE concept within the Industry 4.0 perspective and how an EE exists.
- To determine the benefits of developing the concept of an EE on simplifying order placement by retailers.

SO2: To establish appropriate key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing.

- To identify all factors that are required in deciding the digitalisation.
- To analyse inputs required for the digitalisation.
- To establish all the critical pertinent decision criteria for sharing the apparel orders.

SO3: To propose and evaluate the potential techniques, tools and management software required in transforming the DSC for the UK apparel manufacturing (SMEs).

- To identify and apply numerous methods in digitalising the UK apparel sector.
- To identify all potential digitalisation techniques and tools.
- To determine the right software for digitalising the equitable ordering processes.

SO4: To develop, verify, validate, and illustrate the feasibility for the UK apparel manufacturing (SMEs) to be distributed (shared or allocated) orders equitably.

- To develop the simulation modelling of the order distribution (sharing) processes.
- To verify, validate and illustrate the feasibility of allocating orders using simulation.

1.6 Research significance or contributions

(a) The research aimed to digitalise the DSC through a computer simulation approach on allocating apparel orders equitably to several UK SMEs (manufacturers) working as a single virtual entity. Execution of an equitable order allocation among SMEs aims to ensure manufacturers' survival over a longer period through consistent manufacturing capacity fulfilment at a break-even level as a minimum.

(b) Several blueprint systems (models) were developed: they can enhance apparel order distribution (sharing) across several manufacturers (SMEs) working as a single virtual entity. The models show that it is feasible working as an extended enterprise for the

T&A industry. They can also dictate the small-scale production units to fill in the gaps in their existing production schedules and ensure full utilisation of their assets over time. This follows under the 'proof of concept' aspects because the models were developed by linking the field of this research, i.e. engineering field. Afterwards, the generated models of the ordering system illustrated the feasibility of allocating, distributing, or sharing the received apparel orders equitably. Also, models were linked with both synthetic and actual industrial related data to show the possibility of allocating orders equitably. This proved to be the logical way of approaching the identified problem (Sections 1.3 and 1.4). The research thus illustrated decision science, which from the researcher's viewpoint proves to be one of the contributions to knowledge.

(c) The research shows the quantum benefits of integrating various potential management techniques, tools, and simulation software, including Arena®, in getting breakthrough improvements. SMEs and retailers are expected to accrue the enormous benefits in the long-run implementation of the developed models.

(d) This research contributes to knowledge and practice from its novelty; the research thus, it is an additional literature material for the imminent researchers in the related fields.

(e) Contributions through the four published articles: Section 10.2(b) and Appendices G-J.

1.7 Research scope and limitations

The following are the key aspects which were intensively studied in accomplishing the stated objectives. Some limitations are also mentioned.

(a) The research focused on order distribution, mainly how apparel orders can be equitably distributed to a cluster of SMEs (manufacturers) working as a single virtual entity and not the entire business processes.

(b) The focus of the modelling was on CMT: *cutting* the fabric, *making* (sewing) garments and *trims* along with the cleaning and the packaging processes of the finished garments.

(c) The simulation model(s) developed do not follow under dynamic modelling. Dynamic models consider time-dependent changes in the state of the system. Differential equations usually represent such models.

(d) Both actual and synthetic data were applied.

(e) The term ‘apparel manufacturing’ is used interchangeably with the garment industry, apparel factory, apparel sector, and the clothing industry.

(f) To make a good comparison, a review of other industry’s supply chains was also studied, including the automobile, civil (for the construction section) and computer industry. The review aimed at noting down methods, management techniques, tools and software applied (if any) in transforming the sectors mentioned above.

(g) The term distribution is considered as the act of sharing, dividing, or allocating the received apparel retailers’ orders amongst the SMEs working as an extended enterprise. The SMEs are those who could not secure enough orders from British retailers on their own. In SCM, between the manufacturer and retailers requires distributors: these *distributors* should not be confused with the term *distribution* used in this research.

(h) In executing the output of this research, coming up with an actual prototype was out of scope since various systems should be integrated to enhance the digitalisation.

(i) Implementing the generated results in the industry was not considered as part of the validation processes in this research due to the time constraint.

(j) The research focused on the UK T&A sector. Since the T&A industry operates in similar situations globally, the research results can thus be applied to other countries currently facing similar problems as the UK apparel manufacturing sector.

1.8 Methodology

This is mixed-methods research (multi methodology): qualitative and quantitative approaches. Both epistemological and ontological claims were stated. The nature of research showed the need for undertaking the research framework, which follows pragmatism philosophy. The research was conducted as follows. Firstly, exploring an extended enterprise (EE) within the Industry 4.0 perspective. Considering that it is an Industry 4.0 era, it was thus crucial exploring the meaning of an EE, and how does it exist. The benefits of developing the concept of an EE on simplifying order placement by retailers were also determined. Secondly, establishing the appropriate decision criteria in digitalising equitable order allocation to the UK SMEs working as a single virtual entity. Thirdly, assessing potential management software required in transforming equitable order allocating systems for SMEs. Fourth, developing the digitalised models for enabling equitable order allocation using discrete event-based computer software—Arena® version 16.00.00. Fifth, simulating for several scenarios. Finally, verifying, validating, and applying the design and analysis of computer experiments (DACE).

1.9 Key terms

a) *Equitable order allocation: equitability/equitable* means fair, fitting, appropriate or reasonable as opposed to *equal/equally* terminology, which means exactly the same. For example, if an order comes in (e.g. 10,000 shirts) to five manufacturers, each manufacturer is allocated, e.g. 20% of the order, then this results in an '*equal order allocation*': such an allocation process is not necessarily equitable. For an allocation process to be equitable, the system allocator (e.g. virtual factory) must consider all decision criteria to justify the order distribution (sharing or allocation) process(es). So, equitable order allocation is the process of dividing, sharing, or distributing fairly or reasonably the received orders from retailers to a cluster of SMEs working collaboratively. This is discussed in full in Section 2.7.

b) *Apparel manufacturing industry* (factories or firms) convert fabrics supplied by textile manufacturers into a collection of apparels and other related accessories. The considered apparel manufacturers are the SMEs.

c) *Apparel retailers* request apparel products in large quantities from apparel manufacturers (SMEs) and sell to end-users (customers).

d) *Extended enterprise* is a fundamental concept whereby firms operate synergistically rather than in isolation to achieve firms' mission, vision, core values, goals, and strategies by relying upon well-developed networks of the business collaborators.

e) *Information sharing or exchange* is considered as the act of manufacturers and retailers passing information (data) from one to another electronically or through any other clear agreed and installed systems amongst all the business partners. The exchange of information can either be amongst manufacturers (SMEs) only or SMEs and retailers.

1.10 Thesis structure

The entire thesis is arranged into ten chapters, as follows:

Chapter one provides a summary of an introduction, the general research context, the identified problem statement, research questions, the main research objective, specific objectives, significances (contributions) of the research, limitations and scope, the thesis structure, and the key terms.

Chapter two summarises theoretical background regarding digitalisation of the UK apparel manufacturers (SMEs) and retailers, Industry 4.0 concepts, equitable order allocation (or distribution or sharing), an extended enterprise, virtual factory, management theory, research gaps and research questions. Theoretical underpinnings indicate that most researchers focus on large factories rather than SMEs. The purpose of reviewing the previous studies was not to write what others have said: it mainly helped to make arguments for this study, specifically on answering the research questions from Section 1.4.

Chapter three discusses the modelling and simulation overview. The discrete-event simulation was found to be pertinent to develop an equitable order allocation model for enabling the SMEs working as a single entity. A complete review was also performed concerning the appropriate simulation software and the suitability of each application for modelling apparel production systems. Arena® software package was found to be the appropriate one. Arena® was selected after using the checklists in consideration of the previous evidence and recommendations by several scholars who used the same software package. It was also imperative to identify the best probability distribution function for retailers' demand, whereby the underpinnings suggest the use of the Poisson process for apparel demands. Quality indicators, together with several phases for computer simulation, were also among the discussed issues. Lastly, the verification, calibration and validation processes were also discussed briefly.

Chapter four details the deployed methodology. Under this chapter, the philosophies stance (philosophical claims), research design and approach, sample size, data gathering, and data analysis tools, are discussed. This research followed the pragmatism research philosophy. Both quantitative and qualitative data were considered. For the qualitative data — the ordering processes, standard minute values, decision criteria, order quantities, etc., — semi-structured interview sessions, Likert scale, document reviews and questionnaires were conducted to the UK apparel retailer(s) and manufacturer(s). Quantitative approaches included computer simulations and DACE techniques.

Chapter five explains the role of information sharing and the established pertinent critical success decision criteria for enabling order distribution. Chapter 5 also highlighted the role of sustainable information-sharing practice for an extended enterprise. The primary order allocation inputs for the initial simulations in Chapter 6 were generated from Chapter 5.

Chapter six summarises the developed SRSM (single retailer to a single manufacturer), SRMM (single retailer to multiple manufacturers), MRSM (multiple retailers to a single manufacturer) and MRMM (multiple retailers to multiple manufacturers) models. Both actual and synthetic data are the inputs to the Arena® version 16.00.00 software.

Chapter seven discusses DACE in detail. It was essential to show the model's feasibility of executing order sizes allocation equitably. That is, given multiple orders and multiple scenarios, the MRMM model, should be able to provide a feasible solution or indicate whether it is not possible to fulfil the requested orders.

Chapter eight provides a results summary based on the conducted interview sessions and secondary data (qualitative data), and modelling and simulation results (quantitative data).

Chapter nine discusses in depth the generated qualitative and quantitative results and other general perspectives, including model users and the extended enterprise framework.

Chapter ten concludes, discusses contribution to knowledge, summarises the answers to the questions, provides the recommendations, limitations, and the potential future research works. For additional clarity, Figure 1.2 presents thesis organisation. Finally, references and appendices—the used structured interview, questionnaire, and abstracts of the published and/or accepted articles—are included at the end of the thesis.

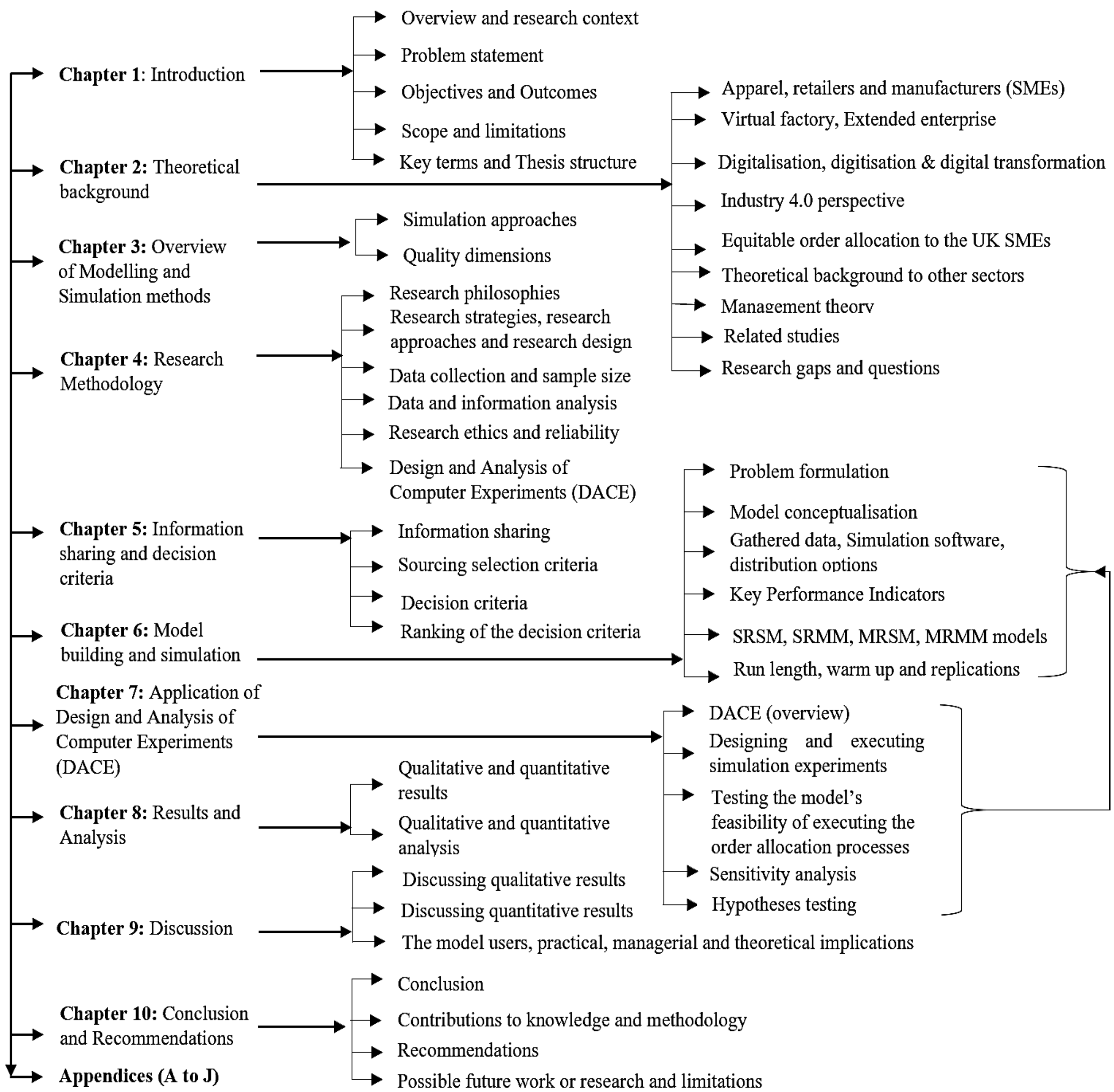


Figure 1.2: Organisation of the entire thesis.

Chapter 2 Theoretical background

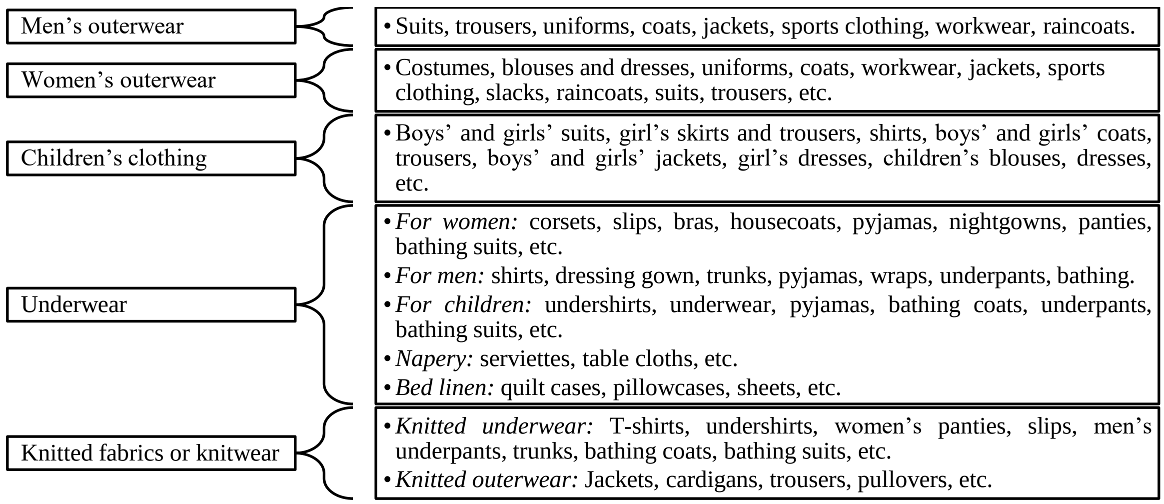
2.1 Introduction

The theoretical background (or literature review or theoretical orientation) helps: first, exploring what is known and why the researched problem exists; second, to find areas for arguments or controversies; and third, identifying key studies and gaps in knowledge, thus formulating research questions which require further exploration (Bolderston, 2008). The theoretical underpinnings for this study aimed at giving practical information, critical analysis of the previous studies and making useful syntheses of the researched problem(s). The conducted background research involved many sources, including journal articles, company reports, conference proceedings, e-books, textbooks, theses, and relevant websites. Although the research is focused on the apparel industry, a supply chain review was conducted for three different sectors: automobile, civil (for the construction section), and the computer industry. The analysis of the three sectors explored the digitalisation concepts regarding their supply chains, specifically order distribution (sharing) systems (if any). This chapter concludes with the research gaps and the research question.

2.2 UK apparel manufacturers—SMEs

2.2.1 Apparel meaning

Apparel (attire, cloth and garment) refers to something that covers or adorns (Caro and Martínez-De-Albéniz, 2013) and can be outer or inner clothing (Nayak and Padhye, 2015). Generally, researchers use the terms apparel and garment interchangeably. The garments have been in the world for over 100,000 years (Kittler *et al.*, 2003). Apparel can be manufactured from cotton, bast fibres, synthetic materials (mainly from the fossil fuel crude oil), cellulosic fibres (viscose), silk, wool, animal skin (leather), etc. Manufacturing garments by the SMEs has existed for an extended period to make the sewing culture a mainstream phenomenon today (Taifa and Lushaju, 2020). Apparel comprises subclasses such as clothing, footwear and accessories (Caro and Martínez-De-Albéniz, 2013). Figure 2.1 shows clothing categories (Geršak, 2013) which can further be classified as basic, fashion or fast fashion garments (Kunz *et al.*, 2016).



Source: Adapted from Geršak (2013, p.3).

Figure 2.1: The classification of clothes (apparel).

2.2.2 What are SMEs?

SMEs are vital to the UK economy because SMEs create jobs and wealth (Reeves *et al.*, 2018). In Europe, SMEs are classified as independent enterprises with less than 250 workers (CSES, 2012) whereas, for the USA, an organisation can have up to 500 employees and still be considered as an SME (LABS, 2019). SMEs have an annual turnover of less than £40 million (about €50 million), or an annual balance sheet total approximately £34 million (less than €43 million) (CSES, 2012). According to the World Bank (2008), the SMEs have between 50 and 300 employees, total assets of less than $15 million and more than $3 million, or an annual total sale which is less than $15 million and more than $3 million. In the business context, two major categories operate as SMEs. The first is the traditional household or cottage factories. Such SMEs are mostly in rural or semi-urban areas, and they contribute many part-time jobs opportunities (LABS, 2019). The second type is generally described as modern SMEs, and such SMEs are mostly technologically creative and innovative, specifically in solving several problems by proposing new approaches: most start-ups enterprises belong to this type (LABS, 2019).

This research focused on SMEs because they create jobs opportunities across the UK; SMEs create competition and foster creativeness and innovativeness across several industries; SMEs can adapt and react quickly to transformation in local and regional economic development; SMEs contribute significantly to exports and trade, and finally, SMEs foster entrepreneurial and private ownership skills (Campaniaris *et al.*, 2011; Reeves *et al.*, 2018; LABS, 2019). It is crucial to support the UK SMEs due to their productivity contributions to the government. Statistically, 99.3% of all the private sector's business is for small businesses, whereas the SMEs account for 99.9% (Reeves *et al.*, 2018). In the UK, the number of SMEs has increased by 2.2 million since 2000: making a 64% increase compared to 4% of the larger business enterprises (Reeves *et al.*, 2018). SMEs and larger enterprises manufacture clothes. The UK SMEs, specifically for the T&A, is much made up of less than 50 employees, but some SMEs have between 50 and 300 employees (Virani and Banks, 2014).

SMEs are crucial to delivering inclusive growth, adapting to megatrends and strengthening productivity, contributing significantly to competitiveness, innovation and employment creation (OECD, 2018). Although digital technologies can expand SMEs' market intelligence and access knowledge networks and distant markets at relatively low cost; they are, however, lagging in the digital transformation (OECD, 2018). SMEs are also disproportionately affected by the quality of infrastructure and institutions, trade barriers and inadequate intellectual property protection (OECD, 2018). Many SMEs do not have enough capacities for securing apparel orders from British retailers: this probably makes them fail to utilise their assets over time effectively.

Another problem is based on technological advancements. During this Industry 4.0 era, technology has massively advanced several industries, leaving the T&A sector lagging (Berg *et al.*, 2017). However, Nayak and Padhye (2015) show the presence of some computerised automation within the apparel industry. For example, there was a time when product development required significant improvement (Tyler *et al.*, 2006), but technological advancements have minimised this challenge (Gill, 2015). The product development cycle could take circa 167 days and the product be manufactured for 39 days (Tyler *et al.*, 2006). Now the major challenge is securing sufficient orders. The EU (2018) also indicates that it is not only the UK SMEs that are lagging behind: the majority of SMEs within the EU are not yet fully digitalised. This creates a digital transformation opportunity for improvement and gaining competitive advantages.

SMEs face stiff competition from large manufacturers. They are supposed to improve their systems and increase efforts to compete with large manufacturers. The one stated approach is to "offset the technological advantages of size by being more flexible and by customising their approach" (Clodfelter, 2015, p.355). The digitalisation process is essential to offset the technological advantages. SMEs require optimal approaches to handle orders easily from retailers than large manufacturers; however, they cannot compete due to their size. This necessitates SMEs to work as a single virtual entity (an extended enterprise) to utilise their capacities and capabilities collaboratively. SMEs can similarly secure orders from retailers by working jointly in an extended enterprise framework. For example, if retailers place apparel orders of 40,000 jackets to a single manufacturer (SME), it is not easy for a single SME with a staff headcount of less than 10 to meet retailer's lead time. Though, if a cluster of SMEs collaborates as a virtual factory, there is a high possibility of allocating the received orders equitably amongst themselves. As a result, retailers can get their products on time, leaving each participating SME benefiting after having utilised their resources.

Each industry has its supply chain. The apparel sector is synonymous with a well-known supply chain, which is sometimes called a textile-fashion supply chain (Jones and Hayes, 2004). The chain comprises long conventional processes embarking from the reception of the raw materials, the order processing up to the delivery of manufactured products. The apparel sector is among the most complex sectors, with uncertainty demands. The industry is labour-intensive (Taplin, 2014; Nayak and Padhye, 2015) and has been with people who mostly possess low skills (Kim *et al.*, 2006), i.e., people with a low-level of the innovation skills in handling and utilising the installed machinery. The sector employs a higher number of workforces (Taplin, 2014).

Since the 1970s, the UK T&A sector has been in long-term critical failure. By the mid-2000s, over two-thirds of the manufacturing capacities were wiped, whereas employment vanished for 90% (Froud *et al.*, 2017). For example, Goworek *et al.* (2012) report that, in 2006, foreign importers sold over 95% of their garments in the UK. Nevertheless, the sector has recently started to improve as compared to the period between the 1970s and the mid-2000s (Jones and Hayes, 2004). These underpinnings suggest that it is now essential for apparel retailers and manufacturers to work as an extended enterprise to overcome the current competition.

2.2.3 UK clothes (apparel) manufacturing companies

The UK T&A sector has several manufacturers: they specialise in all categories of textiles and apparel. Some of the reputable websites with a list of UK apparel manufacturers (SMEs) include Make it British (MiB)[1] which is mentioned as 'the original and only 100% British sourcing event', the UKFT®[2], FreeIndex[3] and Statista[4]. Appendix F presents some UK manufacturers.

2.3 UK apparel retailers

From 1945, British clothing retailers applied an increasing dominance over the domestic textile industry (Toms and Zhang, 2016). Due to the high demands of apparel, retailers order huge volumes of apparels from manufacturers and sell to end-users (customers). Retailers decide to purchase (order) directly from the manufacturers or the middleman (an intermediary between the buyer and the seller). It is vital to choose an option that best meets the retailers' needs. Apparel retailers face at least four typical vendors (Clodfelter, 2015). First, manufacturers: such a vendor involves several factors, including the minimum required order size. Second, wholesalers (merchant middlemen): this option should be considered if a retailer is unable to contact the manufacturer(s) directly because wholesalers also source their products from the manufacturers. Third, brokers (representatives of the manufacturer) who act as the manufacturers' agents: they are also known as non-merchant middlemen. Fourth, rack jobbers (rack merchandisers): they are a special type of suppliers or vendors who have an agreement with a retailer(s) to show and sell products in stores. Rack jobbers are not typical in the T&A sector. Based on the above-explained vendors, this research focused on retailers who decide to source directly from manufacturers (SMEs).

Table 2.1 depicts some of the major UK apparel retailers, who mostly import their products.

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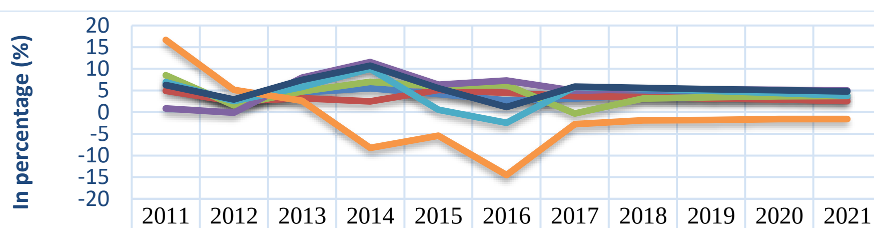
[1] Make it British https://makeitbritish.co.uk/ (attended the event on 29 May 2019 and 30 May 2019).
[2] UKFT https://www.ukft.org/
[3] https://www.freeindex.co.uk/categories/industry/manufacturing/clothing_manufacturer(5)/
[4] https://www.statista.com/outlook/90000000/156/apparel/united-kingdom (accessed on 7 May 2019).

Table 2.1: Some of the UK apparel retailers.

Name (Brand)	Website	Logo
Primark UK	https://www.primark.com/en/	PRIMARK
Matalan	https://www.matalan.co.uk/	MATALAN
Asda (George)	https://direct.asda.com/george/	George.
New Look UK	http://www.newlook.com/uk	NEW LOOK
H&M UK	http://www2.hm.com/en_gb/index.html	H&M
Tesco (F&F)	https://www.tesco.com/direct/clothing/	TESCO direct
Sainsbury's (Tu)	https://tuclothing.sainsburys.co.uk/	Tu
Peacocks	https://www.peacocks.co.uk/	PEACOCKS
Bonmarché	http://www.bonmarche.co.uk/	Bonmarché
Boohoo.com UK	http://www.boohoo.com/	boohoo
Arcadia	https://www.arcadiagroup.co.uk/	Arcadia
Missguided	https://www.missguided.co.uk/	MISSGUIDED
Marks and Spencer (M&S)	http://www.marksandspencer.com/	M&S
Next	http://www.next.co.uk/	next
Clarks	https://www.clarks.co.uk/	Clarks
River Island	https://www.riverisland.com/	RIVER ISLAND
Inditex	https://www.inditex.com/home-uk	INDITEX
Debenhams	https://www.debenhams.com/	DEBENHAMS
Select Fashion	http://www.selectfashion.co.uk/	select
TK Maxx	https://www.tkmaxx.com/uk/en/	TK maxx
Zalando	https://www.zalando.co.uk/	zalando
Quiz	https://www.quizclothing.co.uk/	QUIZ
Sportsdirect.com	https://www.sportsdirect.com/	SPORTSDIRECT.com
John Lewis & Partners	https://www.johnlewis.com/	JOHN LEWIS & PARTNERS
House of Fraser	https://www.houseoffraser.co.uk/	HOUSE OF FRASER SINCE 1849



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total	6.616	2.401	4.54	5.528	4.158	2.721	3.133	3.922	3.693	3.575	3.319
Women's and Girls' Apparel	4.9	2.493	3.196	2.488	5.126	4.513	3.678	3.511	3.127	2.908	2.578
Men's and Boys' Apparel	8.523	1.601	4.806	6.977	5.979	6.224	-0.313	3.12	3.412	3.698	3.744
Sports and Swimwear	0.841	-0.121	7.97	11.553	6.327	7.3	4.907	5.36	5.191	5.183	5.017
Underwear	6.928	2.534	5.836	10.017	0.535	-2.459	5.783	5.533	4.907	4.402	3.825
Hosiery	16.652	5.146	2.609	-8.284	-5.442	-14.514	-2.78	-1.872	-1.783	-1.594	-1.576
Clothing Accessories and Other Clothes	6.228	2.95	7.424	10.722	5.529	1.185	5.876	5.628	5.26	5.082	4.807

Source: Statista (2018).

Figure 2.2: Revenue growth in the UK apparel market (in %).

Figure 2.2 depicts revenue growth in the UK apparel market (in per cent). In 2018, the UK revenue was USD 80,480 million due to the apparel market. The apparel for women and girls had the largest segment. The considered in-scope apparel includes clothing for women, apparel for men, swimwear and sportswear, hosiery and underwear, other clothes (baby clothes, leather clothes, neckwear, gloves, caps, and hats). In contrast, the out-of-scope apparel includes handbags, work clothes, jewellery and watches, umbrellas, and ski suits.

Furthermore, Weinswig (2016) discussed the unit volume sales of several apparel retailers in the UK (Table 2.2). In 2014 and 2015, Marks & Spencer Group plc (M&S) was leading with 6.4% and 6.3%, respectively, as the share of the clothing market in the UK. M&S was the largest UK apparel retailer (Weinswig, 2016). The next retailer in the same period was Asda (George) with 5.6% and 5.5%, respectively. By 2018, the UK's largest clothing retailer was M&S: it had an 8.1% share, followed by Next at 7.1%. The third was Primark, with a 6.9% share of the apparel market by value (Butler, 2018). These unit volume sales of apparels if they would have been made in the UK, to benefit indigenous manufacturers, including SMEs, would have boosted the SMEs profit hugely.

Table 2.2: The unit volume sales of UK apparel companies (million).

Retailer (Brand)	**Leading UK retailers: Share of apparel market (%)**		**Unit volume sales (Million)**
	2014	**2015**	**2015 (2,090.7)**
Primark UK	4.4	4.5	91.9908
Asda (George)	5.6	5.7	117.0792
New Look UK	2.1	2.2	43.9047
H&M UK	1.6	1.7	33.4512
Matalan	2.3	2.2	48.0861
Tesco (F&F)	2.3	2.3	48.0861
Sainsbury's (Tu)	1.4	1.5	29.2698
Marks & Spencer	6.4	6.3	133.8048
Next	4.7	4.8	98.2629
Arcadia	3.1	3.1	64.8117
Clarks	2	2	41.814
River Island	1.3	1.3	27.1791
Inditex	0.9	1	18.8163
Total	38.1	38.6	796.5567

Source: Euromonitor International, as cited by Weinswig (2016).

2.4 Digital transformation, digitisation, and digitalisation

2.4.1 Digitalisation, digital transformation, and digitisation: the differences

Digitisation, digitalisation and digital transformation are conceptual terms which are closely interrelated and frequently used interchangeably and mostly misused in a broad range of literature (Gbadegeshin, 2019; Srai and Lorentz, 2019). This research mostly covered digitalisation. However, digitisation and digital transformation were also considered in ensuring the transformation of apparel manufacturing (SMEs), specifically for developing an equitable ordering system. In the business context, digitisation is the conversion of the analogue—data or information—from a physical format to the digital setup (style). For instance, in the T&A industries, converting handwritten retailer's invoices to a digital copy indicates the digitising process. Regarding apparel orders, digitisation is like when retailers upload their orders on the cloud and then ask the collaborating SMEs to share their information on the cloud as well, waiting for the virtual factory to process the received orders instead of using handwritten documents.

Digitalisation has several definitions, possibly because of the elusiveness of the concept itself (Hagberg *et al.*, 2016; Srai and Lorentz, 2019). Brennen and Kreiss (2016) define digitalisation concerning social life restructuration. In simple elaboration, digitalisation is considered as the use of information technology (IT) and digital media to develop or improve the current business processes. Digitalisation involves the use of digital technologies (Srai and Lorentz, 2019) whereas, from the retailing stance, it generally refers 'to the integration of digital technologies into retailing' (Hagberg *et al.*, 2016, p.696). Digitalisation can also be defined as a transformation from analogue to digital (Hagberg *et al.*, 2016) and to the simplification of the new systems which create the required values such as accessibility, transparency and availability (Amit and Zott, 2001).

Hence, digitalisation is how the new digital world influences people and business activities. For example, digitalisation can be associated with the use of virtual factories to equitably allocate orders to a cluster of SMEs working as a single virtual entity instead of using a person to assign orders to manufacturers manually. The influence instigated by the digitalisation process is thus the digital transformation. For this study, it is considered as the transformation of the existing order distribution or sharing processes of the received apparel orders.

Digitisation comprises the purely "technical and technological conversion of analogue into digital signals as well as its storage and transfer, [whereas] digitalisation on the other side describes all effects, impacts and consequences the availability of digital information triggers" (Schumacher *et al.*, 2016). So, this study focused on changing the current traditional approach through an integration of the internet-connected digital technologies, precisely for handling the retailers' orders to the manufacturers (SMEs).

2.4.2 The digitalisation of UK apparel manufacturers—SMEs

Digitalisation is one of the contemporary topics to apparel companies worldwide, and several enterprises require a significant step-up in this area (Berg *et al.*, 2017). Berg *et al.* (2017, p.3) reported that "most of us in apparel sourcing are way behind—we are far from being digital." However, some enterprises have already made exciting improvements with digitalisation, including digitalising their processes (Weinswig, 2017; Berg *et al.*, 2017). Speeding up the digitalisation is thus needed to assimilate it into a complete transformation: otherwise, digitalisation might end up in disappointment for this sector (Berg *et al.*, 2017).

An effective digitalisation of an order distribution through technological innovation can help to accrue several operational benefits, including efficiency improvement, increase the speed, increase flexibility and trust, resource utilisation (Weinswig, 2017), agility, transparency, and reduce order delivery time (Gökalp *et al.*, 2018). Digitalisation can also improve predictability, decision making, efficiency, accuracy, lead time reduction, enhance collaboration and innovation, better understand and serve the clients' requirements (Berg *et al.*, 2017). Despite the benefits through the implementation of digitalisation (Apparel 4.0), there are challenges associated with it, such as astronomical investment, privacy and security, technical challenges, lack of global standards and social difficulties (Gökalp *et al.*, 2018). Notwithstanding the requirements for implementing digitalisation, the apparel sector requires several digitalised processes, including equitable order distribution to SMEs.

The fashion industry needs fully digitalised systems (Lay, 2018). The digitalisation is required for the order processing and distribution, designing and transfer processes before enforcing for more technological developments. Apparel manufacturing consists of several product varieties, styling and materials, and thus, dealing with continuously changing styles limits the automation degree for the manufacturing systems (Kursun and Kalaoglu, 2009).

Lectra (2018, p.3) states that the fashion business is "rapidly becoming a predominantly digital industry—one where huge volumes of data, digital collaboration, online social interaction, digital marketing, and e-commerce come together to create and sell a physical product to a digital-native demographic." Digitalising equitable order allocation processes would depend on whether SMEs can collaborate because digitalisation needs working in an EE framework. So, having a bigger picture is necessary, precisely on effecting digitalisation in the T&A to respond effectively to the fourth industrial revolution concepts. Many companies are already employing digital technologies globally (Bertola and Teunissen, 2018), including Zara, Tommy Hilfiger, Google Shopping Actions, GAP, Dior, Burberry, ASOS, American Apparel and Amazon (ILO, 2019).

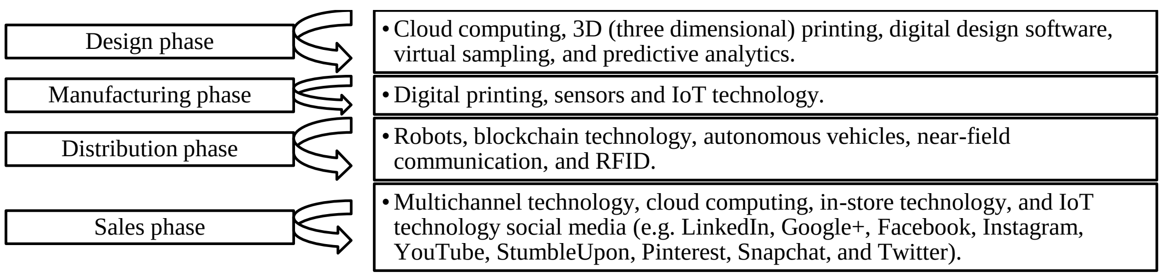
The deployment of digital technologies has so far been fostered by the need for increasing sales and improving services to customers. Studies indicate that digitalisation enhances the retailing side as well as supply chains, cut-throat competition for orders, among others (ILO, 2019). Digitalisation is also required in helping the SMEs to operate digitalised businesses. Both digitisation, digitalisation and digital transformation frameworks are essential in transforming the entire businesses. Thus, the digital business can be described as the business that involves conversions of analogue to digital signals and expanding all activities to the full transformation from the beginning to the end through an integration of the internet-connected digital technologies. Such processes should aim to bring desirable positive impacts triggered with developed advanced business models (BMs).

BMs are defined in numerous ways; for example, some researchers explain BMs in terms of web-based models which result in the 'promised wild profits in a distant future' (Magretta, 2002, p.86). The term BMs started to be extensively used in the 1990s. BMs have other interchangeable terminologies; for example, Morris *et al.* (2005) described BMs as business strategies, economic models, revenue models and business concepts. Whereas, Zott *et al.* (2011) described BMs as patterns, sets, frameworks, methods, structural templates, conceptual models or tools, architecture, a description or statements. The business model is also stated as a method, a design, an architecture, a statement, an assumption, a plan and a pattern (Morris *et al.*, 2005). Table 2.3 provides the BMs' definitions which prove that still, BMs have several meanings.

Table 2.3: Numerous definitions of business models.

Sources	Definitions
Teece (2010, p.172)	"[How] the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit."
El Sawy and Pereira (2013, p.15)	BM is a "communication or planning tool [which] allows entrepreneurs, investors, and partners to examine strategic choices for internal consistency, to surface the assumptions of the business plan, and to understand the vision toward which the business is being built."
Veit *et al.* (2014, p.46)	"A tool for depicting, innovating and evaluating business logic in start-ups and existing organisations, especially in IT-enabled or digital industries."
Wei *et al.* (2017, p.87)	"The activity system intended to create and capture value, which covers transaction content, structure and governance."

Apparel manufacturing supply chain comprises four key phases (Figure 2.3): each phase proposes potential solutions regarding the digitalisation (Weinswig, 2017). The UK apparel manufacturing needs to excel in all the processes. The sector should be digitalised by applying IT-enabled facilities while also enabling sustainable information sharing practice. The sector should adopt digital technologies to have strong interaction with potential retailers. The interaction needs to comply with the data-sharing systems (Svahn *et al.*, 2017).



Source: Adapted from Weinswig (2017, p.4).

Figure 2.3: The digitalisation of the apparel supply chain.

2.5 The virtual factory in apparel manufacturing systems modelling

Research background reveals the presence of a wide range of virtual factory (VF) definitions. This research adopted Jain *et al.'s* (2001, p.595) definition that a VF is "an integrated simulation model of major subsystems in a factory that considers the factory as a whole and provides an advanced decision support capability." In line with the chief research aim, a VF is essential as it would help SMEs to service the retail demands in an agile manner. There are technological advancements through Industry 4.0, and VF is one of the models within the Industry 4.0 framework. VF has the potential of achieving part of the Next Generation Manufacturing (NGM) paradigm (Jain *et al.*, 2001). NGM requires rapid conceiving processes, rapid product and process realisation, enterprise integration (Jain *et al.*, 2001), among other significant requirements. The inclusion of several systems is required to reduce unnecessary delays in accomplishing the manufacturing processes. Collaboration and cooperation, the availability of new tools for decision making and developments in the complexity theory contribute to shaping today's business (Soliman and Youssef, 2001). Such integration must occur at all levels of industries. To expedite the development and modification phases in industries, modelling and simulation can be applied to achieve the aims of the proposed models (Jain *et al.*, 2001). VF requires the integration of several systems and subsystems, and this process can be verified and validated using the simulation method. For enhancing effective and efficient order allocation equitably, a VF is vital as a decision tool or system. Other techniques, tools and systems should be integrated into the VF. The auxiliary systems to be integrated must also be IT-enabled technologies.

2.6 Extended enterprise for apparel manufacturing

For several years, researchers have explored the extended enterprise (EE) concepts. An EE is a conceptual framework to which the associated companies operate collectively with the help of extensive supporting systems, advanced IT systems and effective information sharing practice amongst the business partners. Chrysler Corporation created an EE term back in the 1990s (Stallkamp, 2005; Taifa *et al.*, 2020a). Spekman and Davis (2016, p.44) defined an EE as "collaborative relationships among the key supply chain members whereby both buyers and sellers share a common vision of gaining the competitive advantage and achieving a greater end-user customer satisfaction relative to other competing supply chains." Comparably, Browne and Zhang (1999, p.31) defined an EE as "an enterprise which is represented by all those organisations or parts of organisations, customers, suppliers, and sub-contractors, engaged collaboratively in the design, development, production, and delivery of a product to the end-user." Browne and Zhang (1999) explain the way virtual enterprises and an EE act as the new approaches after the shift of the self-centred closed-enterprises to the global open-enterprises. Both Browne and Zhang's (1999) and Spekman and Davis's (2016) definitions indicate that the EE concept works well if companies are ready to share information. It is no longer a single enterprise: it is the universal enterprise. An EE involves value networks as the business firms under it must form virtual networking by exchanging relevant information. Synchronised information technologies should enable such a process. So, working in an EE unified structure increases connectivity and ability level for a factory, firm or company to react quickly to the changing business opportunities (Erol *et al.*, 2010).

An EE is a group of companies, and it is generally the upstream and downstream supply chain. An EE includes complementors and other companies who are strategically aligned with other business partners. So, in an EE, there is not a single manufacturing enterprise for all collaborating companies. In other explanations, an EE is the so-called value web, because it is not the only upstream and downstream chain: it crosses through. A cluster of SMEs forming an EE manages value chains in their operations. However, through the virtual distributed manufacturing networks and other networks within their collaboration boundaries, each chain to be involved can interconnect with other related chains, thus establishing the value web. The value web differs from the value chain. Value chain involves activities performed by a manufacturing firm(s) to produce the desired products for customers. Value web places customers at the centre. Value chain focuses on the production line while the value web focuses on the production web. Within the EE framework, each apparel manufacturing enterprise deals with its core activities, and where necessary, some non-core activities can be outsourced. SMEs and retailers need to be strongly connected to enable SMEs to receive apparel orders from the retailers (TAP, 2017). UK SMEs also should closely work with retailers to ensure that they deliver products quickly (TAP, 2017).

2.7 Equitable order allocation, distribution or sharing to the UK's apparel SMEs

In this study, *equitability/equitable* means fair, fitting, appropriate or reasonable as opposed to *equal/equally* terminology, which means exactly the same. For example, if an order comes in (e.g. 10,000 jackets) to five manufacturers, each manufacturer is allocated, e.g. 20% of the order, then this results in an *equal order allocation*: such an allocation process is not necessarily equitable. For an allocation process to be equitable, the system allocator (e.g. virtual factory) must consider all decision criteria to justify the order distribution (sharing or allocation) process(es). So, equitable order allocation is the process of dividing, sharing, or distributing fairly or reasonably the received orders from retailers to a cluster of SMEs working collaboratively.

Equitability requires a centralised platform, facilitating platform or the shared workspace where information is shared: such information assists an execution process which considers the pertinent decision criteria. In the digitalised era, a cluster of SMEs can have a centralised or decentralised planning algorithm which could reflect a hierarchy construction from big companies. Here, the business partners could negotiate terms, etc. So, for negotiation purposes, there should be a centralised model or a planned model for communication and negotiations. For example, if five SMEs agree that it should not be, e.g. 20% of each order (equal order allocation), based on SMEs' capacities, capabilities, etc.; thus, initial suggestions might be, e.g. for the bigger factory secure 40% of the order and other SMEs divide the remaining order size. This could form part of negotiations to start with. So, order distribution can be executed centrally or decentrally, and digital technology could support either because there could be multi-agency systems.

Each firm has its individual preferences. But it is not simply preferences that inform the notion of equitability: there is also capability, availability, capacity, quality, standards, qualifications, perhaps even a notion of finder's fee or managerial responsibilities, if necessary or appropriate, etc. Equitable order allocation necessitates companies to work as an extended enterprise to simplify allocating orders amongst collaborators. The combination of SMEs needs to meet all retailers' requirements. To allocate orders, hard constraints such as quality, experience, etc., are needed for each SME to be considered as well. Consideration of the individual preferences together with both qualitative (attributes) and quantitative (variables) criteria proves the whole process to be equitable. In the digitalisation perspective, the planning engine should include the computing cloud. The cloud-based infrastructure assists in creating the flexible (dynamic) digital transformation of order allocation processes.

The Oxford University Press (2020) defines distribution as "the action of sharing something out among a number of recipients" whereas Cambridge University Press (2020) defines it as, to "give something out to several people, or to spread or supply something." Distribution is thus considered as the act of sharing or dividing the received apparel retailers' orders amongst the SMEs; who are working as an extended enterprise. When an order is received (e.g. 50,000 items), the collaborating SMEs must share it equitably; so that each utilises its capacity and capabilities and secures long-term survival. Anecdotal evidence is that apparel

SMEs in the UK might be failing because of also not having enough and consistency of the shared orders.

Retailers source from a mix of suitable suppliers, manufacturers, or vendors (Taifa et al., 2020b) to reduce the long-term risk of depending on a single source (Kraljic, 1983). Sourcing is a strategic and critical process (Kraljic, 1983; Caniëls and Gelderman, 2005) within the T&A sector (Su and Gargeya, 2016). Finding the right manufacturer(s) is a challenging process as statistically within the T&A industry, suppliers are more than retailers. The criticality of the sourcing process requires fulfilment of a number of critical success decision criteria (CSDCs). CSDCs assist in evaluating and selecting the right manufacturers (SMEs). In this study, the selection process(es) of suitable SMEs is referred to as 'SMEs selection and evaluation process (SSEP)'. Many retailers conduct SSEP rooted on either the recommended standard or the traditional approaches (Taifa et al., 2020b). Strategic positioning with the purchasing portfolio matrix is useful (Kraljic, 1983). SSEP can be conducted for the sole (single) or dual (multiple) sourcing (Jain and Hazra, 2017). For single sourcing, all orders are produced by a single manufacturer (SME), while for multiple sourcing, the orders are processed by many manufacturers (SMEs). Absence of an SSEP may result in retailers' sourcing from the 'wrong' SMEs. This may also result in less utilisation of other SMEs' capacities and capabilities which remain without orders. Of course, there are no criteria which can be damaging to retailers; and without criteria, a retailer may not select the best SMEs, resulting in these better SMEs going out of business.

The theoretical evidence shows that the challenges mostly occur when many retailers are sourcing from many SMEs (Scott *et al*., 2015; Taifa *et al.*, 2020a). Establishing a digitalised approach(es) to allocate or distribute orders to manufacturers in an equitable manner could ensure that the manufacturers utilise their manufacturing capabilities and capacities continuously. Without such an approach, the business sustainability of any resurgence in manufacturing in higher labour cost countries, including the UK, is unlikely to prosper.

2.7.1 SMEs selection and evaluation process (SSEP)

The CSDCs comprise a set of qualitative (attributes) and quantitative (variables) criteria preferred by retailers. The manufacturers (SMEs) are expected to meet or exceed the ranking scores of CSDCs in order to secure orders from retailers. To identify CSDCs, the process involves sourcing, which is the determination process of how and where to get apparel products. Priorities from firms differ; however, there are standard decision criteria to select the right manufacturers. Retailers have the deciding factors for making sourcing decisions. Theoretical background indicates the presence of many SSEP studies. There are general and specific CSDCs for executing SSEP within the T&A sector. Dickson (1966) established twenty-three CSDCs, including quality, cost, technical capability, and capacity. Dickson's (1966) criteria form a benchmarking list of CSDCs to several SSEP studies. Although Dickson's (1966) study formed important CSDCs, some criteria for collaborating were not amongst the developed ones. To bridge that gap, Weber *et al.* (1991) reranked Dickson's (1966) CSDCs by reviewing seventy-four studies: their study included a just-in-time (JIT) philosophy. Weber *et al.* (1991) categorised CSDCs into four categories (Figure 2.4).

Extreme important	**Considerable important**	**Average important**	**Slight important criterion**
• Delivery • Quality • Warranties, claim policies • Performance history	• Price • Financial position • Communication system • Technical capability • Management and organisation • Procedural compliance • Operating controls • Desire for business • Reputation and position of the specific industry • Production capacities and facilities	• Attitude • Offered repair service • Amount of the performed past business • Impressions • Labour relations record • Packaging ability • Training aids • Geographical location	• Reciprocal arrangement

Source: Adapted from Weber *et al.* (1991).
Figure 2.4: The supplier selection criteria.

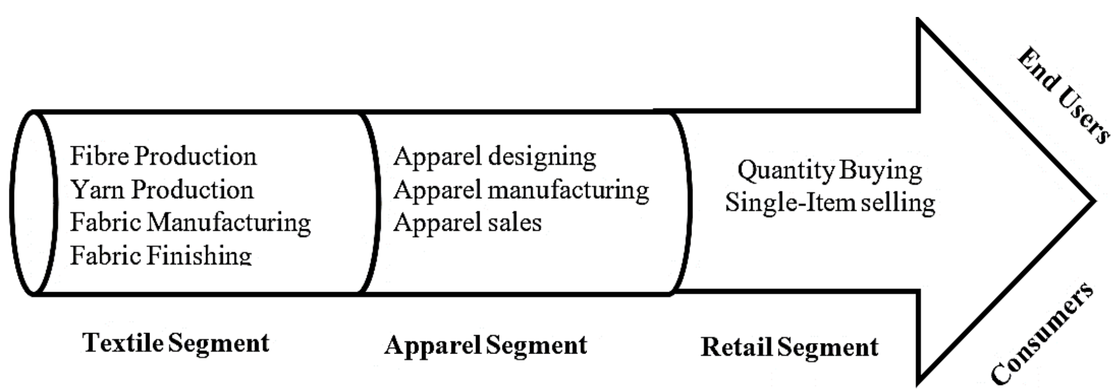
However, within the Industry 4.0 era, IT is one of the enablers. With time, Weber *et al.'s* (1991) and Dickson's (1966) decision criteria have changed their relative importance: both did not include IT factors as part of an Industry 4.0 enablers and EE conceptual framework. An EE should comprise the use of modern telecommunication and IT (Jagdev and Browne, 1998). Jain *et al.* (2009, p.3034) developed SSEP and their study "aimed at providing a broad review of the main approaches to supplier-related issues especially supplier selection, supplier-buyer relationships, supplier-buyer flexibility in relationships in a dynamic supply chain, through the description of the main characteristics, techniques, ongoing developments and research activities" (Jain *et al.*, 2009, p.3034). Ho *et al.* (2010) also established SSEP techniques from seventy-eight studies published between 2000 and 2008. Ho *et al.* (2010) classified the CSDCs into three aspects: the most common criteria, second common criteria and the third criteria cluster. The common criteria were the quality, "delivery, price or cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment" (Ho *et al.*, 2010, p.21). Also, Rosenau and Wilson (2014) created the CSDCs including cost, capacity, capability, minimums, labour and equipment, infrastructure and logistics, throughput, lead time, quality, competition, and distance. The studies by Rosenau and Wilson (2014), Ho *et al.* (2010), Jain *et al.* (2009), Weber *et al.* (1991) and Dickson (1966), among others, formed the general CSDCs: their CSDCs can be applied in several manufacturing industries.

The following are some of the recent research that explored supplier selection within the era of Industry 4.0: Sachdeva *et al.* (2019) proposed a "hybrid intuitionistic fuzzy entropy weight-based multi-criteria decision model with TOPSIS" for the automobile industry. Sachdeva *et al.* (2019) considered price or cost, relationship, Industry 4.0 technologically enabled, rejection rate and delivery delay, as their CSDCs. Ghadimi *et al.* (2019) suggested a multi-agent systems method within the Industry 4.0 framework to address sustainable SSEP; and Kaya *et al.* (2020) developed an Industry 4.0 framework using an integrated fuzzy multi-criteria decision-making approach. The above studies incorporated Industry 4.0-related concepts without full consideration of all essential sustainability tenets.

Despite the substantial contributions in executing SSEP from Ghadimi *et al.* (2019), Rosenau and Wilson (2014), Ho *et al.* (2010), Jain *et al.* (2009), Weber *et al.* (1991) and Dickson (1966), among others, there is high pressure on all enterprises concerning modern slavery issues and environmental factors (Benstead *et al.*, 2018). The above studies did not consider contemporary issues. Their studies did not also consider an EE as an essential conceptual framework for working jointly. During today's business era, the EE concept is crucial for enabling an equitable ordering process(es) amongst SMEs. Thus, it is vital to determine the CSDCs, which can enable equitable order allocation. To do so, the participating firms are only those receiving bulk orders without enough capacities and capabilities to produce within the agreed lead time. In such a situation, working with other firms as an EE becomes a vital idea because bulk orders can be equitably allocated amongst the willing partners to meet retailers' needs. This thus requires well-established and updated CSDCs, which includes sustainability tenets: economic, environmental, and social-related factors. To bridge the gap, a new list of decision criteria was thus established to meet the current needs of allocating orders equitably (Section 5.4). The CSDCs assisted in the developed conceptual models, specifically when SMEs work as an extended enterprise (Figures 6.7 and 6.9).

2.8 Apparel supply chain management (SCM)

SCM was initiated in manufacturing industries in the early 1980s (Harland, 1996). SCM has significantly been considered by various authors and sectors (Lambert and Cooper, 2000; LeMay *et al.*, 2017). SCM for the T&A sector comprises the complex webs in which an upstream includes the definitive suppliers (Cao *et al.*, 2017). Many SCM definitions exist, but for this research, SCM is considered as "the design and coordination of a network through which organisations and individuals get, use, deliver, and dispose of material goods; acquire and distribute services; and make their offerings available to markets, customers, and clients" (LeMay *et al.*, 2017, p.1446). The T&A supply chain is complex and dynamic (Tyler *et al.*, 2006). The domestic supply chain is less complicated compared to the global (international) supply chain, and this is because the global chain requires the integration of other countries' partners within their systems. Figures 2.5 and 2.6 illustrate the simple textile-apparel chain and the general supply chain framework, respectively.



Source: Adapted from Jones (2006).

Figure 2.5: Simple textile-apparel pipeline.

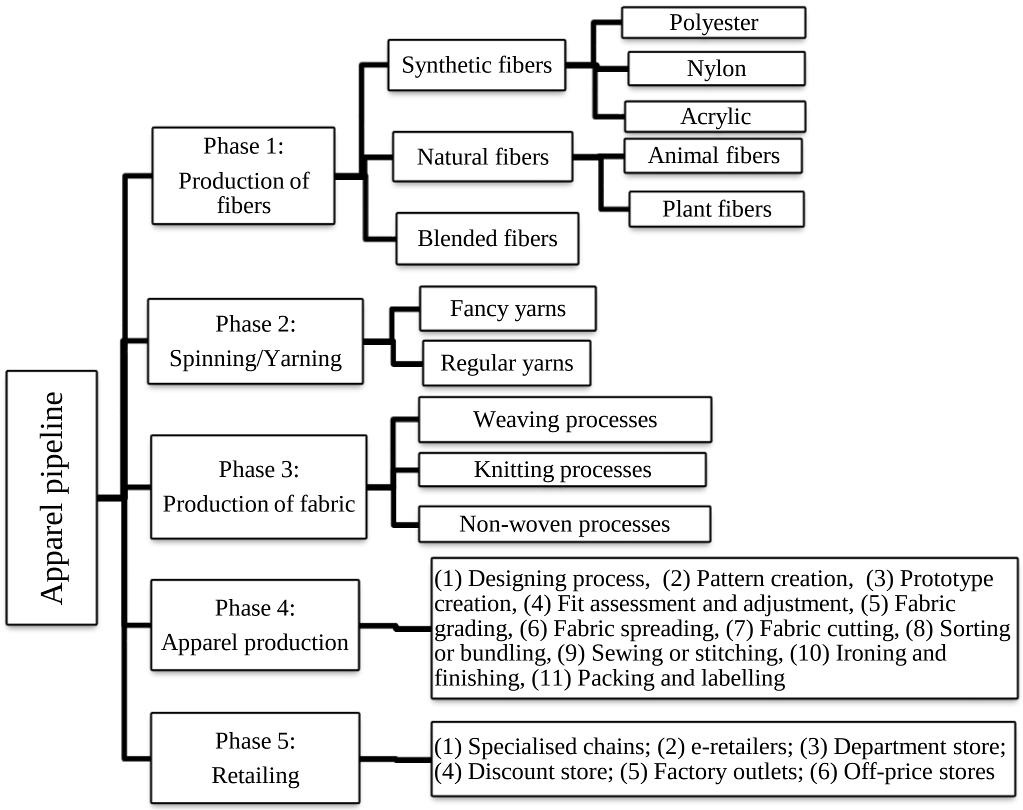
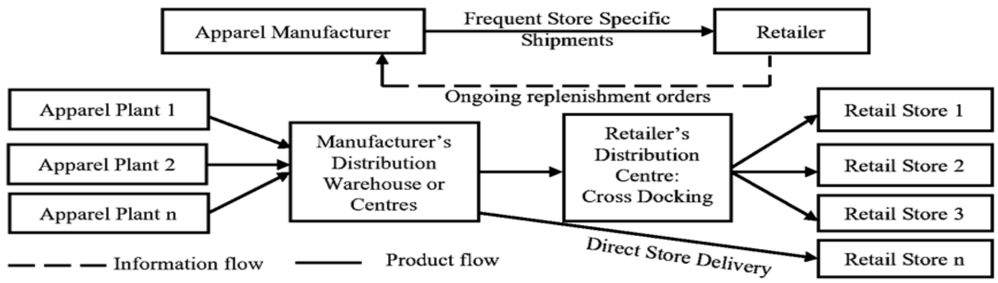


Figure 2.6: The general apparel supply chain framework.

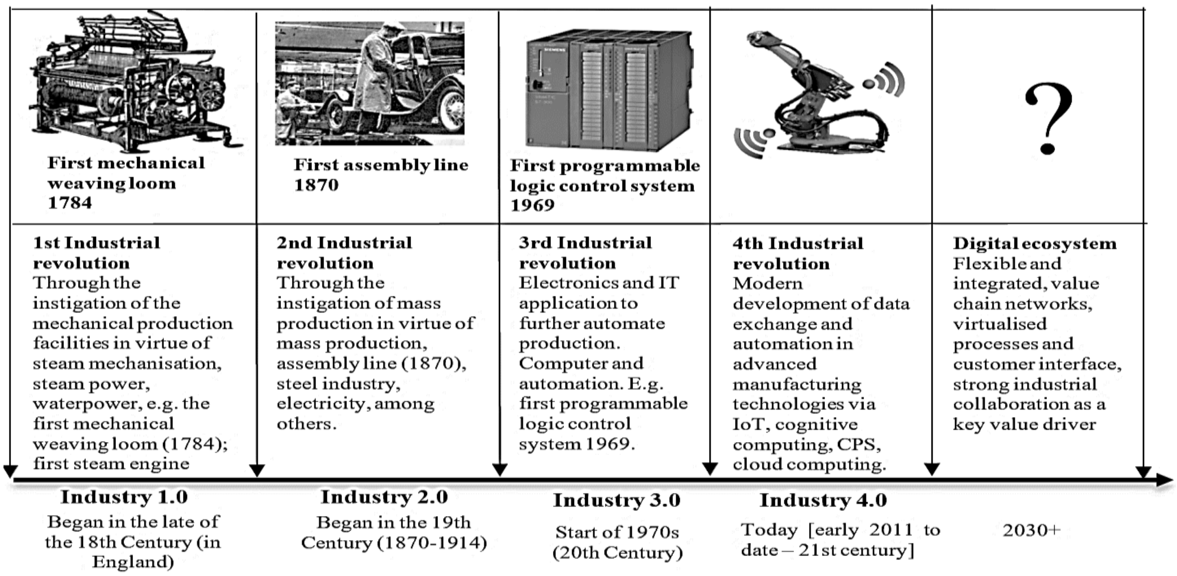
Management of the dynamic and complex chains require digitalised system methods which can bring optimal results. For example, Abernathy *et al.* (2000) discussed the scenario of the US retailers who used to follow the traditional retailing model: they had to wait for six to nine months as the lead time. After the transformation of the retailers' distribution channel, the retailers could wait for not more than seven days. The T&A sector's supply chain is also made of short product life cycles, high product varieties and unpredictable customers' demand (Al-Zubaidi and Tyler, 2004; Bruce and Daly, 2011). Digitalising the SCM requires commitment and reasonable investment. For example, the breakthrough transformation shown in Figure 2.7 required a massive investment in the whole processes of integrating barcodes, EDI, the modern distribution centres, and the promulgation of the standards across the firms (Abernathy *et al.*, 2000). ICT integration is crucial in attaining breakthrough improvements (MacDougall, 2014). Appropriate ICT assists to increase innovativeness, effectiveness and efficiency (Demirkan and Delen, 2013). To succeed in digitalising the apparel supply chain, mainly for the retailing part, ICT can influence a Quick Response (QR) strategy and an accurate response (AR). The critical elements for executing QR and AR strategies rely on the advancement of ICT (Chandra and Kumar, 2000). For SCM, many industries have common things, though, for the T&A sector, the chain is more complex due to many chucks in making apparel (Bruce and Daly, 2011; Mahmood and Kess, 2015).



Source: Adapted from Abernathy *et al.* (2000, p.8).
Figure 2.7: Relation of the lean retailing-apparel supplier.

2.9 Industry 4.0 perspective in apparel manufacturing

Manufacturing industries are transforming their operation systems into full digitalisation and intelligentisation (Zhou, 2013; Brettel *et al.*, 2014; Erol *et al.*, 2016; Sanders *et al.*, 2016; Zezulka *et al.*, 2016). Such a transformation is referred to as Industry 4.0: the fourth technological revolution. The German government established the Industry 4.0 concept in 2011 (Kagermann *et al.*, 2013). Zhou (2013, p.1) explains manufacturing digitalisation and intelligentisation as the "core technology of the new industrial revolution." Figure 2.8 depicts the revolutions from Industry 1.0 to Industry 4.0. The framework of Industry 4.0 has drifted out of the specialised manufacturing treatise to turn out to be a universal concept with mainstream applicability and appeal, proved by several neologisms, e.g., Innovation 4.0, Work 4.0 (Madsen, 2019), Factory 4.0 (Küsters *et al.*, 2017), Apparel 4.0 (Gökalp *et al.*, 2018), Textile 4.0 (Chen and Xing, 2015), etc. Since there is a need for an apparel sector to improve its equitable distribution systems for the SMEs; this sector is urged to develop strong integrated networks. Such networks should incorporate various elements of Industry 4.0. Several key elements are needed to achieve the virtual integration of the digital supply chain. Such elements include autonomous logistics, assimilated planning, integrated execution systems, visibility in logistics, spare part management systems, smart procurement (Procurement 4.0), smart warehousing, prescriptive supply chain analytics, and purchase order management (POM) system: the realisation of the digital supply chain requires Industry 4.0 concepts (Schrauf and Berttram, 2017).



Source: Summarised from Kagermann *et al.* (2013); Schlaepfer *et al.* (2015); Simonis *et al.* (2016); Schrauf and Berttram (2017) and Taifa and Vhora (2019).

Figure 2.8: The industrial revolutions timeline.

2.9.1 Industry 4.0 perspective: Related studies with order distribution

As noted in Section 2.9, Industry 4.0 concepts began in 2011; thus, in the most complex and dynamic sector like apparel sector, the concept is still in its initial phases (Taifa et al., 2020c). Several of Industry 4.0’s technological innovations are yet to be fully realised in numerous manufacturing factories (Strange and Zucchella, 2017), including the apparel industry. Nevertheless, empirical and theoretical studies suggest the potential of renovating supply chains through the Industry 4.0 concepts. The following are recent research that explored the significant roles of Industry 4.0: Ślusarczyk *et al.* (2019) studied the performance of the apparel firms in Malaysian through the Industry 4.0 theoretical framework and its positive influence on the effectiveness of the firms’ production services and processes; Fatorachian and Kazemi (2018) suggested a conceptual Industry 4.0 framework for operationalisation in manufacturing; and Garay-Rondero *et al.* (2019) suggested an abstraction (conceptual) model, which illustrates essential features shaping the latest digital supply chains within an Industry 4.0 concept: their frameworks considered both technological and managerial perspectives. With Industry 4.0 concepts still in its preliminary stages, many studies create conceptual models; there is a conspicuous lack of studies centred on allocating or dividing bulk orders equitably in any industry (Medvedev *et al.*, 2019).

2.10 The theoretical background of other sectors

This section briefly discussed three sectors: automotive, construction and computer.

2.10.1 The automotive distribution system in the UK

The UK automotive industry is considered to be with a turnover of above £71.6 billion, it employs over 169,000 people directly, while more than 814,000 people work across the wider automotive industry (Leech *et al.*, 2017). The UK automotive industry has nine major sports and premium car manufacturers, six centres for design, nine coach and bus manufacturers, six mainstream car manufacturers, nine engine manufacturers, 13 research and development centres, and 2500 suppliers (SMMT, 2016). The automotive industry is among the most competitive industries globally, and each manufacturer needs to take advantage of such competition in making enough profits (Holweg *et al.*, 2009).

Usually, all the supply chain nodes for the automotive industry are interdependent: the poor performance of one side impels the poor performance of other parties. Apart from the manufacturing side, customers contribute massively to the sustainability of the automotive business. It is vital to recognise customers who are enthusiastic about buying automotive products. This entails that the automotive industry, like other industries, needs robust supply chains for serving the targeted customers in a quick response. Several sections of the automotive industry have received outstanding attention from researchers compared to other sides: this includes the production-distribution side (Turner and Williams, 2015). Presently, researchers use digitalised techniques to improve production-distribution. The dynamics of supply chain performance are studied via computer simulation approaches. With the current era, the automotive industry has certainly changed much (SYSPRO, 2012), and the industry has adopted advanced technology in each section (Leech *et al.*, 2017). With all the efforts to advance the automotive industry through Industry 4.0 frameworks; Brandt and Taninecz (2008, p.4) still state that "one of the automotive industry's most intractable problems [has] been effective supply chain management."

To improve the automotive industry requires an effective SCM which is integrated with logistics management (Lešková, 2012). The automotive industry is in a transition period: the industry is implementing fundamental concepts of Industry 4.0. As stated by Leech *et al.*

(2017, p.26), the digitalisation is the “path to securing the UK automotive industry’s future.” The automotive industry focuses on dealerships as their major channels in creating contact and relationships with potential buyers: despite the unique role of dealerships, the industry requires a redesign of its existing infrastructure to influence accessibility and flexibility (EY, 2015). This is due to the necessity of developing market-specific combinations of digital and physical presence in consort with new distribution models. The required digitalised models are considered to improve interaction with potential buyers by offering unique services and ad-hoc product experiences (EY, 2015). The automotive industry needs digitalisation through the creation of a digital twin for the manufacturing processes, physical product, supply chains or a factory itself (Leech *et al.*, 2017). Some of the reported benefits of digitalisation in this industry include easy alteration of several systems and analysis for various purposes (Leech *et al.*, 2017). All these have to be performed through a digital form which enables simulation of numerous situations. Having created a digital twin, it can then be evaluated for multiple resolutions: thus, such a process can simplify any modification due to the presence of a digital form which permits simulation of many circumstances.

According to Leech *et al.* (2017), interview sessions with vehicle suppliers and manufacturers were carried to forecast the benefits of digitalisation in the automobile industry. The results include productivity increase by 3-5%, inventories reduction (12-20%), plant maintenance cost reduction (15-25%), shortening time to market products (15-25%), improving forecasting accuracy (80%), cost of poor quality decrease (5-12%), productivity increase for the technical disciplines—production planning (30-50%), and decrease of machine downtime (20-35%). These are extensive benefits from digitalisation. With the way this industry operates, there is much information and concepts to adapt from it. It is an industry committed to implementing the transformation of all critical activities (WEF, 2016). In the automotive industry, the research background proves that digitalisation is necessary for improving companies. The automotive industry also deals with several parts, and this requires working as tiers. The extended enterprise has been utilised effectively, whereby many SMEs are involved in sharing several orders to keep with the required lead times, quality level, responsiveness, agility, among other performance metrics. The automotive industry involves tiers. Tiers comprise the original equipment manufacturer (OEM). OEM can be explained as the firm or company that manufactures a product to be sold to another company, and the buyer resells the purchased product under its brand name. The operations of OEM within the automotive industry fit and apply the concept of the extended enterprise.

2.10.2 The supply chain in the computer industry

Computer industry involves a range of activities, including the design of the computer hardware and development of computer software, computer networking infrastructures, manufacturing computer components, as well as the provision of IT services. The development of software theory and formalisation of the algorithm and computation concepts by Alan M. Turing resulted in significant discoveries in several manufacturing industries (Lavington, 2012). The existence of the software industry drives the implementation of the ICT facilities in the supply chain (SC). Generally, the SC in the software industry, to one side, has significant differences from other sectors' SC such as construction, apparel, and automotive industry. SC in the software companies can be either a national (domestic) chain or an international (global) chain. The global SC is much vulnerable to security issues: this makes it more complex than the domestic SC.

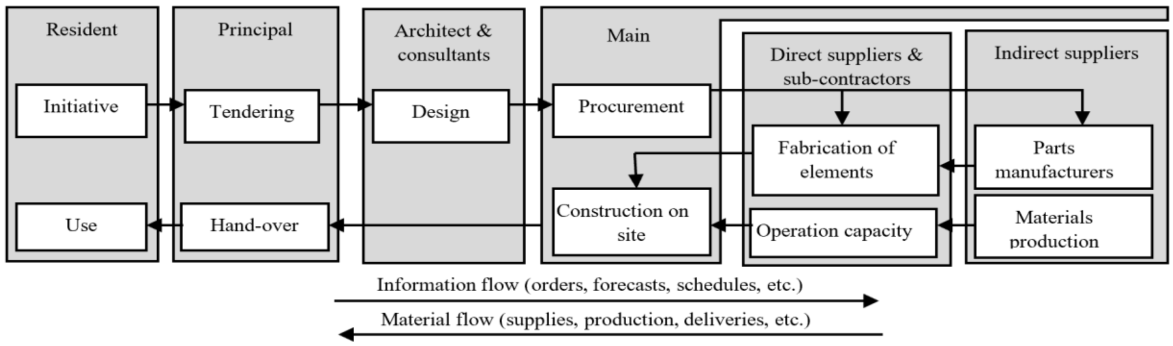
The computer industry's SC can generally be grouped as the computer software and hardware company supply chain. The hardware company SC is considered to be the same as other sectors. Several nodes of the supply chain, such as producers, suppliers, distributors (wholesalers, agents, and brokers), retailers and buyers, are involved in the chain. The standard transport mode, e.g., air, water, roads (trucks) and rail, also assist the inbound and outbound logistics. In dealing with the software SC, each supplier has three sets of control which must be appropriately managed: supplier sourcing (procurement); product development and testing (personnel, environment, software development); and product delivery (maintenance and distribution) (Reddy *et al.*, 2009). Du *et al.* (2013) state that "a software-focused supply chain is a supply chain where software constitutes a significant part of the total value of the product, and goods may not be physically flowing through the supply chain." For the hardware SC, there is a physical distribution of the products. The software supply chain (SSC) involves activities like development, release, deployment and maintenance from the company itself up to the end-users (Jansen *et al.*, 2006). SSC involves the owner of the industry itself and the government of the particular country to which the software is being developed (i.e. for the country's security reasons), manager for information security concerns and the suppliers. SSC has similarities with other industries' supply chains.

SSC can be practised on the concept of make-to-order (pull systems which entail the concepts of just-in-time) or make-to-stock like other industries. The supply chain for the software products shows different features when compared to other industries, especially by considering the internet-based products which can be delivered (transmitted) through networks to the clients. Here, the chain encounters high risks by being vulnerable to external parties who can hack the products (systems). SSC is advancing with great effectiveness and efficiency without compromising the functionality, quality, and assurance. Concerning the software assurance, there are three key elements: security, integrity and authenticity (Reddy *et al.*, 2009). Different sectors depend on the software industry; for example, up to forty per cent of the manufacturing costs of vehicles are due to software and electronics (Broy, 2006). Industry 3.0 chiefly centred on computer and automation (Figure 2.8). Digitalisation through Industry 4.0 technologies also require computer and automation concepts. Industry 4.0 is all about computer industry excellence. This industry has been an innovation driver for the automotive industry for over two decades (Broy, 2006). Despite the significance of this sector within industrialisation, the research background does not indicate the order allocation processes. However, possibly some firms collaborate to distribute software development processes into segments to speed up the delivery and acceptance of the end products.

2.10.3 The supply chain in the construction industry

SCM concept arose with many potentialities in the 1990s for the construction industries (CIs) (Segerstedt and Olofsson, 2010). CIs may possibly be construed as an "extended enterprise in which all firms virtually operate as business units representing the business functions of a factory without walls that acts as a collaborative network of organisational units, regardless of location and regardless who owns them" (Voordijk and Vrijhoef, 2003, p.837). In the CIs, *firms* include an architect, project developer, contractor, an engineering firm, subcontractors and the suppliers; the *business functions* include "marketing, design, engineering, components manufacture, supply and assembly and delivery" (Voordijk and

Vrijhoef, 2003, p.837). So, the CIs are regarded as a make-to-order supply chain. It is contrary to the supply chain of the T&A industry, which can be regarded as a make-to-order, make-to-stock, or hybrid. The CIs is profoundly reliant on the subcontractors and the suppliers of the building materials. Figure 2.9 depicts the supply chain of the CIs.



Source: Adapted from Vrijhoef and Koskela (2000, p.173).
Figure 2.9: Traditional supply chain for the construction industry.

Several firms established strong partnerships with other companies: such practice is still a technical challenge (Cheng *et al.*, 2010) because of high fragmentation of the CIs (Dainty *et al.*, 2001). The partnering processes (about the administrative routines, technical solutions or logistics) are performed literally for creating networks with the suppliers and their potential customers (Dubois and Gadde, 2000). Such partnering is an *integration*, to which the majority perform the supply chain integration (Kahn and Mentzer, 1996; Fawcett and Magnan, 2002). The UK CIs have tried to change from the traditional adversarial to the collaborative aspects (Meng, 2010). Deficiencies were observed in the applied models (Meng, 2010), and this shows that SC is still facing many problems (Vrijhoef and Koskela, 2000). The transformation requires new modern methods on how to handle such situations. The requirement of the transformation in the CIs was justified by Briscoe *et al.* (2004, p.193) that "the industry has suffered from cost overruns, programme delays and poor productivity for a long period." The similar problems in the CIs were stated by Aloini *et al.* (2012). The potential improvements for this sector were further suggested to be in terms of the SCM, benchmarking, lean construction, and partnering (Egan, 1998): thus, the CIs needs a well-formulated, strategically planned, organised and executed supply chain (Aloini *et al.*, 2012). Childerhouse *et al.* (2003) also highlighted the deprived performance status of the CIs, as reported by Egan (1998). Egan (1998) also suggested the use of the business process reengineering, which improved electronics and automotive industries and also proposed to adopt some major concepts of JIT in reducing the cycle-time for designing houses.

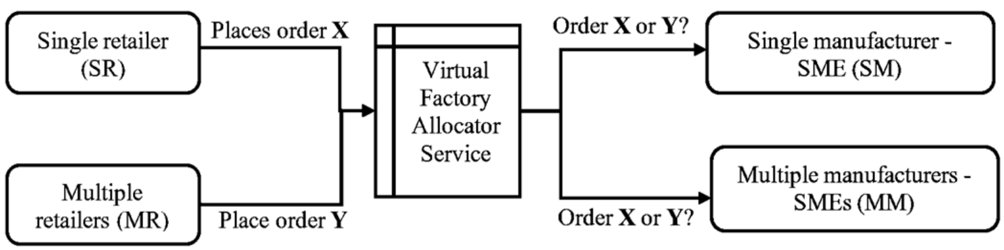
During the 21st Century, ICT facilities have transformed many sectors. The CIs is evidenced to have tried an implementation of the ICT (Web-Based Information System) for its SC networks (Mohamed, 2003). ICT systems helped in managing the construction projects, mainly in getting information and visualising the progress of the projects. Although there are some improvements in the supply chain of the CIs (Akintoye *et al.*, 2000), it is still considered as a rigid sector to adopt changes (Arantes *et al.*, 2015). Integration of the main suppliers needs to be performed with a rethinking of the design and the construction processes (Elliman and Orange, 2000). This industry also has never been in a hurry to use the appropriate SCM practices (Akintoye *et al.*, 2000; Fearne and Fowler, 2006). More efforts are still needed in transforming this sector: the sector involves practices which are in an adversarial way (Cheng *et al.*, 2001), fragmented supply relationships (Kumaraswamy *et al.*, 2000) and a deficiency (Luk, 1998) in trust among the clients, the main contractors and the sub-contractors. The industry exhibits the way contractors apply fewer efforts and use minimal time in considering the suppliers who are positioned at the downstream tiers (Pala *et al.*, 2014). Still, the sector uses much effort and time to the demand side in the SC. The collaborative agreement is required among the stakeholders of the sector. Generally, there are possibly few practices to be benchmarked from this sector that can be adapted in the apparel sector regarding the distribution systems and supply chain at large.

2.11 Related studies or research to equitably allocate orders

Many studies researched order distribution (Zhang *et al.*, 2002; Xiang *et al.*, 2014; Scott *et al.*, 2015; Renna and Perrone, 2015): yet, the term distribution is related to *delivery* or *supply* of the finished products to wholesalers, retailers or the end customers. Many studies explore the two-echelon supply chain (Felfel *et al.*, 2015): one manufacturer to multiple suppliers, wholesalers or customers. Other studies focused on line balancing of the sewing processes, e.g. the studies by Said and Ismail (2013) and Liong and Rahim (2015). Also, Kursun and Kalaoglu (2009) simulated the production line of apparel manufacturing using Enterprise Dynamics® for the sewing line: their study considered 800 hours as the warm-up period at a

95% confidence level. The replication length was 100, and they validated the results by comparing them with the actual system. Similarly, Güner and Ünal (2008) performed the discrete-event modelling for the apparel factory by the Arena® version 7.0 simulation software, specifically for the sewing processes of the t-shirt. The validation process involved the hypothesis testing using the throughput with a 95% confidence interval.

As noted in Section 2.9.1 that Industry 4.0 concepts are still in its preliminary stages, many studies create conceptual models: thus, indicating a conspicuous lack of studies centred on allocating bulk orders equitably in any industry. There are possibilities that the digital business approach for equitable order allocation in the T&A sector has not been embraced suitably. Hardly any research digitalised order processing, especially on enabling equitable order allocation to multiple SMEs as a means of facilitating their survival. Order allocation on its viewpoint is not a new research area within the supply chain in the manufacturing industries. Figure 2.10 shows possible practised scenarios in the T&A sector.



Note(s): X and Y are the order quantities. Multiple manufacturers, i.e. the SMEs, are considered to be working as an extended enterprise. The possible ordering processes: SR to SM; SR to MM; MR to SM and MR to MM.

Figure 2.10: The conceptual model of ordering options from retailers to SMEs.

Based on Figure 2.10, there are four scenarios as follows:

a) Single retailer to a single manufacturer (SME)—SRSM

When a single retailer places apparel orders to a single SME: this can be performed traditionally. The virtual factory allocator service (VFAS) must assess the performance criteria from a single SME conforming whether the manufacturer meets or exceeds the specifications from the retailer before allocating orders to the specific SME.

b) Single retailer to multiple manufacturers (SMEs)—SRMM

When a single retailer places an order to multiple SMEs: this is a multi-sourcing problem. VFAS must assess the performance criteria by checking whether each SME meets or exceeds the specifications from the retailer before allocating orders to the specific SME. For instance, Kawtummachai and Hop (2005) simulated the supply chain consisting of a firm that orders products from multiple manufacturers. The performance measure was the percentage of on-time delivery obtained through the developed order-allocation algorithm. Xiang *et al.* (2011; 2014) also allocated orders with consideration of a single company to multiple suppliers: they used the SIMIO® platform to simulate a discrete model of the supply chain. Four simulation cases were designed: the actual situation of the company; low level in the production load (PL); PL disequilibrium severely; and the low level in PL.

c) Multiple retailers to a single manufacturer (SME)—MRSM

When multiple retailers place an order to a single SME; a manufacturer must prioritise capacity and capability. Guo and Li (2014) considered this scenario with the assumption that the demand occurs as per the stochastic Poisson process. Their study used mathematical modelling with the centralised control to make a single decision, focused on one firm which comprised one warehouse and 20 identical retailers. Similarly, Islam *et al.* (2017) developed mathematical modelling for a single manufacturer with multiple retailers addressing the generalised demand distributions. Their results were validated after performing a sensitivity analysis of their retailers' demand based on an exponential distribution, a gamma distribution, and normal distribution probability function. There was no single demand distribution which was found to be better for all supply chain members.

d) Multiple retailers to multiple manufacturers (SMEs)—MRMM

When multiple retailers place an order to multiple SMEs; the Industry 4.0 concept (digitalisation) can be used. VFAS must assess the performance criteria by checking whether SMEs meet or exceed the specifications before allocating orders. Theoretically, Industry 4.0 includes smart networks, smart products, and smart factories (virtual factories). Until recently, the apparel industry was struggling both for highly innovative techniques, processes and materials (Bertola and Teunissen, 2018). Berg *et al.* (2017) and Bertola and Teunissen (2018), however, appreciate the technological innovations, including automated manufacturing, RFID, digital printing, digital performance management, virtual prototyping, 3D design, augmented reality, etc., in the fashion business. Although much of the SCM-related modelling concepts already conducted, hardly any research looked at order allocation opportunities for multiple retailers to multiple retailers using Industry 4.0 concept, i.e. a virtual distributed manufacturing network. The available studies discussed the distribution of the manufactured products from the manufacturers to the retailers (or wholesalers and customers) including the studies by Karbasian *et al.* (2008) and Kumar *et al.* (2015). So, this study focused on the MRMM scenario to allocate apparel orders equitably. The other scenarios—SRSM, SRMM and MRSM—are within the MRMM scenario.

Furthermore, the quick accomplishment for the received orders should be prioritised by any company, as its failure can cause loss of sales, market share and decrease in company's reputation (Medvedev *et al.*, 2019). Medvedev *et al.* (2019) conducted a comparative critical analytical study of suitable intelligent systems and methods for assigning orders. They aimed to enhance the useful download of production capacities of the participating enterprises. Table 2.4 presents their findings, whereby information systems for order allocation are not available despite the presence of other several systems for similar tasks. So, this shows the need for developing models (systems) that can help to allocate orders equitably.

Table 2.4: Functions of production management in several information systems.

		Parameters					
S/N	Information system (IS)	**Simulation for distributing orders**	Engineering data management	Production Management	Inventory control	Production planning	Dispatching production
IS_1	SAP/R3	**NA**	NA	A	A	A	A
IS_2	ERP – Galaxy	**NA**	NA	A	A	A	A
IS_3	Omega Production	**NA**	A	A	A	A	A
IS_4	Microsoft Dynamics AX	**NA**	NA	A	A	A	A
IS_5	Frigate Corporation	**NA**	NA	A	A	A	A
IS_6	Smart Factory	**NA**	NA	A	A	A	A

Source: Adapted from Medvedev *et al.* (2019, p.3). **Note(s):** ***A*** *(available)* indicates that the particular IS supports the specific parameter whereas ***NA*** *(not available)* does not support it.

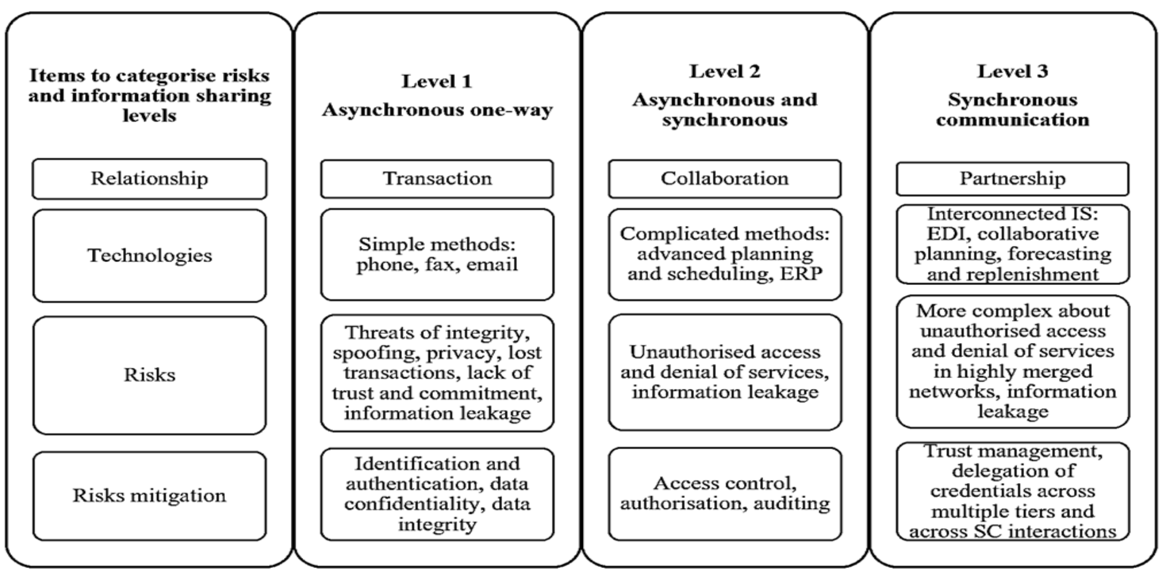
2.12 Management theory on information sharing and collaboration

There are several management theories, including scientific management, classical management, contingency theory, system theory, organisations as learning systems (also known as holistic or integral management theory), among others. For this study, the focus is on the latter management theory. Both retailers and SMEs have systems created through several subsystems: they require operating effectively and efficiently to support the longevity of their businesses. Then, once the (entire) firm is working holistically, this can result from collaborating with other related firms. Through this theory, each firm requires to work jointly with transparency on how to communicate, participate, share details and needs. So, if a cluster of SMEs works jointly, it is possible to share capacities and capabilities to dictate the equitable order allocation. Pull and push systems for order sharing on the computing cloud are not easy to implement due to the constraints linked with it. Despite that collaboration through Industry 4.0 is acknowledged to facilitate capacity utilisation and quick response to existing business prospects; some factors are impending such collaboration through an extended enterprise (Kazantsev *et al.*, 2018). For instance, Kazantsev *et al.* (2018) identified some of the factors that prevent collaborations, such as privacy or confidentiality, information asymmetry, switching costs, competitive pressure and path dependencies. Tran *et al.* (2016) mention costs, complexities, and risks, as some of the factors hindering information sharing. Other factors in executing an extended enterprise are trust, greater transparency of communication and the shared details, openness to share details and understanding of each other's needs, joint problem-solving readiness, and willingness.

For any devoted business partnership between firms, the notion of trust should not be neglected as it influences the entire collaboration processes. There is a discussion by Camarinha-Matos *et al.* (2017) that the significant enabler of Industry 4.0 should be 'collaborative networks'. Camarinha-Matos *et al.* (2017) argue that Industry 4.0 should enhance an increased digitalisation and the interconnection of production systems, business models, products, and value chains. The central feature of such an interconnection happens between the cyberworlds or virtual, i.e., the IoT and CPSs. Companies should research the risks associated with digitalisation to recognise the vision of Industry 4.0 correctly. Despite the notable benefits through information exchange, "managers will always be sceptical about sharing information with trading partners due to the perceived complexities, risks, and costs" (Tran *et al.*, 2016, p.1102). Thus, information sharing willingness turns into a "trade-off between efficiency and the responsiveness of the information resources" (Du *et al.*, 2012, p.89). This mainly happens when using complicated information systems (Tran *et al.*, 2016).

Seamless collaboration and integration within supply chain partners require advanced IT-enabled infrastructures. Several technologies exist in industries, such as mobile computing and extensible mark-up language, wireless application protocol, EDI, RFDI, the internet, etc. But, the critical challenge to several partners can be to the integration of technologies and information sharing (Baihaqi and Sohal, 2013). Collaborating firms should pose questions on which information to share, what are the suitable mechanisms for sharing, how to better utilise information to remain competitive (Baihaqi and Sohal, 2013), and information sharing frequency (Tran *et al.*, 2016). Baihaqi and Sohal's (2013) questions were also stated by Lotfi *et al.* (2013) who emphasised that firms should be aware of what to share, whom to share with, how to share and when to share. Decisions about these questions are often complex, and the design and the deployment of information systems are costly (Tran *et al.*, 2016).

Also, an equitable order allocation amongst a list of firms that operates as a single virtual entity needs information-sharing practice as a collaboration and interaction necessity. In executing this, security and risks should be strictly considered. This is because the information being shared among collaborating members is one of the company's assets; thus, proper security arrangements should be established (Kolluru and Meredith, 2001). Security actions reduce leakage of the proprietary information among members (Tran *et al.*, 2016). An information integration containing various levels of partnership, such as order allocation equitably, necessitates having several levels of risks as described by several researchers (e.g. Kolluru and Meredith, 2001; Tran *et al.*, 2016). Figure 2.11 is a three-level model of information-sharing as proposed by Kolluru and Meredith (2001) and Tran *et al.* (2016).



Source: Adapted from Kolluru and Meredith (2001, pp.234-236) and Tran *et al.* (2016, p.1105).
Figure 2.11: Categories of risks and information sharing levels.

2.13 Identified research gaps in the apparel industry

The theoretical background revealed the following four research gaps:

a) Apparel manufacturers (SMEs) cannot easily secure enough apparel orders on their own (Brill *et al.*, 2019). SMEs thus need to be distributed enough orders for their long-term survival. Therefore, there is a need for developing a strong collaboration between SMEs and retailers.

b) Theoretical underpinnings indicate that an apparel sector still operates much traditionally compared to other sectors (Köksal *et al.*, 2017).

c) So far, it is true that the apparel sector has slightly implemented ICT facilities (Chen *et al.*, 2007). However, due to the revolution of the industrialisation—Industry 3.0 to Industry 4.0—the T&A sector can also be transformed. Grewal *et al.* (2017) recommended future studies to explore the benefits of IoT to retailers. Executing Industry 4.0 concepts in retailing service is crucial (Grewal *et al.*, 2017). Transformation is needed in enabling sharing of bulk orders between the retailers and the manufacturers.

   There is thus a need to develop Industry 4.0-related approach(es), which can handle the complicated distribution systems of bulk orders. Digital transformation success can create a positive impact on the sector and can be the best starting point of shifting the T&A sector to Textile 4.0 (Chen and Xing, 2015), Fashion 4.0 (Bertola and Teunissen, 2018) and Apparel 4.0 (Gökalp *et al.*, 2018).

d) Hardly any study discussed order allocation thru virtually distributed manufacturing networks using digital technologies that could facilitate improved coordination between manufacturers and retailers; thus, stimulating developing an equitable order allocation model(s). The scenario probably not much explored is when multiple retailers place orders to multiple SMEs using computer simulation approaches.

2.14 A summary and the research question

The theoretical background recaps the key factors which hinder the digitalisation of the UK apparel manufacturing sector. The recent underpinnings have emphasised on the Industry 4.0 revolution concept as the way of digitalising and making an intelligentisation. The literature also emphasises information sharing, the creation of collaboration and the beneficial long-term partnership as well as working as an extended enterprise in achieving competitive advantages.

The theoretical underpinnings help to formulate the *research question(s),* which require further research. Therefore, the broader contextual question is: how can an equitable order distribution, sharing, dividing or allocation system be digitalised for UK apparel manufacturing—SMEs? But the driving research question is: *is it feasible for a group of UK apparel manufacturing (SMEs) to work together by equitably allocated or distributed multiple orders?* This question leads to two major assumptions:

a) The UK apparel manufacturing (SMEs) is currently using the traditional (long-established) approaches in handling the received orders. This is in line to when a group of manufacturers would wish to process the received orders as an extended enterprise. That means, the allocation process(es), if available, is not yet fully digitalised.

b) It is also assumed that digitalisation is a necessary concept for UK apparel manufacturing (SMEs). This is due to many advantages reported regarding digitalisation of other processes of textiles and apparel as well as other industries (i.e. automobile, software, among others). Some advantages under digitalisation include an improved efficiency, improved resources utilisation, coordination improvement, increased speed, trust and flexibility (Weinswig, 2017). Deployment of digital technologies has the potential of reducing lead time by 48% (Weinswig, 2017). Moreover, a magazine for the textile network from Germany published in 2017 that the future of fashion is digital (Meisenbach GmbH, 2017). This sector has now installed technologies that embrace the digital age, i.e. from "digital textile printing and digital coating technologies to fully digitalised production processes" (Meisenbach GmbH, 2017, p.14).

Although part of order allocation is not yet researched, it does not mean that always digitalisation is a good thing to an industry. There must be well-articulated conditions for the system being transformed to achieve digitalisation benefits. For example, the study by Kroll *et al.* (2018) pointed out the impact of digitalisation on manufacturing regarding innovation performance and production efficiency of companies. Their study acknowledged the discussion both from the politician perspectives and academic sphere regarding digitalisation. Kroll *et al.* (2018, p.23) highlighted that an "empirically sound analysis of the effects of digitalisation is possible only when the concrete nature and purpose of technologies subsumed under the heading of digitalisation are defined clearly."

Contrary to the previous findings, Kroll *et al.* (2018) found that it is not always necessary to achieve smoothly through digitalisation, mainly when upgrading existing systems. So, this made an essential remark of researching to illustrate the feasibility models of allocating bulk orders equitably to a cluster of SMEs. The model should consider all research gaps and answer the major question regarding the digitalisation of the order distribution. The digitalised network is needed to enable the factories to secure orders in fulfilling their volatile demand from British retailers. The model can be referred to as Digital Equitable Order Allocation Model (DEOAM) as a result. Chapter 3 discusses the modelling and simulation reviews.

Chapter 3 Modelling and simulation methods overview

3.1 Overview of modelling and simulation

Modelling and simulation are inseparable procedures (Matko *et al.*, 1992). Modelling is the process of developing interconnection between crucial entities of the studied real process, while models relate to the constraints, goals and the performance criteria (Matko *et al.*, 1992). Simulation is a numerical method for performing experiments which encompasses some kinds of logical and mathematical models using pertinent designed software to mimic the real-world system's or process's characteristics, structure or operations over extended periods (Ubeda and Allan, 1994). Ideally, experiments should imitate the functioning of the real systems, mostly using suitable computer software (Santner *et al.*, 2018). This research adopted the definition of a *system* which was given by Air Force Systems Command in 1991 as cited by Rossetti (2016, p.4) that "a system is a composite of people, products, and processes that provide a capability to satisfy stated needs." A complete system comprises software, hardware, the facilities, services, materials, data, skilled workforces, and techniques needed to accomplish, give, and sustain system effectiveness (Rossetti, 2016). A system contains multiple elements (inputs) to produce outputs using internal elements.

This study focused on the apparel industry's ordering system in enabling the SMEs to secure orders equitably. In achieving aims, simulations assist in deciding between the existing manufacturing systems or proposing the new ones. Development of virtual distributed manufacturing networks in the apparel industry is much cheaper and less time consuming when executed by simulation rather than trial and error approaches to find optimal solutions for the real system (Coyle, 1996). Simulation research mostly aims at achieving the following; *comparison*: to contrast system alternatives and their performance indicators based on the selected decision criteria regarding definite objectives; *prediction*: to forecast the future system performance; *optimisation*: to minimise or maximise the current system configurations subject to the given soft and hard constraints; and *investigation*: to examine and gain a comprehensive insight into the performance or behaviour of the modelled system subject to the specified inputs or variables (Rossetti, 2016).

The domestic supply chain for the UK apparel sector can be digitalised through computer simulation approaches. The simulation process needs a *model* which is a “representation and abstraction of anything such as a real system, a proposed system, a futuristic system design, an entity, a phenomenon, or an idea” (Balci *et al.*, 2011, p.157). A model can be descriptive or prescriptive (normative): all models which can be simulated fall under the descriptive category (Balci, 2018). Examples of the prescriptive models include a linear programming model (LPM), mixed-integer LPM and the nonlinear optimisation model (Balci, 2018).

3.2 Comparison of programming languages with simulation packages

Choosing an appropriate simulation software to simulate a process requires logical reasoning. Simulation can be accomplished through software packages or programming languages. According to Law and Kelton (2000), at least four reasons are available to support the use of simulation software instead of a general-purpose programming language. First, simulation software packages spontaneously provide several elements necessary to develop a model, resulting in an overall project cost reduction and substantial decrease in programming time. Second, software packages offer a natural structure for simulation modelling. Third, simulation models are commonly simple to adjust and maintain if written in the right simulation software. Fourth, it is easier to detect errors in simulation software because several prospective errors are automatically detected. Since a simulation package includes fewer modelling constructs, there is less chance of getting many errors.

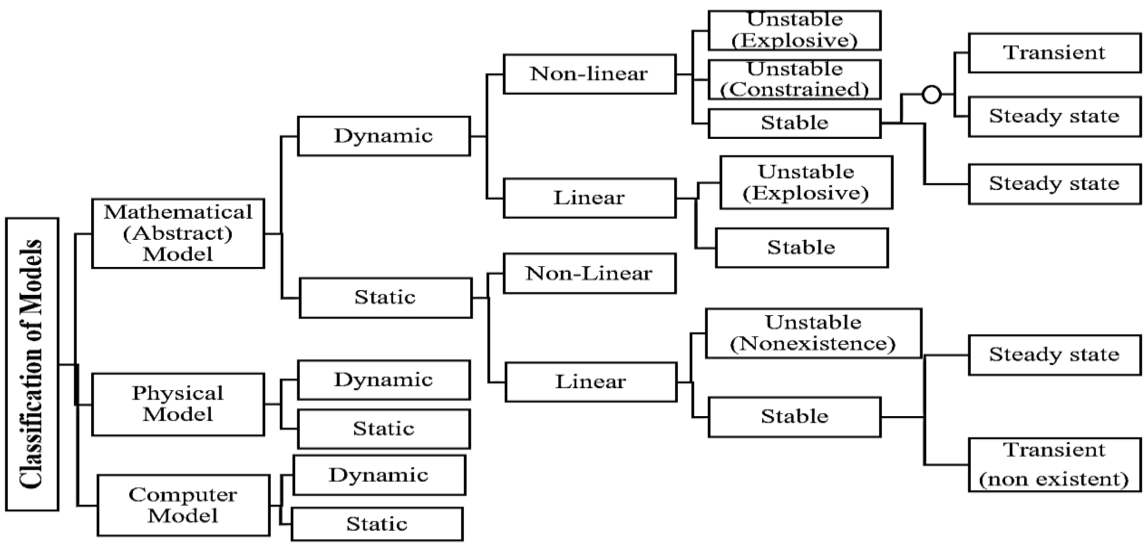
3.3 The general classification of models

Three models are mostly performed to either develop a new system or improve the existing process (system): these include the computer modelling and simulation (CMS) approach, physical model or real-life experimentations (RLE) approach and mathematical modelling (MM) approach, as depicted in Figure 3.1.

3.3.1 Real-life experimentations (RLE) approach versus CMS approach

To obtain optimal results via the RLE approach, it requires physical alteration of the various parameters. The RLE method requires making analysis physically. It is better to use the CMS than the RLE method due to the following reasons (Sacks *et al.*, 1989; Robinson, 1994):

a. Expenses (cost): the RLE approach is usually costlier than the CMS approach, and this can be explicitly substantiated when dealing with a sophisticated project(s) which requires substantial investments.
b. Control the time: when performing the RLE approach, for just one critical analysis, it can take a month whereas, for the CMS method, it takes a few minutes.
c. Safety factor: sometimes, the CMS approach can be required in analysing the effect of certain toxic chemical substances rather than applying the RLE approach.
d. Repeatability concern (replications): for the RLE method, the repeatability is not easy compared to the CMS approach.



Source: Adapted from Balci (2018).
Figure 3.1: Classification of models.

3.3.2 Mathematical modelling (MM) approach versus CMS approach

The MM approach comprises several techniques which can develop solutions for technical problems, sometimes quicker than the CMS approach. MM includes differential-equation methods, queuing theory, regression analysis and linear programming (Robinson, 1994). CMS is more costly than MM. CMS should not be used in solving a problem which can easily be solved by the spreadsheet analysis. It is possible to apply MM in distributing (sharing) orders in a multi-site production environment; however, there may be some critical points where MM cannot be applied. The CMS approach was thus decided based on the evidence and recommendations from the theoretical underpinnings. Some of the reasons provided by Robinson (1994) for choosing CMS instead of the MM approach are as follows:

(a) The simplicity in handling dynamic and transient effects: MM is much more useful and easier to apply if the system parameters are in a steady-state or normal. MM works with average values. For example, modelling a multi-sites production which incorporates the multi-products, multi-stages, multi-retailers and uncertainty demands makes the model to be with the steady states as well as the non-steady states, something which makes MM a bit difficult to apply. So, it is easier to deploy the CMS rather than the MM approach because CMS can handle such a situation and yield the outputs on the dynamism and transient effects. Examples of the transient effect can occur when production of products is at a steady pace at all production sites, and then immediately due to demand uncertainties from retailers, the changes just occur at a given time.

(b) Consideration of the random events' interactions: in modelling the random events within the system, it becomes complex to apply MM because the possibility of such an approach to provide the expected significant outputs is less compared to when applying the CMS. Increases in the random variables always lead to an increase in complexity.

(c) Generation of the non-standard distribution: when modelling systems, there is a high chance of generating non-standard distributions as well as the standard distributions. MM handles the standard distribution better, whereas CMS is capable of handling both distributions to elude any unnecessary assumptions or simplification in tackling the situations. On the contrary, Pidd (2004) states that the queuing theory model as one of the MM approaches can deal with the few distributions of both cases.

(d) Developing the MRMM (multiple retailers to multiple manufacturers) model using the MM approach may be challenging to validate the model if synthetic data are deployed.

3.4 Computer modelling and simulation (CMS) approach: an overview

Computer simulation is among the most effective approaches to solving numerous industrial problems. Computer simulations are "manipulations of arbitrarily chosen symbols referring to objects that are conceptualised from a specific point of view for a specific purpose (in scientific context: a research question)" (Hofmann *et al.*, 2011, p.135). The CMS approach began to be applied before 1950 (Feliz-Teixeira, 2006).

3.4.1 Computer modelling and simulation (CMS) approaches

Tables 3.1 and 3.2 illustrate some of the approaches of the CMS. Simulation models mainly allow observations regarding a specific system to be gathered as a function of time (Rossetti, 2016): from that viewpoint, two categories of simulation models exist—continuous and discrete event simulation (DES). This study explored DES. DES deals with the modelling of a process which evolves by an illustration in which the state variables alter rapidly at distinct points over a period of time (Law and Kelton, 2000; Law, 2015). The fundamental concepts of DES are developed from the queueing theory (Livingston and Sommerfeld, 1989).

Considering the nature of this research where retailers place orders that require to be allocated equitably, thus creates a queue when allocating to SMEs. In DES, observations are collected at chosen points in time when some alterations are made in the system. The chosen points in time are events (Rossetti, 2016). DES impacts the optimisation of sophisticated processes. Ideally, the simulation requires suitable software that generates results which must be validated and sometimes calibrated before being implemented. Typical environments like Arena®, FlexSim®, Enterprise Dynamics® simulation software packages, etc., dictate inclusiveness of both stochastic elements and deterministic elements.

According to Balci *et al.* (2011, p.158), system dynamics simulation (SDS) “uses a model representing cause-and-effect relationships regarding causal-loop diagrams, flow diagrams with levels and rates, and equations.” SDS is the oldest method; it can be described as deterministic mathematical equations (Zemczak, 2012) and has the causal shape loops with negative and positive feedback diagrams of the flow and stock. When modelling a real system, not all elements follow deterministic nature; or the use of mathematical equations. Balci *et al.* (2011, p.158) explain agent-based simulation (ABS) that it “uses a model representing agents and their interactions [whereas] an agent is intelligent, adaptive, and autonomous; a goal or self-directed can have the ability to learn, and change its behaviours based on experience.” Between the three simulation methods—ABS, SDS and DES—DES is the most appropriate one for executing equitable order allocation to a group of manufacturers (SMEs) working as a single virtual entity.

Table 3.1: The sets of simulation models.

Simulation model (SM)	Description
Stochastic SM	The presence of random effects and more than one random parameter; fixed inputs lead to different outcomes.
Deterministic SM	An absence of the random effects; the fixed inputs lead to fixed outputs.
Static SM	Description of the systems occurs at one point in time. There is no time factor consideration.
Dynamic SM	System description as it changes over time; there is a time consideration.
Discrete SM	There are changes in the system state at incremental (distinct) times.
Continuous/dynamic SM	The model consents the system state to change at any time.
Mixed continuous-discrete SM	It is also known as hybrid systems; it has elements of discrete and continuous models.

Source: Adapted from Groenewoud (2011) and Kumar (n.d.).

Table 3.2: Simulation taxonomies.

Type/Area	Description	Typical disciplines	References
Monte Carlo Simulation	Perform numerical integration of the functions which cannot be approached by the direct analytical methods.	Chemistry, mathematics, computational, reliability and nuclear engineering, nuclear physics, computational and statistical physics, probabilistic financial modelling, etc.	Balci *et al.* (2011); Pidd (2004); Ekyalimpa *et al.* (2016)
Continuous Simulation	Applies a model comprising differential equations and the simulation time is exemplified as a continuous parameter.	Computational fluid dynamics and physics, computational and aerospace, solid mechanics, materials science, heat transfer, etc.	Balci *et al.* (2011)
Discrete Event Simulation (DES)	"Uses a model built in terms of logic, and the simulation time is represented as a discrete variable."	Computer science, industrial and systems engineering, business; operations research, management science, civil engineering, etc.	Charris and Arboleda (2013); Balci *et al.* (2011, p.158)
Hybrid Simulation	It is a combination of a DES and continuous simulation.	The hybrid simulation includes continuous simulation and DES.	Ekyalimpa *et al.* (2016)
System Dynamics Simulation (SDM)	"Uses a model representing cause-and-effect relationships regarding causal-loop diagrams, flow diagrams with levels and rates, equations."	Business, decision sciences, organisational sciences, management, economics, social sciences, policy studies, system sciences, etc.	Balci *et al.* (2011, p.158)
Gaming-based Simulation	Part of the model is represented by human activity like training (management gaming), entertainment, educating, etc.	Business, training, education, management, entertainment industry, etc.	Wardaszko (2016); Nadolny *et al.* (2017); Padilla-Zea *et al.* (2015)
Agent-based Simulation	"Uses a model representing agents and their interactions. An agent is intelligent, adaptive, and autonomous."	Biological sciences, computational sciences, economics, physical sciences, cognitive sciences, organisational sciences, sociology, social sciences, etc.	Balci *et al.* (2011, p.158)
Virtual reality (VR)-based simulation	Permits person interaction with a 3D visual representation of an imaginary or a real system in a multisensory, an immersive, and interactive manner.	Computer-aided design and manufacturing, training, real estate, architecture, education, human-computer interaction, entertainment (movies, video games), medical science, etc.	Balci *et al.* (2011, p.159)

3.4.2 Computer simulation approach: advantages and disadvantages

a) Advantages of the computer simulation approach

The computer simulation approach is extensively deployed for exploring and predicting behaviours of complicated systems. It is thus imperative to list some of the reasons why the simulation approach should be used ahead of other methodologies (Figure 3.2).

Influence the best choice ⇒	• Helps to select an optimal solution before consuming resources.
Allows time manipulation ⇒	• It is possible to make time compression or expansion when analysing any scenario. Time can be set up to one year or more.
Analyse capital investments ⇒	• The process of imitating the system to be installed before an actual investment helps in saving money.
Helps to understand systems ⇒	• Helps to know well the problem at the time of developing a model. After simulating the model, it permits the simulator to analyse the systems' performance for an elongated time.
Visualising a plan ⇒	• Simulation dictates viewing the numerous parameters in 3D, high level of magnification, and at various angles.
Permits an exploration ⇒	• Simulation approach dictates exploring a system at various levels of thoughts. It is possible to explore the operating procedures of the system, the new policies (if any) and the methods before consuming resources.
Problem identification (diagnose problems) ⇒	• Contemporary industries have sophisticated systems. Exploration of the systems' parameters is cumbersome; however, with simulation, it is easy to study interactions of different variables and get an in-depth insight into it.
Identify the constraints ⇒	• It is easy to detect the bottlenecks from various systems' entities—products, customers, and materials.
Shorten the development time ⇒	• When designing a new system, the time can be reduced. An excellent robust system can also be performed within a short time by altering various parameters before the actual installation.
Training purposes ⇒	• It is easier to train people because a system can be well visualised.
Gaining approval ⇒	• Brings the consensus, which can result from disapproving the conclusion that was already approved.
Enables what-if analysis ⇒	• Helps to execute 'what-if analysis' in selecting appropriate solutions amongst the promising scenarios.
Prepare for changes ⇒	• Having described 'what-if analysis', it is easy to prepare for significant changes to the industry.

Source: Adapted from Maria (1997); Banks (1998); Banks (1999); Vieira (2004); Kieran *et al.* (2007); Bruzzone and Longo (2012); Charris and Arboleda (2013).

Figure 3.2: Benefits of using the simulation approach.

b) Disadvantages (limitations) of the computer simulation approach

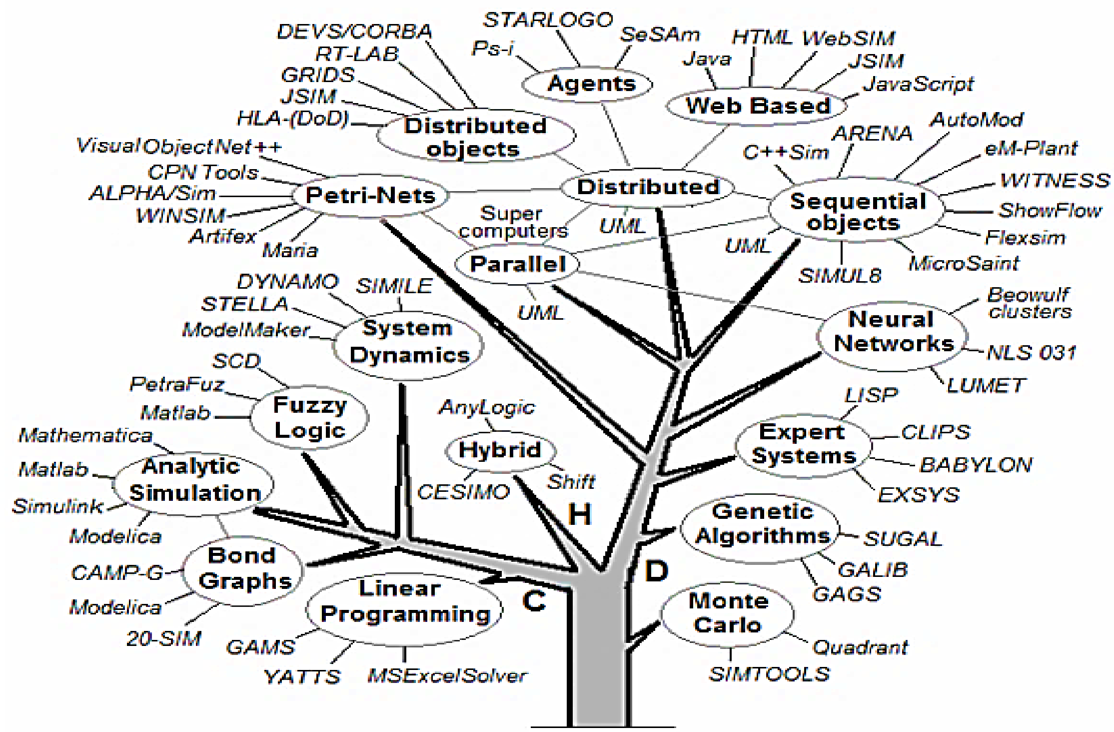
Although the simulation approach is acknowledged to possess numerous benefits, yet it has some disadvantages, as follows (Matko *et al.*, 1992; Banks, 1998):

(a) Expenses: getting a licence and the training require money. Computer time must also be sacrificed to get the required knowledge and skills to build models.
(b) Require special training: a simulator must be trained either through face-to-face sessions from the vendor of the specific software, YouTube videos, or an expert who already deployed the same software.
(c) Interpretation of results: simulation findings are challenging to clarify, and if misinterpreted, its implementation can mislead users.
(d) Validation difficulties: it is challenging to validate results.
(e) Generally, the CMS approach provides suboptimal solutions.

Many authors solved several problems using the CMS approach (Table 3.2). When comparing CMS, MM and RLE method, the theoretical underpinnings suggest the use of CMS as it offers more benefits than the rest. So, to realise equitable order allocation, it is better to deploy CMS because it covers numerous problems compared to other methods.

3.4.3 Simulation software: The selection process

Simulation approaches can be classified in numerous ways. Figure 3.3 shows various approaches and tools which can be deployed in executing discrete modelling and simulation of an equitable order allocation. However, neither Monte Carlo (statistical simulation), system dynamics, nor analytic methods are suitable for discrete modelling (Feliz-Teixeira, 2006). Instead, they are suitable for modelling strategic supply chains and other related problems. From Figure 3.3, it is not straightforward to decide the type of software to simulate a process. The difficulties are due to the presence of many software packages from vendors. In selecting the appropriate software, the analyst must analyse some technical parameters of the specific software. So, to answer the third research question (Section 1.4), the selection process of suitable discrete-event simulation software had to be performed.



Source: (Feliz-Teixeira, 2006, p.44).
Figure 3.3: Simulation tree with multiple approaches and tools.

Selection of the appropriate software is not an easy task. Sampedro (2013) identified six parameters for selecting the appropriate software (Table 3.3). These parameters are (A) complex system design evaluation; (B) service systems; (C) SCM; (D) what-if scenarios; (E) business process re-engineering and workflows; (F) manufacturing systems; and (G) debottlenecking. Among the listed software packages in Table 3.3, Arena® possesses more parameters than the other software packages. Kieran *et al.* (2007) also developed a software selection checklist (Table 3.4): the checklist assists in reducing the biases in selecting the appropriate software package, but still it is not sufficient to get the most suitable software.

Table 3.3: Parameters for selecting appropriate software.

Parameters	Software or package
A	Simul8®, Arena®, AnyLogic®, SIMPROCESS®, and AutoMod®.
B	Arena®, Simul8®, and ExtendSim®
C	Arena®, AnyLogic®, SAS® Simulation Studio®, and FlexSim®.
D	Arena®, SIMPROCESS®, Enterprise Dynamics®, and Simul8®.
E	Arena®, ProModel®, FlexSim®, Simcad Pro®, Simul8®, and SIMPROCESS®.
F	AutoMod®, Simcad Pro®, GoldSim®, FlexSim®, Plant Simulation®, ProModel®, and Simul8®.
G	ShowFlow®, Plant Simulation®, and Simul8®.

Source: Adapted from Sampedro (2013).

Table 3.4: Checklist for the simulation software selection.

Criteria	**Possibilities**		
	Yes	**No**	**Partially**
Captures the essence of the system at the screen image			
Standard interface			
Permits usage of the templates which can be altered or customised			
Permits usage of the different kind of details at the various levels			
Garners the statistics in an automatic way			
Permits an autonomy in making a customised screen display.			
Allows customisation of the control logic by the codes.			

Source: Adapted from Kieran *et al.* (2007).

Apart from the checklist presented in Table 3.4, the other criteria to be considered in selecting the appropriate software package include the suggested criteria in Figure 3.4. Considering that there are many simulation software packages, a review of the most suitable software was conducted, as shown in Table 3.5. It is also imperative to consider other aspects like the support for training by vendors, input distribution fits, a computer or laptop specifications and recommendations from previous related studies. From Figures 3.2 to 3.4, and Tables 3.3 to 3.5, the potential software packages include Arena®, Simul8® and FlexSim®. Among the three, the prominent simulation software for this study is Arena®.

Suitability	Can the package simulate an order distribution system?
Software or hardware	Which Operating Systems are compatible with the software? What are the hardware platforms required to run the model?
Model building	How is it easy to make a model? Which debugging supports are available? How many entities can be accommodated? Is it possible to import data externally?
Model runs	Can the model run fast? Can the speed be adjusted?
Reporting features	Are there standard reports to be generated after the run? Are there graphical reports, e.g. Histogram, time series? Is it possible to export the results?
Visual features	Is it possible to print a display which includes the conceptual model? How fast is it to make a model display?
Statistical features	Are there standard distribution and other recommended statistical features to be generated by the package at the end of the simulation runtime?
Presence of support	Does the vendor provide training, full support to a modeller and upgrade the package? Are there documents which can help in modelling?
Confidence level	Is there any evidence research for the applicability of the package? What is the company's size for the software?
Cost or expenses	What is the required training cost, and how much does it cost to get any support? Is there any maintenance cost to be incurred? What is the price to purchase the software package?

Source: Adapted from Robinson (1994).

Figure 3.4: The required criteria for making decisions about the software.

Table 3.5: Comparison of the numerous simulation software packages.

Software name (*Vendor*)	**Major explanation of the software**	**Field/area for application**	**Simulation methodology supported**	**Output analysis support**	**Optimisation *(Operating systems)***	**Source/ citation**
FlexSim® *(FlexSim Software Products, Inc.)* [5]	It is "used to develop, model, simulate, visualise, and monitor dynamic flow process activities and systems in an object-oriented software environment." In building a model, it is possible to use flex script, C++, or internal language.	Manufacturing, supply chains, material handling processes, shared access storage network (SANS), logistics operations, warehousing, etc.	Discrete Event (*3D Animation*)	Results can be observed as a predefined and user-defined report and graphs. Allows results exportation to other software packages using DLL, ODBC, DDE, and SQL.	OptQuest for optimisation engine is present *(Windows)*	Nordgren (2003, p.197)
Arena® *(Rockwell Automation)* [6]	"Arena is an object-based, hierarchical modelling tool that addresses a wide range of applications. […] provides a decision support tool that combines the capabilities and power of a simulation language ..." It is the "world's leading discrete event simulation platform serving the majority of Fortune 100 companies."	Food and beverage, supply chain, healthcare, mining, manufacturing, logistics operations, government, call centres, packaging, etc.	Discrete-Event; Continuous model and mixed models (*2D* and *3D Animation*)	Output Analyser provides the capability in evaluating the statistical reliability of the results. It links with Excel and Visio. It dictates testing procedures, i.e. confidence intervals, correlogram, analysis of variance, t-tests, moving averages, and data filters.	OptQuest® for Arena® *(Windows)*	AnyLogic (2015); Hammann and Markovitch (1995, p. 523); Oliveira *et al.* (2011)
SIMUL8® *(SIMUL8 Corporation)* [7]	"Object-oriented modelling tool, that incorporates programming language and model visualisation capabilities that enables it to create accurate, flexible, and robust simulations more rapidly."	Manufacturing, service industry or business process, SCM, operations scheduling, etc.	Discrete Event (*3D Animation*)	Dictates output viewers to link to Excel and Visio.	Presence of OptQuest *(Windows)*	Concannon *et al.* (2003, p.1488); Kieran *et al.* (2007)
AnyLogic® *(AnyLogic North America)* [8]	"It is proprietary simulation software based on the object-oriented conception. It combines three main simulation methodologies: system dynamics, discrete-event, and agent-based modelling."	SCM, complex system design evaluation, military and transportation systems, business process evaluation, etc.	Agent-Based, System Dynamics and Discrete Event (*3D Animation*)	Reports, model execution charts, logs, output to the fully in-built unified database or any external data source (text files, spreadsheets, databases).	OptQuest *(Windows, Mac, Linux)*	Merkuryeva and Bolshakovs (2010, p.169); AnyLogic (2015)

[5] FlexSim® (https://www.flexsim.com)
[6] Arena® (https://www.arenasimulation.com/)
[7] Simul8® (https://www.simul8.com/)
[8] AnyLogic® (https://www.anylogic.com/features/)

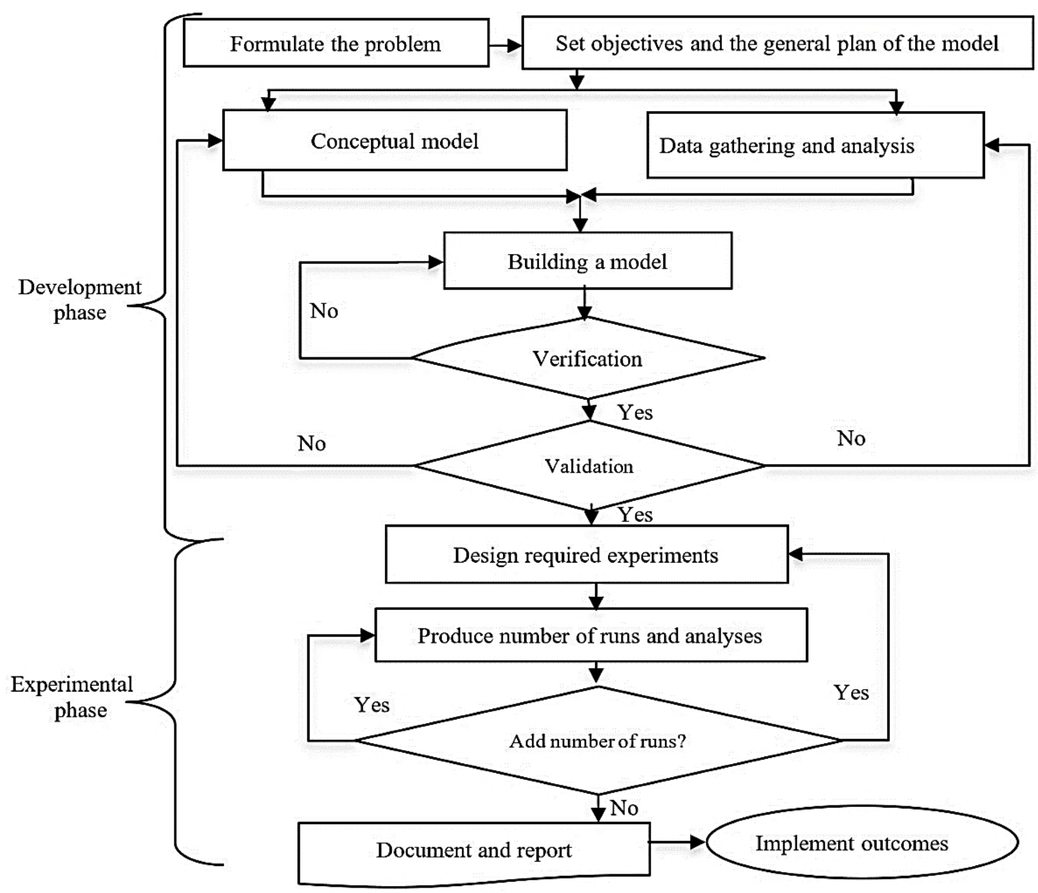
Enterprise Dynamics® *(Incontrol Simulation Solutions)*[9]	"It is an object-oriented software system used to model, simulate, visualise, and monitor dynamic-flow process activities and systems."	Material handling, manufacturing, logistics, etc.	Discrete Event (*3D Animation*)	Link to external systems to read and write information via Windows Sockets links or DDE, DLL, SQL, ODBC, DLL, and DDE.	Numerous combined links to optimisers *(Windows)*	(Nordgren, 2001, p.269)
Simio® *(Simio LLC)*[10]	"Simio is a simulation modelling framework based on intelligent objects (…) may be reused in multiple modelling projects."	Manufacturing systems, service systems, military operations, supply chain transportation systems, etc.	Discrete Event (*3D Animation*)	Analysis plots, sensitivity analysis, data in pivot tables are comprehensive; custom dashboards can be exported to external packages.	OptQuest *(Windows)*	(Pegden and Sturrock, 2010)
ProModel® Optimization Suite *(ProModel Corporation)*[11]	It is a "windows-based application with an intuitive graphical interface and object-oriented modelling constructs that eliminate the need for programming."	Manufacturing systems, supply chain systems, etc.	Discrete Event (*3D Animation*)	Dictates output viewer numerically, a variety of graphical representation or spreadsheet format, as well as Minitab	Via SimRunner *(Windows)*	(Harrell and Price, 2000, p.197)
SAS® Simulation Studio *(SAS)*[12]	"Uses discrete-event simulation to model and analyse systems based on the Java programming language and is a flexible, general-purpose, an object-oriented package designed to provide modelling and analysis tools."	Manufacturing systems, healthcare, education, retail, transportation, etc.	Discrete Event (*3D Animation*)	Analysis support can be performed through the SAS software products.	SAS/OR software *(Windows)*	(Hughes *et al.*, 2013, p.4026)
Witness® Simulation *(Lanner Group)*[13]	Model "a variety of discrete (e.g., part-based) and continuous (e.g., fluids and high-volume fast-moving goods) elements." "It is a discrete-event simulation package (…), has an object-oriented modelling environment. Its concept is based on the Queuing Theory."	Manufacturing, healthcare, oil and gas, defence, nuclear, etc.	Discrete Event (*3D Animation*)	Multi-response charts or tables, parameter sensitivity report, confidence intervals, boxplot and variance charts, and direct connection to Minitab.	Algorithms integrated comprise Tabu search, simulated Annealing, Six Sigma and Hill Sigma algorithm *(Windows)*	(Waller, 2012; Markt and Mayer, 1997, p.713; AnyLogic, 2015; Semanco and Marton, 2013, p.195)

Note(s): DDE: Dynamic Data Exchange; **3D**: three dimensional; **ODBC**: Open Database Connectivity; **SQL**: Structured Query Language; **DLL:** Dynamic-link library.

[9] Enterprise Dynamics® (https://www.incontrolsim.com/product/enterprise-dynamics/)
[10] Simio® (https://www.simio.com/index.php)
[11] ProModel® (https://www.promodel.com/)
[12] SAS® Simulation Studio (https://www.sas.com/en_gb/software/simulation-studio.html)
[13] Witness® Simulation (https://www.lanner.com/technology/witness-simulation-software.html)

3.4.4 Phases for modelling and simulating

There are phases to follow when modelling and simulating a process. These can be termed as simulation methodology. Rossetti (2016, p.9) stated six steps to follow: (1) ***D****efine* the specific problem; (2) ***E****stablish* key performance indicators for the assessment aims; (3) ***G****enerate* alternatives solutions; (4) ***R****ank* substitute solutions; (5) ***E****valuate* and replicate during the process, and (6) ***E****xecute* and assess the solution. Rossetti's (2016) simulation modelling can be termed based on the first letter of each phase as a *DEGREE*. To develop a virtual distributed manufacturing network that assists manufacturers to secure orders, the models should come up with optimised solutions, predicting the future digitalisation performance and thorough comparison of the traditional and digitalised approaches. Banks (1998) described the crucial steps to follow in modelling and simulating, as depicted in Figure 3.5 and Table 3.6. Figure 3.6 depicts a synopsis of the simulation process(es).



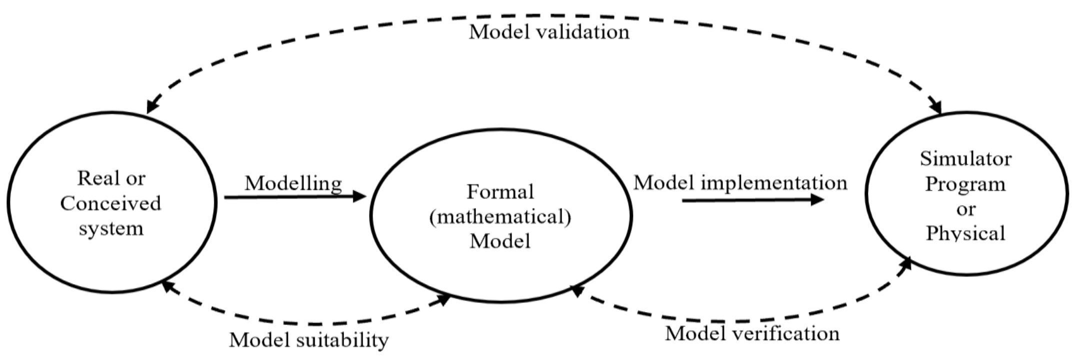
Source: (Banks, 1998). Adapted with permission from ©John Wiley & Sons, Inc.

Figure 3.5: The recommended steps for modelling and simulation processes.

Table 3.6: The simulation project phases.

Phase	Type	Explanation
Formulate the problem	Interpretive	To define the order allocation problem together with the desired objectives.
Model conceptualisation	Analytical	Abstracting the model to be developed in consideration of the characteristics, system's elements, and interactions.
Data gathering	Developmental	Determine, stipulate, and collect data for supporting the built model.
Model development	Developmental	The conceptualised model is captured using the relevant simulation software.
Verification process	Analytical	Relates to an evaluation of the transformational accuracy and answers the question of whether the created model was performed in the right way (Have I built the model in the right way?). The verification process focuses on the model development phases.
Validation process	Analytical	Checks whether the developed model is right. It relates to the developed model (Have I built the right model?)
Evaluation	Analytical	Scrutinises the simulation outputs to make interpretations and recommendations.
Documentation	Interpretive	Make evidential or supportive information.
Implementation	Developmental	To implement an optimal solution to industries.

Source: Adapted from Banks (1998).



Source: Adapted from Groenewoud (2011, p.25).
Figure 3.6: A glimpse of the simulation development processes.

3.5 Probability distribution

The probability distribution for random variables can be described as "a function that maps from the range of the random variable to a real number" (Rossetti, 2016, p.234). Modelling and simulating a model can be DES or continuous simulation. Discrete distribution is when considering parameters or variables as a countable or finite value; for instance, number of apparel products being produced, number of employees, number of machines, number of shifts, number of items in stock, number of trucks, and the like. Continuous distribution can be considered when variables or parameters are uncountable, e.g., the behaviour of retailers in purchasing products, the satisfaction of customers, and the like. The continuous distribution considers real numbers between 0 and 1. Some of the probability distribution functions (PDFs) in Table 3.7 were enabled or included in the deployed discrete Arena® simulation software (Chapters 6 and 7). All PDFs are built-in functions, and they all match the distributions in the Arena® Input Analyser, except the *Johnson* PDF.

Table 3.7: Common standard simulation input probability distributions.

Probability distribution	**Arena® generation**	**Parameter Values**	**Application (modelling)**	**Category**
Exponential ($1 / \lambda$)	*EXPO (Mean)*	Mean $\lambda = 0$	• The time between events, e.g. time between failure, interarrival time of customers • Time to finish a task, lead time, i.e. repair and service time	Non-negative continuous distribution: *Range (γ, ∞) where γ is usually zero or other specific positive value.*
Weibull (α, β)	WEIB (*Beta, Alpha*)	α>0, (shape), β>0 (scale)	• The time between events, e.g. time between failure, interarrival time • Time to complete a task, i.e. repair and service time	
Poisson (λ)	*POIS* (*Mean*)	Mean	• The number of events for a certain period, for example, a number of processes between failure. • Only applicable to discrete data. • The number of products per hour, for example, a number of boxes on a pallet of random size.	Non-negative discrete *Range: {0, 1, 2, …}*
Gamma (α, β)	*GAMM (Beta, Alpha)*	Beta, Alpha α>0, shape, β>0 (scale)	• The time between events, e.g. time between failure, interarrival time • Time to complete a task, i.e. repair and service time	Non-negative continuous distribution *Range (γ, ∞) whereby γ is typically zero or other specific positive values.*
Erlang (r, β)	*ERLA (ExpoMean)*	r>0, integer, β>0 (scale)	• The time between events, e.g. time between failure, interarrival time • Time to complete a task, i.e. repair and service time	
Lognormal	*LOGN* (*LogMean, LogStd*)	*r >0*, integer, *Beta >0* (scale)	• Time to complete a task, time to failure • It has higher hump than gamma, Erlang and Weibull	
Triangular	*TRIA* (*Min, Mode, Max)*	a=min, m=$mode$, b=max	• Distribution of a first pass • Applied in the absence of data as a rough model (if data is limited)	
Uniform	*UNIF (Min, Max)*	a=min, b=max	• Generation of random variables for sampling • Distribution of a first pass • Applicable for both continuous and discrete values	Bounded Continuous distribution: *Range [a, b] whereby a < b is usually positive values*
Beta	*BETA (Beta, Alpha)*	Shape, scale	• Time to accomplish a provided task, e.g. in a PERT network • Applied in the absence of data as a rough model • Modelling proportions: the percentage of defects in a batch.	

Normal, N (μ, δ^2)	*NORM (Mean, StdDev)*	Mean, StdDev	• Dimensions, e.g. weight and size • Errors, e.g. weight and size measurements • Typical for quality inspection processes and control modelling	Non-negative continuous distribution: *Range (γ, ∞); γ is usually 0 or other positive values.*
Discrete uniform DU (a,b)	*DISC (Prob1, Value1, Prob2, Value2, ...)*	*a≤b*	• Generation of random variables for sampling • Equal occurrence over a range of integers • Distribution of a first pass • Applicable for both continuous and discrete values	Bounded discrete: *Range* $\{X_i, X_i, \ldots, X_n\}$
Continuous	*CONT (Prob1, Value1, Prob2, Value2, ...).*	Mean	• Incorporate empirical data for continuous random variables directly into the developed model.	Bounded continuous distribution: *Range* $[X_i, X_n]$
Johnson SU	*JOHN (shape1, shape 2, scale, location)*	Gamma, γ Delta, δ, Lambda, λ	• Influences fitting several data sets from both bounded and unbounded distribution forms.	Unbounded: *Range (-∞, ∞)*; and bounded: *Range [ξ, ξ+λ]*

Source: Adapted from Robinson (1994); Banks (1998); Law and Kelton (2000); Kelton *et al.* (2004) and Rossetti (2016).

For this research, retail demand is one of the critical factors that requires thorough attention to model the required digitalised system for order allocation equitably. The retail demand must be with a clearly defined probability distribution function (PDF). The applied PDFs in several studies are in Table 3.8.

Table 3.8: Probability distribution functions (PDFs) used in several studies.

Researcher	**PDFs**	**Order category**	**Some of the stated assumptions**	**Outcome**
Adelson (1966)	Compound Poisson distribution	Demand size	• Orders arrive independently and singly	Derived CPD from the probability of creating function.
Zheng and Federgruen (1990)	Poisson distribution	Demand size	• Lead time is zero • Backlogging and Linear holding costs • Considered one-period demand.	They formulated a new computational algorithm for best (*s*, *S*) policies.
Matheus and Gelders (2000)	Poisson distribution	Demand arrivals	• Fixed lead time and quantity • Customer population includes a big group	Developed solution algorithm.
Kawtummachai and Hop (2005)	NORM Mean (units), STD (units/day)	Retailers' orders	• No demand variations • Cogitate only demand pattern	Developed a solution algorithm and used simulation.
Springael and Van Nieuwenhuyse (2006)		Consumers' quantity	• Considered as a stochastic variable	Derived the density function and cumulative distribution function.
Dominey and Hill (2004)	Poisson distribution	Customers' orders	• Order sizes are independent random variables • Customer arrival time vary	Considered a single classical period inventory model.
Hill and Johansen (2006)		Customers' demand	• Customer accepts the available products • Demand is discrete	The applied policy iteration algorithm.

Vaidyanathan (2011)		Consumers' demand	• Customers can change a product if the favourite one is not in the assortment	Developed algorithms to forecast demand and assortment optimisation
Chuang and Oliva (2014)		Consumers' demand	• Poisson mixtures (PMs) are appropriate only for empirical data showing over-dispersion - a variance or mean ratio ø >1.	Proposed two PMs, i.e. the Conway–Maxwell – Poisson distribution and the Poisson–Tweedie family.

Many researchers, e.g., Zheng and Federgruen (1990); Matheus and Gelders (2000); Dominey and Hill (2004) and Hill and Johansen (2006), explained the advanced inventory management models, and all deduced that the demand process of customers follows the *Poisson process* (Table 3.8). Based on the probability theory, the distribution of interarrival times of retailers' demand is an exponential distribution. Interarrival time of orders can be established based on historical data, direct observation, interviews feedback or numerical forecasting methods. This research considered historical data and actual data from the apparel industry. For the cases where neither case of information sources was available, the plausible assumptions were made to explain the random processes using probability models.

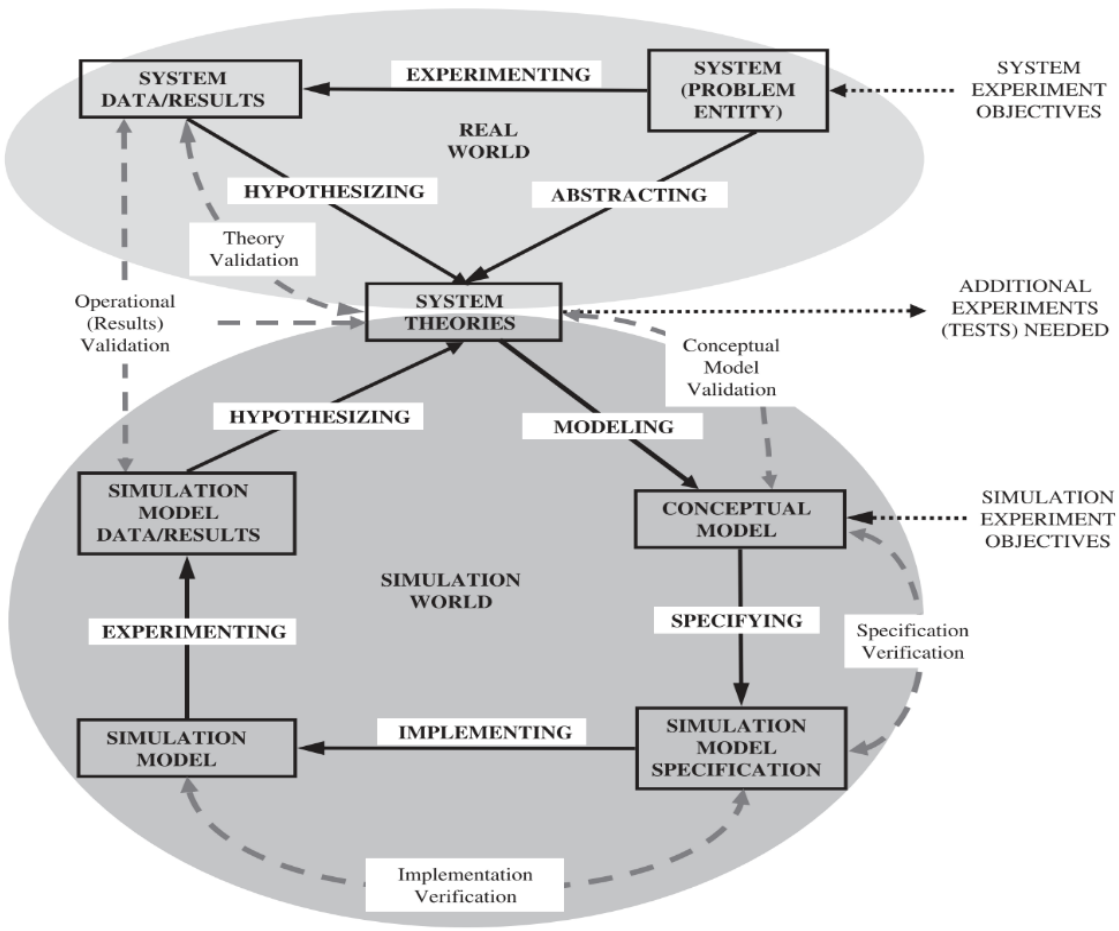
There are less stated assumptions on why consumers' orders or demand follow the Poisson process. For instance, Matheus and Gelders (2000, p.308) explained that "the Poisson assumption is appropriate if the customer population consists of a large group of individuals acting independently." Nevertheless that most researchers use Poisson distribution to fit customers' demand (Table 3.8), other researchers, including Adelson (1966), challenged the use of such distribution that it is a poor-fitting of data since after sometimes there is a high possibility of variations occurrence which shifts the earlier used distribution in an actual manner. Adelson (1966) suggests the use of Compound Poisson distribution (CPD) although he used Poisson distribution in his research. Mathematically, a probability distribution can be referred to as CPD when it is possible to represent its characteristic function, as shown in equation 3.1 (Prékopa, 1957).

$$\varphi(u) = \exp\left\{i\gamma u + \int_{-\infty}^{0}\left(e^{iux} - 1\right)dM(x) + \int_{0}^{\infty}\left(e^{iux} - 1\right)dN(x)\right\} \quad (3.1)$$

Whereby γ is a constant, M(x) and N(x) are well-defined on $(-\infty, 0)$ and $(0, \infty)$ as intervals, respectively, both are monotone non-decreasing, $M(-\infty) = N(\infty) = 0$, additionally, the provided integrals $\int_{-1}^{0} x dM(x)$, $\int_{0}^{1} x dN(x)$ exist.

3.6 Calibration, verification, and validation of the developed model

With DES, the precise simulation environment provides both a quantitative (e.g. using cumulative sourcing performance indices) and qualitative verification of the feasible options (e.g. through visual animation) (Moll *et al.*, 2009). Verification deals with model development consistency. Validation proves that the model results adequately represent reality. Model development included inputs from credible sources to reduce validation difficulties. It was not easy to obtain all actual data from the apparel industry; for such a case, synthetic data was used. Figure 3.7 indicates an interaction of simulation and real-world scenarios during the verification and validation processes. Validation can be executed through objective or subjective approaches (Table 3.9). The detailed validation and verification processes are in Section 8.3.1.



Source: (Sargent, 2013, p.15).

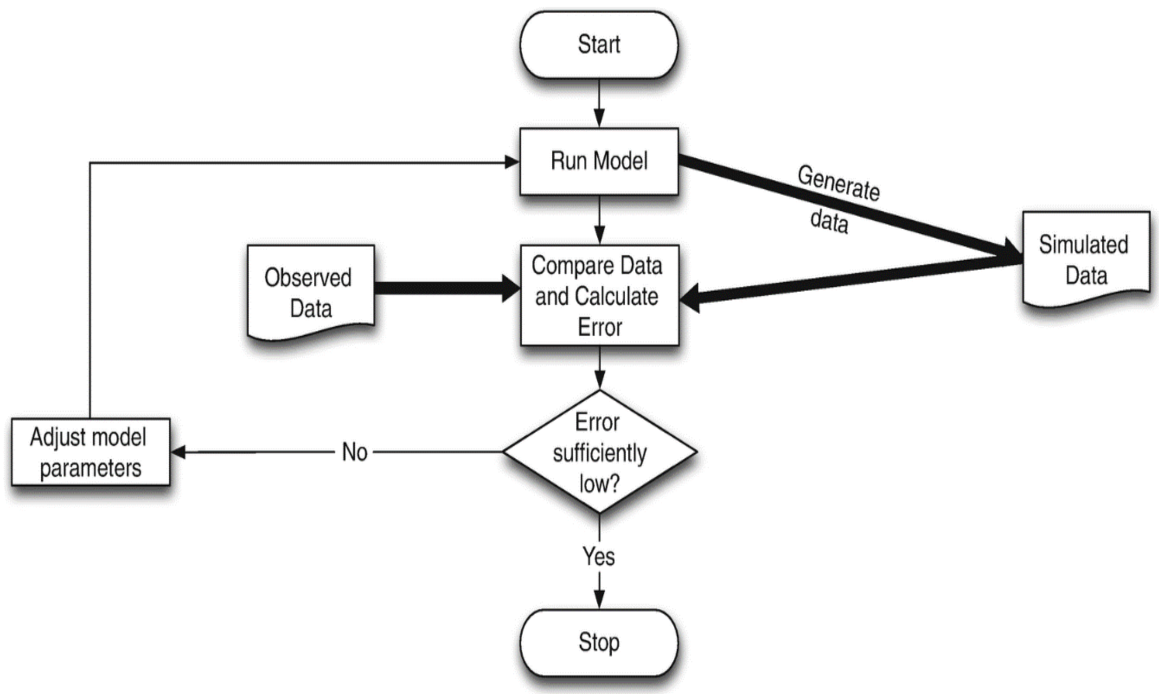
Figure 3.7: Real-world and simulation interactions with validation and verification.

Table 3.9: Operational validity organisation.

Decision method	Non-observable system	Observable system
Objective method	• Compare with other available models using statistical tests	• Compare by statistical tests and appropriate procedures
Subjective method	• Explore models behaviour • Compare with other models	• Comparison by graphical displays • Explore model behaviour

Source: Adapted from Sargent (2013, p.19).

Calibration "is the estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set": this requires the configuration process of the developed model's factors to conform to some noted or observed past data of the real system (Malleson, 2014, p.243). The process comprises exploring for the parameter values to be combined so that the developed model can generate data similar to the collected data from the real process(es) (Malleson, 2014). Figure 3.8 depicts a general structure of how to perform the calibration process. The developed model in Chapter 6 was not calibrated from any specific industry as this was out of scope. Additional discussion on the calibration, verification and validation is in Section 8.3.1.



Source: Adapted from Malleson (2014, p.244).

Figure 3.8: A synopsis of the calibration processes.

3.7 Quality in developing a simulation model

Although the simulated model was validated, the aspect of quality must also be assured. Therefore, all the developed models should adhere to the quality indicators in Figure 3.9. Further discussion of the quality indicators of the developed model is in Section 9.2.6.

Complexity	• A model is easy to be well-interpreted and communicated
Adaptability	• A model being able to handle changes whenever required
Correctness	• A model being accurate for all imported and generated information
Detailedness	• To have enough information which can make an executable model
Composability	• A model being able to be established by uniting different parts, modules or elements
Testability	• Enables an analyst to carry appropriate test in checking the validity
Efficiency	• A model being able to allow alterations of data or inputs
Interoperability	• Data exchange with other packages and also being able to use other related information from external packages or applications
Flexibility	• A model being able to allow alterations of data or inputs
Reusability	• How easy the model can be reused to make a similar model for other applications
Integrity	• A model being able to protect the accessibility of the sensitive information from illegal applications, software or people
Cohesion	• A model having a degree of allowing related information or elements to be used in making simulation model and not otherwise
Maintainability	• A model being able to be maintained whenever there are errors, external variations or problems which can affect its efficiency
Coupling	• Having a good degree of enabling elements or data to depend on the internal logic
Modularity	• A model should be with the lowest level for coupling and the uppermost level for cohesion and indicator
Portability	• A model should run from many software packages or hardware associated with it

Source: Compiled from Balci (2015).

Figure 3.9: Indicators for the quality of a simulation model design.

Chapter 4 Research methodology

4.1 Introduction

This chapter evaluates the research operation, philosophical research underpinnings, research framework, types of the pertinent data, sampling technique, data collection approaches and methods for analysing the gathered data and the results. It is vital to study each method in detail before using it to acquire deep understandings: all involved steps in research should be logically sound. It is not only worthy of knowing what methods (or techniques), tools, tests, experiments, philosophy, how to apply them, and when to apply: it is also vital to know why a specific method, tool, etc., are applied to get an intended solution.

4.2 Research philosophy

Paradigm explains "a system of ideas, or world view, used by a community of researchers to generate knowledge. It is a set of assumptions, research strategies and criteria for [the] rigour that are shared, even taken for granted, by that community" (Fossey *et al.*, 2002, p.718). Pathirage *et al.* (2008, p.514) define research philosophy as "epistemological, ontological and axiological assumptions and undertakings that guide an inquiry in a research study, implicitly or explicitly." PhD research is educational research; this thus necessitated major paradigms of educational research: scientific, critical and interpretive (Scotland, 2012). Scotland (2012) also explains a paradigm into four major components: epistemology, ontology, methodology, and methods. According to Pathirage *et al.* (2008), axiology must also be considered when discussing the research philosophy.

There are always dilemmas in selecting a suitable research philosophy. Scientists face a dilemma which results in quantitative-qualitative discussions (Mkansi and Acheampong, 2012). Therefore, to understand fully the philosophy to be adopted for research, it needs differentiating ontology, epistemology, and axiology philosophies. The philosophies should be linked with this study's aim, which digitalises the order allocation processes for a cluster of SMEs working as a single virtual enterprise. The order allocation process equitably should be discussed both ontologically and epistemologically to find the appropriate underpinning philosophies. Figure 4.1 depicts some of the research philosophy paradigms.

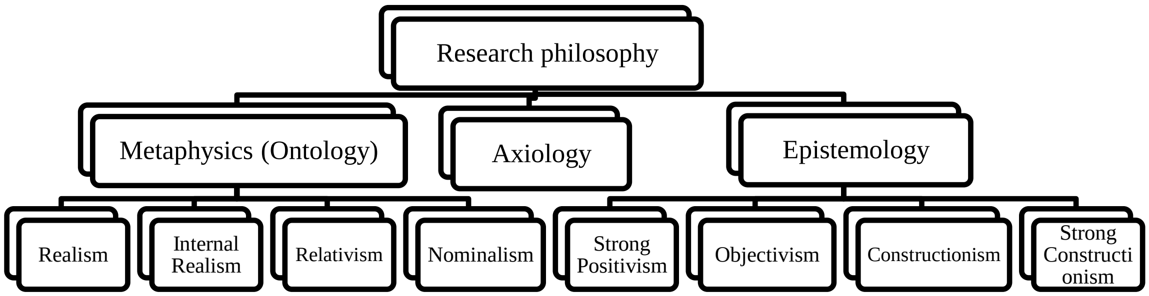


Figure 4.1: Some of the research philosophy paradigms.

4.2.1 Axiology

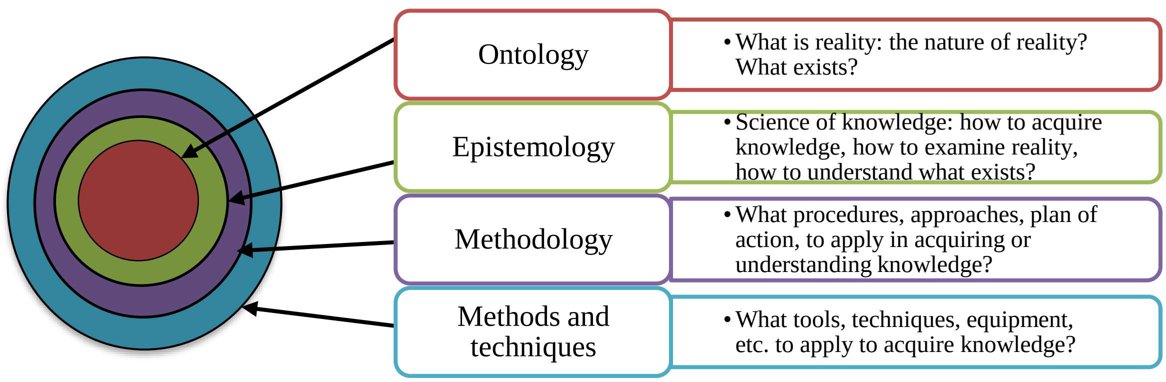
Axiology, following its Greek etymology, “axios is worth [value], and logos is a reason, theory [science]” (Hart, 1971, p.29). In other terms, axiology is the science of value: thus, it is the branch of the philosophical stance that deals with values and principles. Axiology forms one of three dominant research paradigms, including ontology and epistemology. It discusses all significant ethical issues required to be accounted for in carrying out research. Axiology explores the philosophical method in deciding the value or the right decisions (Kivunja and Kuyini, 2017). When researching there is an integration process of several people, machines, equipment, among others: this thus requires discussing ethical principles for this research. Ethical principles can be aligned with questions to be asked to all participants and how to report the findings by avoiding exclusive language that shows biases. Therefore, it is essential to design research which acknowledges diversity, promotes equality, conveys respect to all people, etc. The research ethics discussion is in Section 4.9.

Ethical issues should also lead a researcher to develop a study which cannot consider one-person superior to the other based on culture, sex, religion, beliefs, or any other related unethical issues (NHMRC, 2018). In this study, axiology is much needed as it helps to identify, scrutinise, and understand ideas and concepts related to wrong and right behaviour in the entire study. This research considered the UK apparel manufacturers and retailers; hence, there are participants contacted for helping to gather pertinent data (information). There are hints of the questions required to be considered in designing research under axiology concepts. These include the values to abide by; which moral principles and features should be considered; how to respect participants; how to secure participants’ goodwill; how to execute research in a respectful, socially and non-violent manner; and how to lessen or circumvent harm or risk considering that this research involves industries (NHMRC, 2018). The risks can be related to legal, physical, economic, social, etc. (NHMRC, 2018).

4.2.2 Ontology and epistemological stances

In conducting computer modelling and simulation (CMS), it involves applying knowledge, precisely when deploying them for teaching and training, or to gain knowledge through virtual experiments. Nevertheless, the developed CMS models do not signify reality as they are (Tolk, 2015). All models are only valid within their specified limitations subject to the provided soft and hard constraints, which according to Tolk (2015) draw in the famous quote of Box and Draper (1987, p.424) that 'all models are wrong.' Tolk's (2015) argument may be highly discussed in scientific fields. For this study, the question is, how to view digitalisation of an equitable order allocation ontologically and epistemologically? How can someone learn something from the developed models? What are the general philosophical stances of this study? So, the following sections discuss these questions in the general perspectives.

Figure 4.2 shows the general concept of research paradigms. Based on Easterby-Smith *et al.* (2018), the four key features of a research design begin with an inner ring: *ontology*. According to van Inwagen and Sullivan (2007) and Fine (2012), it is challenging to describe metaphysics. Metaphysics is a vast domain, and foremost, metaphysicians attempt to address questions on how the world is—with the nature of reality (Fine, 2012). This study considers ontology as an associated sub-field, partly within metaphysics philosophy.



Source: Summarised from Easterby-Smith *et al.* (2018).
Figure 4.2: Fundamental structures of the research philosophy.

Philosophically, the ontology provides fundamental assumptions regarding the nature of reality (what exists) (Fine, 2012). Therefore, while a metaphysics may comprise an implicit ontology—how the theory illustrates that the world may also imply certain entities in the world—they are not necessarily a similar domain of study (van Inwagen and Sullivan, 2007; Hofmann *et al*., 2011). In the CMS domain, two leading application areas were identified by Hofmann *et al.* (2011): first, the referential ontologies to answer the question "what do we model?", second, methodological ontologies to answer the question "how do we model?" In the CMS domain, however, the tricky question is "what kind of ontology to adopt?"

According to Partridge *et al.* (2013), researchers are argued to consider two interlinked logical issues: one is to apply a similar term ontology to describe distinct issues, that is the model and the real world; and second is a distinct viewpoint on what ontology is, i.e. relativism or realism. Models are represented differently, and they form a central part of the computer modelling and simulation systems. For the developed model to be useful in this research, one of the most fundamental conditions is that experts and industries' personnel should accept what the icons in a model exemplify. Therefore, in the realist philosophical stance, this is straightforward (Partridge *et al.*, 2013). However, in the idealist philosophical stance, ideas are not straightforward. If a simulator considers idealism, the concepts play a central role, and the model must reflect (maybe represent) them (Partridge *et al.*, 2013).

The second ring in Figure 4.2 is epistemology. It is due to two Greek words: episteme (knowledge, understanding or acquaintance) and logos (account, argument or reason) (Steup and Neta, 2020); thus, forming the science of knowledge. Therefore, epistemology represents all assumptions regarding the most elegant ways of examining the natural limits and scope of human knowledge (Tolk, 2015).

The subsequent ring in Figure 4.2 epitomises the research methodology or the manner to which research techniques, approaches or methods are congregated to get a coherent and cogent picture of the research at hand. For instance, participants, data collection, equipment (apparatus or instruments), data analysis tools, among others, are some of the elements of the research methodology.

The last ring in Figure 4.2 epitomises the independent techniques and methods that are deployed to garner pertinent data and rational analysis. According to Easterby-Smith *et al.* (2018), there is no rule-of-thumb in arranging the four rings in Figure 4.2. However, since techniques and methods are the most visible parts for any research: thus, the four stances were arranged as shown in Figure 4.2. The other three parts in Figure 4.2 increase hiddenly from inside to outside and contribute much to the research vitality, strength and logic (Easterby-Smith *et al.*, 2018).

For example, this research chiefly focused on digitalising the ordering allocation process among manufacturers (SMEs) using the computer simulation approach (Arena® software). It is possible to see the used software without concentrating on ontology, epistemology, among others. But both paradigms are essential in strengthening this research, together with vitality and logical aspects. The absence of the philosophical paradigms can lead to failure in classifying the research design, understanding, and recognising the design which can work better or the one which cannot execute well the research aims. Philosophical paradigms are also essential to understanding the constraints of this research based on the nature of the research or knowledge structure.

Additionally, some scholars, including Tolk (2013, p.3) studied teleology as the "study of action and purpose, resulting in methods, or how [people] apply knowledge." Greek etymology for teleology is telos (end, purpose, goal) and logos (explanation, reason).

Table 4.1 depicts the differences between ontologies and epistemologies with respect to the detailed information on the purposes, initial points, design aspect, data category, analysis, and possible results. Despite the presence of several categories in Table 4.1, in this study, only a few stances are discussed, including positivism and constructionism. Further explanations can be referred from the textbook written by Easterby-Smith *et al.* (2018), etc. Based on Table 4.1, this study partially fits with strong positivism (epistemology) and nominalism (ontology). The study also relates to constructionism (epistemology) and relativism (ontology). Also, due to the computer modelling and simulations and qualitative methods deployed—mixed-methods approach—this makes use of pragmatism stance (Section 4.2.5). Therefore, the undertaken philosophy is discussed in Section 4.2.6.

Table 4.1: Different epistemological with their methodological implications.

Ontology →		**Nominalism**	**Relativism**	**Internal Realism**	**Realism**
Epistemology →		**Strong Constructionism**	**Constructionism**	**Positivism**	**Strong Positivism**
Qualitative ↔					**Quantitative**
Methodology	Purposes	Invention	Convergence	Exposure	Discovery
	Initial points (terminus a quo)	Critiques	Involves questions	Propositions	Hypotheses
	Designs	Reflectivity and engagement	Surveys and cases	Multi cases; extensive surveys	Experiments (or practical or tests)
Methods and techniques	Types of data	Discourse and experiences	Primarily words with some numbers	Primarily numbers with some words	Facts and numbers
	Analysis or interpretation	Understanding; making sense	Triangulation and comparison	Regression and correlation	Falsification or verification
	Results	New actions and relevant insights	Generation of theories	Testing of theories and generation	Confirmation (or attestation) of theories

Source: Adapted from Easterby-Smith *et al.* (2018).

4.2.3 Positivism philosophy

Between the 1930s and 1960s, positivism philosophy dominated in social science as an epistemological paradigm, whereby the principal point of view relied on the way researchers considered the social world that it exists externally (Gray, 2004). The properties of the social world were also considered to be measured directly using observation. Gray's (2004) concepts were supported by Easterby-Smith *et al.* (2018) who described the fundamental concepts of positivism being the way the social world exists externally, and that all its elements are measured using objective approaches instead of inferred subjectively by intuition, reflection or sensationalism. Realism and objectivity were pronounced from the Scientific Revolution onwards. Natural scientists applied this philosophy through the patient accumulation regarding facts to provide scientific laws (Gray, 2004). Although social scientists and natural scientists considered positivism, yet, the same was explained as "one of the heroic failures of modern philosophy" (Williams and May, 1996). Some of the key features of positivism philosophy include the following: (a) the observer must be independent; (b) there should be an irrelevance of human interests; (c) involved explanations must illustrate causality; (d) deductions and hypothesis are considered to make good research progress; (e) considered concepts, ideas or opinions should be explained in a way that they can be measured; (f) units of the required analysis should be carried out in simplified terms; (g) statistical probability is required to generalise; and (h) sampling process needs large numbers which are selected randomly (Easterby-Smith *et al.*, 2018).

4.2.4 Constructionism philosophy

Based on the constructionism philosophy, there is no single truth or reality (Williamson, 2018). Shapira-Lishchinsky (2015, p.973) describes the constructivist as the "approach holds that exposing the learner to new experiences creates perturbations—forms of mental disquiet that challenge the learner to understand and make sense of new information generated by the new experience." In the simulation, constructionism can be related to as a simulation-centred approach to which the simulator applies existing knowledge (information) to get much knowledge. As this study focused on the CMS, simulations thus foster constructivist learning to all stakeholders of this domain by involving participants' psychomotor, cognitive and affective learning areas, which can lead to a more profound and more memorable experience (Sims, 2002; Shapira-Lishchinsky, 2015). This study can develop models through visualisation after the animation stage, which can assist stakeholders in making potential decisions in effecting equitable order allocations to several SMEs.

4.2.5 Pragmatism philosophy

Pragmatism was derived from Pragma, a Greek word, which means 'action' or 'deed' (Johnson and Duberley, 2015). Pragmatism began in the early 20th Century's writings of the American philosophers—John Dewey (1916) and William James (1842–1910)—as cited by Gray (2004) and Easterby-Smith *et al.* (2018). Pragmatism is a "philosophical orientation which pays attention to the practical consequences rather than the metaphysical origins of ideas" (Smith, 2020, p.1). Researchers have explored and applied CMS and validation from the epistemological viewpoints of pragmatism, critical-rationalism, logical empiricism (positivism), relativism, Lakato' methodology of scientific research programs and hermeneutics, Bayesianism, empiricism, classical rationalism, several sociological viewpoints, historico-critical relativism, Glasersfeld's radical constructivism, and Paul Feyerabend's anarchistic science view (Hofmann, 2013). To date, there is no universal agreement on the most appropriate epistemologies for CMS (Hofmann, 2013). Although these philosophical stances are crucial, this study only discussed pragmatism philosophy.

Easterby-Smith *et al.* (2018) described pragmatism as a philosophy that compromises relativism and internal realism. For example, from Table 4.1, the initial points (terminus quo) for internal realism and realism are propositions and hypotheses, respectively. This is aligned with this research, precisely in Chapter 7, whereby propositions and hypotheses were considered to show the feasibility of the built model in Chapter 6. Also, the reason given by Easterby-Smith *et al.* (2018, p.82) about relativism and internal realism is that "[pragmatism] does not accept [the presence of the] predetermined theories or frameworks that shape knowledge and truth." This study also focused on information sharing practice as one of the key enablers of Industry 4.0 concepts; thus, "information systems [are] often seen as [a] pragmatic discipline with prominence on practical research, theory and practical implications" (Mkansi and Acheampong, 2012, p.134). Saunders *et al.* (2012) argue that pragmatics recognise multiple tactics of performing and interpreting research: there are multiple realities when interpreting research. Pragmatism concentrates on what works by applying the suitable approach. Saunders *et al.*'*s* (2012) argument does not mean that whatever research method applied can lead to optimal results. Pragmatism research stance requires the use of many research methods. The use of a single approach or mixed-methods approach should be able to demonstrate and provide the meaningful best feasible solution. So, when considering pragmatism philosophy, the results are both theoretically and methodically relevant and rigorous (Saunders *et al.*, 2009).

This research requires design science concepts. The major philosophical distinction of design science is ontological because the artefacts (i.e. artificial phenomenon) to be studied are created first (Mingers, 2001). Thus, such study has pragmatic based research interest instead of a theoretical-cognitive (O'Keefe, 2014; Kabak *et al.*, 2019), and it solves practical problems instead of describing or forecasting hypothetical reasons (Holmström *et al.*, 2009). Therefore, the underpinning philosophy of design science is pragmatism (O'Keefe, 2014). Pragmatism focuses more on the utility of solution than generalisability; as a result, the practice should benefit from the model (O'Keefe, 2014). Despite that this study considered design science that resulted in pragmatism, other researchers placed CMS under classical positivism due to that simulators acquire knowledge by observing a real process or system and simulation is also not performed in its natural environment (Kabak *et al.*, 2015; 2019).

According to Winsberg (2019), the epistemology of computer simulation (EOCS) can be Pragmatism philosophy on the practical aspects. Thus, if EOCS follows pragmatism stance, "a good part of the reason we should trust simulations is not because of the simulations themselves, but because of the interpretive artistry of those who employ their art and skill to interpret simulation outputs" (Winsberg, 2019). According to Ören and Yilmaz (2013, p.162), a primary significance of the philosophical implication on modelling and simulation was the "positivist paradigm promoted by the French philosopher Auguste Comte (1844)." Similarly, positivists assume that there is an objective reality from the ontological perspective, and representational epistemology believes that individuals can understand such reality and employ symbols to show this objective reality precisely (Ören and Yilmaz, 2013).

Contrary to the positivists perspective, pragmatists through systems thinking perspective believe a model validity based on the subjective and qualitative assessments of its contextual practicality (Ören and Yilmaz, 2013). Here, a computer model is not deemed completely incorrect or correct, but its credibility and acceptability slightly depend on the subjective analysis of qualitative attributes (Ören and Yilmaz, 2013). Similarly, according to Hofmann (2013, p.64), some researchers combine pragmatism and realism to form pragmatic realism in today's era, which suggests that scientists create and apply computer models which are as "realistic as possible, given the constraints of current knowledge, skills, computing power and available time." The vital discussion on modelling in the form of a pragmatic realism philosophy can be referred from Beven (2002).

4.2.6 The undertaken philosophical stance

There was a time when several researchers did not support the deployment of the mixed-methods approach: these days, the mixed-methods approach is a standard approach in solving researchable problems (Gray, 2004; Mkansi and Acheampong, 2012). Considering the nature of this research which required a mixed-methods design, *pragmatism philosophy* was found to be a suitable philosophy in framing this study. Other philosophies, including *positivism* and *constructionism*, may not be strongly appropriate on their own. Some researchers, e.g. Johnson and Duberley (2015) combined *pragmatism* and *critical realism* to reinforce the notion that a "correspondence theory of truth is ultimately unattainable because of the projective role of the epistemic subject." Such inevitably results in an anti-positivist theory of knowledge: all knowledge is socially constructed (Johnson and Duberley, 2015).

Practically, the question of how to apply CMS knowledge looks superfluous, because it is applied by implementing the simulation (Tolk, 2013). Nevertheless, researchers have often discussed the CMS's applicability under the validity perspective (Tolk, 2013; Hofmann, 2013): "under which constraints can I use [computer modelling and simulation] application and expect valid results?" (Tolk, 2013). Therefore, pragmatism research philosophy was considered due to how pragmatics of CMS can dictate the need for validation. Also, computer models are focused concepts and simplifications of reality, bringing forth a transformed conceptualisation into a feasible simulation system (Tolk, 2013; Hofmann, 2013). Although the majority apply pragmatism, CMS can also support positivism, however, "the concept of internal consistency of axioms and rules are supportive of naturalistic research and rationalism and constructivism" (Tolk, 2013). Whilst the obtained findings through constructivism are not necessarily reliable, they should nonetheless be dependable, and though objectivity is not in the naturalistic research's scope, findings must be controlled by the confirmability principle (Tolk, 2013).

Pragmatism philosophy allows the integration of many research methods. Such methods can include the mixed-methods approach. Integration of multiple methods makes pragmatism philosophy better for this research. Some of the reasons which approve the use of pragmatism philosophy for this study are due to that there are questionnaires filled, the conducted interview sessions, collected actual and synthetic data, modelling and simulation of multiple models, and experiments. The integration of all these methods thus helps in demonstrating and getting feasible solutions for the identified questions in Section 1.4.

4.3 Research strategies or approaches

4.3.1 Appropriate strategies for the identified research questions

The commonly referred approaches include quantitative, qualitative and mixed-methods approaches (Williams, 2007; Mkansi and Acheampong, 2012). To achieve the main research objective, a pragmatism philosophy suggested the use of a mixed-methods approach (multi-methodology): qualitative and quantitative approaches. Within the adopted mixed-methods approach, Table 4.2 illustrates the research questions together with the applied strategies. The reasons for the selected strategies are also provided.

Table 4.2: The applied research strategies in line with the research questions.

Research Questions	Strategy	Clarification
RQ1. What is an extended enterprise within the Industry 4.0 perspective?	Qualitative	It is an Industry 4.0 era whereby numerous sectors are slowly transforming. To explores the meaning of an extended enterprise (EE), and how does it exist, a qualitative strategy is thus advantageous. Also, the qualitative strategy helps to determine the benefits of developing the concept of an EE on simplifying order placement by retailers.
RQ2. What are the key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing?	Qualitative and quantitative techniques	The qualitative approach in gathering decision criteria is appropriate; however, analysing the most critical decision requires software - Minitab® - and a few statistical computations (quantitative).
RQ3. What are the potential techniques, tools, and management software required in transforming the apparel sector and how to evaluate those techniques, tools, and software?	Qualitative	Determining the decision support tools and techniques required to digitalise the distribution process requires the qualitative strategy.
RQ4. How to develop, verify and validate the feasibility models for the UK apparel manufacturing (SMEs) regarding the process(es) of distributing (sharing) orders equitably?	Qualitative and quantitative techniques	Quantified measures are performed using the Arena® software to simulate models and DACE to show the feasibility of the developed model; however, for the verification processes, the qualitative measures can be applied.

4.3.2 The scope of the performed research background

The research background focused on the apparel industry. However, the automotive, civil (the construction section) and computer industries were also reviewed regarding their supply chain systems. The key ideas focused on the SCM, specifically for the received orders and products distribution (sharing), exchanging information and the deployment of ICT facilities in digitalising the above sectors. The scope of the searched literature sources included reputed international journals, companies' reports, conferences proceedings, e-books, textbooks, theses, and websites. The primary focus was on UK apparel manufacturing. The literature regarding the CMS approach was studied starting in the 1950s up to this date. The aim was to establish the past simulation-based projects or case studies related to order distribution between the retailers and the manufacturers in a digitalised way.

4.4 Research data approaches

Any scientific research process necessitates the so-called research methods in making a clear understanding. Such methods can be either deductive, inductive, or abductive. Deductive reasoning is related to the hypothesis-testing method to research, and when reasoning deductively, the argument moves from common tenets to specific instances (Williamson, 2018). For inductive reasoning, the process initiates with specific instances and ends with general principles or statements (Williamson, 2018). Table 4.3 details the significant differences between inductive and deductive research. The research on hand followed both deductive reasoning (deduction) and inductive approach. To make valid reasoning, there must be a good start which states a scientific proposition, e.g. apparel manufacturing has not been digitalised fully. Then, the undertaken scientific approaches should be explicitly performed in examining the possibilities of reaching logical conclusions and recommendations. The reason being to either revive or establish the digitalised equitable order allocation systems and concepts as a means of moving out the commonly used analogue concepts. But, to validate the model, hypotheses testing can be performed. By testing the hypothesis, this fits with deductive reasoning.

Table 4.3: The crucial differences between the deductive and inductive methods.

Deductive research	**Inductive research**
- Build-up theory to data. - Most applicable to natural scientific disciplines - Regarded as a structured method - Elucidate causal interconnections amongst variables - Involves satisfactory sample selection in generalising pertinent conclusions.	- Build-up data to theory. - Most applicable to social sciences - Regarded as a flexible structure which allows alteration - Find out connotations of humans' attribute to various events - Not as much concern with the need for taking a broad view

Source: Adapted from Pathirage *et al.* (2008, p.5).

4.5 Research design

The research design is an overall strategy that provides a framework which helps in integrating several components of the research (study) in a comprehensible and logical way (Sileyew, 2019). The research design provides the fundamental basis that guides on how to solve the identified problem, both effectively and efficiently. In designing the framework, the methods, techniques, and procedures to assist data collection and analysis can also be mentioned or included. Usually, the research problem being addressed helps to determine the nature of the research design to be undertaken. Based on the research philosophy and the research strategy, this research used the mixed-methods approach: qualitative (interviews, observation, questionnaires) and quantitative (computer modelling and simulations). Several research designs are in Table 4.4, whereby this research used ‘experimental research design.’ Having identified appropriate research design—*experimental design* (Table 4.4); the conceptual framework for the entire study was thus designed. It was developed in consideration with the research paradigm, research strategy, and design to tackle the research questions in Section 1.4.

Table 4.4: Several kinds of research designs.

Design category	Explanation	Significance and application	Limitations
Longitudinal design (within-subjects designs, repeated-measures designs, multi-level growth modelling)	Perform interview sessions by following the same sample of participants in a logically spaced time point.	Helps to explain processes over time and to describe why the spotted patterns are there (Easterby-Smith *et al.*, 2018).	Can cause attrition, i.e. some subjects can quit from the study at any time point before completion, leaving invalid conclusion (Kalaian and Kasim, 2011).
Cross-sectional designs	Perform interview sessions to a fresh sample of participants each time they are conducted.	Mostly, it belongs to positivist traditions, when relying on surveys and questionnaires. Associates with constructionist research when performing ethnographic study (Easterby-Smith *et al.*, 2018).	Difficult to explain processes over time and to describe why the spotted patterns are there (Easterby-Smith *et al.*, 2018).
Comparative research design	Several cases (scenarios) are assessed based on the same research methods and by setting similar conditions.	Assists to perform the comparative study to assess order allocation methods (Medvedev *et al.*, 2019).	The researcher cannot control the variables; so, cannot manipulate them when performing causal-comparative research which occurs at ex post facto (Brewer and Kubn, 2010).
Experimental research design	Such a design involves manipulation and controlled testing of the desired experiment to understand causal processes. At least one input is configured to determine the effect on a dependent variable or parameter.	It establishes the relationship between dependent variables and independent. Examples include order allocation (a single retailer to multiple suppliers) (Kawtummachai and Hop, 2005; Xiang *et al.*, 2011).	It can generate artificial results; involves an artificial environment — low realism.
Case study design	It involves an in-depth analysis of a system, process, organisation, events, or individuals, generally, over an extended time.	Multiple cases fit more with positivist epistemology, while a single case comes from a constructionist epistemology (Easterby-Smith *et al.*, 2018).	Does not allow generalisability of concepts from its results (Eriksson and Kovalainen, 2012); but there are single cases which are uniquely interesting.

Figure 4.3 illustrates the framework for this research. The framework also considered the computer simulation’s phases, the research questions and objectives: this clearly outlines the

various undertaken steps in the development, experimental and reflective phases of the study. The framework addressed the research problem about model development.

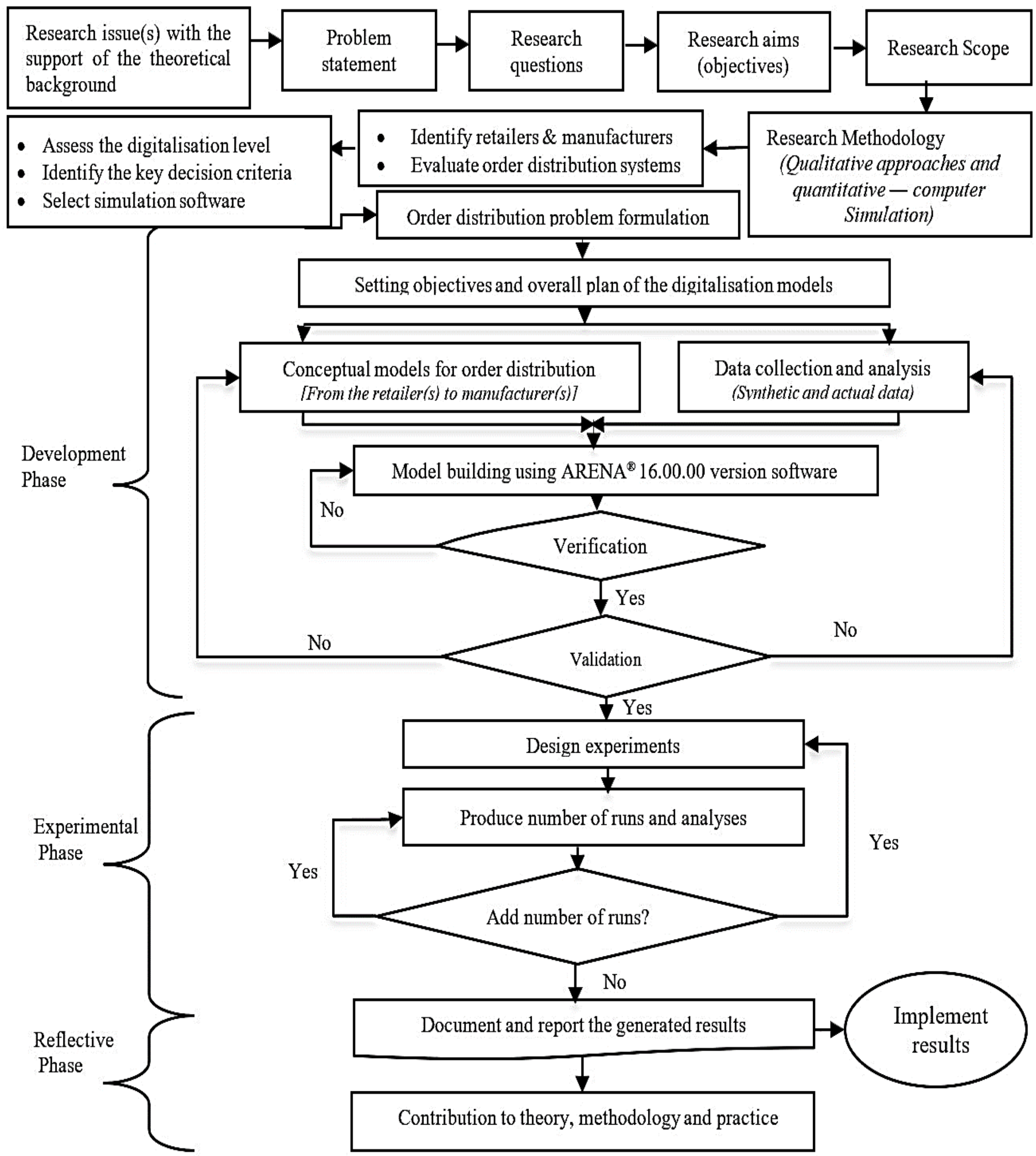


Figure 4.3: Research framework to digitalise the order allocation processes equitably.

Having described the research questions (Section 1.4) and objectives (Section 1.5), Table 4.5 shows its execution summary: the keywords, methods, tools, and techniques are listed.

Table 4.5: Summary of the considered research questions, objectives, methods, and tools.

Research Questions	**Research objectives with the key activities**	**Keywords**	**Methods, tools, techniques**
RQ1. What is an extended enterprise within the Industry 4.0 perspective?	*To explore an extended enterprise within the Industry 4.0 perspective.* a) To define an EE concept within the Industry 4.0 perspective and how an EE exists. b) To determine the benefits of developing the concept of an EE on simplifying order placement by retailers.	Industry 4.0 Extended enterprise Manufacturers Apparel retailers SMEs	Literature reviews Interview sessions Survey Questionnaire
RQ2. What are the key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing?	*To establish appropriate key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing.* a) To identify all factors that are required in deciding the digitalisation. b) To analyse inputs required for the digitalisation. c) To establish all the critical pertinent decision criteria for sharing the apparel orders.	Decision criteria Domestic supply chain Apparel manufacturers Digitalisation inputs Selection criteria	Likert scale Document reviews Checklist Brainstorming Linear weighted method
RQ3. What are the potential techniques, tools, and management software required in transforming the apparel sector and how to evaluate those techniques, tools, and software?	*To propose and evaluate the potential techniques, tools and management software required in transforming the DSC for the UK apparel manufacturing (SMEs).* a) To identify and apply numerous methods in digitalising the UK apparel sector. b) To identify all potential digitalisation techniques and tools. c) To determine the right software for digitalising the equitable ordering processes.	Digitalisation techniques Digitalisation tools Digitalisation software Suitable software	Document Reviews Checklist Brainstorming Expert judgement
RQ4. How to develop, verify and validate the feasibility models for the UK apparel manufacturing (SMEs) regarding the process(es) of distributing (sharing) orders equitably?	*To develop, verify, validate, and illustrate the feasibility for the UK apparel manufacturing (SMEs) to be distributed (shared or allocated) orders equitably.* a) To develop the simulation modelling of the order distribution (sharing) processes. b) To verify, validate and illustrate the feasibility of allocating orders using simulations.	Problem formulation Conceptual Model building Simulation Validation Validation techniques Feasibility model	ARENA® Hypotheses testing ANOVA Face to face Sensitivity analysis DACE Experiments

4.6 Data collection methods and design

Table 4.6 shows the differences between the three methods regarding data collection methods. This research considered a mixed-methods approach. The multi-methodology covers both the qualitative and quantitative aspects. As per Kothari (2004), the quantitative method can be subdivided into the experimental approach, inferential approach, and simulation methods based on the nature of the research. This study used a simulation approach and computer experiments. For the qualitative data, including the ordering processes, standard minute values, decision criteria, order quantities, lead time, etc., such data were collected from the UK apparel retailers and manufacturers using semi-structured interview sessions, document reviews, Likert scale and questionnaires.

Table 4.6: Some of the data collection approaches for quantitative, qualitative and mixed-methods approach.

Qualitative method	Quantitative method	Mixed methods
• Observations • Individual interviews (unstructured, semi-structured and structured interviews) • Visual data analysis • Documentary reviews • Focus group discussion (6 to 12 participants) • Action research • Case study • Likert scale, etc.	• Laboratory experiments or tests • Field experiments • Quasi-or natural experiments • Survey • Computer experiements, etc.	• Combination of the methods deployed under quantitative and qualitative approaches.

It is important discussing the needed date and where these data are found within this thesis. Amongst the discussed methods include some of the given methods in Table 4.6.

a. Likert (or summated rating) scale method

It is a standard methodological tool involved in studies that deploy questionnaires to measure participants' responses in survey research. The Likert-type scale permits participants to reveal their stances on matters along a quantitative continuum (Lewis-Beck *et al.*, 2004). The commonly deployed is a five- or seven-point scale. Achieving the fourth research questions required initial findings from the firms' performance rating. Thus, the gathered CSDCs to rank several SMEs were rated using the Likert scale in Section 5.4.3. Appendix E presents the used questionnaire. The ranking of CSDCs is an input process to the modelling and simulation processes in Section 6.5.9. Some modifications were also executed in the developed model; nonetheless, all inputs from the Likert scale findings are fundamentally imperative in accomplishing equitable order allocation processes. To execute Likert scale, questionnaires were distributed during the 'Make it British' exhibition event to garment manufacturers, sample makers and retailers at the Business Design Centre, London in the

UK on 29th and 30th May 2019. At least five participants successfully rated their firms. The summary of the findings is in Table 8.2.

b. Semi-structured interviews

To collect data mainly to achieve the first and the second research objectives, face-to-face semi-structured interviews were performed at UK T&A firms. Interviews helped to understand the need for digitalisation, the current ordering processes status, possible extended enterprise systems and benefits that can be accrued by working collaboratively as a single virtual entity. Similarly, interviews contributed to the contemporary and standard critical success decision criteria for SSEP, exploring any possibility of SMV consideration within apparel SMEs and equitable order allocation amongst SMEs. This research deployed both primary and secondary sources. The mainly deployed techniques for the primary data were semi-structured interviews (Appendices A and B), and questionnaires (Appendices C and D). Sections 8.2.1 to 8.2.6 present some findings from the conducted interviews.

c. Documentary reviews

For the secondary data, it included various reports, theses, published articles and various information from websites about the T&A sector and its SCM. Due to the unavailability of sufficient SMV data to cover several apparels, secondary data were adapted mainly from Brother Industries (1995) (Table 6.3) to simulate the model in Chapter 6. More results contributed by other researchers are in Table 6.2. This study utilised the data in Table 6.3.

d. Observation

Observation method is among the oldest and fundamental base research techniques that assist in collecting data using the researcher's senses, mainly by listening and looking systematically and meaningfully (McKechnie, 2008). Although for qualitative data interviews were the primary data gathering approach, there was a time when the observational technique seemed appropriate. Observation method was applied at the T&A's firms to scrutinize the entire distribution processes at retailers' distribution centres.

4.7 Determining the sample size

The sample size was considered for qualitative and quantitative data gathering processes. Qualitative data collection involved interviews. Sampling process mainly comprises two major techniques: probability and non-probability. Despite that probability sampling techniques minimise errors, this study used non-probability sampling (*deliberate, purposive or judgment sampling*) (Onwuegbuzie and Leech, 2007): it is sometimes referred to as subjective or selective sampling. This sampling was used based on the nature of this research which focused on specific T&A firms that are of much interest. The technique dictates getting information-rich cases. The considered firms answered the research questions in Section 1.4. Figure 4.4 presents criteria to select non-probability sampling methods. For quantitative data analysis—computer simulation data gathering and analysis—its considered sample size computation was the *Half-width method* (Section 6.6.3).

Group	Technique	Likelihood of sample being representative	Types of research in which it is useful	Relative costs to deploy the technique	Control over sample contents
Purposive	Extreme case Heterogeneous Homogeneous Critical case Typical case Theoretical	Low, dependent on researcher's choices	Unusual or special Key themes In-depth interview Importance Illustrative Inform emerging theory	Reasonable	Specifies selection criteria
Haphazard	Convenience	Very low	Ease of access	Low	Low
Quota	Quota	Reasonable to high	Alternative to probability sampling needed	Moderate high to reasonable	Specifies quota selection criteria
Volunteer	Self-selection	Low	Exploratory research	Low	Low
	Snowball	Low	Where cases difficult to identify	Low	Quite low

Source: (Patton, 2002; Saunders *et al.*, 2012; Tangpattanakit, 2017, p.136).

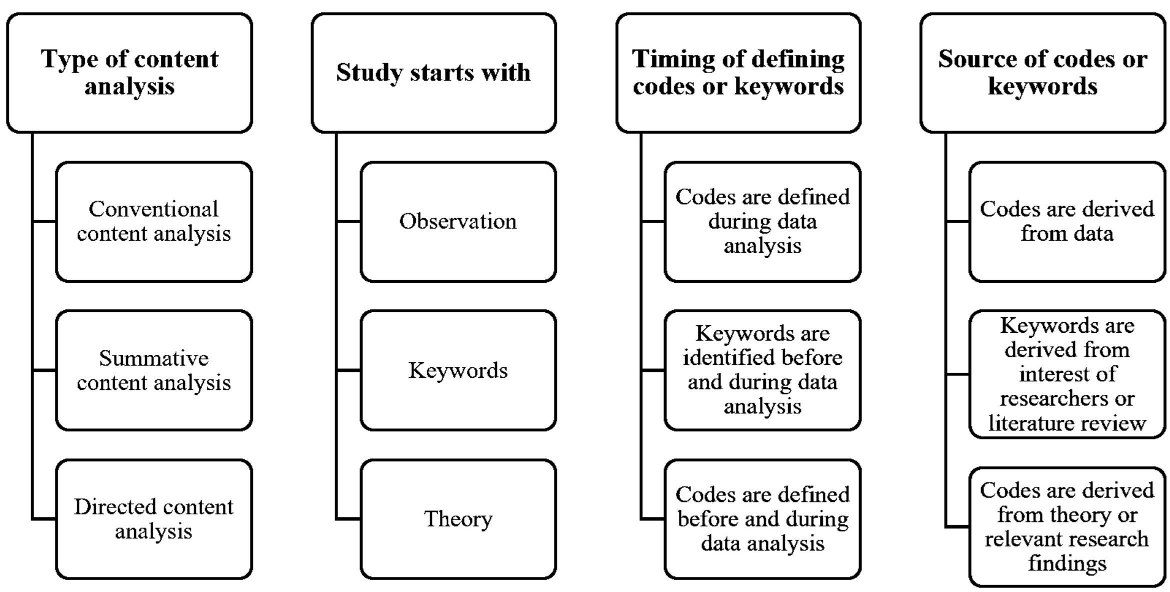
Figure 4.4: The options of non-probability sampling methods.

4.8 Data and information analysis

Data analysis process for quantitative information considered various tools and techniques, including the Arena® version 16.00.00 software, Minitab® version 18 and Microsoft® Excel

2016. The Arena® software includes Input Analyser, Process Analyser (PAN), Output Analyser, Arena Visual Designer and OptQuest® tools: these tools answered the fourth specific objective. For qualitative information, analysis can be performed using content analysis, hermeneutics, framework analysis, grounded theory, phenomenography, discourse analysis, narrative analysis (Bengtsson, 2016): this study used content analysis.

Content analysis is a commonly applied qualitative research method which portrays a family of analytic techniques varying from "impressionistic, intuitive, interpretive analyses to systematic, [and] strict textual analyses" (Hsieh and Shannon, 2005, p.1277). Downe-Wamboldt (1992, p.314) defined content analysis as "a research method that provides a systematic and objective means to make valid inferences from verbal, visual, or written data in order to describe and quantify specific phenomena." This qualitative analytical approach can be applied to any field (Bengtsson, 2016). Applicability of content analyses is nowadays categorised as summative, conventional and directed content analysis: all three categories interpret data from the content of the text, thus adhering to the naturalistic paradigm (Hsieh and Shannon, 2005). The differences between the three approaches are based on threats to trustworthiness, origins of codes and coding schemes (Hsieh and Shannon, 2005). Figure 4.5 depicts the differences between the three categories used to execute content analysis of the collected qualitative data.



Source: Adapted from Hsieh and Shannon (2005, p.1286).
Figure 4.5: Key coding differences amongst the categories of content analysis.

Thus, the gathered qualitative data from the two UK T&A firms (Table 8.1) using Appendices A, B and D were analysed using a content analysis approach. In order to analyse data, at least five steps were followed. Firstly, transcribing the recorded interviews; secondly, reading the transcripts thoroughly and repetitively; thirdly, the coding process: involved labelling pertinent sections, phrases, words or sentences from the interviewees; fourth, creating themes: decided the crucial codes so that to combine related codes to generate concepts, themes, etc.; fifth, labelling codes categories and selecting the related ones; and finally writing the interview results in Section 8.2. Therefore, all four specific research objectives (Section 1.5.2) benefited from the analysed qualitative data.

4.9 Research ethics

Both qualitative and quantitative approaches were deployed, forming the mixed-methods approach. Interview sessions—semi-structured questions and questionnaires—were conducted to apparel industry experts, i.e. retailers and manufacturers (SMEs), to collect an in-depth understanding regarding the digitalisation of their sector, specifically on enabling an equitable order allocation system. In line with axiology research philosophy, it is essential to abide by the research ethics (values). Therefore, ethical guidelines, best practice and code of conduct were strictly followed both during the data collection period, data analysis and after submission of this research. Both data and participants are protected, including personal identifiers. In achieving that, several documents were submitted to the University Research Ethics Committee. These documents included the participatory information sheet, data management plan, introductory letter, interviews to manufacturers and retailers, performance attributes for making decisions, consent form, standard allowed minutes (SMV) and the information about recording audio, video, and photographs. This research was thus ethically approved by The University of Manchester's Research Ethics Committee [Reference Number 2019-5608-9079].

4.10 Research reliability and validity

According to Easterby-Smith *et al.* (2018, p.110), the process of checking the "consistency of measurement in a composite variable" is reliability. Leung (2015), likewise, describes the reliability in quantitative research, as the replicability of the processes and the results, and for qualitative research, as the measure of consistency. The reliability can be established by combining scores on a set of questions, items, or entries. The methods like Cronbach's Alpha (internal consistency or homogeneity), alternate-form reliability (or equivalence), test-retest reliability (or stability), principal components analysis, etc., can be implemented to establish reliability (Bolarinwa, 2015).

Usually, when conducting qualitative approaches, it is easier computing the internal consistency of the structured questionnaires rather than semi-structured and unstructured (Taifa, 2016). The list of questions is best described as guidelines instead of instruments for the non-structured questionnaire or unstructured one. Considering that this study deployed both qualitative and quantitative approaches; thus, for the qualitative approach, there is a loss of reliability.

Similarly, the validity of the questionnaires' details can also be tested using techniques such as face validity, content validity, known-group validity, hypothesis testing validity, factorial validity, discriminant validity, predictive, convergent validity, clean dataset, etc. (Radhakrishna, 2007; Bolarinwa, 2015). Researchers argue that the term validity should be used for quantitative and not qualitative methods (Rolfe, 2006). The more recommended term to use is trustworthiness (Sandelowski, 1993; Rolfe, 2006; Carcary, 2009) which "becomes a matter of persuasion whereby the scientist is viewed as having made those practices visible and, therefore, auditable" (Sandelowski, 1993, p.2).

Thus, establishing the trustworthiness of the qualitative questionnaire can require experts to review the questions (Radhakrishna, 2007). Nevertheless, if validity is used in qualitative research; Leung (2015) describes it as the appropriateness of the used techniques, methods, tools, processes, and data. In this study, the face validity technique was also applied to test the validity of the used questionnaire guidelines. A review assisted in validating the used questions. Though several researchers do not consider the face validity method as an active measure of validity, nevertheless, according to Bolarinwa (2015, p.196), this technique is "the most widely used form of validity" in several countries.

4.11 Application of Design and Analysis of Computer experiments (DACE)

4.11.1 Meaning of computer experiment

An experiment can be defined as “a test or series of runs in which purposeful changes are made to the input variables of a process or system so that [to] observe and identify the reasons for changes that may be observed in the output response” (Montgomery, 2013, p.1). Some of the reasons for conducting experiments include screening factors or characterisation, optimisation, confirmation, discovery, developing robustness, among others (Montgomery, 2013). Experiments include computer experiments and physical experiments: the results from such experiments must be validated. To increase the validity of physical experiments, sometimes it involves randomisation, blocking and replication methods. For the randomisation technique, the “treatments are assigned to experimental units at random and are applied in random order” whereas for the blocking technique “the experimental units are grouped to be as similar as possible” (Santner *et al.*, 2018, p.2). It is vitally essential to perform adequate replications when simulating a model, that is, an experiment should be “run on a sufficiently large scale to prevent unavoidable measurement variation in the output from obscuring treatment differences” (Santner *et al.*, 2018, p.2).

Computer experiment is the process of conducting several runs of the code at several input configurations (Sacks *et al.*, 1989). Such an experiment is also referred to as a simulation experiment because it studies a computer simulation. The complexity of scientific phenomena requires an investigation by sophisticated computer codes or models (Sacks *et al.*, 1989; Welch *et al.*, 1992). Computer (simulation) experiments have been used remarkably for an extended time in exploring the relationships between inputs for a specific system to generate outputs.

Experiments are sometimes called computer simulator experiments (Santner *et al.*, 2018): such experiments involve the deterministic simulator (computer model) which applies a mathematical model using computer code to generate outputs through alteration of inputs. The deterministic system does not allow randomness in developing outcomes of a system. Deterministic models (or process, algorithm, procedure, etc.) always generate the same outputs (identical observations) from the provided inputs (Sacks *et al.*, 1989). Whereas, the stochastic system includes some randomness or uncertainties with certain probabilities. The stochastic system has both exogenous variables (i.e. variables decided outside the model) and endogenous (i.e. variables defined within the model). Computer simulator experiments have at least four features which are not present in physical experiments: yield deterministic output (Sacks *et al.*, 1989; Welch *et al.*, 1992; Santner *et al.*, 2018); experiments consume much development time; should there be any omitted parameter, sometimes the results can be biased due to the used mathematical model which computes based on the output-input ratio elements; and sometimes computer experiments require a large number of input variables than the physical experiments (Santner *et al.*, 2018).

4.11.2 The rationale of DACE

Both in Sections 3.6 and 8.3.1, the discussion focused on the calibration, verification, and validation concepts. These were conducted as part of the simulation phases (Figure 4.3). Next vital step is the application of DACE to this study. Section 4.11 lays fundamental concepts on DACE, whereas its implementations are in Chapter 7. Research background reveals several applications of DACE concepts. The design and analysis are interlinked (Kleijnen, 2018): to choose an experimental design, thus undertakes a metamodel (emulator, surrogate) to analyse the experimental results critically. Sacks *et al.* (1989) suggest three aims of DACE: to tune the computer code to physical data, to optimise a functional of the response, and to predict the response at untried inputs. Sacks *et al.* (1989) focused on predicting as the key objective, thus leading in modelling and prediction to create a cheap surrogate that dictates *what-if* questions to optimise the considered factors.

This research digitalised equitable order allocation across a cluster of SMEs working as a single virtual entity. The development phases of equitable order allocation were successfully executed (Chapter 6). This thus required applying DACE concepts to illustrate the feasibility of allocating order quantities across SMEs. Therefore, to be sure whether the developed model is experimentally able to allocate orders equitably given multiple factors, multiple inputs with the least changes, it was vital to apply DACE concepts. An interesting question posed was: *does the model developer ready to prove or show that the aim of this research* *has been achieved*? To answer this question, it required a sub-question that, *what should be performed to execute the feasibility of the developed model?* Ideally, through the application of DACE, the computer simulation experiments should either enable order allocation (i.e. manufacturers are allocated orders) or 'not feasible' (meaning the received orders are not allocated equitably).

Through DACE, the experimental setup assists in generating meaningful data which are crucial to executing the feasibility of allocating bulk orders. The identified information should then be broken down to data. The subsequent steps should be on how to get the required data and where to get the data from. So, this should help to identify the proper method(s). The method should help to design experiments which generate the required data in an unbiased environment: such experiments can thus be for predicting through data assimilation, comparison purposes, data gathering, uncertainty quantification (characterising any uncertainty within the computer simulation), bias correction, inverting a problem, or showing the robustness for designing a system. In performing this, it is possible to look at several methods such as the Taguchi method, sensitivity analysis, an orthogonal array, among others. However, the easy way should be performed by identifying the suitable information that helps to choose an appropriate method.

4.11.3 The need for DACE

The statistical experiment illustrates how to get the required data to be analysed. This should mean experimenting on gathering the needed data to execute the feasibility of order allocation by the developed model. Experiments can be either through simulations to generate some data regarding the allocation of bulk orders across several companies or through a real-world scenario. If order allocation processes were conducted in a real-world, it could have been merely by allocating orders across several companies. However, such a process requires answering two questions: what data are needed and how would they be analysed. The decision criteria, e.g., the average lead time, quality, standard minute values, price (cost), IT, capacity, capability, etc. (Figures 5.7 and 5.8), must be considered. But this can be conducted using computer simulations. Instead of using physical industry (factories), a simulation model can be used to generate the needed data. Thus, when performing physical experiments, there are natural variations, but for computer experiments, there is no natural variation, though the variations can be introduced. In this study, computer simulation is deterministic—the same information to be put leads to the same outputs (results). Therefore, that is where DACE originally started. DACE needs putting the same information in and looking at the outputs (response). Tweaking information leads to different results.

According to Sacks *et al.* (1989), there are stochastic simulations. Sacks *et al.* (1989) modelled the deterministic output as the realisation of stochastic processes, through a statistical base for designing computer experiments (selecting the inputs) for the prediction purposes. For stochastic simulations, traditional statistical analysis techniques are useful things to use. Therefore, in applying DACE to this study, setting the value for each variable, it would be a purely deterministic simulation and would generate the same results for the simulations. But it makes much more sense and meaning to include the stochastic elements. The stochastic elements should be modelled using the statistical and stochastic packages available in the Arena® software. The most interesting part of this process is generating the response of different allocations in consideration to different volumes of order quantities. Hence, the simulations provide all such data because the simulations should show that having a cluster of manufacturers working together it is a feasible way for them to meet bigger order quantities with the help of information sharing and IT-related infrastructure. So, DACE is applied to generate data to show that this is a feasible way for manufacturers to work together. Working together is a pathway to sustainable growth, assists manufacturers work on bigger order sizes and allows them to take advantage of digital technologies currently available. DACE is the design and analysis of the MRMM model's simulation.

The simulations for this study comprise some stochastic elements. When starting modelling processes, it is also vital to start looking at stochastics processes. This necessitates simulating to generate data which results in plotting several distributions. Such distribution helps to calculate an average and standard deviation. This becomes a computer representation of a physical situation. Hence, there might be no reason for not supporting this as a similar thing to a physical (real) situation. If a model is run for several times, many values will generate a normal distribution which generates an average. It is essential to compare different scenarios.

In such a case, there should be hypotheses, e.g., scenario A (*Hypothesis 1: H1*) that, on average, would be better than scenario B (*Hypothesis 2: H2*). This necessitates the use of *t-tests, Z-tests*, or other testing procedures to use the generated statistics from the simulated data (Section 7.6). So, the most significant hypothesis should be selected (Section 7.6.3).

Moreover, it is vital to distinguish between DACE as a general approach and robust design as a potential application of DACE. The robust design can be created through the application of DACE, but this research did not create a 'robust design' of an equitable order allocation model. For the robust design, this could have involved thinking about the developed model or system—computer model—with questions like 'what settings are needed for the low, medium or high to overcome fluctuations (i.e. to make it more robust)?' When looking at the robust design, it involves trying more to look at different levels of the impact of parameters on the outcomes. If there is one highly sensitive parameter, it then necessitates watching (observing) it. This might establish, probably, that the presence of a high level of other parameters negates the sensitivity or not. In such a situation, the DACE would involve the concept of the Taguchi technique. Creating a robust design of equitable order allocation to firms working jointly is a benefit of using simulation, and it could be future work (Section 10.4). Once a group of firms have agreed to work jointly, the robust design could show how they can best work together, what level of information sharing they should have, etc.

DACE is about creating experiments to get data in the most efficient way to avoid biases or if there is a systematic bias how the same can be managed to get data in a way someone would manage to subtract that. With DACE, it requires looking at how to get the data to support hypotheses or to understand the impact of the treatment. There is a need for formulating a hypothesis (Section 7.6), e.g. these treatments have no effects or vice versa. Then, it needs to look at the generated results. The null hypothesis would be that the treatment does not affect; the alternative hypothesis would be that there is an effect by the treatment. Here, it is a process of comparing two things, i.e. the generated data and *t*-tests. Hence, this study applied simulation data to provide information data to show the feasibility of working together and the feasibility of allocating orders equitably. Further discussion on DACE, hypotheses testing, and sensitivity analysis is in Chapter 7.

Chapter 5 Information sharing and decision criteria

5.1 Information sharing

Information sharing has different connotations. In this study, it is considered as the process of exchanging valuable business-related information from one entity to another company, people or systems' units. Li *et al.* (2014, p.1441) defined information sharing as "the extent of the exchange of critical information that may facilitate inter-firm collaboration among supply chain members." For instance, if the supply chain (SC) involves manufacturers (SMEs), retailers and customers; there should be a well-established means of sharing useful commercial information amongst all partners. Such a process creates supply chain visibility (SCV) (Kaipia and Hartiala, 2006; Wang, 2012). The creation of the SCV does not mean that participants are responsible for sharing all information: they need to share relevant and meaningful information (Kaipia and Hartiala, 2006).

The content of exchanged information and information sharing frequency are the two significant elements of achieving SCV (Wang, 2012). Successful inter-firm collaboration enhances supply chain responsiveness and efficiency. For many years, several SCM initiatives—Efficient Consumer Response, Vendor Managed Inventory, (Groenewoud, 2011) and Collaborative Planning, Forecasting and Replenishment (CPFR) (Kolluru and Meredith, 2001; Wang, 2012)—have been recommended to enhance collaboration measures (Hill *et al.*, 2018). CPFR is acknowledged to be the most effective initiative: its elements include information sharing, collaborative forecasting and automated replenishment, as all enhance SCV (Hill *et al.*, 2018).

Four crucial questions must be answered as a means of influencing better outcomes of information sharing practice—"what to share, whom to share with, how to share and when to share" (Lotfi *et al.*, 2013). Information sharing comprises the real-time exchanging of information on collaborative plans and forecasts along with order entries, material flow, billing and shipping with SC partners (Wang *et al.*, 2014). Sharing order entry makes the fundamental aim of this research: enabling order allocation equitably. Information can be classified as, first, the private information (not for sharing); second, the public information (for everyone); and third, the shareable information (to be shared amongst the parties) (Figure 5.1). The different business partners working as an extended enterprise must enable effective and transparent communication means in sharing critical business intelligence information: this practice must be linked with specific business objectives.

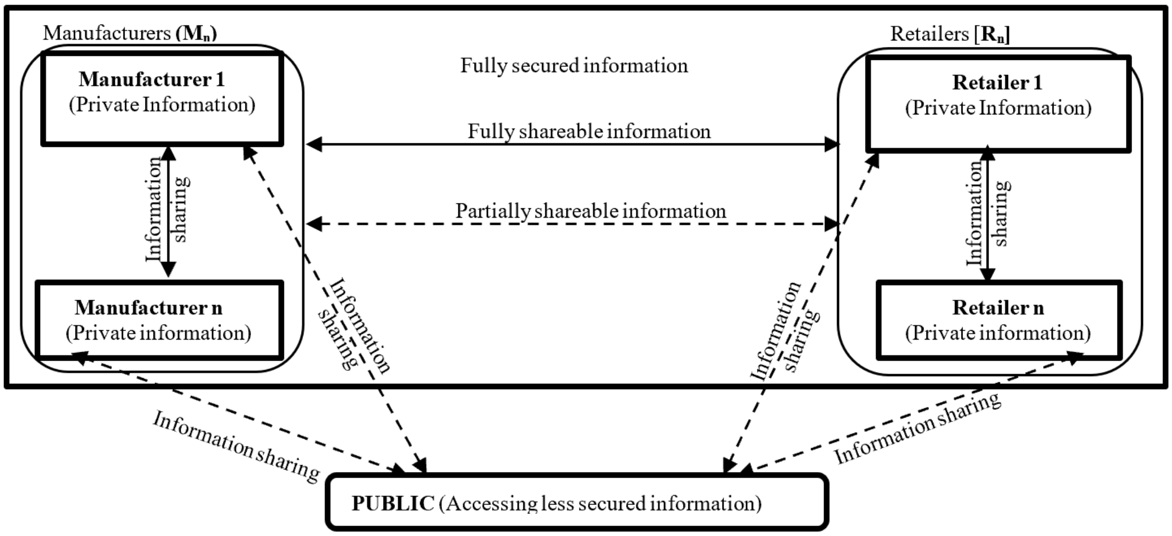


Figure 5.1: An overview of information sharing concepts between the retailers, manufacturers (SMEs) and the public (potential customers).

The UK T&A sector needs robust information-sharing practice to link the manufacturers and the retail segments. Having reliable communication in dynamic connectivity seems to be a critical factor in enabling an extended enterprise framework successfully. The information to be shared can be strategic (e.g. long-term corporate aims, customer information, marketing, etc.) or tactical (e.g. logistics, operations, scheduling purchasing, etc.) (Kumar and Pugazhendhi, 2012). Nowadays, even operational information such as detailed schedule, apparel packaging status, etc., can be shared amongst the business entities because of advanced ICT. Despite the value of exchanging business information, many firms are hesitant to share information, mostly strategic information (Li *et al.*, 2014). Some managers are sceptical about exchanging information with their business collaborators because of the perceived and/or experienced risks, costs and complexities (Tran *et al.*, 2016). So, commitment to share information develops a trade-off amongst partners (Tran *et al.*, 2016). Information sharing practices contribute to creating mutual benefits for the supply chain partners and enhance their efficiency and effectiveness (Wang *et al.*, 2014).

The critical aspects of exchanging business information include information intensity and information quality (Baihaqi and Sohal, 2013; Wang *et al.*, 2014): the two aspects need effective ICT facilities (Wang *et al.*, 2014). Information intensity can be described as the extent to which companies share different forms of information with their collaborating firms (Baihaqi and Sohal, 2013). In contrast, information quality is the degree to which the shared business information fulfils or satisfies the companies' or customers' requirements (Baihaqi and Sohal, 2013). Whether relying on the pull or push strategy, companies require advanced ICT systems to shorten the time of exchanging information. Each supply chain member must receive any shared information immediately. Figure 5.2 illustrates an example of the push-pull strategy in the supply chain.

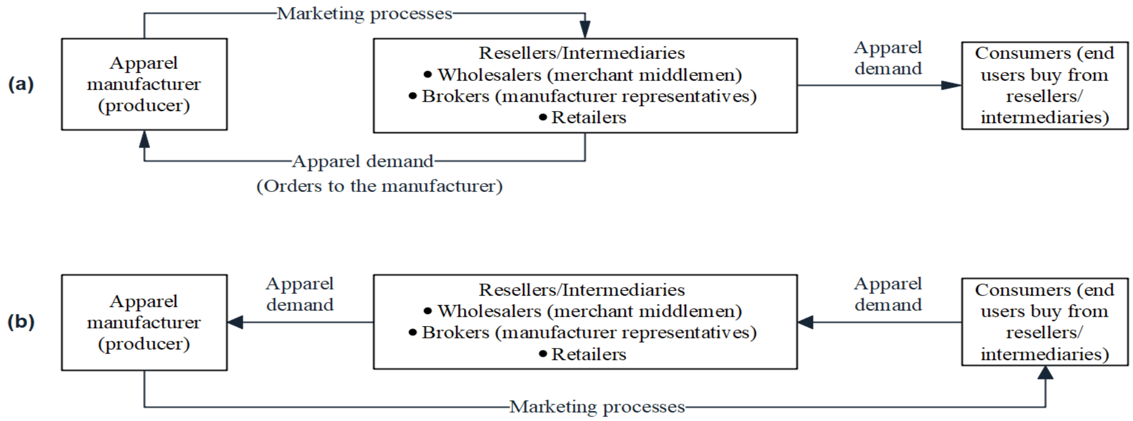


Figure 5.2: An example of (a) push and (b) pull strategy within the supply chain.

Information sharing is crucial in facilitating systems to manage communication efficiently, transaction processing, executive information, decision support, management information and enterprise (Li, 2005). It plays a unique role in creating a successful supply chain. Figure 5.3 shows the general networking process for the apparel industry. Information sharing should be well-established both internally and externally: all departments must share essential information to enable the fulfilment of the ultimate companies' goals. Also, external partners must be considered by sharing the relevant and sufficient information with their business partners on time. Similarly, along with the flows of the information, cash flow and order flow, still, within the supply chain members, there is a physical flow of the semi-finished, the finished, and the returned apparel items. For the industry to achieve higher profits, it needs to adapt to the systems approach (Sahin and Robinson, 2002). In the business context, the systems approach can be open or closed, and this approach explores the entire organisation, mostly the market elements, in consideration of both internal and external parameters to achieve substantial profits. Therefore, the systems method plays a vital role in recognising, examining, and coordinating the interactions among the entities successfully (Sahin and Robinson, 2002).

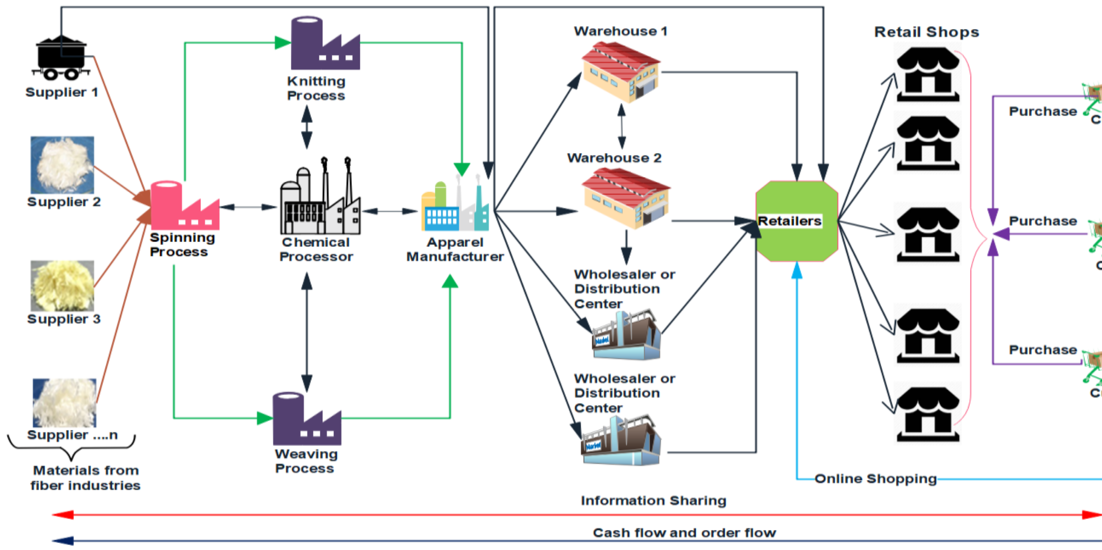


Figure 5.3: The vital network of the apparel industry linked with information sharing.

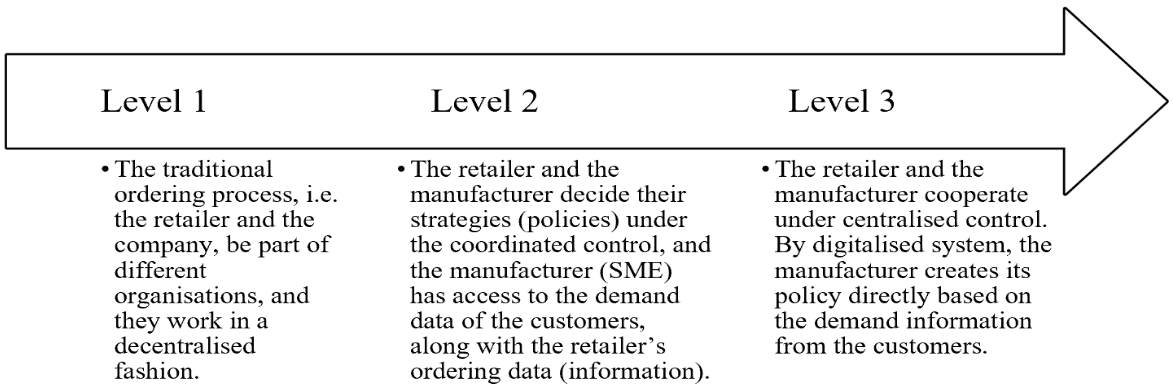
Industries also require performance objectives (POs) (Table 5.1). POs should be linked and enhanced by sharing information. Employees of companies should be well involved in executing their jobs to enhance companies' performance. Retailers expect SMEs to perform substantially in achieving the POs. SMEs also can prioritise their critical success factors. For example, if a cluster of SMEs working as a single virtual entity, its successful long-term partnerships can be achieved if none of the partners is much lagging in achieving the POs. When equitably allocated a quota of orders to manufacturers, retailers would expect high-quality products, speed in manufacturing, affordable price, flexibility in products, volume flexibility and on-time delivery (quick response). Over time, retailers can become regular customers to such a group of SMEs working collaboratively.

According to Cheng and Wu (2005), the two-level supply chain has three information-sharing levels (Figure 5.4). Level 1 is not suitable for the current Industry 4.0 era, whereas Level 3 is the most pertinent one as it involves digitalised technologies under centralised control. The VFAS or VFSS helps to centralise decisions on allocating orders equitably amongst the business partners.

Table 5.1: The performance objectives (POs) as the criteria for selection.

POs	Implication	Key Performance Indicators
Quality	Being right	Produce according to the specifications Product reliability and retailers' satisfaction The product being attractive
Speed (time)	Being fast	Cycle time for processing one unit Short response time for the secured order
Cost	Being productive	Efficiency
Flexibility	Being able to change, customisation, resilience	Product flexibility, mix flexibility, volume flexibility, delivery flexibility
Dependability	Being on time, trust, and stability	On-time delivery

Source: Adapted from Slack *et al.* (2013).



Source: Summarised from Cheng and Wu (2005).

Figure 5.4: Information sharing levels under a two-level supply chain in the industry.

5.2 Benefits of information sharing practice

An extended enterprise framework needs enhanced information sharing. Enterprises need to collaborate as the competition has shifted from being amongst the companies, and currently, it is between the supply chains. This is because when "organisations work independently of their up-stream suppliers and down-stream customers, costs and inefficiencies tend to build up at the interfaces" (Al-Zubaidi and Tyler, 2004, p.321). Thus, the manufacturers and retailers must enhance information sharing practice, which dictates collaboration. Table 5.2 depicts some benefits of an effective information sharing practice.

Table 5.2: Some benefits of information sharing practice in businesses.

Benefits	Sources
Enhances quick response to customer needs	Sukati *et al.* (2012); Wang *et al.* (2014)
Forrester or bullwhip effect reduction	Hsu *et al.* (2008)
Enhance proper resource utilisation	Lotfi *et al.* (2013)
Reduction of uncertainties	Vanpoucke *et al.* (2009)
Smoothing production	Kumar and Pugazhendhi (2012)
Enhances inventory management	Lee *et al.* (2000); Kumar *et al.* (2017)
Cash flow improvement and lowering stock levels	Howard and Squire (2007); Bailey and Francis (2008)
Supply chain coordination and cost reduction	Lee *et al.* (2000); Vanpoucke *et al.* (2009)

5.3 Performance attributes for deciding on working collaboratively

In executing extended enterprise concepts, *yes, no,* or *partially* decisions can be made before collaborating for any order entry: these answers are under decision theory (theory of choice). This entails having a specific set of questions which should be asked to participating factories and/or retailers who are ready to collaborate. Table 5.3 depicts some decision points. Both the manufacturers and the retailers must show the willingness by answering *yes, no* or *partially*. The reply from the manufacturers (SMEs) and retailers should have a provability notion. However, there are some questions or logical sentences which have no provability notion; for such sentences (questions), appropriate assumptions must be considered to reach the point for consensus among partners. The presented information in Table 5.3 should be shared amongst collaborating members (Appendix C).

Table 5.3: Decision points for working as an extended enterprise.

Attributes	**Description**	**Actor**	**Yes**	**No**	**Partially**
Materials flow	Do they share scheduled information about receiving the raw materials?	SMEs			
Production	Do they share technologies used to make products?				
Design	Do they share information about the design exercise?				
Engineering changes	Does the company share information on any change which can affect the existing products?				
Collaborative forecasts and plans	Are there any tools for predicting the productions and sales as the means of reducing the Forrester effect (Bullwhip effect)?	Both			
Product quality	Do they meet the retailers' quality specifications?	SMEs			
Production cost	Are the retailers happy with the production costs?	Retailers			
Completeness	Do they get complete information from the retailers?				
Order entry	Do they have an online order entry system?	Both			
Order tracking	Do they track the shared order entries?	SMEs			
Shipping and billing	Are they willing to share on how to ship retailers' orders?				
Delivery plan	Do they meet the delivery schedule commitment?				
Delivery speed	Do they respond quickly to the placed orders?				
Flexibility	Are they flexible in case of the variation of the retailers' orders?				
Accuracy	Do they receive precise information from retailers?	Retailers			
Price	Do they discuss the product prices?	Both			
Reliability	Do they get trustworthy or consistent information?				
Adequacy	Are they satisfied with the information they get from the retailers?	SMEs			
Availability	Do they have available products in stock?				
Dependability	Are they on time in manufacturing the apparel products?				

Reliability	Are they able to continue working at an acceptable quality level?					
Timeliness	Do they meet the production schedule?					
Internal connectivity	Do they have good connectivity amongst themselves, i.e. within the companies' departments?					
External connectivity	Do they have good connectivity with their external partners?	Both				
Relevance	Do they make relevant products for the retailers' needs?	SMEs				
Accessibility	Are they reachable by the retailers all over?					
Credibility	Do both partners believe and trust the information being shared?	Both				
Frequency	Do they update their information frequently?	Both				
Resources	Do they have enough machine capacity?	SMEs				
	Capacity variance: is there any variation in their capacity?					
	Do they have enough workforce?					
	Do they have enough raw materials?					
	Do they have enough machines?					
Retailing	Do they use sales forecast techniques?	Both				
	Do they perform the cross-selling and up-selling?	SMEs				
	Do they follow the make to order (no stock company) approach?					
	Do they follow the make to stock (cloth stock company) approach?					
	Do they sell to a wholly-owned chain of stores?					
	Do they sell to the independent retailers of varying types?					
	Do they sell to the large independent chain stores or mail orders?					
	Do they sell to the wholesalers?					
Retailer linkages	Does the firm discuss orders problems with their retailers?	Both				
	Do they have continuous improvement programmes due to the feedback (comments) from the retailers?	Both				
	Do retailers get involved in making plans or goals?	Retailers				
	Are the retailers aware of the production capacity of the company?					
	Do they get informed if the production schedule is changed?					
Level of information: involvement	Is there any proprietary information-sharing practice?	Both				
	Do they get information about the production capacity?	Retailers				
	Do they share information about the technology know-how?	Both				
Support techniques or tools	Do they use EDI, POS, and RFID technologies?	Both				
	Do they use emails and fax to get their orders?	SMEs				
	Do they use phones to get their orders?	Retailers				
	Do they use the traditional way, i.e. face-to-face, to get their orders?					

Note(s): SMEs = manufacturers; both = retailers and SMEs.

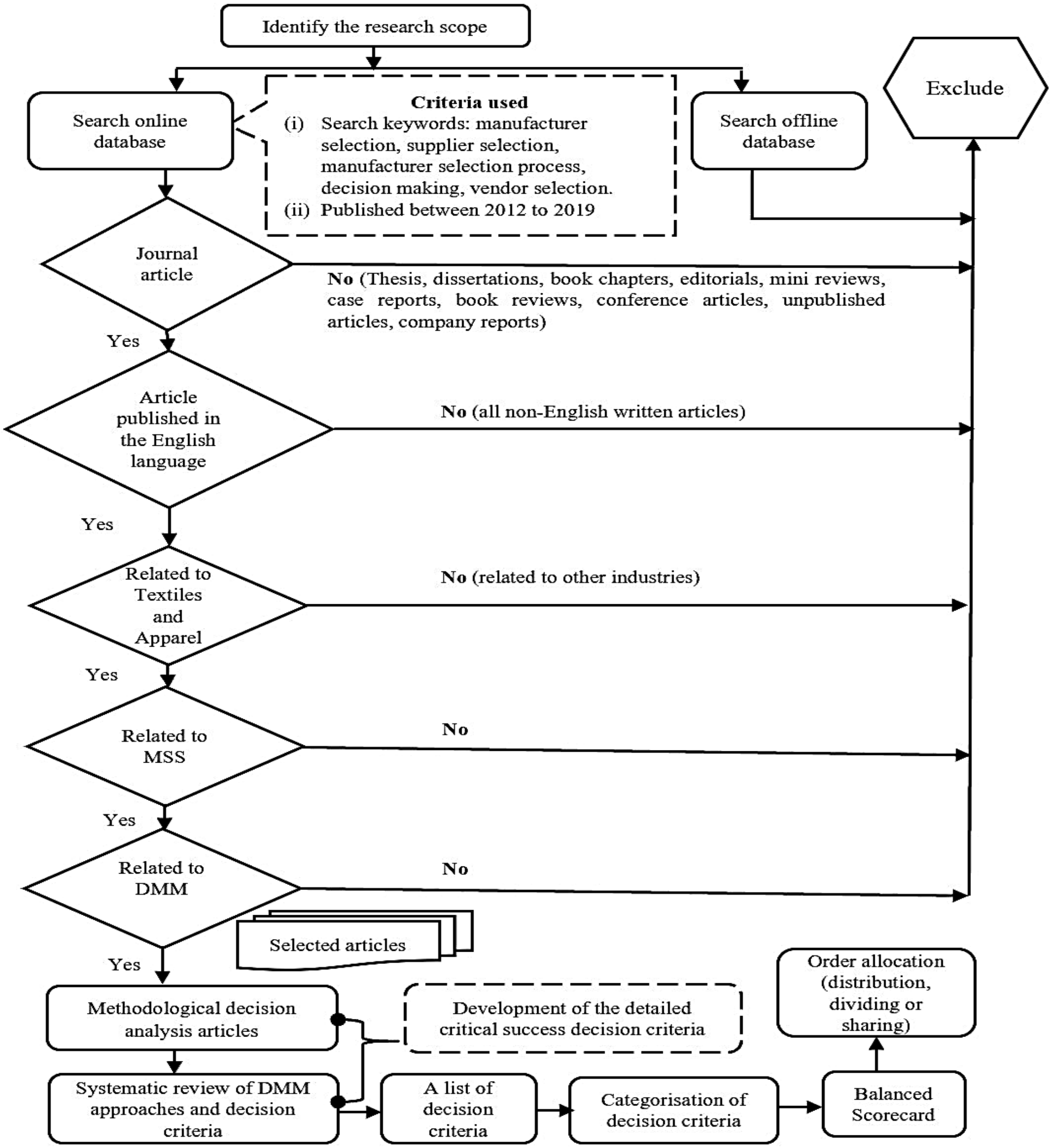
5.4 Performance ranking of apparel manufacturers (SMEs)

5.4.1 Development of the pertinent decision criteria

Section 5.4.1 is an implementation of the discussion from Section 2.7.1. The digitalisation of the apparel domestic supply chain can be successful after making robust decisions using suitable techniques. In most apparel companies, the determination of the parameters like retail sales forecasting and marketing, apparel assembly line balancing, cut order planning, marker planning, production planning and scheduling, and plant locations were heavily dependent on the key staff's judgement (Wong *et al.*, 2013). Within the Industry 4.0 era, it is crucial to establish a new list of the decision criteria, which are rational (logically sound).

This research established decision criteria using the methodological decision analysis model (Figure 5.5) by systematically analysing: (a) eighty-five articles (general) between 2008 and 2018 (Taifa et al., 2020b); and (b) forty-one (specific to the T&A industry) research articles published by reputable houses between 2012 and 2019 regarding apparel supplier evaluation and selection. This also involved qualitative data from two apparel companies. Figures 5.6 and 5.7 depict a summary of Pareto chart and the Balanced Scorecard (BSC), respectively. From Figure 5.6, 80% of all the decision criteria include QLT, PRC, DLV, FLE, CSR, SER, PFC, ENV, TEC, GCO, ICS, PH, FPO, GEL, MO, PCE, CSI, MSI, and RPI: the full forms are in Figure 5.6 and Table 5.4. Minitab® version 18 summarised the CSDCs to generate the BSC (Figure 5.7) and the Pareto chart (Figure 5.6).

It is the most competitive market era due to advancement of the Far East T&A industry. UK retailers are advised not to be driven simply by manufacturing cost when selecting the right manufacturers. Their sourcing decisions should involve a mixture of criteria, depending on the required products. Achieving high quality coupled with low cost, reflects qualifying criteria rather than winning criteria (Soliman and Youssef, 2001). It is an Industry 4.0 era which has many concepts related to next-generation manufacturing (NGM). NGM needs rigorous knowledge and extensive use of IT enablers to improve business (Soliman and Youssef, 2001).



Note(s): DMM = Decision making methods; MSS = manufacturer (supplier) selection. In addition to the stated criteria in Figure 5.5, an evaluation was conducted on the articles' quality. Some of the quality assessment questions were adapted from Downs and Black (1998). The checklist included the following: (a) Is the objective of the research explained explicitly in the particular article? (b) Is the article clearly stating the nature of the industry: textiles and clothing, T&A, textiles and garment, textiles and fashion business, among others? (c) Are the primary outputs to be measured portrayed in the first part (introduction) or the third part (methodology)? (d) Are the methods for selecting and evaluating the manufacturers clearly stated? (e) Does the article describe the significant findings of the study explicitly? (f) Did the article show the prioritisation of the considered decision criteria? (g) Are the limitations of the research described explicitly? (*Some of these results were published in Appendix H*).

Figure 5.5: A methodological decision analysis model.

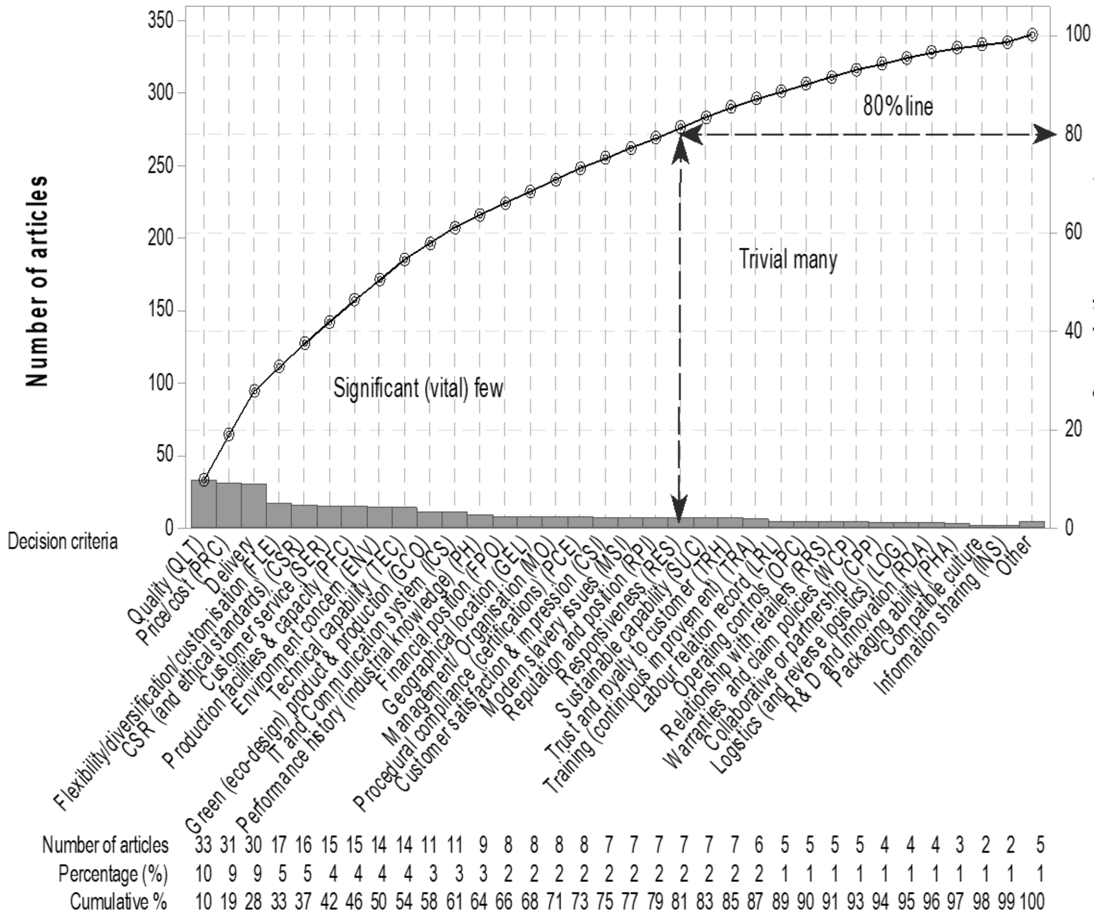


Figure 5.6: Pareto chart generated by Minitab® version 18 to identify primary decision criteria (representing 80% of the criteria reported in academic literature) from 2012 to 2019. The results were systematically compiled from the T&A industry only.

5.4.2 The Balanced Scorecard (BSC) and corporate social responsibility (CSR)

The BSI (2020) describes BSC as a "strategic planning and management system that organisations use to communicate what they are trying to accomplish; align the day to day work that everyone is doing with strategy; prioritise projects, products, and services; and measure and monitor progress towards strategic targets." Robert Kaplan and David Norton created the BSC, which is not concerning strategies: it is about enhancing strategies applicability (Nair, 2004). While business firms, both manufacturers and retailers, can fail because of multiple reasons; the main one is the incapacity to execute balanced strategies rather than lack of robust strategies (Nair, 2004). Therefore, BSC helps to decrease such incapacity by transforming companies "from monitoring to measurement; from measurement to management and from management to direction setting" (Nair, 2004, p.2).

Figure 5.7 shows the major four clusters of BSC: financial or stewardship, internal processes, innovation and learning or organisational capacities, and stakeholders or customers (Kaplan and Norton, 1996). All the clusters ranked the developed CSDCs for each SME (Figure 5.6).

Perspectives of the Balanced Scorecard	• **Some of the performance measures for the manufacturer evaluation processes**
Financial perspective	• **FPO**: Financial stability, annual profit, annual growth, annual revenue
Internal process or business processes perspective	• **QLT**: Quality assurance, quality planning and quality control • **DLV**: Delivery speed, delivery logistics, quantity compliance, reliable delivery, and on-time delivery • **PRC**: Reasonable or affordable selling price, ordering cost, and compliance with the sector's price trend • **PFC**: Production and scheduling planning, number of machines, capacity planning, capacity flexibility, and raw materials • **TEC**: Skilled operators, type of technology, future technology, technology innovation, and technology utilisation • **MO**: Presence of the stable management team, a visionary organisation regarding the customers, the good hierarchy of leadership • **FLE**: Product flexibility, mix flexibility, volume flexibility, deliver flexibility, customisation • **OPC**: Quality control measures, inventory management systems • **REA**: Recovery options in case of an emergency
Customers or stakeholders perspective	• **PH**: Awards received, customers served, market target, previous expertise, quick response records, customers' feedback • **APB**: Include customers served, production records, ability to do business, core competencies in the business • **SER**: Problem resolution, response, customer feedback, ability to repair, ability to repair on time • **GEL**: Distance, accessibility, proximity to customers, trade/business barriers, available infrastructure • **RPI**: The status of the company, the position of the company in the particular sector, customers' feedback • **TRH**: A firm belief in the reliability of the company, truthful of the company • **CHS**: Problem resolution capability, quick response to problem-solving, integrity in handling customers' complaints • **WCP**: The time range for the warranties, satisfaction regarding the claims • **ATT**: Management and organisation point of view • **CSI**: Customer satisfaction, customer feedback, market share, and brand adherence (royalty) information • **RES**: Quick response. • **PHA**: Standard package compliance, product delivery handling
Innovation and learning (organisational capacities or learning and growth) perspective	• **RDI**: New product development, new design capacity and capability, technological support, invention capability, new technical capability, new product development lead time. • **LRL**: Human resources relation, the number of strikes per year, absenteeism records, labour turnover. • **ICS**: Information sharing, IT infrastructure, communication mode, IT systems compatibility, the security of the IT infrastructures. • **SUC**: Being able to maintain production throughout the year. • **PCE**: Complying with international standards (e.g. ISO 9000) and/or other industrial certifications (e.g. UKFT). • **DFP**: Business growth, goal-oriented, increase the market share, etc. • **TRA**: Train staff, training aids, training schedules. • **CPP**: Working as an extended enterprise, collaborating with other firms.

Note(s): See Figure 5.6 for the full form of the given decision criteria.
Figure 5.7: The proposed Balanced Scorecard for the SMEs evaluation processes.

Likert scale tool (Appendix E) ranked all SMEs (Section 5.4.3) to hypothetically allocate orders equitably using the classified CSDCs by BSC (Figure 5.7). So, completing the ranking process(es) is reinforced by the BSC. Manufacturers can have robust strategies but may not have classified strategies. BSC helps in achieving such incapacity to categorise the CSDCs to rank the right SMEs: SMEs can hence be allotted bulk orders equitably (Chapter 6). In addition to the BSC (Figure 5.7), researchers and organisations should nowadays pay much attention to corporate social responsibility-related issues: this is due to the pressure increase, explicitly to the environment and humanity aspects. Sustainability covers three connected tenets: environmental (planet), social (people) and economic (profit) concerns. About this study, there are contemporary decision criteria that must not be overlooked in today's sourcing decision process: these include environmental and modern slavery issues.

5.4.3 Ranking of the pertinent decision criteria

The decision criteria in Figures 5.6 and 5.7 were considered to distribute the apparel orders to the five manufacturers (SME_1 to SME_5) which were assumed to process(es) the basic, fashion and fast fashion garments. Figure 5.8 shows the hierarchical structure of the CSDCs for SME_1 to SME_5: the CSDCs were weighed with relative importance (Tables 5.4 and 8.2).

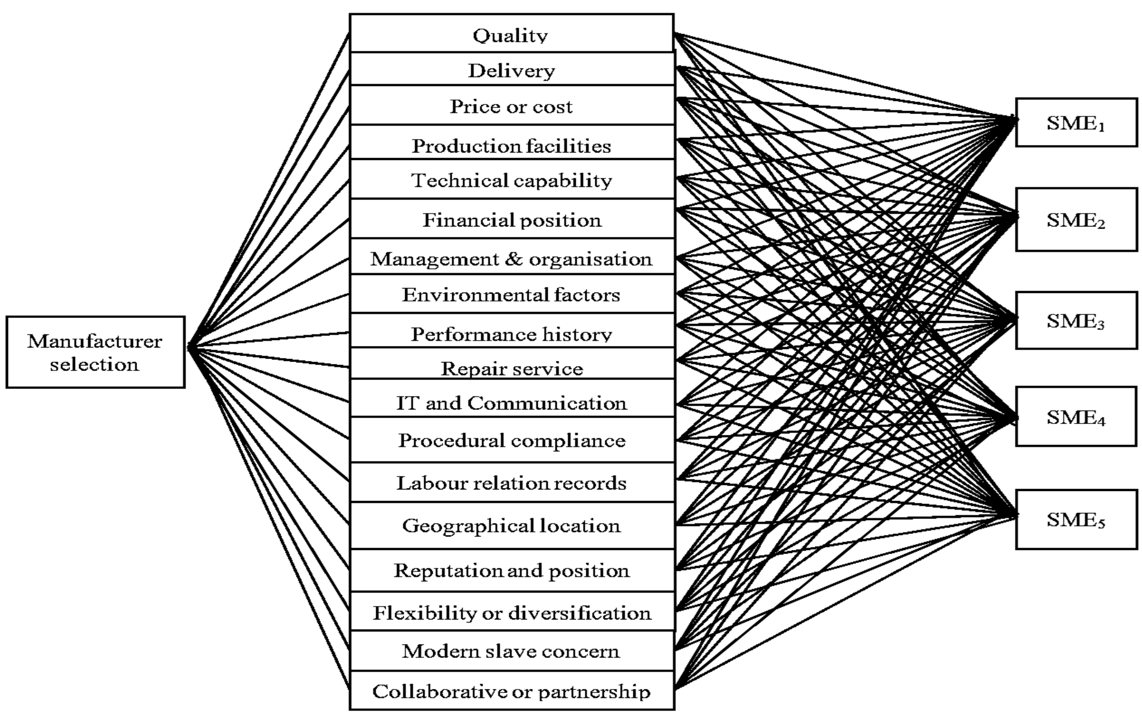


Figure 5.8: The hierarchical structure for the decision criteria.

Likert scale and linear weighted-point method (LWPM) show the evaluation of SMEs and generate initial inputs on executing order distribution in Sections 6.5.4 and 6.5.9. Although many methods can rank SMEs, the LWPM was selected as it is widely used (Narasimhan *et al.*, 2001) due to that the implementation costs are reasonable, it is highly reliable, and it can combine quantitative and qualitative CSDCs into a standard system (SCRC SME, 2011). One of the LWPM's limitations is that "the weights for various supplier performance attributes used in the weighted, additive scoring model are arbitrarily set" (Narasimhan *et al.*, 2001, p.28). Taifa *et al*. (2020a) mentioned other methods to execute SSEP. Some of the essential steps under the LWPM to distributing orders are as follows (Paul *et al.*, 2011):

(a) *Develop the survey*: identify the list of the potential SMEs; then determine the key evaluation categories; weigh each assessment group; determine and weigh the subgroups; describe the scoring system for the groups and the subgroups.
(b) *Manufacturer audit and selection*: assess SMEs directly and select after reviewing the results of the complete evaluation processes.
(c) It is also vital to execute a continuous review of SMEs: this helps to be updated and monitor whether the SME is making the products as per the specified requirements.

The established sourcing decision criteria in Figure 5.8 were hypothetically applied to rank apparel manufacturers (SMEs) as follows:

a) Financial perspective (FLP)

FLP consists of *the financial position* (FPO) criterion. FPO refers to whether the firm has sufficient and stable capital flows. FPO also relates to the terms for payment. The five-item Likert-scale ranked all five SMEs: excellent (5), good (4), fair (3), poor (2), and very poor (1). Equation 5.1 computes the total scores for the FLP. W_i and W_{FPO} are the assigned weights for FLP and FPO, respectively.

$$FLP = W_i \times [(W_{FPO} \times FPO_s)] \tag{5.1}$$

b) Internal business process perspective (IBPP)

IBPP comprises quality, delivery, price (cost), production facilities and capacity, technical capabilities, management and organisation, and flexibility. In ranking quality and price criteria, it was assumed that retailers and manufacturers have long-term strong cooperative relationships. Hence, this tends to simplify the ranking processes of these criteria.

i. *Quality (QLT)*: this consists of quality control (QC), quality planning (QP) and quality assurance (QA). For each classification, the excellent score was rated (5), good (4), fair (3), poor (2), very poor (1), and not performed (0). Equation 5.2 calculates the total scores. W_j, W_{QC}, W_{QP} *and* W_{QA} are the assigned weights for the IBPP, QC, QP and QA, respectively.

$$QLT = W_j \times [(W_{QA} \times QA_s) + (W_{QP} \times QP_s) + (W_{QC} \times QC_s)] \tag{5.2}$$

ii. *Delivery (DLV);* first, it relates to *logistics* (LS) aspects of transporting the manufactured apparel. The scores were assigned as follows: excellent (5), good (4), fair (3), poor (2), very poor (1), and not effective (0). Second is about the *lead time* (LT). LT is the latency between the total time it takes from order entry up to when the particular order is delivered to the retailer. All models considered the CMT category only. The scores for LT were assigned as follows: *very poor* for a total order lead time of more than 60 days (1); *poor* for a total order lead time of 35 to 60 days (2); *fair* for a total order lead time of 30 to 35 days (3); *good* for a total order lead time of 25 to 30 days (4); and *excellent* for a total order lead time of 20 to 25 days (5). Equation 5.3 computes the total DLV scores. W_j, W_{LT} and W_{LS} are the assigned weights for the IBPP, LT and LS, respectively.

$$DLV = W_j \times [(W_{LS} \times LS_s) + (W_{LT} \times LT_s)] \tag{5.3}$$

iii. *Price or cost (PRC)*; first, it is about the *selling prices* (SP) of the apparel products. The rating of scores are as follows: very low prices (1), low prices (2), acceptable prices (3), high prices (4), and extremely high prices (5). Second, it is about the *ordering cost* factor *(OC)*. It was considered whether the company uses Electronic Data Interchange in simplifying the ordering processes. The ranking was as follows: not available (0), very poor (1), poor (2), fair (3), good (4), and excellent (5). Equation 5.4 computes the total PRC scores. W_j, W_{OC} and W_{SP} are the assigned weights for the IBPP, OC and SP, respectively.

$$PRC = W_j \times [(W_{SP} \times SP_s) + (W_{OC} \times (OC_s)] \tag{5.4}$$

iv. *Production facilities and capacity (PFC):* first, this is about the *types of machinery* (MC) available such as cutting, spreading, sewing equipment, among others. The scores were rated as follows: excellent (5), good (4), fair (3), poor (2), very poor (1), and not effective (0). Second, it relates to the *minimum order quantities* (MQ). The scores were rated as follows: extremely high (5): there are no minimum order requirements; very high (4): runs only large order quantities; high (3): runs medium to large order quantities (wholesalers); acceptable (2): runs small to medium order size; satisfactorily (1): runs small order size only. Equation 5.5 computes the total PFC scores. W_{MC}, W_{MQ} and W_j are the assigned weights for the MC, MQ and IBPP, respectively.

$$PFC = W_j \times [(W_{MC} \times MC_s) + \left(W_{MQ} \times MQ_s\right)] \tag{5.5}$$

v. *Technical capability (TEC):* refers to the physical infrastructure and workforces' skills to manufacture apparel. The scores were rated as follows: very poor (1), poor (2), fair (3), good (4), and excellent (5). Equation 5.6 computes the total TEC scores. W_{TEC} and W_j are the assigned weights for the TEC and IBPP, respectively.

$$TEC \ = W_j \times (W_{TEC} \times TEC_s) \tag{5.6}$$

vi. *Management and organisation (MO);* relates to the ability to deal or control workforce as well as factory's facilities and assessing the level of commitment. The scores were rated as follows: very high (5), high (4), acceptable (3), poor (2), and very poor (1). Equation 5.7 calculates the total MO scores. W_{MO} and W_j are the assigned weights for the MO and IBPP, respectively.

$$MO = W_j \times (W_{MO} \times MO_s) \tag{5.7}$$

vii. *Flexibility (FLE):* how the firms can manage the demand uncertainty, the production changes, product style or volume changes, both predicted and unpredicted. The scores were assigned as excellent (5), good (4), fair (3), poor (2), and very poor (1). Equation 5.8 computes the total FLE scores. W_{FEL} and W_j are the assigned weights for the FLE and IBPP, respectively.

$$FLE = W_j \times (W_{FLE} \times FLE_s) \tag{5.8}$$

Therefore, the total IBPP scores were calculated by equation 5.9.

$$IBPP = QLT + DLV + PRC + PFC + TEC + MO + FLE \quad (5.9)$$

c) Customer/stakeholder perspective (CRP)

i. *The geographical location (GLE)* of manufacturers (SMEs); the scores were assigned as follows: very close proximity (5), close proximity (4), far (3), and very far (2).
ii. *Performance history (PH);* it concerns the history of the manufactured apparel. The ranking was as follows: excellent (5), good (4), fair (3), poor (2), very poor (1), and new firm (0).
iii. *Services (SER);* in general, it concerns the way SMEs serve retailers. The scores were rated as follows: excellent (5), good (4), fair (3), poor (2), and very poor (1).
iv. *Reputation and position in the industry (RPI);* the ranking was as follows: excellent (5), good (4), fair (3), poor (2), and very poor (1). The total CRP scores were computed by equation 5.10. W_k, W_{GEL}, W_{PH}, W_{SER}, and W_{RPI} are the assigned weights for the CRP, GEL, PH, SER and RPI, respectively.

$$CRP = W_k \times [(W_{GEL} \times GEL_s) + (W_{PH} \times PH_s) + (W_{SER} \times SER_s) + (W_{RPI} \times RPI_s)] \quad (5.10)$$

d) Innovation and learning (organisational capacity) (ILOP) perspective

i. *Procedural compliance/certification (PCE);* generally, this assesses whether the factory (SMEs) conforms to the international standards or some other certifications. The scores were rated as follows: very poor (1): an SME does not have any certification document; poor (2): an SME is a member of the UKFT; high (3): either ISO 9000 or the UKFT certifies the SME; very high (4): ISO 9000 and the UKFT certify the SME. ISO stands for The International Organisation for Standardisation.

ii. *IT and communication systems (ICS);* assesses the availability of ICT infrastructures. The scores were rated as excellent (5), good (4), fair (3), poor (2), and very poor (1).

iii. *Collaborative/partnership planning (CPP);* the ranking was as follows: excellent (5), good (4), fair (3), poor (2), and very poor (1).

iv. *Labour relation and training (LRL);* the ranking was as follows: excellent (5), good (4), fair (3), poor (2), and very poor (1). Equation 5.11 calculates the total ILOP scores. W_{PCE}, W_{ICS}, W_{CPP}, W_{LRL}, and W_l are the assigned weights for the PCE, ICS, CPP, LRL and ILOP, respectively.

$$ILOP = W_l \times [(W_{PCE} \times PCE_s) + (W_{ICS} \times ICS_s) + (W_{CPP} \times CPP_s) + (W_{LRL} \times LRL_s)] \quad (5.11)$$

e) Corporate Social Responsibility (CSR)

i. *Modern slavery issues (MSIs);* these relate to whether the factory involves child labour, human trafficking, indentured servant and forced labour, long working hours issues, etc. whereby victims (workers) are forced to work through intimidation and violence. The ranking was based on assessing the extent to which the particular factory (e.g. an SME) avoids modern slavery issues and how they comply with other social-related business ethics standards and code of conduct in their entire production. The ranking was as follows: very high (5), high (4), fair (3), poor (2), and very poor (1).

ii. *Environmental concern (ENV);* to what extent does the firm take actions regarding environmental issues. The scores were rated as follows: very high (5), high (4), fair (3), poor (2), and very poor (1). Equation 5.12 computes the total CSR scores. W_{MSI}, W_{ENV}, and W_m are the assigned weights for the MSIs, ENV and CSR, respectively.

$$CSR = W_m \times [(W_{MSI} \times MSI_s) + (W_{ENV} \times ENV_s)] \quad (5.12)$$

Equation 5.13 determined the total scores for each manufacturer (TSEM). For equations 5.1 to 5.12, the subscript “s” (e.g. MSI_s) represents the ranked scores for each criterion.

$$TSEM = FLP + IBPP + CRP + ILOP + CSR \quad (5.13)$$

Table 5.4 depicts a summary of the decision matrix for the manufacturer selection. Table 8.2 presents the Cumulative Sourcing Performance Index (CSPI). The total weight for all the five categories is 1 while for the decision criteria, each category was assigned 1 point, making a total of 5 weights. The computations were made using Microsoft® Excel 2016. It is feasible to code, develop an algorithm or external auxiliary system which includes all participating firms and the related decision criteria. Then, synchronise the particular system with the developed models in Section 6.5.9 for easy alteration and order allocation.

Table 5.4: A summary of the decision matrix for the manufacturers (SMEs) selection.

Category	Weight (W_x)	Critical success decision criteria (CSDCs)		Weight (W_y)	Apparel manufacturers' (SMEs) scores				
					SME_1	SME_2	SME_3	SME_4	SME_5
Financial	W_i	Financial position (FPO)		W_{FPO}					
Internal business process	W_j	Quality (QLT)	Quality assurance (QA)	W_{QA}					
			Quality Planning (QP)	W_{QP}					
			Quality control (QC)	W_{QC}					
		Delivery (DLV)	Logistics (LS)	W_{LS}					
			Lead time (LT)	W_{LT}					
		Price/cost (PRC)	Selling prices (SP)	W_{SP}					
			Ordering cost factor (OC)	W_{OC}					
		Production facilities and capacity (PFC)	Types of machinery (MC)	W_{MC}					
			Minimum order quantities (MQ)	W_{MQ}					
		Technical capability (TEC)		W_{TEC}					
		Management and organisation (MO)		W_{MO}					
		Flexibility (FLE)		W_{FLE}					
Customer or stakeholders	W_k	The geographical location (GLE		W_{GEL}					
		Performance history (PH)		W_{PH}					
		Services (SER)		W_{SER}					
		Reputation and position in the industry (RPI)		W_{RPI}					
Innovation and learning (organisational capacity)	W_l	Procedural compliance (PCE)		W_{PCE}					
		IT and communication systems (ICS)		W_{ICS}					
		Collaborative or partnership planning (CPP)		W_{CPP}					
		Labour relation and training (LRL)		W_{LRL}					
Corporate social responsibility	W_m	Modern slavery issues (MSIs)		W_{MSI}					
		Environmental concern (ENV)		W_{ENV}					
Total scores	$\sum W_x$			$\sum W_y$					

The findings from Section 5.4.3 (ranking SMEs using the Likert scale tool) is summarised in Table 8.2. The ranking of CSDCs is an input process to the modelling and simulation processes in Section 6.5.9. Some modifications were performed in the developed system; however, all inputs from Section 5.4 are crucial in accomplishing equitable order allocation processes. Further discussions on order allocation options are in Section 6.5.4.

In summary, the findings in Chapter 5 and Section 8.2.7 answered the second research question: what are the key decision criteria in digitalising the DSC in terms of an equitable order allocation for the UK apparel manufacturing? So, to distribute the apparel orders, essential criteria (Figure 5.6) were selected using a qualitative approach: methodological decision analysis model and interview sessions. Chapter 5 has also highlighted how an extended enterprise concept requires an enabled information sharing practice. This practice must be correlated with specific business objectives. The UK T&A sector must establish and sustain an information-sharing practice to link the manufacturers (SMEs) and the retail segments. Factories have similarly continued to avoid information-sharing practice due to trust issues, among other factors. Having reliable communication in the dynamic connectivity seems to be a critical factor in enabling the successful extended enterprise which works collaboratively.

Chapter 6 Model Building and Simulation

6.1 Overview

The research framework in Figure 4.3 was fully followed in this chapter mainly to answer part of the fourth research question (Section 1.4) and the main objective (Section 1.5.1). Modelling and simulations were thus executed to allocate bulk orders to multiple SMEs equitably. The simulation results are in Chapter 8.

6.2 Problem formulation

In formulating the problem for the simulation purposes, the following guidelines should be considered: create the domain boundary of the problem; collect all the data and the required information regarding the problem domain; identify the key decision-makers and the stakeholders for the problem(s) at hand; identify the needs and objectives of the key decision-makers and the stakeholders; state the constraints to be considered in the model; and state all essential assumptions required to be considered in the model (Balci, 2012).

An illustration of the problem formulation, definition or structuring is as follows: consider an order entry (e.g. 50,000 items) required by apparel retailers. These orders are placed to a manufacturer (SME). A single SME is considered to have less capability and capacity to process all 50,000 items (e.g. shirts). However, if several SMEs work together collectively as an extended enterprise, they can process (manufacture) the requested orders. The question is: how to allocate these items digitally with consideration to multiple factors. In this research, the equitable order allocation is what is referred to as distribution (Section 2.7). Therefore, distribution is considered as sharing equitably among all the collaborating SMEs.

The order distribution (sharing) processes are classified into four scenarios, as follows:

a) Placed orders from a single retailer to a single manufacturer (SRSM): a traditional approach can be used here to process the received orders.
b) Placed orders from a single retailer to multiple manufacturers (SRMM): such a scenario is considered as a multi-sourcing process.

c) Placed orders from multiple retailers to a single manufacturer (MRSM): for this case, the manufacturer needs to prioritise its capacity and capability.

d) Placed orders from multiple retailers to multiple manufacturers (MRMM): this is the most challenging scenario. For this category, the concept of Industry 4.0 (digitalisation) can be used. Table 6.1 depicts the classification summary of the problem formulation.

Table 6.1: Types of order categories.

Scenario	Apparel retailer	Apparel manufacturer	Assigned code	Hint	Decision criteria for order distribution
A	Single	Single	SRSM	Traditional approach	See the CSDCs from Figures 5.6 to 5.8
B	Single	Multiple	SRMM	Multi-sourcing	
C	Multiple	Single	MRSM	Prioritised capacity	
D	Multiple	Multiple	MRMM	Collaborative capacity	

Table 6.1 is represented diagrammatically by Figures 6.1 to 6.4: these figures comprise some of the potential product specifications from retailers. To the manufacturers' side, the critical decision criteria to be considered in distributing the orders are also shown.

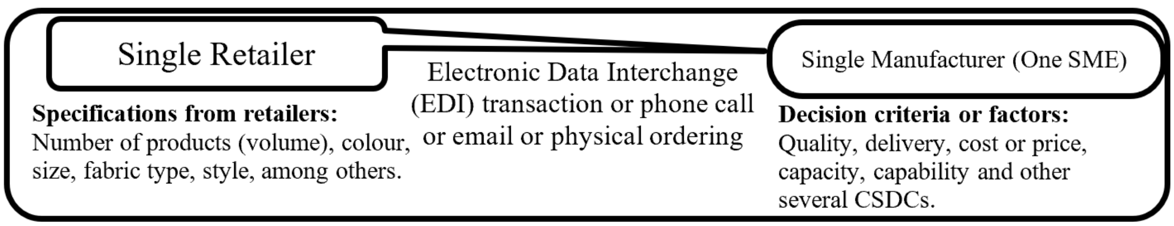


Figure 6.1: Scenario A - apparel orders from a single retailer to a single manufacturer.

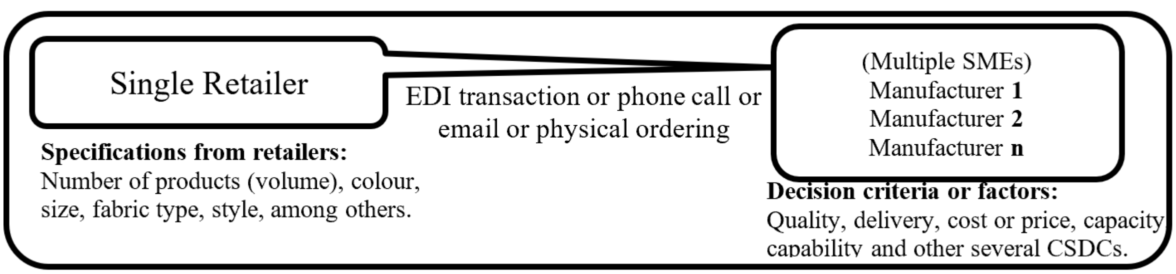


Figure 6.2: Scenario B - apparel orders from a single retailer to multiple manufacturers.

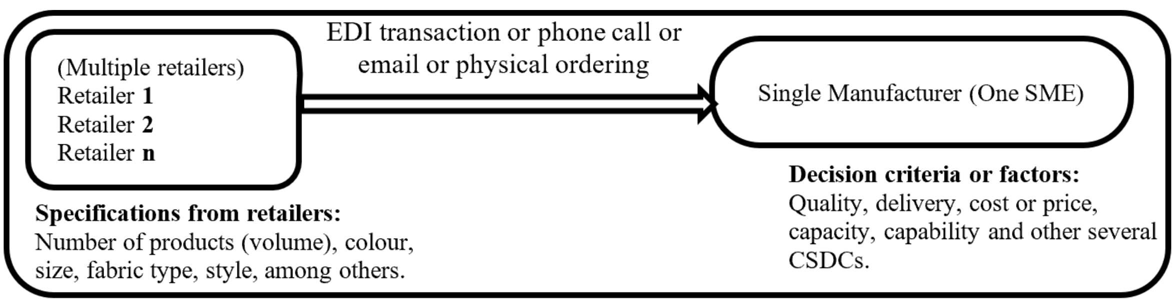


Figure 6.3: Scenario C - apparel orders from multiple retailers to a single manufacturer.

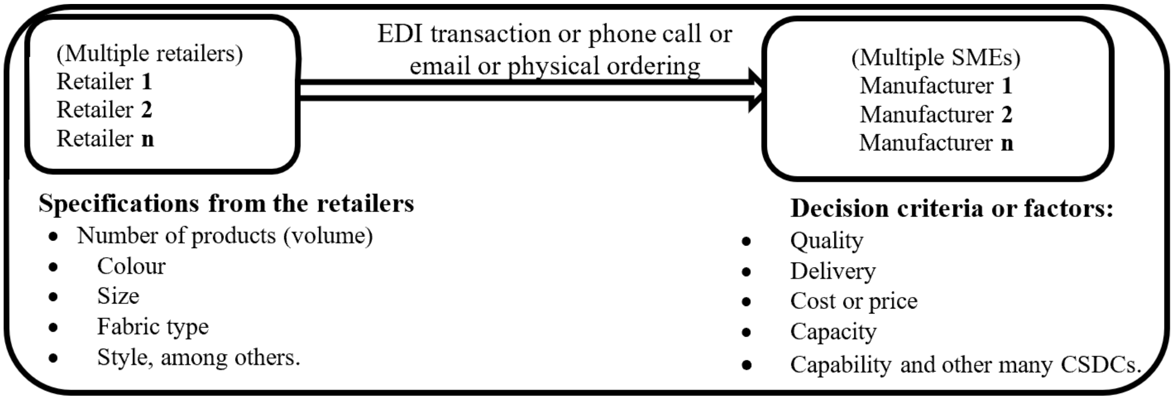
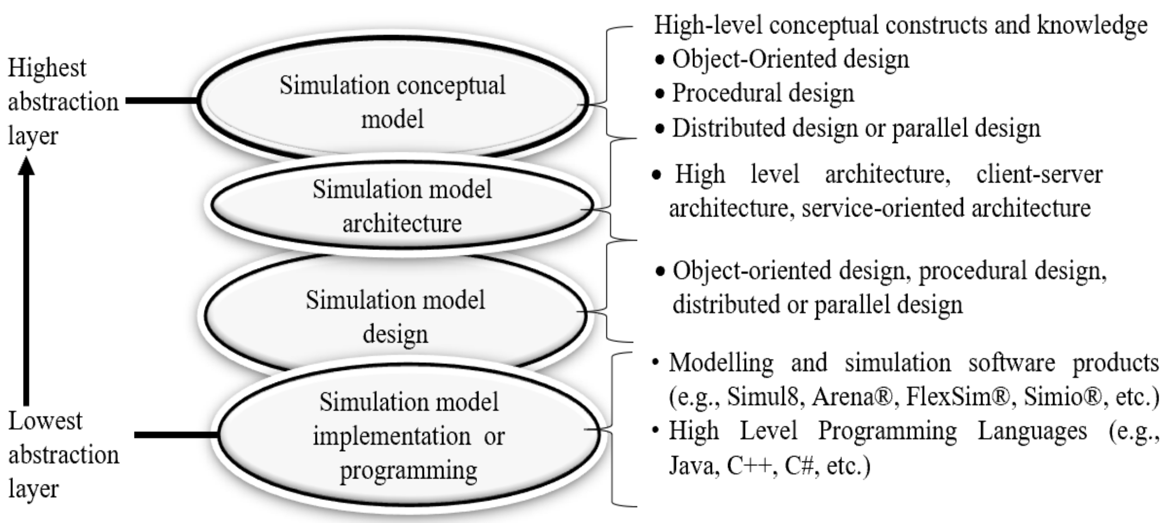


Figure 6.4: Scenario D - apparel orders from multiple retailers to multiple manufacturers.

6.3 Conceptual model

A conceptual model is a description of a process, procedure or system, composed of logical thoughts which are applied to simulate or comprehend a matter the particular model characterises. Balci *et al.* (2011, p.157) describe the conceptual model as a "repository of high-level conceptual constructs and knowledge specified in a variety of communicative forms (e.g., animation, audio, chart, diagram, drawing, equation, graph, image, text and video) intended to assist in the design of any type of large-scale complex application." The conceptual model needs to detail the objectives, outputs, inputs, and the contents (model scope, level of details, assumptions, and simplifications). There are different layers of a simulation model abstraction (Figure 6.5).



Source: Adapted from Balci and Ormsby (2007, p.176) and Balci (2012, p.877).

Figure 6.5: Layers of the simulation model abstraction.

Figures 6.6 to 6.9 depict the conceptual models for the formulated categories in Figures 6.1 to 6.4, respectively: they are for the SRSM, SRMM, MRSM and MRMM models, respectively. Conceptual frameworks considered modelling from retailers to manufacturers because apparel orders are placed from retailers. If the model could be modelled from the manufacturers to the retailers, this could be interpreted as sharing the completed apparel products rather than processing the received orders in an extended enterprise (EE) setup. The detailed conceptual model is depicted in Figure 6.10.

Figure 6.7 (SRMM) and Figure 6.9 (MRMM) depict the developed conceptual frameworks (models) in an extended enterprise. Such conceptual frameworks identify the top level of ordering processes from retailers to a cluster of SMEs (manufacturers). The two models (Figures 6.7 and 6.9) can assist in processing the received apparel orders in an EE viewpoint. Ideally, retailers can place orders either directly to their desired SMEs (i.e. traditional approach) or through an EE set up. For an EE, a cluster of SMEs receive bulk orders and use the developed CSDCs to rank and allocate the received orders equitably. Retailers also use their criteria to select suitable SMEs. SMEs working as a single virtual entity thus allocate bulk orders: the SMEs act as single sourcing for retailers' apparel items.

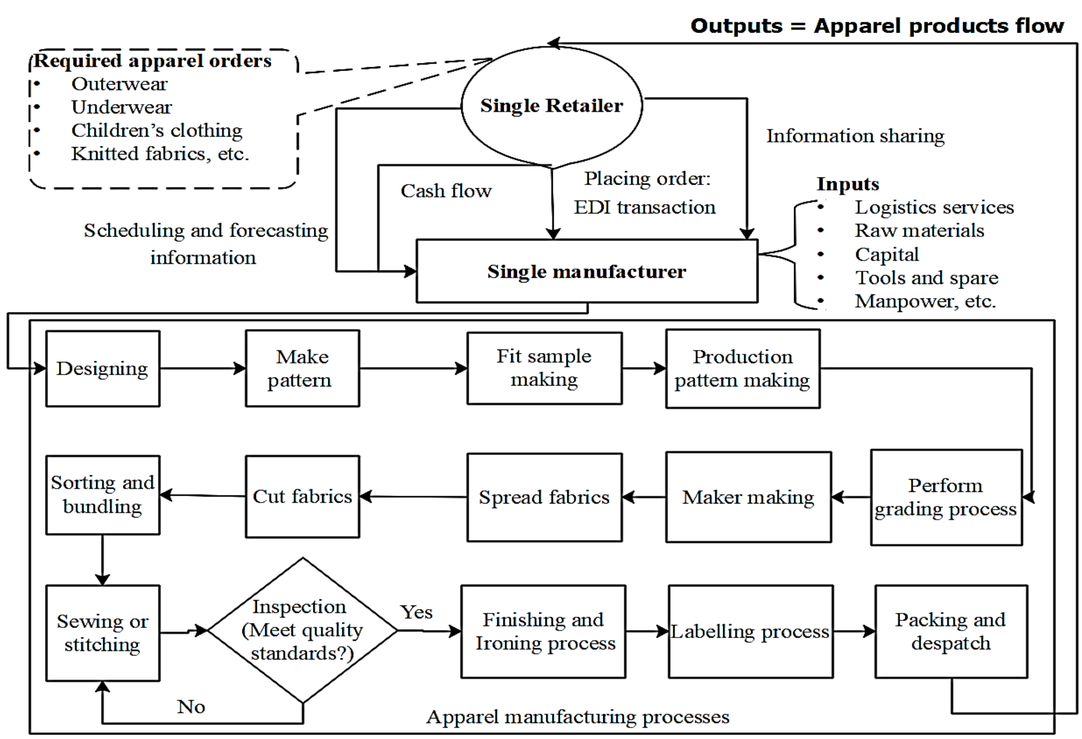


Figure 6.6: Conceptual model for a single retailer to a single manufacturer (SRSM).

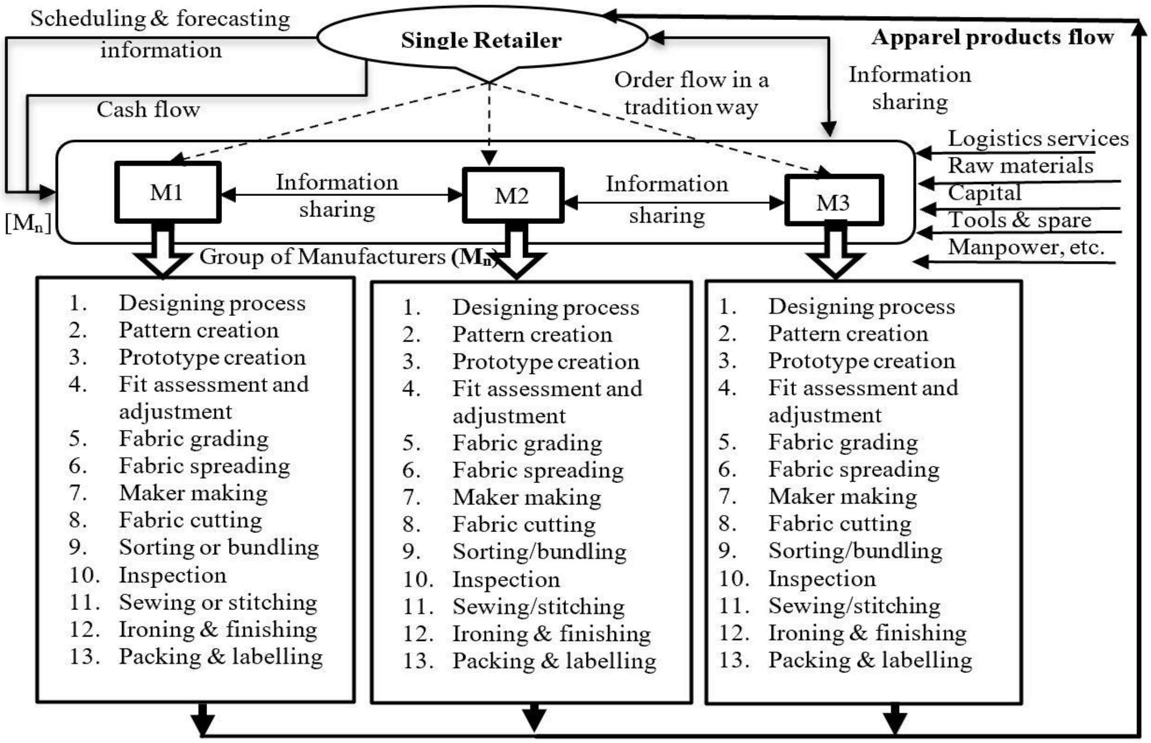


Figure 6.7: Conceptual model for a single retailer to multiple manufacturers (SRMM).

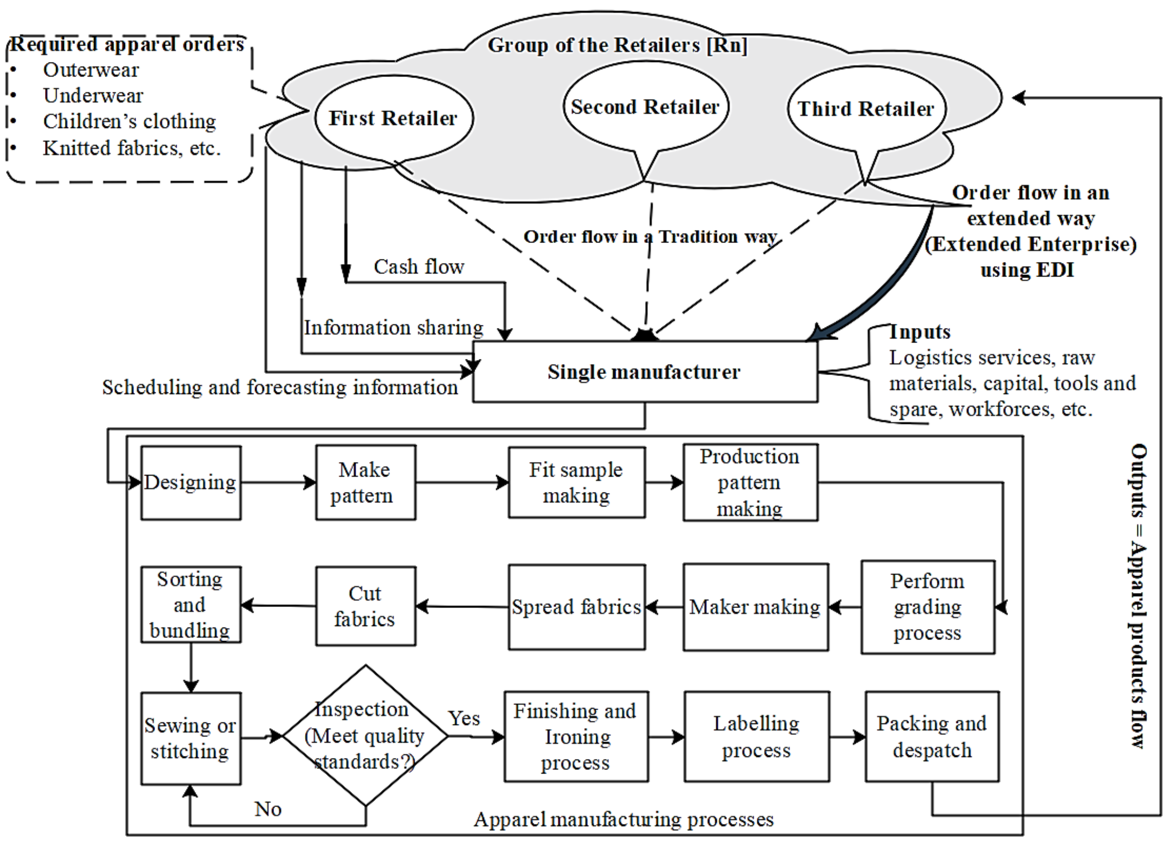


Figure 6.8: Conceptual model for multiple retailers to a single manufacturer (MRSM).

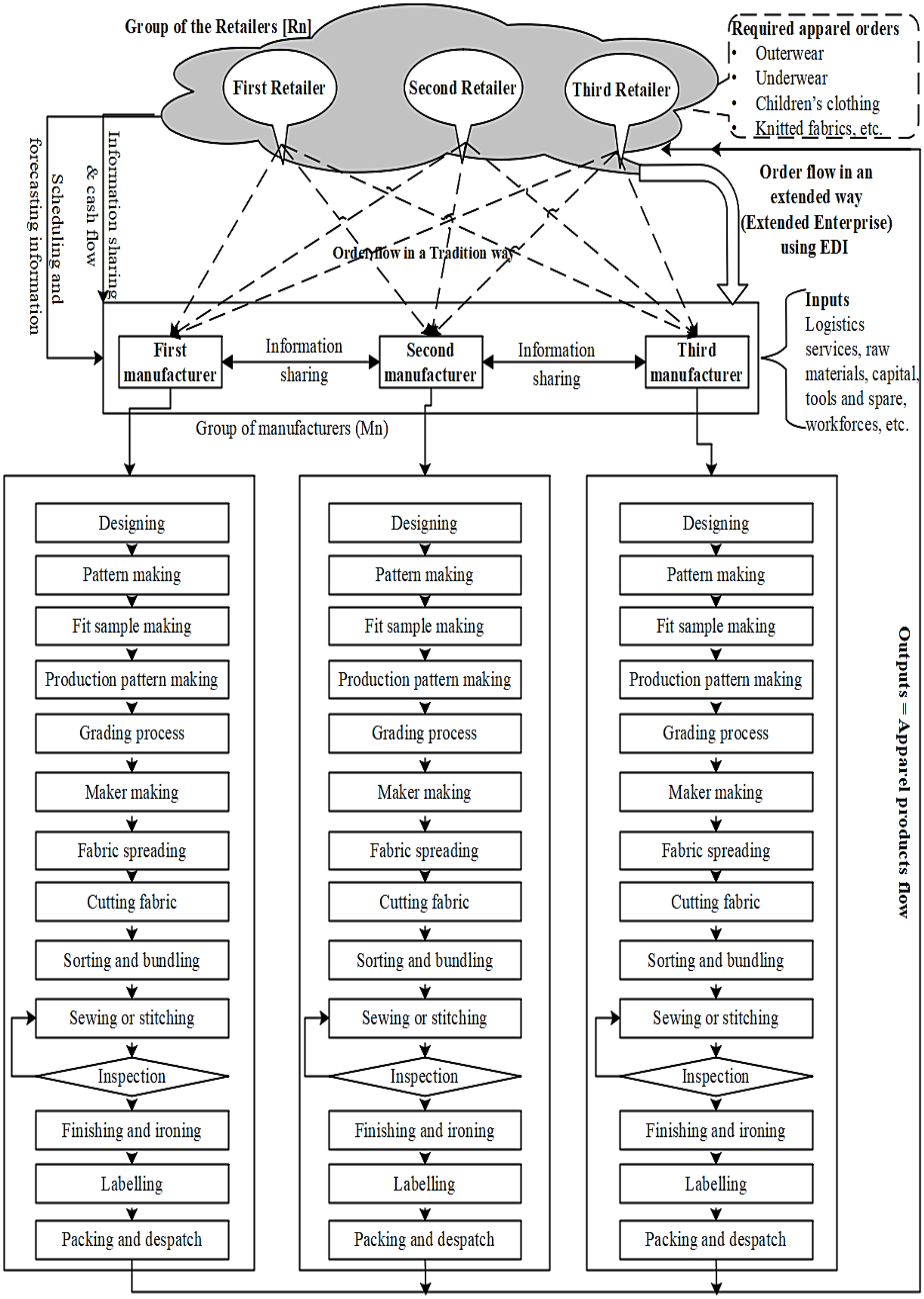


Figure 6.9: Conceptual model for multiple retailers to multiple manufacturers (MRMM).

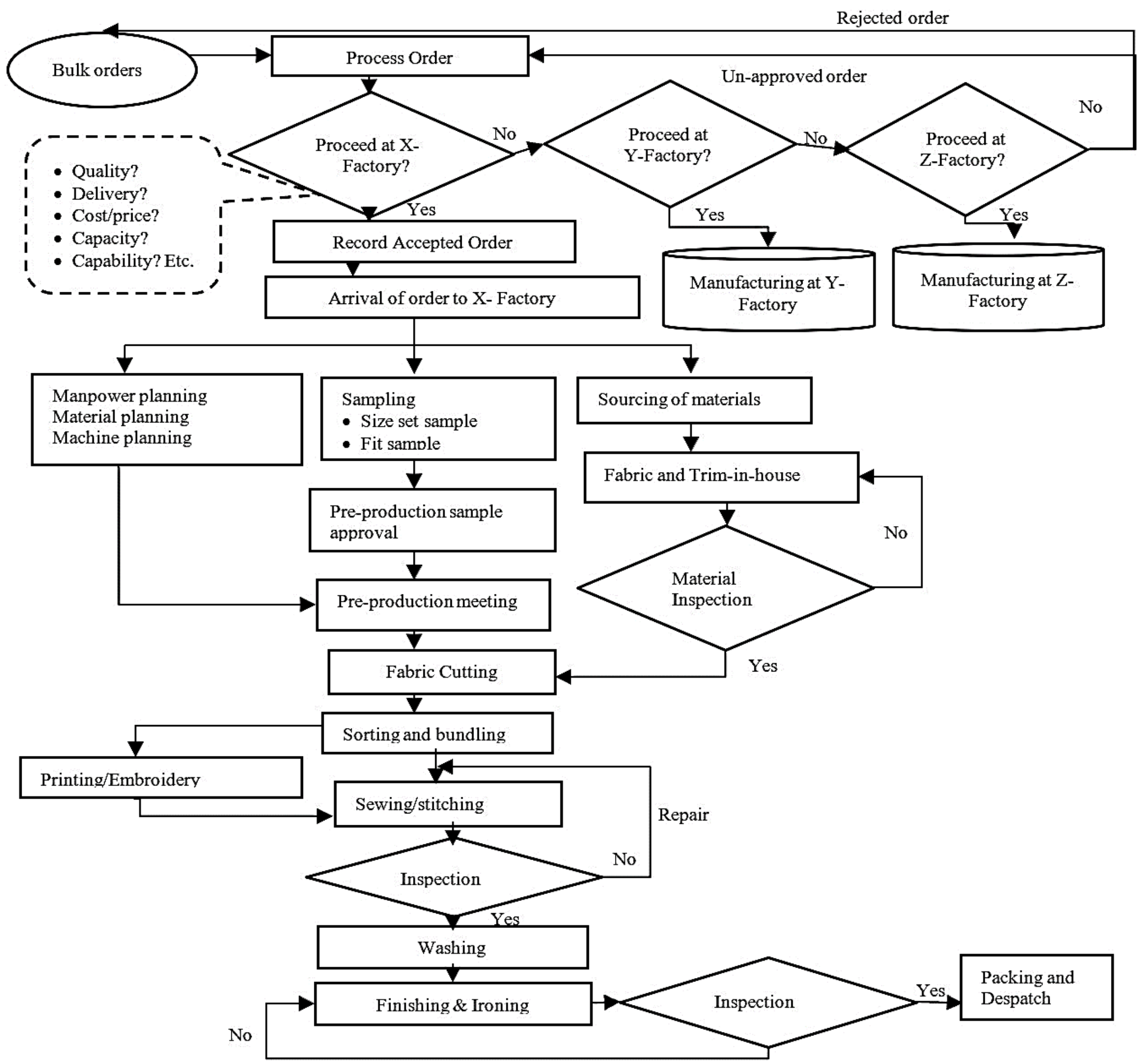


Figure 6.10: A detailed conceptual model about the order distribution (sharing).

Apparel manufacturers focus on one of the two main production methods: CMT or fully factored production (Kunz *et al.*, 2016). CMT stands for *cutting* the fabric, *making* (sewing) garments and *trims* along with the cleaning processes and the packaging processes of the finished garments. The trimming process usually includes putting the labels, hang tags, price ticketing and packaging. For the CMT, customers are generally required to offer materials, including the required fabrics and the patterns; while for the fully factored production solution, the factory regularly supports product development, patterns, sourcing the fabrics, as well as printing and trimmings (Kunz *et al.*, 2016). An order distribution (sharing) model for this study can thus consider either of the two. Garment production can be performed based on the steps listed in Figures 6.6 to 6.10. Each step has the sub-steps within it. But most researchers focus on sewing operations as the major bottleneck process. In the T&A sector, planning activity usually focuses on the sewing processes because sewing accounts for up to 80% of the resources and the required skills (Collins and Glendinning, 2004).

6.4 Preliminary simulation data

6.4.1 Standard Allowed Minutes (SAM) or Standard Minute Values (SMV)

SAM or SMV is the total time needed to finish one process or operation when working at standard performance. SAM should be established using existing conditions with standard and specific methods when there are several repetitive activities (Nabi *et al.*, 2015). SAM can be computed as the sum of the base time (B_t), idle time (I_t) and fatigue allowance time (F_t): F_t includes relaxation, contingency, machine delay allowance, among others; and B_t includes the performance rating (P_r) and the stopwatch time (S_t) (equations 6.1 and 6.2) (Güner and Ünal, 2008).

$$SAM = B_t + F_t + I_t \tag{6.1}$$

$$SAM = (B_t \times P_r) + F_t + I_t \tag{6.2}$$

In the apparel industry, SAM can differ from one factory to another due to garments design, garment size, type of garments, type of fabrics, type of machines, type of sewing technology, stitching accuracy, number of operations, number of workers, seams length, etc. SAM data are essential in manufacturing distributed orders to different manufacturers. Each stage has its standard time. Table 6.2 summarises SAM data for basic garment products.

Table 6.2: SAM for the basic garment products (the sewing processes).

Product	SAM (Mean)	SAM (Range)	Sources
Crewneck T-Shirt	8	6 to 12	Sarkar (2011)
Formal full sleeve shirt	21	17 to 25	
Polo Shirt	15	10 to 20	
Formal trouser	35	N/S	
Women blouse	18	15 to 45	
Sweatshirt (Hooded)	45	35 to 55	
Bra	18	16 to 30	
Jacket (Suit)	101	70 to 135	
T-shirt style (UK)	12		Collins and Glendinning (2004)
T-shirt	11.96		Nabi *et al.* (2015)
Polo-shirt	14.552	N/S	Jalil *et al.* (2015)
Polo-shirt	12.92		Ahmed *et al.* (2018)
Ladies long shirt	15.56		Syduzzaman and Golder (2015)

Note(s): N/S = not stated; unit = minutes.

Table 6.3 presents a summary of the SMV or SAM data from the ‘Sewing data book’ by Brother Industries (1995). The provided data are the average (mean) data. Nevertheless, in the Arena® software, the processing time data were entered as Normal distribution functions. The NORM consists of the mean (μ) and STD (σ). If the primary data regarding the processing time are collected, the Arena® *Input Analyser* tool determines the suitable probability distribution for each specific process. Since there is not any formula to convert *mean* into STD; an arbitrary STD was used: $\sigma = 3$. Statistically, the STD is a measure which indicates the variation of a set of values. For this study, the value for STD is ‘time factor’ for each process within the Arena® software. By setting a high STD, it means the values are widely spread over a larger range, while a low STD, implies that the values are near to the *mean* of the values. An alteration of the STD can be performed to analyse the influence of STD in the generated desirable results. A detailed discussion of the available probability distribution functions within the Arena® software is in Table 3.8. Based on Tables 6.2 and 6.3; this study used SAM data from Table 6.3 due to its sufficient data for basic garments in modelling the SRSM, SRMM, MRSM and MRMM models.

Table 6.3: SMV or SAM to manufacture garments.

Garment/apparel type	Name of the working process	SMV (Seconds)	Total
Men’s jacket	The process of the front body	2,323	7093
	Process of facing	1,008	
	The process of the back body	589	
	Process of collar	415	
	Process of sleeve	644	
	Process of assembly	2,114	
	Process of finishing	7,093	
Men’s trouser	Process of parts	530	2067
	The process of the back body	392	
	The process of the front body	239	
	Process of assembly	906	
Men’s dress shirt	Process of parts	73	1085
	Process of cuff	207	
	Process of collar	219	
	Process of sleeve	91	
	The process of the back body	27	
	The process of the front body	96	
	Process of assembly	372	
Women’s jacket	Process of parts	256	4443
	The process of front body lining	149	
	The process of back body lining	85	
	Process of facing	142	
	Process of collar	295	
	Process of sleeve	649	
	The process of the back body	192	
	The process of the front body	1281	
	Process of assembly	1398	

Table 6.3 ***Cont'd***

Women's skirt	Process of parts	263	1858
	The process of body lining	245	
	The process of the front body	156	
	The process of the back body	520	
	Process of assembly	674	
Women's pants (trousers)	Process of parts	281	2240
	The process of body lining	303	
	The process of the back body	93	
	The process of the front body	422	
	Process of assembly	1141	
Women's blouse (long sleeve)	Process of parts	101	1925
	Process of cuff	119	
	Process of sleeve	359	
	Process of collar	209	
	The process of the back body	36	
	The process of the front body	155	
	Process of assembly	946	
Women's blouse (short sleeve)	Process of parts	68	1950
	Process of sleeve	167	
	The process of the back body	322	
	The process of the front body	417	
	Process of assembly	976	
Training jacket	Process of parts	140	1433
	Process of sleeve	82	
	Process of collar	36	
	The process of the back body	82	
	The process of the front body	304	
	Process of assembly	789	
Training pants (trousers)	Process of parts	181	1018
	The process of the front body	266	
	Process of assembly	571	
Training pants	Process of parts	78	550
	Process of assembly	472	
Polo shirts	Process of parts	141	847
	Process of sleeve	70	
	The process of the back body	18	
	The process of the front body	84	
	Process of assembly	534	
Jeans pants (trousers)	Process of parts	286	938
	The process of the back body	98	
	The process of the front body	170	
	Process of assembly	384	
Jeans jacket	Process of parts	315	1957
	Process of sleeve	126	
	Process of collar	120	
	Process of cuff	139	
	The process of the back body	56	
	The process of the front body	418	
	Process of assembly	783	
Working wear (shirts)	Process of parts	305	1543
	Process of collar	192	
	Process of sleeve	115	
	Process of cuff	180	
	The process of the front body	304	
	Process of assembly	447	
Working wear (jacket)	Process of parts	810	2700
	Process of collar	112	
	Process of sleeve	107	
	Process of cuff	132	
	The process of the front body	702	
	Process of assembly	837	

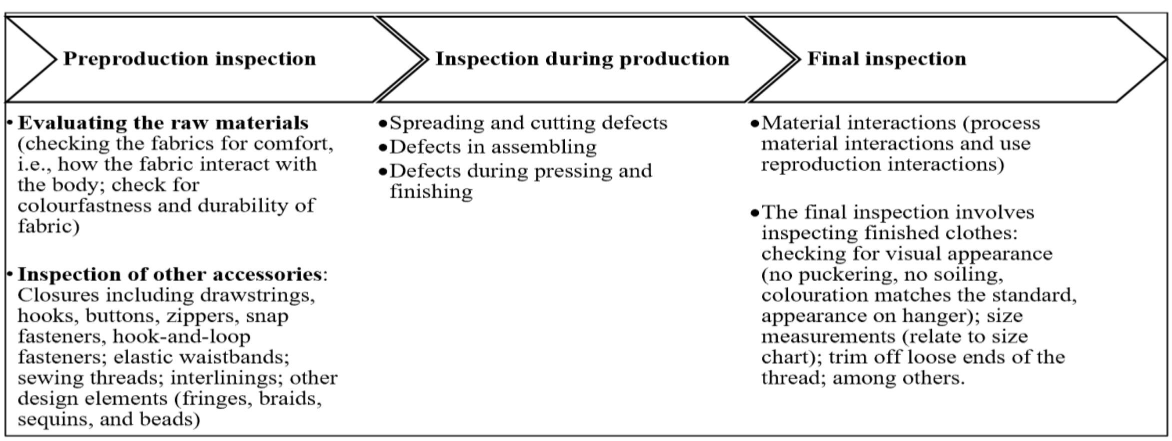
Table 6.3 ***Cont'd***

Working wear (pants/trousers)	Process of parts	258	1267
	The process of the back body	334	
	The process of the front body	172	
	Process of assembly	503	
T-shirt	All processes	197	197
Men's trunks	Process of parts	38	397
	The process of the front body	174	
	Process of assembly	185	
Men's brief	All processes	182	182
Panty	All processes	101	101
Brassiere	All processes	740	740
Pyjama shirt	Process of parts	199	885
	Process of collar	110	
	Process of sleeve	54	
	The process of the back body	26	
	The process of the front body	160	
	Process of assembly	336	
Pyjama trousers	Process of parts	90	416
	Process of assembly	326	

Source: Summarised from Brother Industries (1995).

6.4.2 Garment inspection: quality control (QC) and quality assurance (QA)

QA and QC are challenging areas within the T&A industry (Keist, 2015). QA is not QC, but QC is an aspect of QA (Keist, 2015). In the T&A, QA involves the practice of creating, manufacturing, evaluating, and assessing garments to determine whether they meet or exceed the required quality level for the industry's target market (Kadolph, 2007). QA focuses on the product from the initial conceptual design until when the product is sold to a customer. For QC, it is generally understood as evaluating the product quality after being manufactured and sorted into unacceptable and acceptable classes (Keist, 2015). Figure 6.11 shows some processes about an inspection practice in manufacturing apparel.



Source: Summarised from Keist (2015).

Figure 6.11: Some procedures for quality control and assurance in the T&A industry.

To assign data in Arena® for an inspection, there are quality approaches which must be decided, especially for the mass-produced garments. Tables 6.4 and 6.5 indicate the AQL (acceptable quality level). These tables can be read as follows: consider that the placed orders for making trousers is 2000, and the selected inspection level is level II. Then, from Table 6.4 (applies for the single sampling plans), the corresponding letter is *K* (Table 6.5). Letter *K* shows that 125 products should be taken randomly. The standard tolerance is 1.0% (critical defects), 2.5% (major defects) and 6.5% (minor defects). As a result, acceptable defected apparel products can be seven major and fourteen minors. Table 6.6 shows the sampling methods for garment inspections.

Table 6.4: The code letters in selecting the inspection's process sample size.

Lot or Batch Size	General Inspection		
	I	II	III
2 -8	A	A	B
9-15	A	B	C
16-25	B	C	D
26-50	C	D	E
51-90	C	E	F
91-150	D	F	G
151-280	E	G	H
281-500	F	H	J
501-1,200	G	J	K
1,201-3,200	H	K	L
3,201-10,000	J	L	M
10,001-35,000	K	M	N
32,001-50,000	L	N	P
150,001-500,000	M	P	Q
500,001-0ver	N	Q	R

Source: Adapted from Yusof *et al.* (2015, p.1802).

Table 6.5: AQL chart and sample plans.

Lot or Batch Size	Sample Size Code Letter	Sample Size	Acceptable Quality Level (AQL)									
			1.0%		1.5%		2.5%		4.0%		6.5%	
			Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
2-8	A	2	0	1	0	1	0	1	0	1	0	1
9-15	B	3	0	1	0	1	0	1	0	1	0	1
16-25	C	5	0	1	0	1	0	1	0	1	0	1
26-50	D	8	0	1	0	1	0	1	1	2	1	2
51-90	E	13	0	1	0	1	1	2	1	2	2	3
91-150	F	20	0	1	0	1	1	2	2	3	3	4
151-280	G	32	0	1	1	2	2	3	3	4	5	6
281-500	H	50	1	2	2	3	3	4	5	6	7	8
501-1,200	J	80	2	3	3	4	5	6	7	8	10	11
1,201-3,200	K	125	3	4	5	6	7	8	10	11	14	15
3,201-10,000	L	200	5	6	7	8	10	11	14	15	21	22
10,001-35,000	M	315	7	8	10	11	14	15	21	22	21	22
35,001-150,000	N	500	10	11	14	15	16	18	23	25	23	25
150,001-500,000	P	800	14	15	21	22	18	20	25	28	25	27
500,001 and over	Q	1250	21	22	21	22	20	22	28	30	28	30

Source: Adapted from Yusof *et al.* (2015, p.1802).

Table 6.6: Sampling methods for the garment inspections process.

Method	Clarification
No inspection	Garments are sold or bought without being inspected. It is rarely applied.
Skip-lot sampling	An operator does not take samples from each production lot
100% inspection	Inspection is carried out for every unit.
Spot checking	It is half of '100% inspection.' Random inspection is performed for the products which are made for shipment.
Arbitrary sampling	Inspection is performed for a 10% sample of any lot size. It is the most widely and popular method.
Statistical acceptance sampling	It is widely recognised and accepted internationally. Samples are inspected based on the clear statistics from the lot size set by acceptable standards.
Lot-by-lot sampling	An operator takes samples from each production lot

Source: Summarised from Keist (2015).

6.4.3 Types of apparel orders

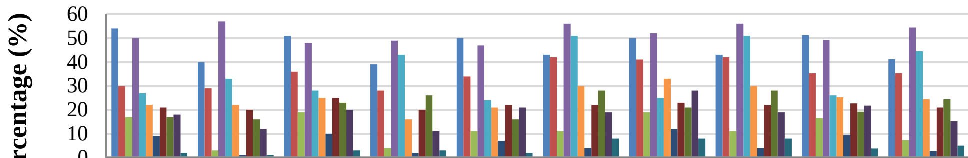
Apparel professionals categorise the apparel products into three groups (Table 6.7): the fashion garments, basic garments and the fast fashion garments (Kunz *et al.*, 2016). The SRSM, SRMM, MRSM, and MRMM models are basically developed concerning the 'basic garments' category.

Table 6.7: The fundamental characteristics of apparel products.

Items	Basic Garments	Fashion Garments	Fast Fashion Garments
Product characteristics	Most common in menswear	Very common in womenswear	Women's and young men's wear focus
	Standardised	Differentiated (individualised)	Focus on unique
	Utilitarian	Romanced with atmosphere	Romanced with new
	Infrequent changes in styling	Frequent changes in styling	Incessant changes in styling
Product presentation	Simple presentation	Project a fashion image	Represent immediate fashion image
	Related sets/individual items	Coordinated groups	Great variety of unique items
Production type	Partially to fully automated	More labour-intensive	Highly efficient supply chain
Inventory control	Similar inventory consistently	Zero-to-zero stock's inventory	Zero-to-zero stock's inventory
	Steady, predictable demand	Demand peaks follow by obsolescence	Total failure or immediate success
	Automated replenishment based on POS	Selection limited by the current fashion	Selection limited by immediate replacement with new styles
	Predictable selection	Seasonal changes in stocks	Biweekly replacement with a new style
Appeal to customer	Logical	Emotional	Passionate
	Intrinsic value	Extrinsic; externally created value	Extrinsic; externally created value
	Tangible product	Intangible fashion image	Unexplainable fashion image
	Meeting a need	Directing or creating a need	Directing or creating a more frequent need
	Price: the major consideration	Appearance: a significant selection factor	Appearance: the primary selection factor
	Replacement	Adding variety to a wardrobe	Adding endless variety to a wardrobe
Selection process	Comparative shopping	Impulse shopping	Dedication to shopping
	Easy price comparisons	Value difficult to assess	Difficult to assess the value

Source: Adapted from Kunz *et al.* (2016).

Figure 6.12 summarises types of the most purchased clothing accessories in the UK (2015-2018). The percentages in Figure 6.12 indicate the number of men and women who purchased clothes between 2015 and 2018. For *men*, they are in this order: jeans, top/t-shirt/sweatshirt, trousers, jumper/cardigan, shirt/blouse, jacket, sportswear, coat, shorts, suit, and other types. For *women*, they are in this order: top/t-shirt/sweatshirt, jumper/cardigan, jeans, trousers, shirt/blouse, coat, jacket, sportswear, shorts, other types, and suit.



	Apr-18		2017		2016		2015		Average	
	Men (%)	Women (%)	Men (%)	Women (%)	Men (%)	Women (%)	Men (%)	Women (%)	Men (%)	Women (%)
Jeans	54	40	51	39	50	43	50	43	51.25	41.25
Trousers	30	29	36	28	34	42	41	42	35.25	35.25
Shorts	17	3	19	4	11	11	19	11	16.5	7.25
Top/T-shirt/Sweatshirt	50	57	48	49	47	56	52	56	49.25	54.5
Jumper/Cardigan	27	33	28	43	24	51	25	51	26	44.5
Shirt/blouse	22	22	25	16	21	30	33	30	25.25	24.5
Suit	9	1	10	2	7	4	12	4	9.5	2.75
Jacket	21	20	25	20	22	22	23	22	22.75	21
Coat	17	16	23	26	16	28	21	28	19.25	24.5
Sportwear	18	12	20	11	21	19	28	19	21.75	15.25
Other type	2	1	3	3	2	8	8	8	3.75	5

Source: Summarised data between 2015 and 2018 from the Mintel website[14].
Figure 6.12: Types of clothes purchased by women and men in the UK.

6.4.4 The apparel ordering process

As a retailer, ordering an apparel product is not an easy process. A retailer needs to know the type of required garments, order size, design of the garment (e.g. style, colour, etc.), despatch method (physical collection or to be shipped by the manufacturer), and the lead time (i.e. the required completion time for the placed order). To develop models, it was assumed that the ordering process is for basic products (Table 6.7). To identify the number of orders to be placed, it is imperative to use basic stock planning (BSP). BSP can be defined as a tool used by retailers in planning purchases of basic or fashion merchandise (Clodfelter, 2015). BSP helps to know the number of products to be ‘on order’ or ‘on-hand’ to avoid stock out. BSP requires information on the average sales volume per week (ASVP), the

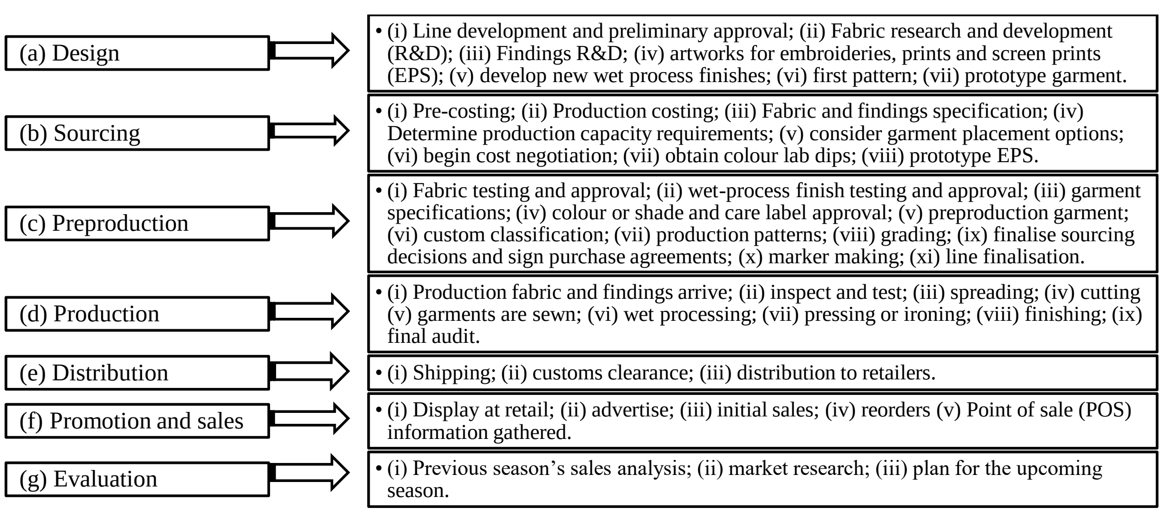
[14] Mintel at http://academic.mintel.com/ (accessed March to May 2018).

reorder period (RP), reserve stock levels (RS) and the delivery period (DP). Equation 6.3 computes the maximum number of products under the BSP (Clodfelter, 2015).

$$Maximum = ASVP \times (RP + DP) + RS \tag{6.3}$$

- *Maximum*: number of products required to be on hand or work-in-progress orders at any reordering point.
- *ASVP:* use past records to determine it.
- *RP:* the amount of time between apparel orders.
- *DP:* the time between order placement and when a product is ready on the sales floor.
- *RS:* number of products required to meet unanticipated sales for avoiding stock out.

Based on the quantitative data collected from one of UK retailers, the sales capacity per week is £20 to £25 million, and the average order size is 7,600 to 14,400 per season. These figures are the held stock in their distribution centre before restocking. This retailer classifies its ordering process into three seasons, i.e. spring, summer, and winter, in a year, with two to three phases in each season. Thus, on average, the company's order size is 22,800 to 43,200 per year, i.e. if only a single phase is considered for each season. In modelling and simulating, only a single phase was considered. According to Kemp-Gatterson and Stewart (2009), the design activity can take 2-3 weeks, sourcing (2-3 weeks), pre-production (2-6 weeks), production (1-2 weeks), distribution (1-3 weeks for domestics and 3-5 weeks for importing), promotion and sales (3-6 weeks) and evaluation takes (2-4 weeks). This apparel production cycle is detailed in Figure 6.13.



Source: Summarised from Kemp-Gatterson and Stewart (2009).
Figure 6.13: The apparel production cycle.

In the UK, the speed to market (lead time) is an essential factor for sourcing. Lead time is mostly two weeks within the UK (the time from manufacturing to store) (CSWEF, 2015). From the conducted interview session to the UKR1, the response was:

> "[…] the lead time varies. We recently explored a new fashion model. This model started in Leicester, UK. From the day we had a meeting with [manufacturers] to look at the products they can produce to be in the store is 3 weeks. This is a fast-fashion model, that is, from inception to delivery to market. Normally fast fashion is around 6 weeks. Mostly the fast fashion products are from Turkey. We generally talk for an average of 12 weeks for a normal call."

6.5 Model building and simulation using the Arena® software

6.5.1 Overview

Four conceptual frameworks were identified: they were lined up with a research purpose of executing an equitable order allocation. The proposed concepts are illustrated in Figures 6.6 to 6.9 for the SRSM, SRMM, MRSM and MRMM scenarios, respectively. Based on the theoretical orientation, it was found that the MRMM conceptual framework is the most challenging to develop using simulation, and hardly any research developed one in the apparel industry.

In this study, modelling and simulation thus illustrate the MRMM model. The other three conceptual frameworks are briefly explained because they are the subsets of the MRMM model. Section 6.5 comprises the software package details (Section 6.5.2), the required simulation data (Section 6.5.3), order distribution options (Section 6.5.4), KPIs (Section 6.5.5) and the four distribution models (Sections 6.5.6 to 6.5.9). The supply system for this study consists of two parts: manufacturers (M_i) and retailers (R_j), whereby i and j represent the number of SMEs and retailers, respectively.

6.5.2 Software package

The Arena® simulation software version 16.00.00 simulated the MRMM model. The used laptop had the following specifications: processor was of the 8th generation Intel® Core™ i7-8550U; installed random access memory (RAM): 16.0 GB and 64-bit operating system.

6.5.3 Simulation data

Data collection is a significant part of simulating an actual system. Synthetic data and actual (real) data were retrieved and collected, respectively, based on their availability. Afterwards, confirmations were conducted in determining the completeness and suitability of the specific data before using them to develop models. Some of the collected data include the interarrival time of the apparel orders, the number of orders (volumes), probability distribution functions for each operation, operation (processing) time—SAM (Table 6.3), the number of machines, the number of retailers and manufacturers, and others.

6.5.4 Order distribution (allocation) options

Three options can be considered in executing equitable order allocation, as follows:

a) **Option I**: by using an external system, e.g. programmed algorithms, Microsoft® Excel and other pertinent software, to rank each manufacturer in proportion. This option comprises quantitative and qualitative CSDCs: subjective and objective decisions are executed. The decision criteria are soft constraints, e.g. several styles, workers relationship, trust, experience, reputation, etc., while hard constraints include lead time, cost, or price, etc. (Figures 5.6 and 5.7).

b) **Option II:** directly inputting a few selected decision criteria in Arena®. This option comprises subjective decisions and mostly comprises qualitative methods. Table 6.8 illustrates the ranking processes and Section 5.4.3 discussed this option intensively.

Table 6.8: Sample of the ranking processes when directly inputting a few selected decision criteria in the Arena® software.

Sample of criteria	Manufacturer (Mz_1)	Manufacturer (Mz_2)	Manufacturer (Mz_3)
Lead time	Small	Medium	Large
Quality	Poor	Best	Good
Quantity, etc.	Poor	Best	Good

c) **Option III**: equal distribution; this option involves only SMEs with similar capabilities, capacities, and other CSDCs, to work collaboratively (i.e. in an EE framework). The ranking process of SMEs is performed, and bulk orders (volumes) are distributed equally.

So, the SRSM, SRMM, MRSM, and MRMM models were developed based on options I and II. Section 5.4.3 (ranking of the pertinent CSDCs) highlights the execution of options I and II. Initially, Sections 5.4 and 8.2.7 findings were used as inputs in Arena®. Option II was also performed in executing Arena® *Process Analyser* and the *Output Analyser* tools to illustrate the feasibility of order allocation through DACE (Chapter 7).

6.5.5 Key performance indicators (KPIs)

The KPIs for the four conceptual models in Figures 6.6 to 6.9 are as follows:

(a) Enabling an equitable distribution (sharing) of bulk orders (volumes) amongst several manufacturers, i.e. SMEs, working as a single virtual entity.

(b) Manufacturing (production) throughput time: it is the total amount of time required for an entity (i.e. apparel product) to go through all the manufacturing processes.

(c) Total produced apparel: include all the manufactured products by all five SMEs.

(d) Resources utilisation for the machines and operators; the Arena® software generates the scheduled utilisation (SU) and instantaneous utilisation (IU). According to Rossetti (2016), the mathematical computation of IU and SU relies on two parameters—*NR* and *MR*—for a resource. Assume *NR(t)* is the number of busy resource units at time *t*; thus, the time-average number of busy resources is as given by equation 6.4. If *MR(t)* is the number of scheduled resource units at time *t*, the time-average number of scheduled resource units is as given by equation 6.5. Then, *IU* at time *t* can be computed as given by equation 6.6. Therefore, the *IU* is "the time-weighted average of the ratio of these variables [i.e. *NR* and *MR*]" whereas for the *SU*, it is "the time-average number of busy resources divided by the time-average number scheduled" (Rossetti, 2016, pp.559-561).

$$\overline{NR} = \frac{1}{T}\int_0^T NR(t)dt \tag{6.4}$$

$$\overline{MR} = \frac{1}{T}\int_0^T MR(t)dt \tag{6.5}$$

$$IU(t) = \begin{cases} 0 & NR(t) = 0 \\ 1 & NR(t) \geq MR(t) \\ NR(t)/MR(t) & otherwise \end{cases} \tag{6.6}$$

Similarly, equations 6.7 and 6.8 compute the *IU* and *SU*, respectively, at time *t*. If *MR(t)* is constant, then $\overline{SU} = \overline{IU}$ (Rossetti, 2016). The generated resource utilisation results through the Arena® software are in Sections 8.3.3 and 9.2.2.

$$\overline{IU} = \frac{1}{T}\int_0^T IU(t)dt \tag{6.7}$$

$$\overline{SU} = \frac{\overline{NR}}{\overline{MR}} = \frac{\frac{1}{T}\int_0^T NR(t)dt}{\frac{1}{T}\int_0^T MR(t)dt} = \frac{\int_0^T NR(t)dt}{\int_0^T MR(t)dt} \tag{6.8}$$

6.5.6 Single-retailer to single-manufacturer (SRSM) model

This category presents an order distribution (equitable order sharing) model connecting a single retailer (Ra_1) with a single manufacturer (Mw_1). Figures 6.1 and 6.6 represent the problem formulation and the conceptual framework of the SRSM model, respectively. Mw_1 receives demanded orders from Ra_1. Ra_1 uses EDI to order apparel from M_{W1}. Then, Mw_1 processes all orders, and ultimately despatches products through the available logistics.

6.5.7 Single-retailer to multiple-manufacturers (SRMM) model

The SRMM model presents an order distribution (order sharing) connecting a single retailer with multiple manufacturers. Figures 6.2 and 6.7 illustrate the problem formulation and the conceptual model for the SRMM model, respectively. The manufacturers (Mx_1 to Mx_5) receive orders from a retailer (Rb_1). The interarrival time of the retailers (customer) follows the Poisson process as elaborated in Section 6.5.9 for the MRMM model. Other processes are the same as performed in Section 6.5.9.

6.5.8 Multiple-retailers to single-manufacturer (MRSM) model

This category presents an order distribution (sharing) model—MRSM model—connecting multiple retailers with a single manufacturer (SME). The manufacturer (My_1) receives orders from retailers (Rc_1 to Rc_5). It is assumed that the manufacturer (My_1) immediately processes the received orders from retailers without delay. After completing processing the retailers' demand, the manufacturer (My_1) collects all the manufactured apparel products at the distribution centre ready for dispatching to retailers through the available logistics services.

The problem formulation and the conceptual model for the MRSM model are in Figures 6.3 and 6.8, respectively. If retailers place bulk orders (volumes), it is challenging how a single manufacturer can meet the agreed lead time, considering that many SMEs are limited in sizes, and they have low capacities and capabilities. As a result, working synergistically is the best alternative: this thus brings a need for developing the MRMM model (Section 6.5.9).

6.5.9 Multiple-retailers to multiple-manufacturers (MRMM) model

The MRMM model is the major one in this study as it proposes a solution for multiple retailers and manufacturers (SMEs) setup. This category presents an order distribution or sharing model—MRMM model—connecting multiple retailers with several manufacturers (SMEs) working as a single virtual entity. The MRMM model reduces some weaknesses of the SRMM model. The retailers' demands are random variables which follow the Poisson process distribution (Table 3.8). Manufacturers receive orders from retailers, and they process the received orders immediately as per the available standard procedures. After finishing to process the retailers' demands, the manufacturers collect all the manufactured apparel products at the distribution centres (DCs) ready for dispatching to retailers through the available logistics services. The problem formulation and the conceptual model for this category are depicted in Figures 6.4 and 6.9, respectively.

Some of the initially considered assumptions in building the SRSM, SRMM, MRSM and MRMM models include the following:

a) The accepted orders cannot leave the system before completing all the processes.
b) There is no disruption factor which can interfere with the production processes.
c) Each machine has at least one operator at a time.
d) The raw materials are considered to be available. So, the issues of inventory management were not considered in this study.
e) All models chiefly considered the CMT (cut-make-and-trim operations) category only.
f) SMEs process (manufacture) similar apparel products: if the accepted orders are for dresses, all collaborating partners are assumed to be able to process dresses as well.

g) There is no machine breakdown.
h) There is no absenteeism for the workers, and the machine efficiencies are constant.
i) It is assumed that on average, it takes 2 to 3 weeks to manufacture the products and takes 1 week to deliver the products in the UK. Any user of the developed models can change the parameters to fit the requirements.
j) It is assumed that retailers and manufacturers have a long-term strong cooperative relationship. So, all the basic ordering information remains effective whenever an order is placed unless there are massive changes in the basic information. The delay of the placed order was thus not illustrated in this study.
k) Multiple means more than one; therefore, for multiple retailers and multiple manufacturers, only five are used for each category to illustrate the concept.

It must also be noted that apparel manufacturing comprises a complex supply chain with demand uncertainty and dynamics. The decision process regarding who (i.e. manufacturer) should make what (i.e. apparel orders) depends on the total rating scores accumulated from all the considered pertinent decision criteria. In this study, the rating scores are referred to as the 'Cumulative Sourcing Performance Indices (CSPIs)' for the five SMEs (Tables 5.4 and 8.2). Figure 6.14 illustrates the followed major phases in building simulation models.

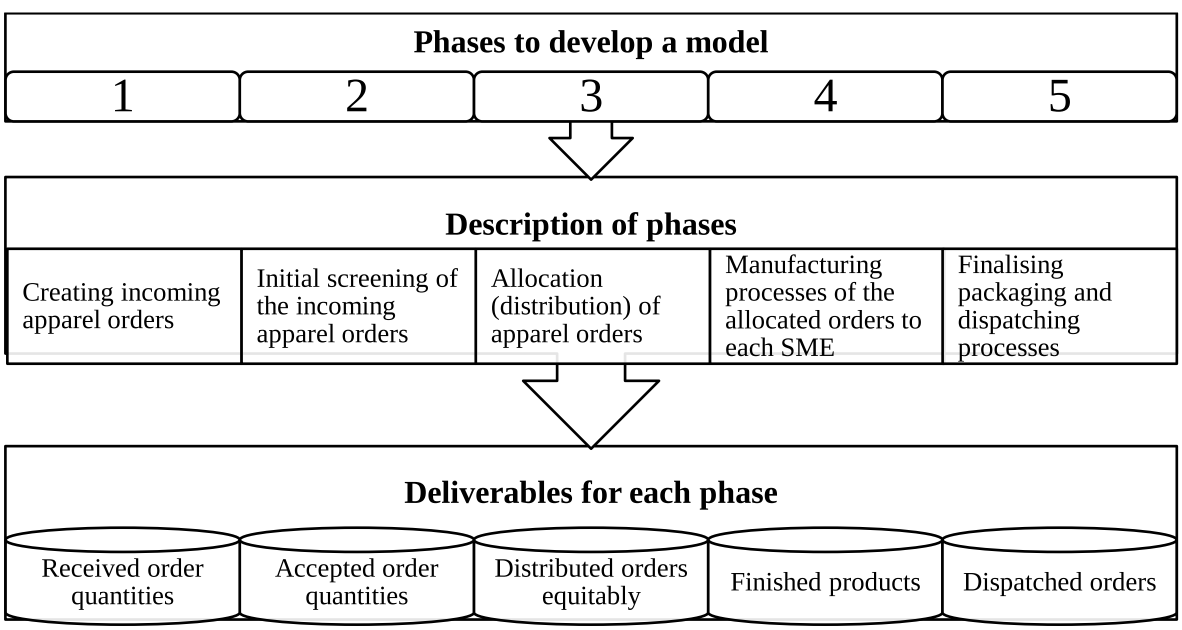
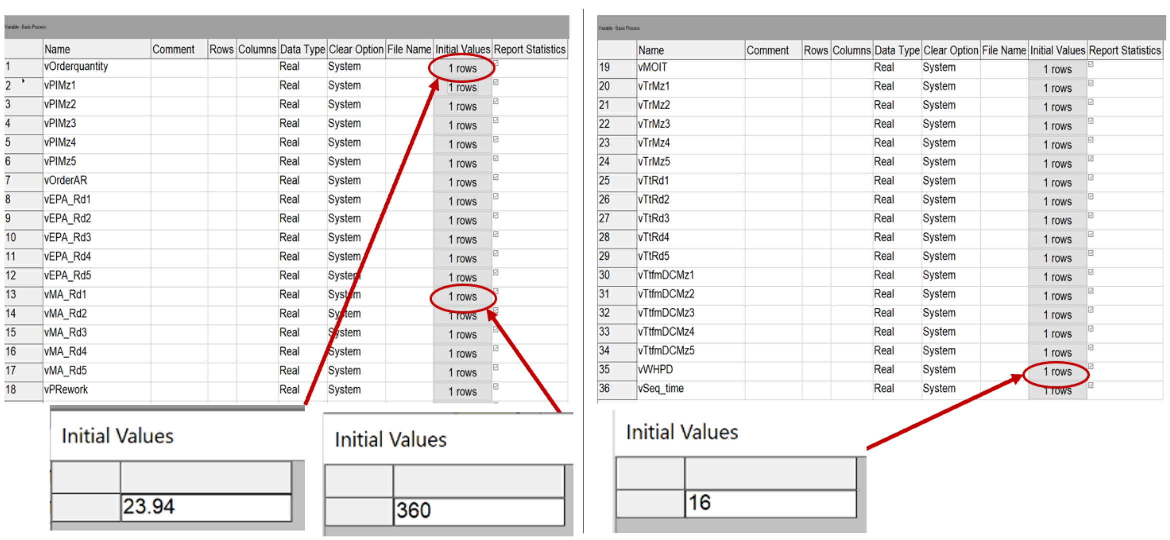


Figure 6.14: The followed phases in building the MRMM model in Arena®.

In the Arena® software, variables are initialised in the Variable Spreadsheet (Figure 6.15) or using the ASSIGN module. Both tactics were used in developing the MRMM model. Some of the variables considered in modelling the MRMM model are as follows:

- Mz_1 to Mz_5: represent five apparel manufacturers.
- Rd_1 to Rd_5*:* five apparel retailers, i.e. multiple retailers.
- *Apparel Orders:* the various types of apparels demanded by Rd_1 *to* Rd_5.
- *vOrderAR:* represents an order acceptance rate from retailers.
- $vPIMz_1$ to $vPIMz_5$*:* the CSPI of each manufacturer, i.e. Mz_1 *to* Mz_5, respectively.
- $vEPA\_Rd_1$ to $vEPA\_Rd_5$: represent entities per arrivals (EPA) received from Rd_1 *to* Rd_5, respectively.
- vMA_Rd_1 to vMA_Rd_5: the maximum arrivals (MA) to be received from Rd_1 to Rd_5, respectively.
- *vPRework* is the probability of reworking or repairing at each inspection station.
- $vTrMz_1$ to $vTrMz_5$*:* the transfer times between machines at each workstation of SMEs.
- $vTtRd_1$ to $vTtRd_5$*:* the transportation time from the DCs to Rd_1 to Rd_5, respectively.
- $vTtfmDCMz_1$ to $vTtfmDCMz_5$*:* the transportation time from manufacturers to DCs.
- *vSeq_time*: sequencing time to assign the processing time for each process.
- *vOrderquantity:* represents the received orders from retailers.
- *vMOIT* is the mean order interarrival time for the received orders from retailers.



Note(s): Other several names of each process, resource, entity, counter, operator, etc., were entered in their full form without being initialised as variables.

Figure 6.15: Some initialised variables by the Variable spreadsheet module in Arena®.

The following are the phases (Figure 6.14) executed in building the MRMM model in Arena.

a) Creation of incoming demands (apparel orders)

In Arena®, entities are generated using the CREATE module 'based on interarrival time' (random arrivals) or a 'specified schedule'. The generated entities are then sent to the next module for further processes. As stated in Section 6.4.4, one of UK retailers (Rd_1) places an average (mean) order size of 7,600 to 14,400 per season. Rd_1 classifies its order processing into three seasons, i.e. winter, summer, and spring, in a year, with two to three phases in each season. In modelling, a single-phase was considered to determine 'entities per arrival', and three phases were considered to determine the 'maximum arrivals'. On average, the company's order size is 22,800 to 43,200 per year, for three seasons (if only a single phase is considered for each season). The lead time varies depending on the product (apparel). The average order size for the three phases is 129,600 per year.

When manufacturers (SMEs) receive orders, three scenarios can happen:

(a) **Scenario I**: If the ordered products are available with the manufacturers (in stock), the retailer(s) can depart with the product immediately.
(b) **Scenario II**: If the ordered products are not available with the manufacturers (in stock), the retailer(s) may depart without the product (i.e. lost sales or customer).
(c) **Scenario III**: If the ordered products are not available with the manufacturers (in stock), the retailer may have to wait for the product to be manufactured. Such orders are referred to as 'back-ordered': this scenario involves longer lead time than other scenarios.

The developed model assumed scenarios II and III, that is, the MRMM model assumes that all accepted orders must be processed from the beginning to the end. Initially, an entity was created to illustrate the apparel demand. The interarrival time of the retailers' demands occurs according to the Poisson process. The Poisson process was selected based on the theoretical underpinnings' results in Table 3.8. Consistency with probability theory, this indicates that the duration between retailer arrival is exponentially distributed (EXPO) with a mean of $(1/\lambda)$ for *one year*. Such demand happens to a time between order arrivals with an EXPO with a mean (average) of $(1/120)$ days = 120 units per day (equation 6.10). For the maximum arrivals, three phases were considered in a year, thus resulting in 360 units per year (equation 6.11). Arena® has four categories of units, i.e. seconds, minutes, hours, and days. Also, the mean (average) time between retailers' arrivals was initially assumed to be one month (equation 6.9): one month equals 30 days. Noting that in Chapter 7, the variation of the interarrival times was altered to simulate experiments.

$$\frac{1}{\lambda} = \frac{1\ month}{1\ retailer} \times \frac{12\ months}{1\ month} = \frac{12\ months}{Retailer} \tag{6.9}$$

$$\frac{1}{\lambda} = \frac{\left(^{43{,}200}/_{12}\right) units}{1\ retailer} \times \frac{1\ month}{30\ days} = \left(\frac{1}{120}\right) days \tag{6.10}$$

$$\frac{1}{\lambda} = \frac{\left(^{129{,}600}/_{12}\right) units}{1\ retailer} \times \frac{1\ month}{30\ days} = \left(\frac{1}{360}\right) days \tag{6.11}$$

Five retailers, i.e. Rd_1 *to* Rd_5, are considered in modelling the MRMM model. The actual order size is from Rd_1 only. Order sizes for the other four retailers—Rd_2 *to* Rd_5—were hypothetically added by 5%, 10%, 15% and 20% to the Rd_1 order size, respectively. Recall, for the first retailer (Rd_1), the average order size is 22,800 to 43,200 per year (for three seasons); thus, let Q be the order sizes (quantities) and j be the number of retailers. So, equation 6.12 computes the entity per arrival (EPA).

$$Q_j = The\ order\ size\ for\ Rd_1 + Percentage\ of\ Rd_1 \tag{6.12}$$

$$Q_2 = 43{,}200 + (5\% \times 43{,}200) = 45{,}360\ order\ size\ per\ year$$

$$Q_3 = 43{,}200 + (10\% \times 43{,}200) = 47{,}520\ order\ size\ per\ year$$

$$Q_4 = 43{,}200 + (15\% \times 43{,}200) = 49{,}680\ order\ size\ per\ year$$

$$Q_5 = 43{,}200 + (20\% \times 43{,}200) = 51{,}840\ order\ size\ per\ year$$

When computing for the 'maximum arrivals', the average order size for three phases of Rd_1, is 129,600 per year. Thus, using equation 6.12, the order sizes for the other four retailers are 136,080 for Rd_2, Rd_3 (142,560), Rd_4 (149,040) and Rd_5 (152,820) per year. Afterwards, equation 6.9 calculated the average order sizes so that to convert orders exponentially per day, as depicted in Table 6.9. Retailers use EDI to place orders.

Figure 6.16 shows the logic in creating incoming apparel demands and for order fulfilment from retailers. In Figure 6.16, the named '*Order Arrival*' within the CREATE module creates apparel order entities into the system following the Poisson process with an average of 1 day (equations 6.9 to 6.11). EPA is based on the *Poisson process* of 120 orders. In Figure 6.16, ‘POIS (120)’ is not shown because it was defined and initialised in the variable sheet module (Figure 6.15). The first batch of orders is created at 0 days into the system.

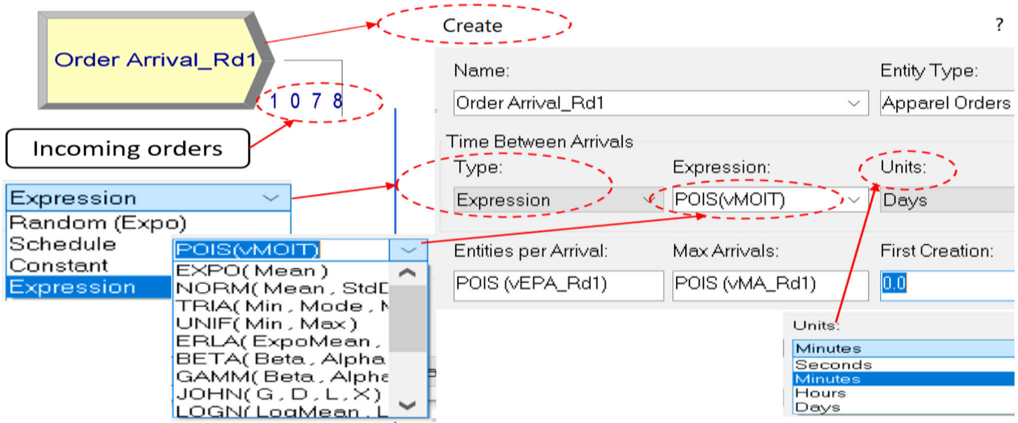


Figure 6.16: Generation of apparel orders (entities) using the Create module in Arena®.

Table 6.9: Creation of the demanded orders for the MRMM model.

S/N	Name	Entity Type	Type	Expression	Units	Entity per Arrival	Maximum Arrival	First creation
1	Order Arrival_Rd$_1$	Apparel Orders	Expression	POIS (*vMOIT*)	Days	POIS (*vEPA_Rd$_1$*)	POIS (*vMA_Rd$_1$*)	0.0
2	Order Arrival_Rd$_2$	Apparel Orders	Expression	POIS (*vMOIT*)	Days	POIS (*vEPA_Rd$_2$*)	POIS (*vMA_Rd$_2$*)	0.0
3	Order Arrival_Rd$_3$	Apparel Orders	Expression	POIS (*vMOIT*)	Days	POIS (*vEPA_Rd$_3$*)	POIS (*vMA_Rd$_3$*)	0.0
4	Order Arrival_Rd$_4$	Apparel Orders	Expression	POIS (*vMOIT*)	Days	POIS (*vEPA_Rd$_4$*)	POIS (*vMA_Rd$_4$*)	0.0
5	Order Arrival_Rd$_5$	Apparel Orders	Expression	POIS (*vMOIT*)	Days	POIS (*vEPA_Rd$_5$*)	POIS (*vMA_Rd$_5$*)	0.0

Initially, all variables in Table 6.9 were defined, as shown in Table 6.10. The variables were defined for easy alteration in Chapter 7 to illustrate the feasibility of allocating orders.

Table 6.10: Defined variables for the initial order arrivals.

Entities per Arrival (EPA)	vEPA_Rd$_1$= 120	vEPA_Rd$_2$= 126	vEPA_Rd$_3$= 132	vEPA_Rd$_4$= 138	vEPA_Rd$_5$= 144
Max Arrivals (MA)	vMA_Rd$_1$= 360	vMA_Rd$_2$= 378	vMA_Rd$_3$= 396	vMA_Rd$_4$= 414	vMA_Rd$_5$= 432

The received orders (Figure 6.16) are then assigned the arrival time using the ASSIGN module (Figure 6.17). The time is assigned as ‘Arrival Time = *TNOW*’. In Arena, the *TNOW* variable holds the current simulation time. When the entity departs to the next step, the total elapsed time in the system can be calculated for further analysis. The purpose of assigning time for the arriving entities (orders) is for capturing the waiting times in the queue. Such data assisted in establishing the warm-up period (Section 6.6.2). After assigning the arrival time to all orders, the orders are then recorded in the RECORD module, named '*Record Received Orders'* (Figure 6.17). Notice that the expression option in the RECORD module collects statistics in the simulation of the MRMM model.

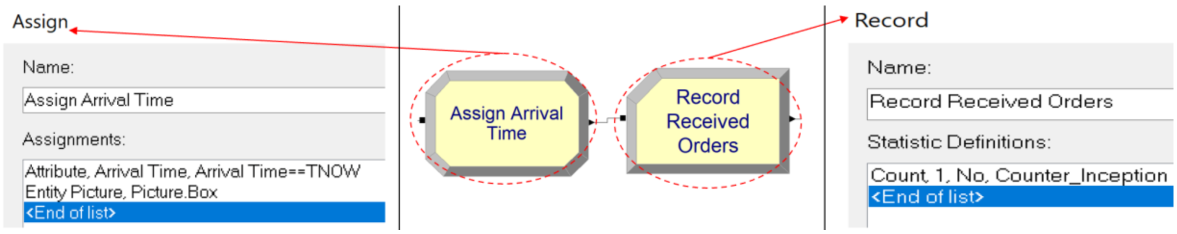


Figure 6.17: Assigning the interarrival time and recording all the received orders.

b) Initial screening of the incoming orders

Next was to execute initial order fulfilment using the DECIDE module, named '*Order to be Accepted?*' (Figure 6.18). Under this stage, a variable named '*vOrderAR'* was defined to dictate alteration of order acceptance rate.

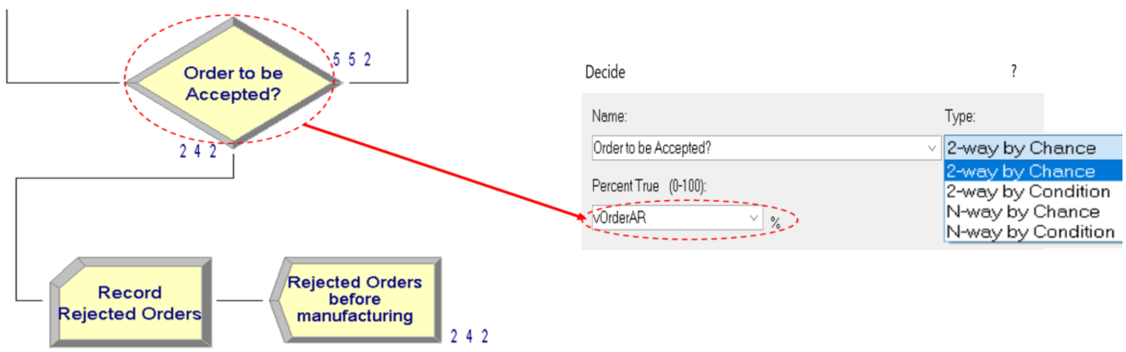


Figure 6.18: Order acceptance rate.

Initially, 70% of the received orders were assumed to be accepted, and 30% are rejected, as stated by retailer Rd_1 through an interview. An initial screening of the received orders involves assessing the availability of resources including available machine capacity, capacity variance, number of the required workforces, raw material availability, machine availability and the possibility of meeting the required lead-time. These assumptions were from Rd_1, who experienced with 30% rejection of their ordered apparel to several manufacturers. Rejected orders are recorded using the RECORD module, named '*Record Rejected Orders*' which are then disposed of through the DISPOSE module, named

‘*Rejected Orders before manufacturing*’. For the accepted orders are recorded in the module named ‘*Record Accepted Orders*’. The accepted entities are then seized using the SEIZE module, named ‘*Seize Server Enter the Manufacturers*’: the entities wait in a queue until when an operator (technician) is available to process the order. The waiting entities are then recorded using the RECORD module (Figure 6.19). When the resource, e.g. an operator or technician, is available, the entities (orders) remain in the DELAY module and delays by a specified time. This can vary based on the real situation of SMEs. Initially, the delay time was assumed to follow NORM distribution. In the DELAY module, the amount of time spent by each order can be assigned as wait, non-value-added, value-added, transfer or other time. If there are any associated costs, they can also be computed. Once these formalities are completed, the server and the operators are both released using the RELEASE module.

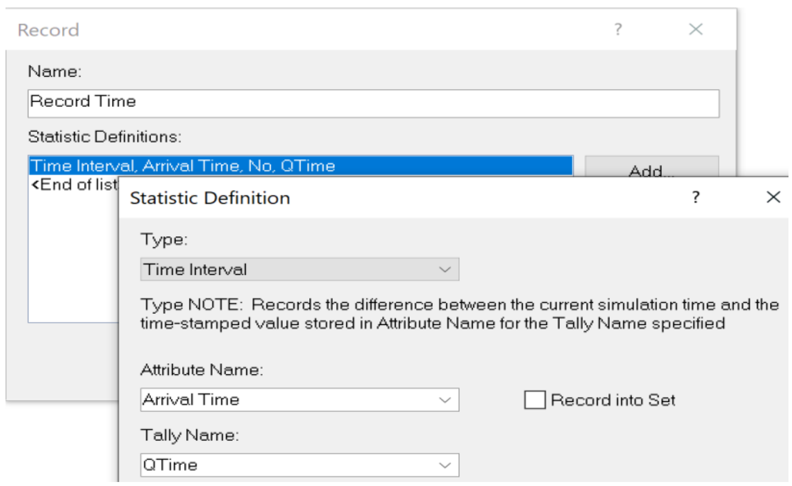


Figure 6.19: Recording the time interval between the current simulation time and the time-stamped value stored in the attribute named ‘Arrival Time’.

c) Distribution or allocation of incoming demands (apparel orders)

From the RELEASE module, the accepted orders are transferred to the DECIDE module, named ‘*Order Distribution*’. At the distribution station, this module executes order distribution (order sharing) equitably amongst SMEs, i.e. Mz_1 to Mz_5, corresponding to the first scenario of the cumulative sourcing performance index (equations 8.1 to 8.7). The DECIDE module executes decision-making processes in Arena® (Figure 6.20). In Figure 6.20, the $vPIMz_1$ to $vPIMz_5$, are the defined variables corresponding to the initial allocation for Mz_1 to Mz_5, respectively. The variables were initiated to dictate execution of order allocation using the *Arena® Process Analyser* tool (Section 7.2.3). Initially, Mz_1 was assessed and rated to secure 23.95% of all orders, Mz_2 (20.28%), Mz_3 (17.86%), Mz_4 (18.56%), and Mz_5 (19.36%). Distributed orders are then recorded at each manufacturer, with the RECORD module named '*Record distributed orders to* Mz_1' to '*Record distributed orders to* Mz_5', corresponding to Mz_1 to Mz_5, respectively. Other options for distributing orders are discussed in Section 6.5.4. These are the starting points; significant changes were made by altering different scenarios and rerun the model to generate distributions.

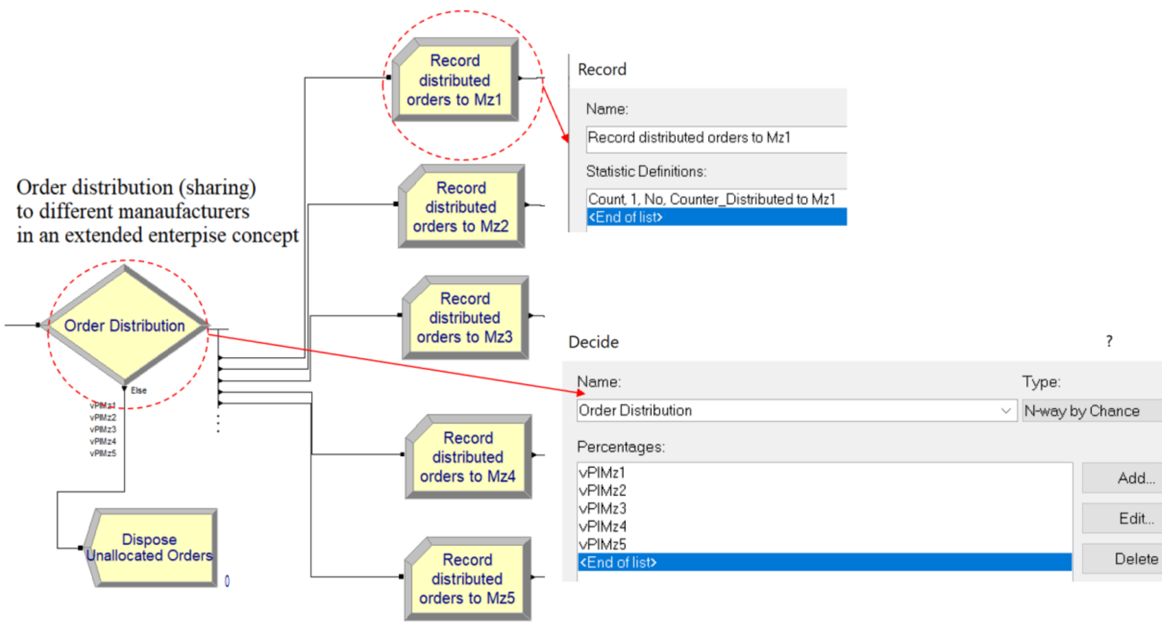


Figure 6.20: Execution of order allocation process using the Decide module.

The distributed entities from the DECIDE module (Figure 6.20) are then transferred using the LEAVE module to enter each manufacturer. This is accomplished using the ENTER module, named '*Production planning* Mz_1' to '*Production planning* Mz_5', corresponding to the five manufacturers. When an order entity reaches the ENTER module, there is a delay to dictate other processes to be undertaken. This module describes a station corresponding to a physical location where the processing of orders occurs—manufacturers (SMEs). Under this module, the order undergoes an estimated *delay* that follows a NORM (1, 1) distribution (in days) to dictate decision criteria rating for each manufacturer. Orders are then transferred to the subsequent DECIDE module for categorising the received orders.

The arriving orders (Figure 6.16) were initially not categorised, i.e. the received orders were not specified whether they belonged to a trouser, jeans, shirt, etc. One of the assumptions is that all manufacturers are assumed to handle similar products: if orders are jackets, then all manufacturers should have capabilities and capacities to process the same. Equitable order allocation cannot be executed to an SME who has no ability to manufacture a particular product. Four types of clothes (i.e. jeans, trouser, Top/t-shirt and jumper) purchased by men and women in the UK (2015-2018) were considered in all the developed models (Figure 6.12). These types of apparels were summarised from Figure 6.12. In modelling the four types were selected using Pareto's diagram in Figure 6.21. The number of clothes sets can be altered based on the software limitation. Four categories were initially thought to suffice an illustration of an equitable order allocation process.

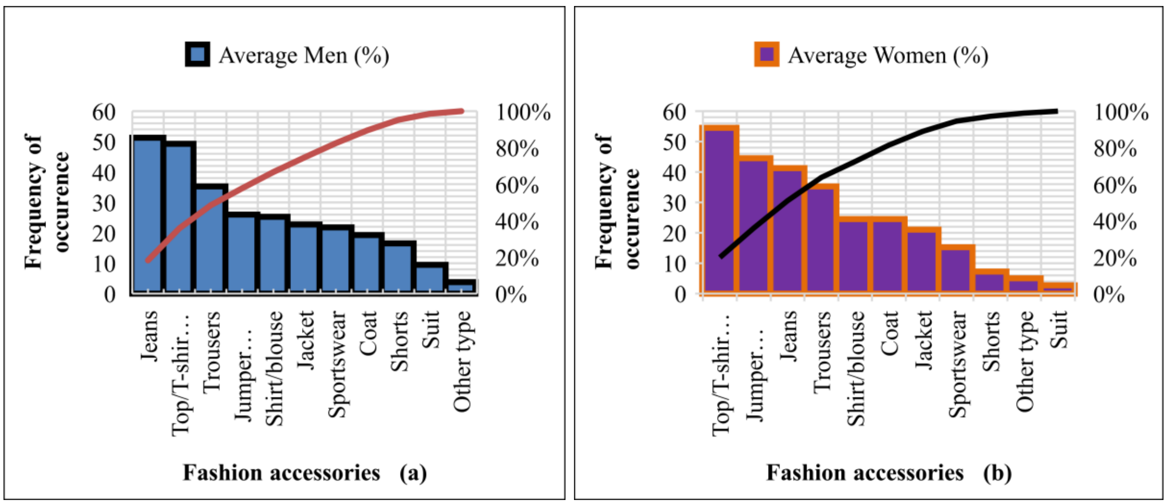


Figure 6.21: Pareto's diagram about the most purchased clothes in the UK from 2015 to 2018; (a) for men and (b) for women.

The received orders from the DECIDE module (Figure 6.20) are jeans, trousers, shirt, and skirt, with the assumed distributions of 34.3%, 28.0%, 22.2% and 15.5%, respectively. The proportion can be altered based on the received orders' specifications. Orders are distributed using the DECIDE module (Figure 6.22).

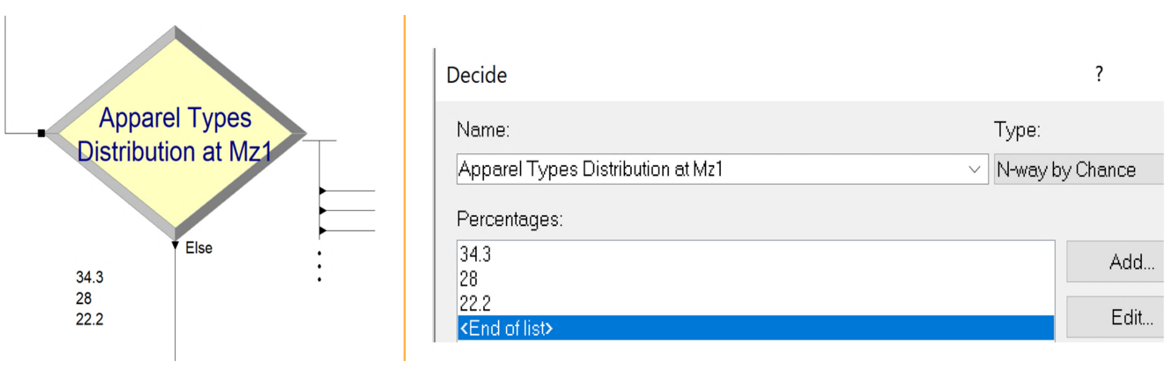


Figure 6.22: Distribution of apparel corresponding to the specific clothes types for the first manufacturer.

Then, the orders pass through the ASSIGN module to specify the entity types (jeans, trousers, shirt, and skirt). This module also assigns entity pictures to apparel orders for the identification purpose: jeans (blue colour), trousers (green), shirt (red), skirt (yellow). For animation, the real picture can be used for each particular product type. The entity attributes — 'Apparel Index 1' to 'Apparel Index 5'— are also assigned corresponding to five manufacturers. Within the ASSIGN module, it is possible to make multiple assignments as performed in Figure 6.23. The ASSIGN module adds variables, changes variables, creates variables, initialises variables, among other functions.

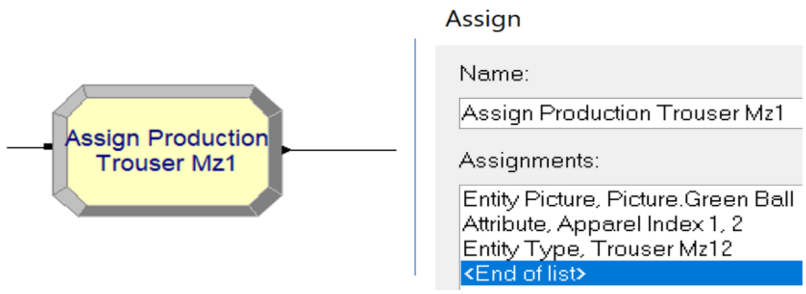


Figure 6.23: Production planning in the Assign module before allocating orders to Mz_1.

The developed model involves waiting for lines (queues) in assigning manufacturers, operators, machines, etc., which brings in the concepts of queuing systems. The demands (volumes) are from apparel retailers. Based on queuing theory, there are two calling populations: the finite calling population (FCP) and an infinite calling population (ICP). In FCP, the arrival rate experienced by the developed system is assumed to decrease naturally as retailers arrive to place orders using either EDI or traditionally (using phone calls, email, or the physical ordering process). For ICP, the arrival rate to the developed ordering systems does not decrease as it is assumed that several retailers place orders to SMEs. This study, thus, assumed the FCP category because the number of apparel retailers is known, and their ordering capacity can be quantified. An arrival rate also decreases naturally.

Having completed finalising all formalities, the accepted and assigned orders (Figure 6.23) wait in a queue so as operators at each manufacturer can assign the sequence of each product type. This process is executed using the PROCESS module labelled '*Sequence Assign Process*' corresponding to each manufacturer. Initially, the processing time for this action follows an EXPO (0.5) (Figure 6.24). To assign the sequence for each product type follows the ‘queue-ranking rules.’ These include HAV (highest-attribute-value), LAV (lowest-attribute-value), LIFO (last-in-first-out) and FIFO (first-in-first-out). Sometimes, LAV and HAV are also called the ‘lowest-value-first’ and ‘highest-value-first’, respectively. FIFO ranks the entity types in the order (series) the received entities arrived at the queue: the entity which arrives earlier is processed first. On the contrary, LIFO ranks entities that recently arrived in a particular queue. For LAV and HAV, the ranking is based on the predefined attributes of the received entities. For instance, if the KPIs included computation of the ‘due dates’ and the arrival dates have earlier been assigned in the ATTRIBUTE module; selecting LAV would thus mean the same as selecting EDD-ranking rule (earliest due date). The subsequent arriving items would be given priority based on increasing due dates. HAV focuses on the defined priorities in the assigned resources. As a result, the developed models employed FIFO as the ‘queue-ranking rule’ because retailers always need their items in the chronological sequence as to how they were ordered. It is not logical to bypass retailers’ orders unless there are specified terms and conditions such as express production services. The waiting time in a queue for each order is recorded as well.

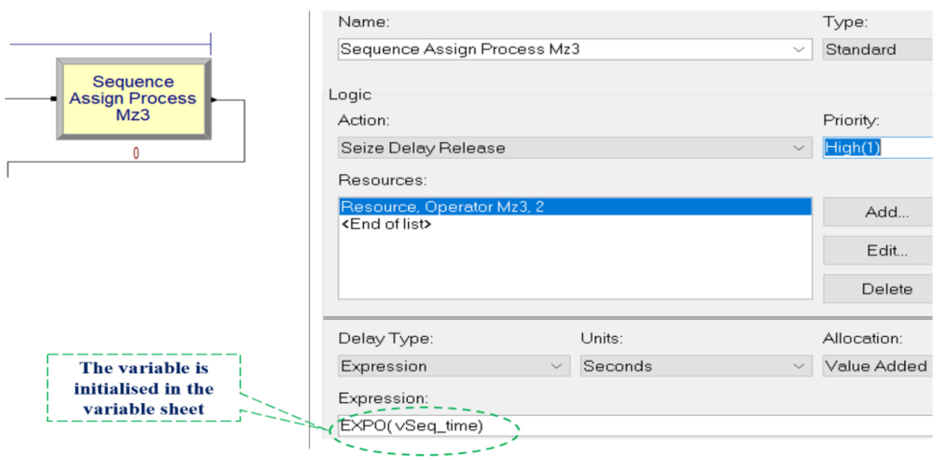


Figure 6.24: The sequencing process to assign the processing stations for the third manufacturer.

Next is the ASSIGN module that assigns the sequence of each work process station. Production (manufacturing) sequencing (scheduling) can be decided based on the lead times, order size, batch size and bundle size, style changes frequency, preventive maintenance schedule, number of holidays or vacations, and the number of shifts (shift information). All these situations are not coded in the system. However, an algorithm can be programmed and be linked with Arena® to execute the same. In this system, only the time is estimated for such a process. The assigned orders are then transferred to the working station through the LEAVE module under the specified sequence. The delay time through this process was initially defined as 10 minutes; but the transfer time depends on several factors, including the given sequence whether it is FIFO, HAV, among others.

d) Manufacturing of apparel orders at manufacturers (SMEs)

Apparel manufacturing data for Jeans pants (trousers), Men's Trousers, Polo Shirts and Skirt are presented in Tables 6.11 to 6.14, respectively. All data for the first manufacturer (M_{Z1}) are secondary data summarised from Brother Industries (1995) (Table 6.3), while for M_{Z2} to M_{Z5} were estimated with reference to M_{Z1}. SAM (SMV) is an averaged data. However, in this model, the production time for each activity follows a Normal distribution at all the five manufacturers' workstations. Here, the finalised received orders are processed at five different workstations named 'Workstations at Manufacturer (Mz_1)' to 'Workstations at Manufacturer (Mz_5)', respectively, to the five SMEs. Example of the processing station for the sewing process and the scheduling processes is depicted in Figure 6.25.

Table 6.11: Estimated SMV (seconds) for a Jeans pant (trouser).

Manufacturer	Process of parts	Process of the back body	Process of the front body	Process of assembly	Inspection process	Finishing process
Mz_1	Norm (286,3)	Norm (98,3)	Norm (170,3)	Norm (384,3)	Norm (10,3)	Norm (15,3)
Mz_2	Norm (280,3)	Norm (90,3)	Norm (160,3)	Norm (380,3)	Norm (10,3)	Norm (15,3)
Mz_3	Norm (282,3)	Norm (100,3)	Norm (172,3)	Norm (381,3)	Norm (10,3)	Norm (15,3)
Mz_4	Norm (270,3)	Norm (88,3)	Norm (169,3)	Norm (370,3)	Norm (10,3)	Norm (15,3)
Mz_5	Norm (288,3)	Norm (92,3)	Norm (175,3)	Norm (384,3)	Norm (10,3)	Norm (15,3)

Table 6.12: Estimated SMV (seconds) for Men's Trouser.

Manufacturer	Process of parts	Process of the back body	Process of the front body	Process of assembly	Inspection process	Finishing process
Mz_1	Norm (530,3)	Norm (392,3)	Norm (239,3)	Norm (908,3)	Norm (10,3)	Norm (15,3)
Mz_2	Norm (520,3)	Norm (390,3)	Norm (238,3)	Norm (900,3)	Norm (10,3)	Norm (15,3)
Mz_3	Norm (525,3)	Norm (389,3)	Norm (232,3)	Norm (901,3)	Norm (10,3)	Norm (15,3)
Mz_4	Norm (532,3)	Norm (388,3)	Norm (259,3)	Norm (910,3)	Norm (10,3)	Norm (15,3)
Mz_5	Norm (521,3)	Norm (395,3)	Norm (243,3)	Norm (902,3)	Norm (10,3)	Norm (15,3)

Table 6.13: Estimated SMV (seconds) for a Polo Shirt.

Manufacturer	Process of parts	Process of sleeve	Process of the back body	Process of the front body	Process of assembly	Inspection process	Finishing process
Mz_1	Norm (141,3)	Norm (70,3)	Norm (18,3)	Norm (84,3)	Norm (534,3)	Norm (10,3)	Norm (15,3)
Mz_2	Norm (140,3)	Norm (65,3)	Norm (19,3)	Norm (87,3)	Norm (530,3)	Norm (10,3)	Norm (15,3)
Mz_3	Norm (143,3)	Norm (65,3)	Norm (20,3)	Norm (82,3)	Norm (531,3)	Norm (10,3)	Norm (15,3)
Mz_4	Norm (142,3)	Norm (67,3)	Norm (18,3)	Norm (89,3)	Norm (540,3)	Norm (10,3)	Norm (15,3)
Mz_5	Norm (132,3)	Norm (71,3)	Norm (17,3)	Norm (73,3)	Norm (542,3)	Norm (10,3)	Norm (15,3)

Table 6.14: Estimated SMV (seconds) for a Skirt.

Manufacturer	Process of parts	Process of body lining	Process of the back body	Process of the front body	Process of assembly	Inspection process	Finishing process
Mz_1	Norm (263,3)	Norm (245,3)	Norm (156,3)	Norm (520,3)	Norm (674,3)	Norm (10,3)	Norm (15,3)
Mz_2	Norm (260,3)	Norm (248,3)	Norm (159,3)	Norm (527,3)	Norm (680,3)	Norm (10,3)	Norm (15,3)
Mz_3	Norm (253,3)	Norm (251,3)	Norm (150,3)	Norm (522,3)	Norm (671,3)	Norm (10,3)	Norm (15,3)
Mz_4	Norm (262,3)	Norm (267,3)	Norm (158,3)	Norm (519,3)	Norm (670,3)	Norm (10,3)	Norm (15,3)
Mz_5	Norm (262,3)	Norm (241,3)	Norm (157,3)	Norm (523,3)	Norm (672,3)	Norm (10,3)	Norm (15,3)

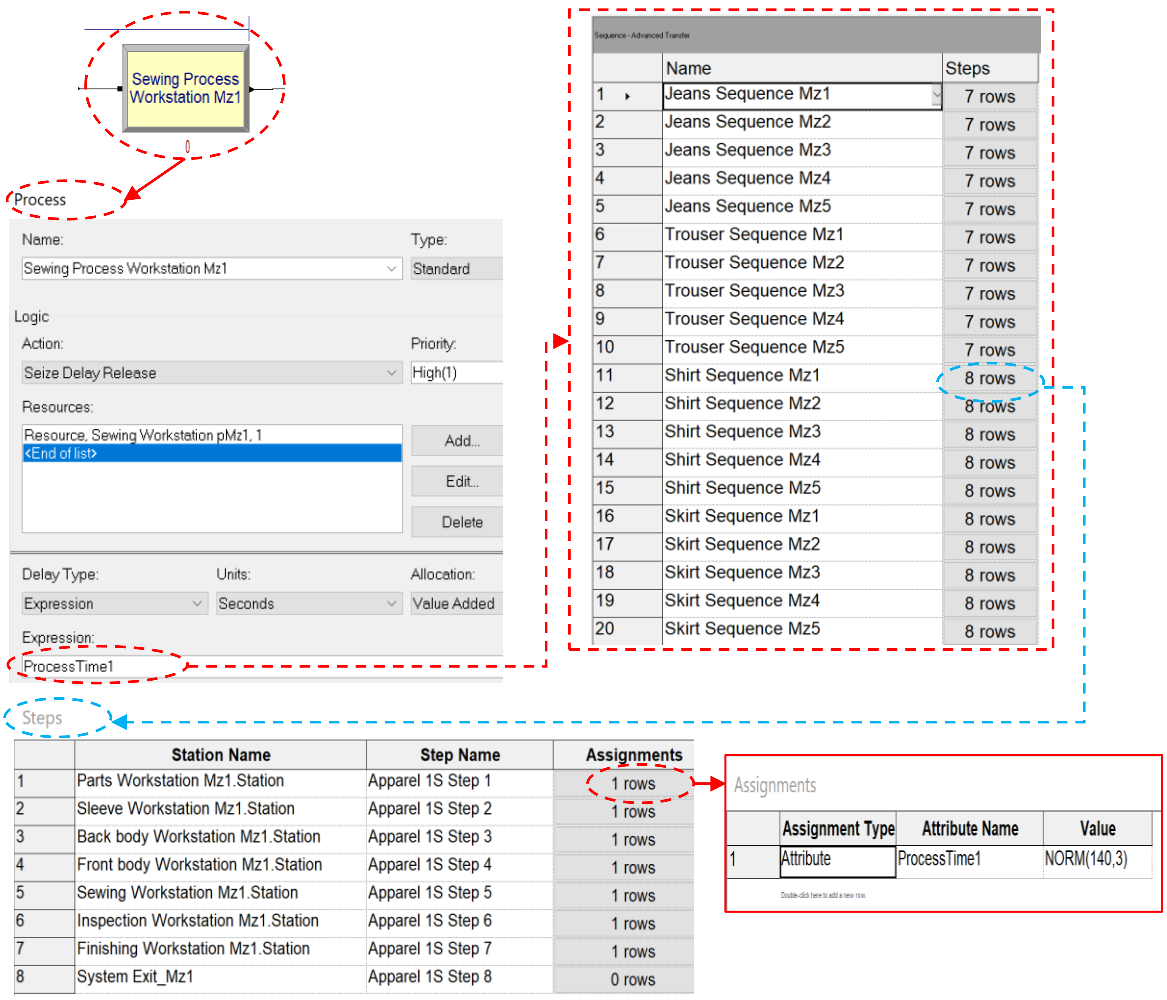


Figure 6.25: Processing station and scheduling production at the sewing process for the first manufacturer.

Any entity being processed from the sewing workstations (Figure 6.25) enters another workstation through the ENTER module. This module defined a station or a set of stations equivalent to the defined logical location at which the resource processes entities (items). Within Arena®, entities can be specified to be transferred using a free transporter, exit conveyor or without any defined mode of transport, that is, 'none'. The processed entities for the MRMM model have 'none' defined mode of transport or the material handling equipment between one machine to the other; however, the delay time was assumed to be 10 minutes. Figure 6.26 is an example of the ENTER module.

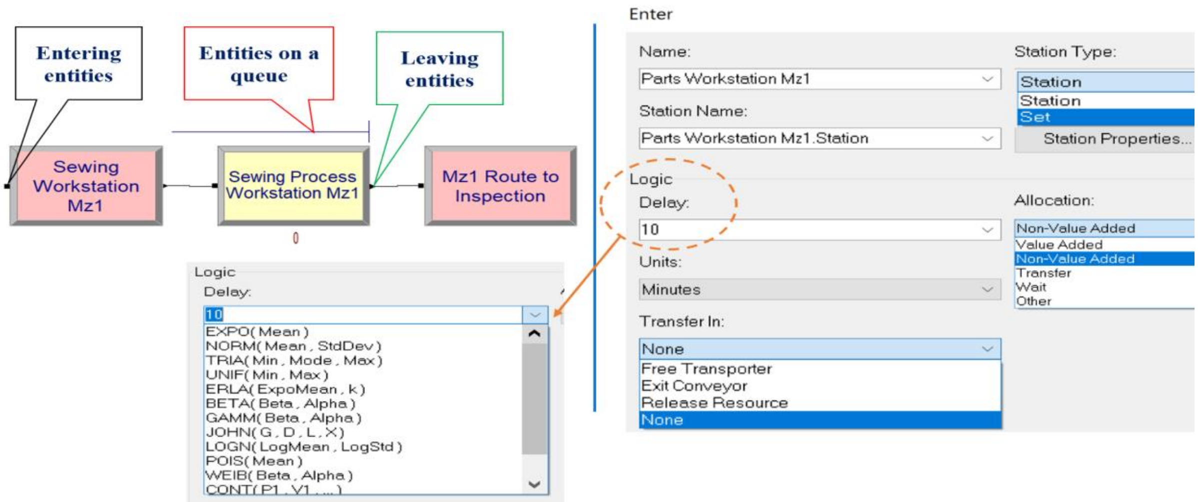


Figure 6.26: This is an annotated screen capture of the Enter module at the sewing workstations for the first manufacturer (Mz_1).

Once the entities have entered the ENTER module (Figure 6.26), they are processed based on the specified time. Afterwards, the entities leave the PROCESS module using the ROUTE module (Figure 6.27) to a specified station, or any subsequent station for further processes. Destination type can be by sequence, attribute, expression or to the next station. Transfer time to the next station was defined using EXPO (*vTrMz*). The $vTrMz_1$ to $vTrMz_5$ are the variables to specify the transfer time for the particular entity (Figure 6.15).

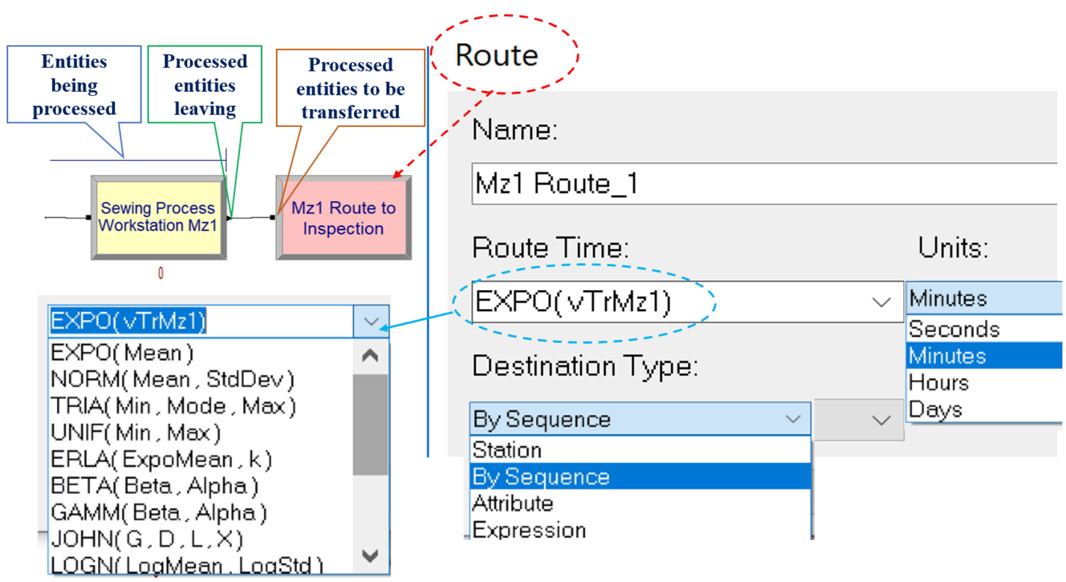


Figure 6.27: The Route module after the sewing workstations for the 1st manufacturer.

In summary, Figure 6.28 is an illustration of all the required workstations for the third manufacturer (Mz_3). All five SMEs were simulated with a similar number of workstations (Figures 6.33 and 6.34). The number of workstations can be altered depending on the factory. The SAM data was entered using the PROCESS module correspondingly to the processes required for each apparel category (Tables 6.3, 6.11 to 6.14). The subsequent process is an inspection which was conducted at the workstations named '*Require Repair?*' for each manufacturer. The variable *'vPRework'* was initialised, as the probability of reworking or repair at each inspection station. It was assumed that 5% to 10% of various types of apparels are inspected. This is based on an 'Arbitrary sampling method' (Table 6.6). This method allows for 10% of the produced products to be inspected for any lot size. The DECIDE module executed an inspection process. However, this depends on the production records of each manufacturer (SME).

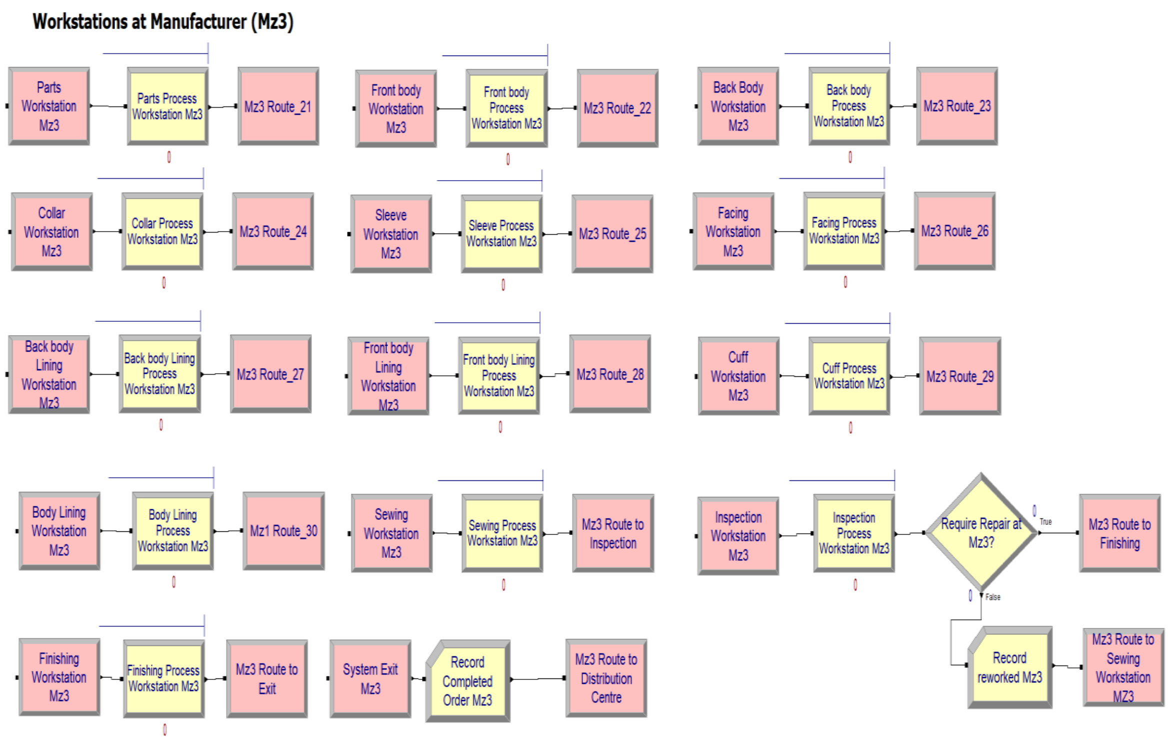


Figure 6.28: The workstations at the third manufacturer (Mz_3).

e) Capacity for each manufacturer

Resources are used to process any incoming entities. Within Arena®, entities can be delayed; delayed and released; seized and delayed; or seized, delayed, and released, depending on the function of the defined resource(s). In this study, the entities (items) are the received apparel orders from retailers. All resources seize, delay, and release all the received entities at each PROCESS module. Apparel manufacturers, i.e. Mz_1 to Mz_5, process the received orders through the resource utilisation. The resources include raw materials, equipment, machines, and workforces. The resources in Arena® were defined in the RESOURCE module. The module defines resources as *Fixed Capacity* or *Based on Schedule*. Since the resources differ between manufacturers, this study defined resources based on the latter category.

Figure 6.29 depicts an overview of the defined resources. Arena® software has four conditions of resources: idle, busy, inactive, and failed. Any resource becomes '*idle*' whenever there is not an entity (unit) which seizes it. If there is any entity that seizes the resources, the particular resource becomes at the *busy* state. Whenever the software makes the resource unavailable, that is an 'inactive' state, and the state becomes 'failed' when the software makes the resource to be in the failed condition. Scheduled capacity for each manufacturer involves three rules: preempt, ignore and wait. All these rules are defined using the SCHEDULE module. Additionally, the *scale factor* field (Figure 6.29) does not affect whenever defining resources as capacity type schedules.

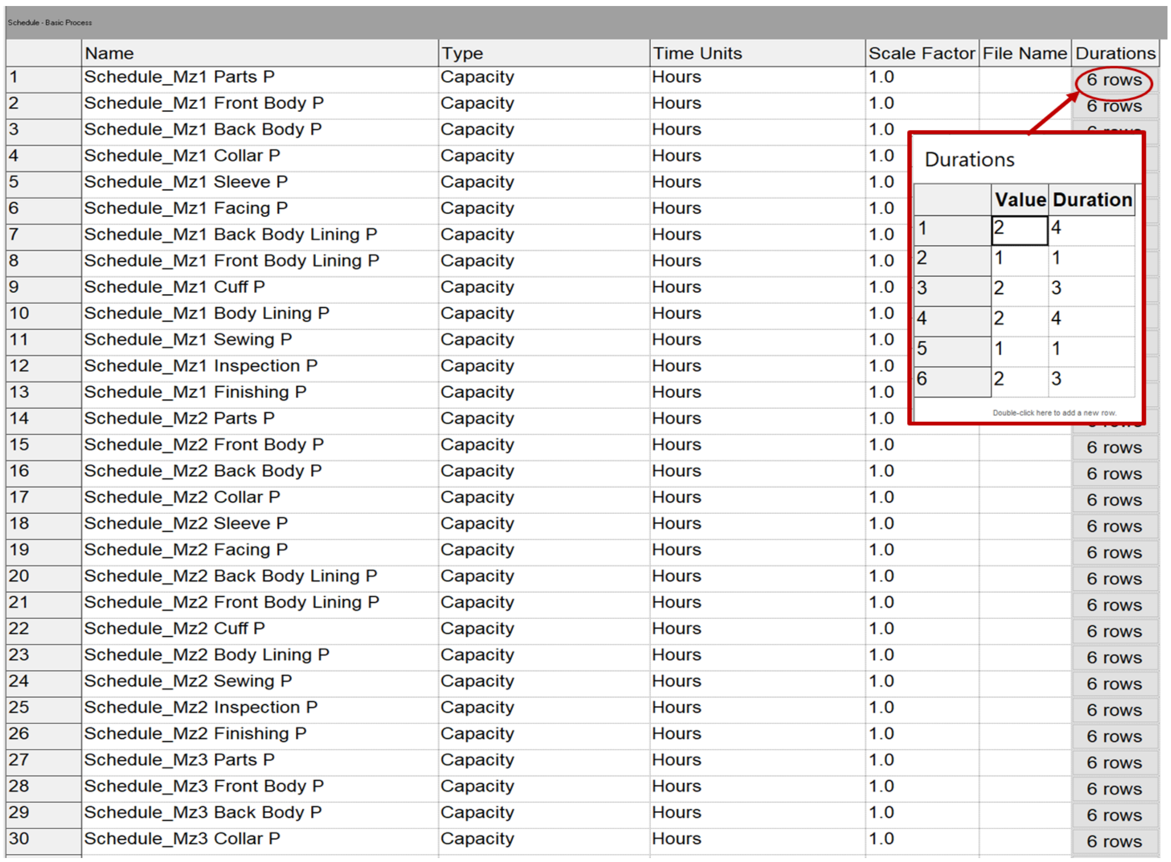
In this study, the wait scheduling rule was used, as shown in Figure 6.29. According to Rossetti (2016, p.556):

(a) *Preempt rule* "interrupts the currently processing entity, changes the resource capacity and starts the time duration of the schedule change or failure immediately. The resource will resume processing the preempted entity as soon as the resource becomes available (after schedule change or failure)."

(b) *Wait rule* "waits until the busy resource has finished processing the current entity before changing the resource capacity or starting the failure and starting the time duration of the schedule change or failure."

(c) *Ignore rule* "starts the time duration of the schedule change or failure immediately but allows the busy resource to finish processing the current entity before effecting the capacity change."

From Figure 6.29, this means that the production is for 16 hours (4+1+3+4+1+3), i.e. two shifts, each comprises 8 hours. For the first 4 hours of the simulation, thus the available resources (capacities) are 2; for 1 hour there is only 1 resource; 3 hours (2 resources); 4 hours (2 resources); 1 hour (only 1 resource); and 3 hours (2 resources). It was also assumed that whenever there is only one hour (in the duration column of Figure 6.28) means other workers (resources) are on break, which can be interpreted as the lunchtime (day shift) and dinner (night shift). The duration for each manufacturer varies depending on the real scenario.



	Name	Type	Time Units	Scale Factor	File Name	Durations
1	Schedule_Mz1 Parts P	Capacity	Hours	1.0		6 rows
2	Schedule_Mz1 Front Body P	Capacity	Hours	1.0		6 rows
3	Schedule_Mz1 Back Body P	Capacity	Hours	1.0		
4	Schedule_Mz1 Collar P	Capacity	Hours	1.0		
5	Schedule_Mz1 Sleeve P	Capacity	Hours	1.0		
6	Schedule_Mz1 Facing P	Capacity	Hours	1.0		
7	Schedule_Mz1 Back Body Lining P	Capacity	Hours	1.0		
8	Schedule_Mz1 Front Body Lining P	Capacity	Hours	1.0		
9	Schedule_Mz1 Cuff P	Capacity	Hours	1.0		
10	Schedule_Mz1 Body Lining P	Capacity	Hours	1.0		
11	Schedule_Mz1 Sewing P	Capacity	Hours	1.0		
12	Schedule_Mz1 Inspection P	Capacity	Hours	1.0		
13	Schedule_Mz1 Finishing P	Capacity	Hours	1.0		
14	Schedule_Mz2 Parts P	Capacity	Hours	1.0		
15	Schedule_Mz2 Front Body P	Capacity	Hours	1.0		6 rows
16	Schedule_Mz2 Back Body P	Capacity	Hours	1.0		6 rows
17	Schedule_Mz2 Collar P	Capacity	Hours	1.0		6 rows
18	Schedule_Mz2 Sleeve P	Capacity	Hours	1.0		6 rows
19	Schedule_Mz2 Facing P	Capacity	Hours	1.0		6 rows
20	Schedule_Mz2 Back Body Lining P	Capacity	Hours	1.0		6 rows
21	Schedule_Mz2 Front Body Lining P	Capacity	Hours	1.0		6 rows
22	Schedule_Mz2 Cuff P	Capacity	Hours	1.0		6 rows
23	Schedule_Mz2 Body Lining P	Capacity	Hours	1.0		6 rows
24	Schedule_Mz2 Sewing P	Capacity	Hours	1.0		6 rows
25	Schedule_Mz2 Inspection P	Capacity	Hours	1.0		6 rows
26	Schedule_Mz2 Finishing P	Capacity	Hours	1.0		6 rows
27	Schedule_Mz3 Parts P	Capacity	Hours	1.0		6 rows
28	Schedule_Mz3 Front Body P	Capacity	Hours	1.0		6 rows
29	Schedule_Mz3 Back Body P	Capacity	Hours	1.0		6 rows
30	Schedule_Mz3 Collar P	Capacity	Hours	1.0		6 rows

Durations

	Value	Duration
1	2	4
2	1	1
3	2	3
4	2	4
5	1	1
6	2	3

Note(s): value = resources (capacity) available; duration = available time for the specific resource.

Figure 6.29: Part of the scheduled capacity.

The outputs of Figure 6.29 are the inputs in Figure 6.30. This means the scheduled capacities are assigned at the respective workstations. It should be noted that when using the RESOURCE module, adding the required resources (capacities) involve the total quantities for the entire simulation time. The quantity is not how many machines are required or present; it shows how many resources are needed to process (work) on the entering entities, i.e. apparel units.

	Name	Type	Schedule Name	Schedule Rule	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	Operator Mz1	Based on Schedule	Schedule_Operator Mz1	Wait	0.0	0.0	0.0		0 rows	☑
2	Operator Mz4	Based on Schedule	Schedule_Operator Mz4	Wait	0.0	0.0	0.0		0 rows	☑
3	Operator Mz5	Based on Schedule	Schedule_Operator Mz5	Wait	0.0	0.0	0.0		0 rows	☑
4	Operator Mz2	Based on Schedule	Schedule_Operator Mz2	Wait	0.0	0.0	0.0		0 rows	☑
5	Operator Mz3	Based on Schedule	Schedule_Operator Mz3	Wait	0.0	0.0	0.0		0 rows	☑
6	Front Body Workstation pMz1	Based on Schedule	Schedule_Mz1 Front Body P	Wait	0.0	0.0	0.0		0 rows	☑
7	Back Body Workstation pMz1	Based on Schedule	Schedule_Mz1 Back Body P	Wait	0.0	0.0	0.0		0 rows	☑
8	Collar Workstation pMz1	Based on Schedule	Schedule_Mz1 Collar P	Wait	0.0	0.0	0.0		0 rows	☐
9	Sleeve Workstation pMz1	Based on Schedule	Schedule_Mz1 Sleeve P	Wait	0.0	0.0	0.0		0 rows	☑
10	Facing Workstation pMz1	Based on Schedule	Schedule_Mz1 Facing P	Wait	0.0	0.0	0.0		0 rows	☐
11	Back Body Lining Workstation pMz	Based on Schedule	Schedule_Mz1 Back Body Lining	Wait	0.0	0.0	0.0		0 rows	☑
12	Front Body Lining Workstation pMz	Based on Schedule	Schedule_Mz1 Front Body Lining	Wait	0.0	0.0	0.0		0 rows	☑
13	Cuff Workstation pMz1	Based on Schedule	Schedule_Mz1 Cuff P	Wait	0.0	0.0	0.0		0 rows	☐
14	Parts Workstation pMz1	Based on Schedule	Schedule_Mz1 Parts P	Wait	0.0	0.0	0.0		0 rows	☑
15	Finishing Workstation pMz1	Based on Schedule	Schedule_Mz1 Finishing P	Wait	0.0	0.0	0.0		0 rows	☑
16	Sewing Workstation pMz1	Based on Schedule	Schedule_Mz1 Sewing P	Wait	0.0	0.0	0.0		0 rows	☑
17	Inspection Workstation pMz1	Based on Schedule	Schedule_Mz1 Inspection P	Wait	0.0	0.0	0.0		0 rows	☑
18	Finishing Workstation pMz5	Based on Schedule	Schedule_Mz5 Finishing P	Wait	0.0	0.0	0.0		0 rows	☑
19	Sewing Workstation pMz5	Based on Schedule	Schedule_Mz5 Sewing P	Wait	0.0	0.0	0.0		0 rows	☑
20	Back Body Lining Workstation pMz	Based on Schedule	Schedule_Mz5 Back Body Lining	Wait	0.0	0.0	0.0		0 rows	☐
21	Collar Workstation pMz5	Based on Schedule	Schedule_Mz5 Collar P	Wait	0.0	0.0	0.0		0 rows	☐
22	Front Body Lining Workstation pMz	Based on Schedule	Schedule_Mz5 Front Body Lining	Wait	0.0	0.0	0.0		0 rows	☑
23	Sleeve Workstation pMz5	Based on Schedule	Schedule_Mz5 Sleeve P	Wait	0.0	0.0	0.0		0 rows	☑
24	Inspection Workstation pMz5	Based on Schedule	Schedule_Mz5 Inspection P	Wait	0.0	0.0	0.0		0 rows	☑
25	Back Body Workstation pMz5	Based on Schedule	Schedule_Mz5 Back Body P	Wait	0.0	0.0	0.0		0 rows	☑
26	Facing Workstation pMz5	Based on Schedule	Schedule_Mz5 Facing P	Wait	0.0	0.0	0.0		0 rows	☑
27	Cuff Workstation pMz5	Based on Schedule	Schedule_Mz5 Cuff P	Wait	0.0	0.0	0.0		0 rows	☐
28	Parts Workstation pMz5	Based on Schedule	Schedule_Mz5 Parts P	Wait	0.0	0.0	0.0		0 rows	☑
29	Parts Workstation pMz4	Based on Schedule	Schedule_Mz4 Parts P	Wait	0.0	0.0	0.0		0 rows	☑
30	Collar Workstation pMz4	Based on Schedule	Schedule_Mz4 Collar P	Wait	0.0	0.0	0.0		0 rows	☐
31	Back Body Lining Workstation pMz	Based on Schedule	Schedule_Mz4 Back Body Lining	Wait	0.0	0.0	0.0		0 rows	☐

Note(s): Failures are initialised as '0' because there is not any resource which is assumed to be in a 'failed condition'. Busy/hour and idle/hour should be initialised if costs associated are to be collected.

Figure 6.30: Part of the assigned scheduled capacity at each workstation.

f) Finalising packaging and dispatching processes to retailers

The processed apparel products are then transported to the distribution centre through the available logistics services, ready to be packaged and dispatched to each retailer. At the packaging workstation, a dozen is defined as 12. However, in apparel manufacturing, packaging differs depending on the type of clothes or apparel. All products are recorded using the RECORD module at five separate sections, equivalent to a number of destinations. The PROCESS module is responsible for processing the completed entities (apparel products). The process was assumed to follow the NORM (1,1) minutes per entity. The HOLD module (Figure 6.31) is used to accumulate at least 12 products for allowing the packaging process before transporting apparel to each retailer.

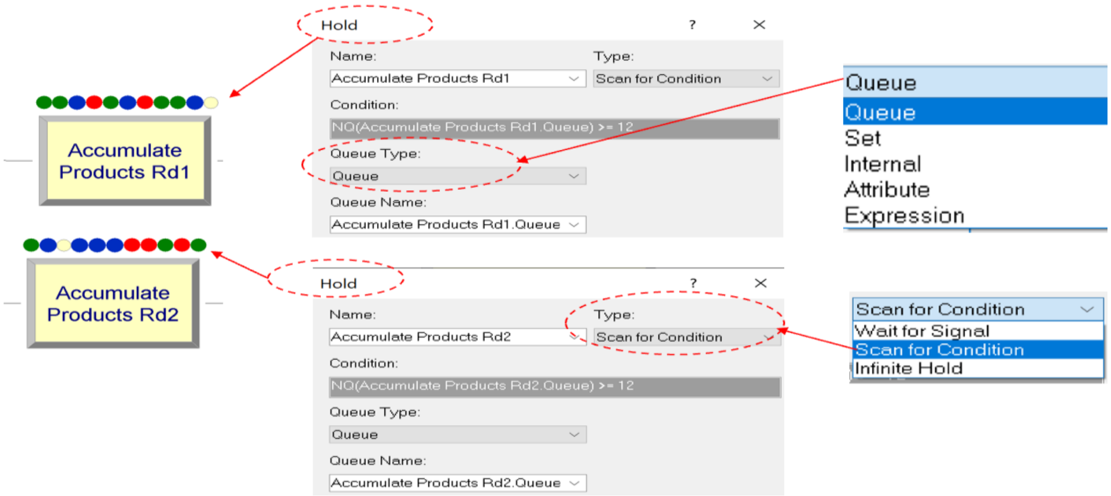


Figure 6.31: The Hold module details for Mz_1 and Mz_2.

Once all tasks are completed, the manufactured products are dispatched. The ROUTE module named *'Route for Transporting Products'* executes this process. It was initially assumed that on an average it takes 3 days to do so. It follows a normal distribution (in days) of NORM (3,2). Eventually, the last module is DISPOSE named '*Orders Arrive*', representing entities leaving the model after reaching the final destination.

Thus, the basic MRMM model is complete (Figures 6.32 to 6.34); though, there are issues related to statistics collection. Several procedures and processes were performed to develop the MRMM model to execute equitable order allocation. In this report, only the fundamental concepts are explained. There are other several procedures, specifically on developing models which are not explained in this report. For the detailed model development processes in Arena®, the reference can be made from the Arena® software manual[15], Kelton *et al.* (2004); Rossetti (2016), among others. Within Arena®, some statistics categories were used to capture necessary information to execute the DACE concepts in Chapter 7. These include *Frequency* (tabulated percentage of time spent in specified categories), *Output* (captured at each of the replication lengths), *Counter* (record with the count option), *Tally* (observation-based) and *DSTAT* (time-based). After developing and running the MRMM model, named '*mrmm.doe'*, it created a matching Microsoft® Access file named '*mrmm.mdb*'. The generated database was stored in the same file from the simulated '*mrmm.doe'*.

[15] Arena® simulation software at https://www.arenasimulation.com/

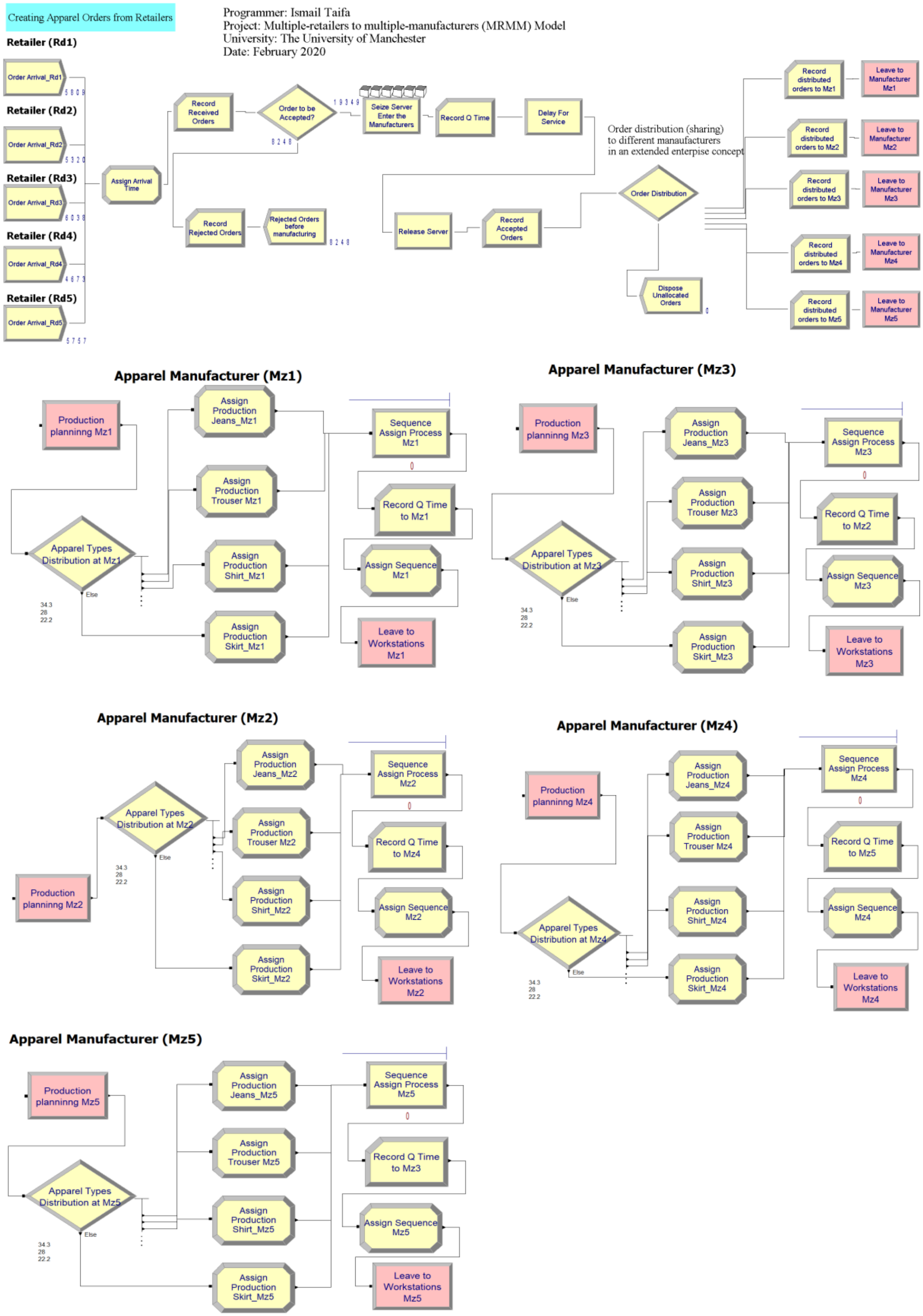


Figure 6.32: Part 1 of the final modelled and simulated MRMM model using Arena®.

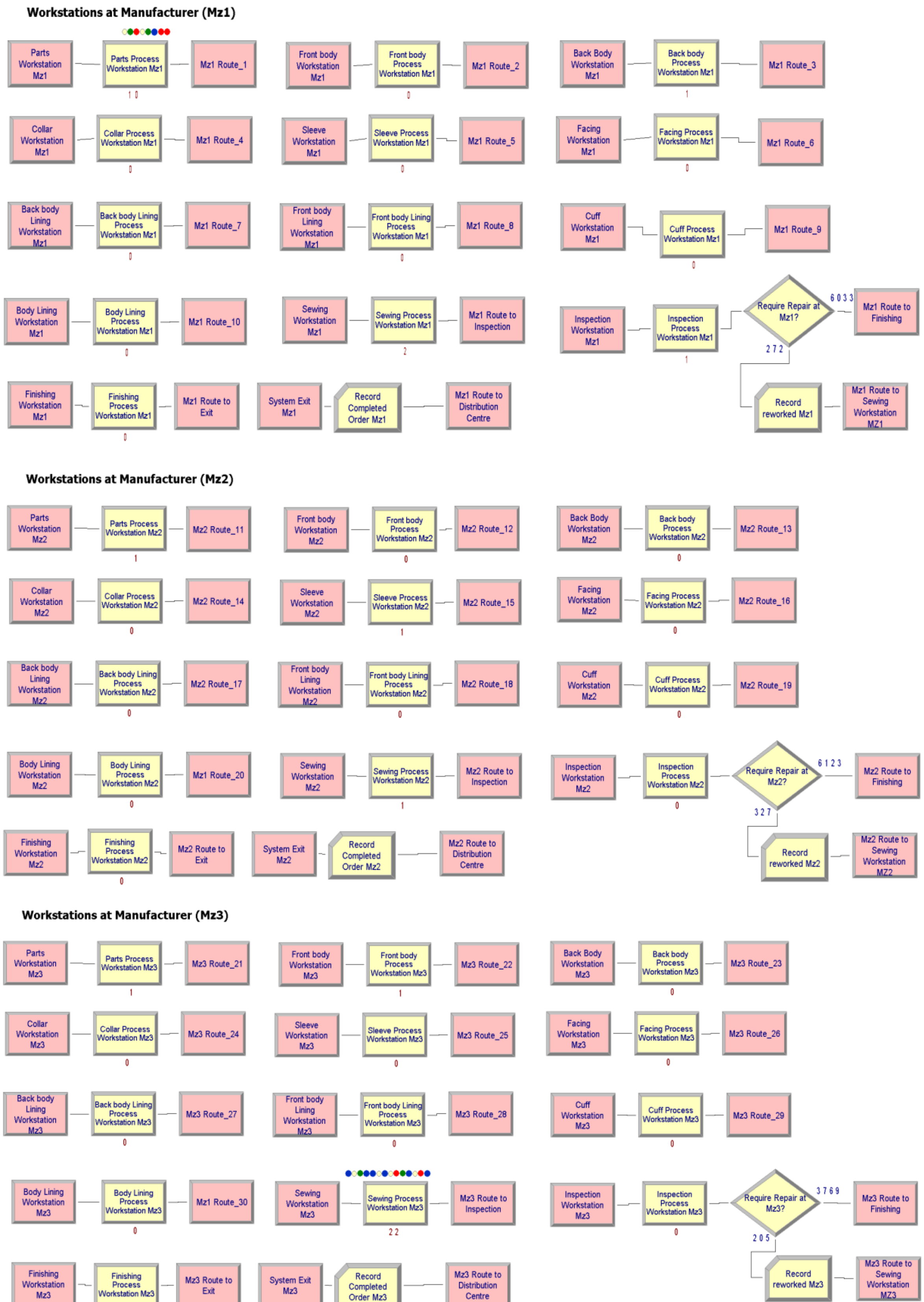


Figure 6.33: Part 2 of the final modelled and simulated MRMM model using Arena®.

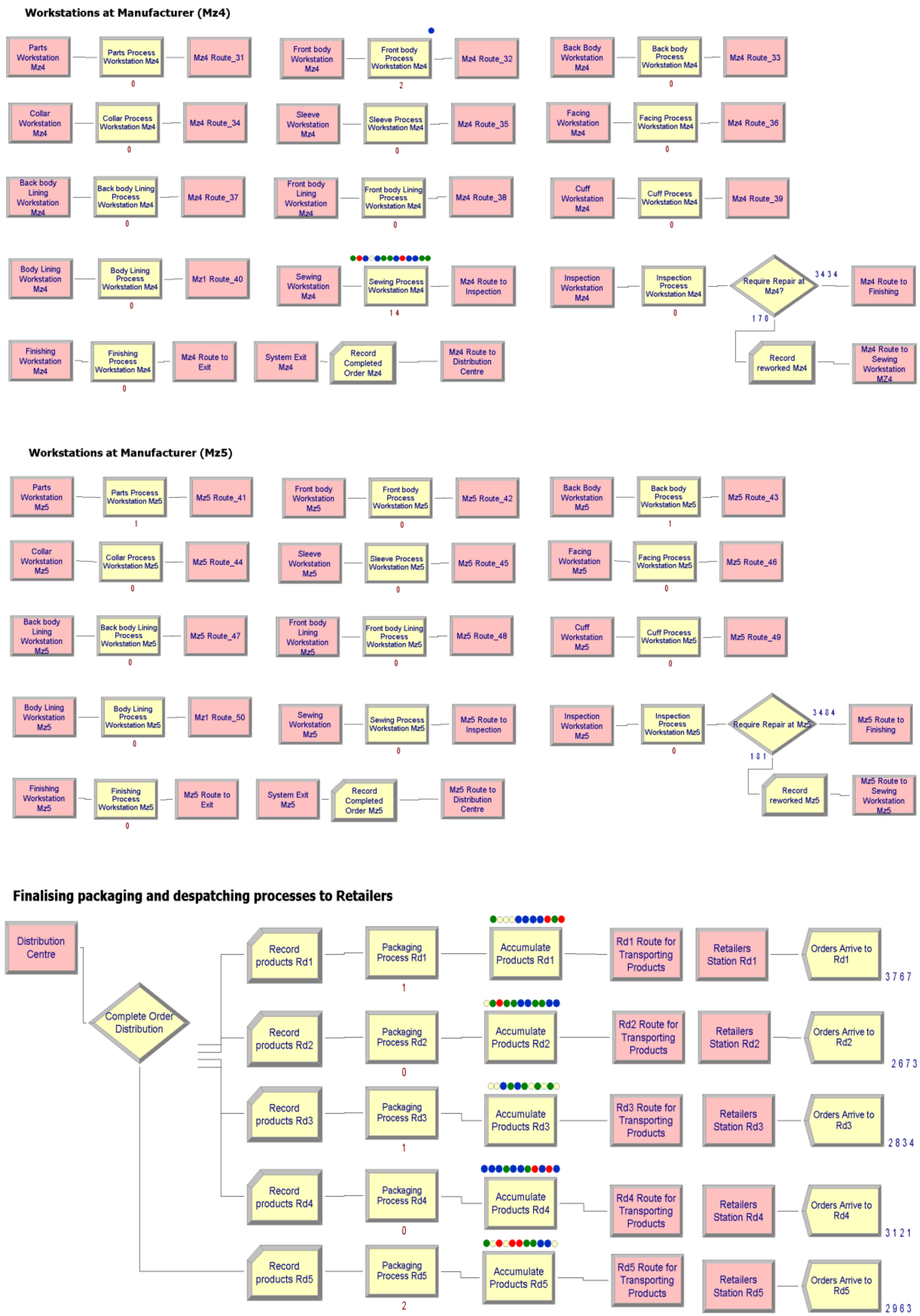


Figure 6.34: Part 3 of the final modelled and simulated MRMM model using Arena®.

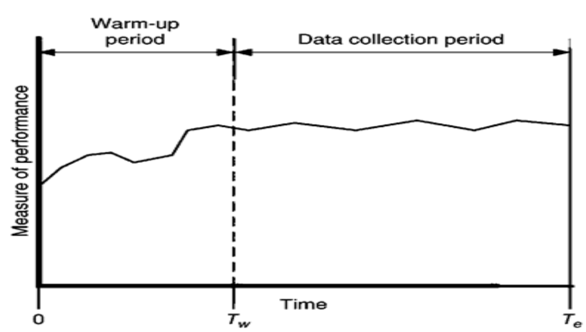
6.6 Run-length, warm-up period and number of replications

6.6.1 Simulation run length

The MRMM model (Figures 6.32 to 6.34) is now ready to be set up and run. Set up was performed after checking the model, and Arena® displayed that '*No errors or warnings in [the] model*'. Manufacturers are assumed to operate into two shifts of 8 hours each, making a total of 16 hours a day. In a week, they work for 6 days. So, the manufacturers work for ~ 4,992 hours (299,560 minutes) per year: $(52\,\text{weeks} \times 6\frac{\text{days}}{\text{week}} \times 2\frac{\text{shifts}}{\text{day}} \times 8\frac{\text{hours}}{\text{shift}})$. Initially, the system is assumed to be without any order, and all resources (machines and operators) are idle: but this is not perfect in a real situation.

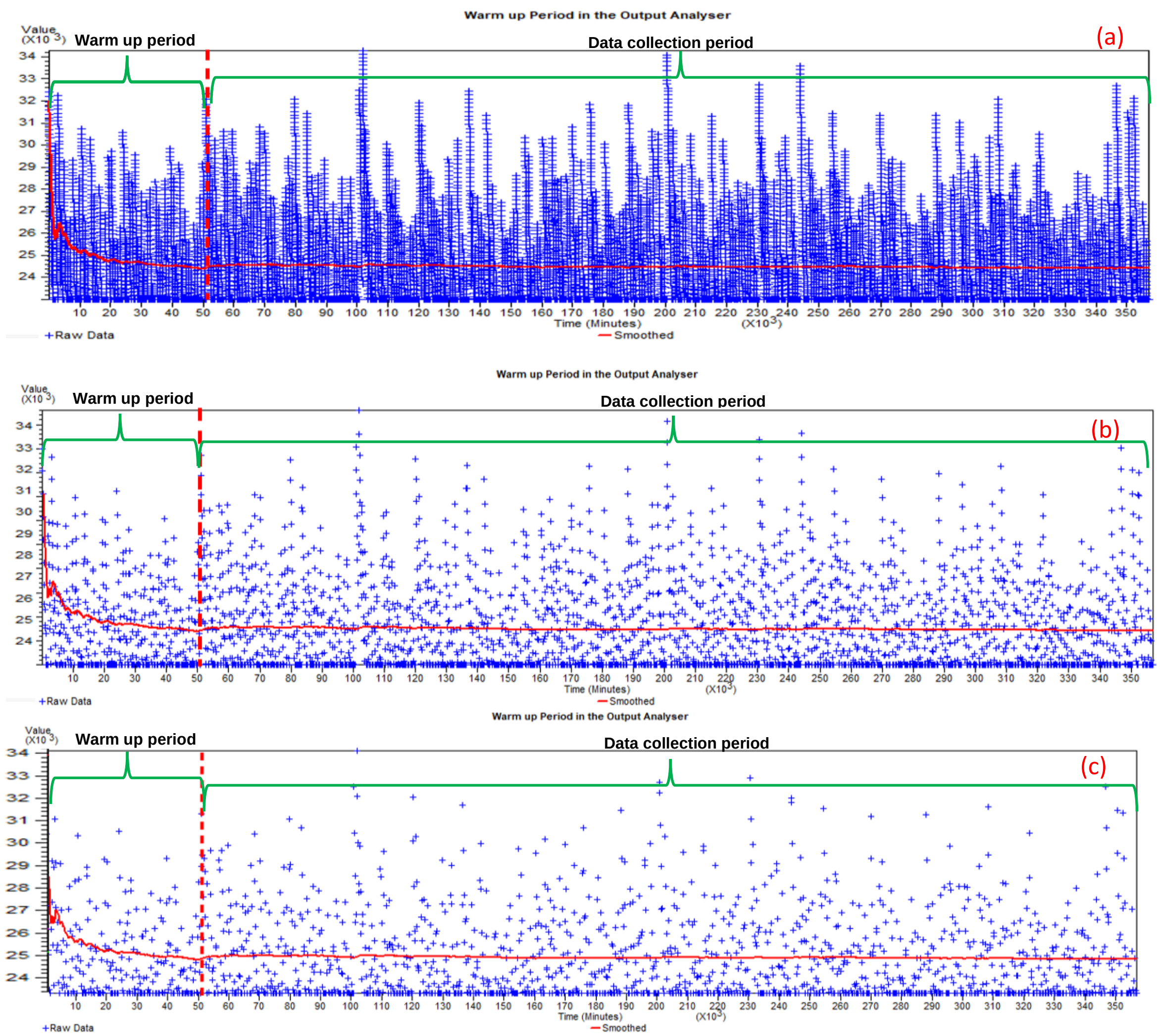
6.6.2 Warm-up period (WUP)

The actual simulation results were gathered after completion of the WUP to allow the simulated models to display a steady-state condition. To obtain an accuracy of an estimated performance for a simulated model, two vital issues should be considered: all initialisation bias must be removed, and sufficient output data must be produced (Hoad *et al.*, 2010). Hoad *et al.* (2010) elaborated five major approaches for estimating WUP including hybrid methods, initialisation bias test, statistical methods, heuristics approaches and graphical methods. In determining the WUP, there is less guidance on the required length of each replication. However, it is advised logically to run the system bigger than the expected WUP. For the MRMM, the system was thus run for 349,560 minutes (5,826 hours) to determine the reasonable WUP, and the model was monitored to detect the steady-state condition. Figure 6.35 illustrates the conceptual graph for the WUP.



Note(s): T_w = time for warming up and T_e = total time to collect desired data or results.
Source: (Rossetti, 2016, p.329).
Figure 6.35: Illustration of the warm-up period.

The WUP was stated after having established an output performance measure using the "Statistic data module". As per Arena® version 16.00.00 software, this creates a summary of results in the systems. The summary was analysed using the tool called 'Arena Output Analyser'. According to Rossetti (2016), when determining the WUP in the Output Analyser can be reasonably assessed by the Welch plot. However, since the Output Analyser does not automatically execute the Welch plot analysis, this thus requires observing each replication individually using the Moving average command in Arena®. Figure 6.36 depicts plots of the WUP for the MRMM model. The generated data were smoothed for the selected replications by the cumulative, exponential and the moving average options.



Note(s): a) The size of the batching time interval is closer by 10 minutes. (b) Closer by 20 minutes. (c) The batching size is closer by 200 minutes. Order quantities are plotted on the y-axis.

Figure 6.36: Cumulative average plots to compute the warm-up period.

Since the WUP requires time persistent data, thus the computation of such data through the Output Analyser can be performed using the Batch/Truncate dialogue based on *observation-based* or *time-based category*. The batching interval considered *time-based* as a suitable category of batching. The data were batched based on the time interval of 10 minutes, 20 minutes, and 200 minutes (Figure 6.36(a)-(c)). From Figure 6.36, the vertical dashed red line indicates the time the system becomes steady. For the entire study, the WUP was 50,000 minutes (~ 834 hours) while the steady-state period (data collection period) was ~ 4992 hours (or 299,560 minutes) per year. The total simulation time was 349,560 minutes (Figure 6.37).

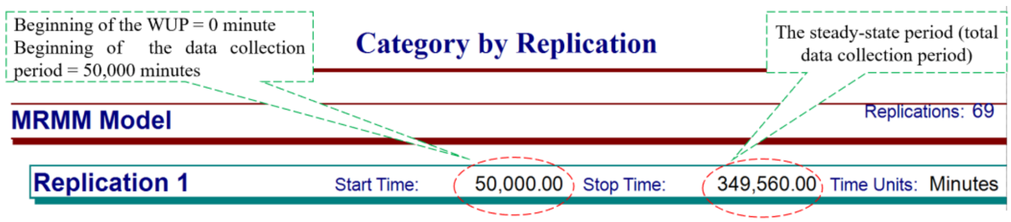


Figure 6.37: The warm-up and data collection period.

6.6.3 Determining the number of replications

Replication means an independent repeat run of each set up in the software. Having set the WUP (Figure 6.36), afterwards was to compute the required number of replications. A replication is "the generation of one sample-path, which represents the evolution of the system from its initial conditions to its ending conditions" (Rossetti, 2016, p.300). If there are many replications performed in Arena®, the generated outputs give a 95% confidence interval (CI) automatically for the key performance indicators and other performance attributes. It is not possible to generate a standard deviation (STD) in Arena®. Instead of the STD, Arena® provides 'half-width' value for a 95% CI (Rossetti, 2016). So, by performing a pilot run, it is possible to identify the required number of replications (N_m). Using fewer replications whenever running a simulation can result in the loss of correctness and accuracy. Using many replications can also lead to wastage of time and cost. It is thus essential to have the appropriate replications to achieve the correct results without wasting time, cost and compromising the quality of the generated results. To execute this, the appropriate number of replications (N_m), given m replications, was performed using a half-width method represented by equation 6.13 (Truong *et al.*, 2016; Rahimikelarijani *et al.*, 2018).

$$N_{(m)} = \left(\frac{STD(m) \times t_{m-1,1-\frac{\alpha}{2}}}{\bar{X}_m \times \varepsilon} \right)^2 \tag{6.13}$$

From equation 6.13, *m* stands for the first number of replications (*Rep*) which was assumed to be 30 and its waiting times in hours. $\bar{X}_{(m)}$ is the sample (data) mean from *m* simulation runs; $STD(m)$ is the standard deviation from m simulation runs; $t_{m-1,1-\frac{\alpha}{2}}$ represents a student's *T*-distribution with *m*-1 degree of freedom. A confidence interval (significance level) of 95% (α = 0.05) was considered. Then, ε represents an allowable percentage error, $\varepsilon = \left|\bar{X}_{(m)-\mu}\right|/|\mu|$, and μ is the true mean (Truong *et al.*, 2016). The allowable percentage (ε) of 5% with $t_{4,\,0.975}$ gives the *p*-value of 2.045. From Table 6.15, the required replications, $N_{(m)}$, was found to be 69. From Table 6.15, the mean and the STD were calculated using equations 6.14 and 6.15, respectively.

$$\bar{X}_{(m)} = \frac{\sum_{i=m}^{m} x_i}{m} \quad (6.14)$$

$$STD_{(m)} = \frac{\sqrt{\sum_{i=m}^{m}(x_i - \bar{X})^2}}{m-1} \quad (6.15)$$

Whereby, X_1, X_2, …, $X_{(m)}$ are the samples observed from the simulated data.

Table 6.15: The initial replication results from the queue of 'Seize Server Enter the Manufacturers'.

Replication	Waiting Time	Replication	Waiting Time	Replication	Waiting Time
1	301.65	11	312.04	21	324.42
2	296.65	12	323.86	22	311.92
3	303.27	13	310.57	23	334.42
4	304.13	14	315.53	24	323.58
5	315.63	15	330.85	25	306.45
6	331.66	16	322.73	26	317.13
7	308.72	17	319.06	27	312.29
8	317.00	18	321.90	28	334.51
9	307.79	19	321.89	29	320.49
10	314.06	20	330.43	30	310.49
Mean, $\bar{X}_{(m)}$					316.84
SDV, $STD(m)$					63.92
$N_{(m)}$					**68.08**

6.6.4 Terminating conditions

In modelling an equitable order allocation system, precise measurements purposes for simulation responses are usually needed. The purposes and how the specific system works helps to determine to accomplish and evaluate simulation experiments. Over a while, the final decision through the simulated system necessitates being decided based on two categories. First, an *infinite horizon*; here, there is no well-specified ending condition or time: this type of horizon is also referred to as steady-state simulations (Rossetti, 2016). Second, the *finite horizon*, a clearly specified ending condition or time that determines whether or not to stop the simulation (Rossetti, 2016). SMEs were assumed to work for 6 days a week with two shifts of 8 hours each. Hence, the terminating condition is 'finite horizon' which depends on the set replication length (Section 6.6.3).

6.7 Initialisation between replications

The WUP, Initialise Statistics and Initialise System fields provide flexibility in collecting final statistics. Arena® software allows four possible options to initialise between replications (Figure 6.38) with the interaction between the three fields as follows:

a) **Scenario I**: *Both the system and statistics are checked*. The developed system is set to empty and idle, and the generated statistics are cleared (reset) after each replication. The statistics are then cleared again at the specified time of the WUP, so the reports only show the generated model statistics after the WUP. If this scenario is used, it leads to 69 statistically independent collected reports. In this case, each replication begins at time 0 (days) with an empty system, and each runs for 349,560 minutes. If there are the held apparel orders which are forwarded to the next replication, they are all lost.

b) **Scenario II**: *the system is checked, and statistics is unchecked*: such a scenario leads to 69 independent replications whereby each replication begins at time 0 (days) with an empty system and each run for 349,560 minutes. The created reports are cumulative, i.e. report for replication 2 would consist of the statistics for the first two replications, report 3 would comprise statistics for the first three replications, etc.

c) **Scenario III**: *the system is unchecked while statistics are checked*. The developed system begins idle and empty during the first replication. After the WUP time units, the statistics are cleared, and a summary for WUP is generated. Such a scenario leads to 69 replications whereby the first replication begins at time 0 (days), the second at 699,120 minutes, etc. Since the system is not initialised between replications; the time (duration) thus keeps advancing, and any apparel orders held are carried forward to the next replication. The generated report comprises single replication, i.e. 69th replication.

d) **Scenario IV**: *Both the system and statistics are unchecked*. Here, at the beginning of the first replication, the developed system starts idle and empty. After WUP time units, the generated statistics are cleared, and a summary for WUP is generated. Such a scenario, thus leads to 69 replications whereby the first replication begins at time 0 (days), the second at 699,120 minutes, etc. Since the system is not initialised between replications, the time (duration) thus keeps advancing, and any apparel orders held are carried forward to the next replication. The generated report is cumulative, and the 69th replication's report is the same as if only a single replication of 24,119,640 minutes would have been set.

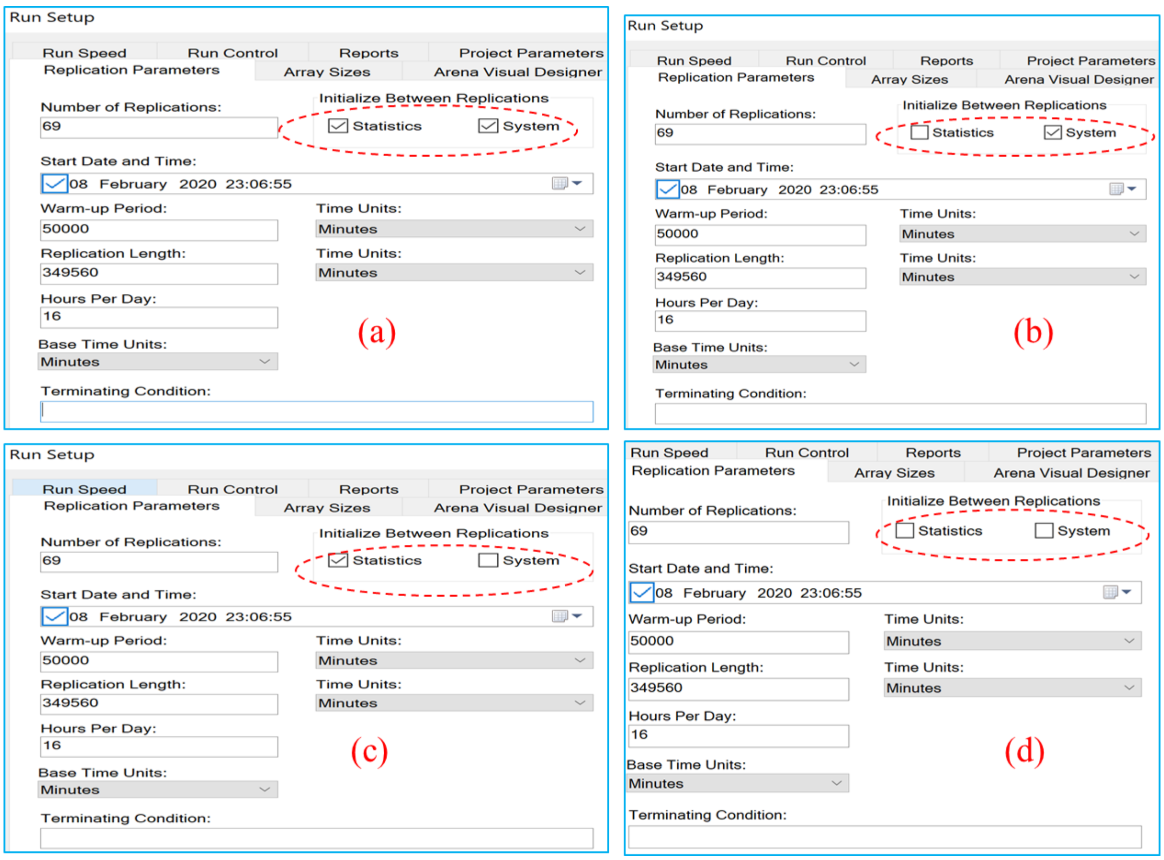


Figure 6.38: Initialisation between replications: (a) scenario I; (b) scenario II; (c) scenario III; (d) scenario IV.

This research thus considered *Scenario I* (Figure 6.38(a)) in setting an initialisation of replications for the MRMM model. In Arena® software, this scenario is the default setting. Each simulation run began and ended using the same rules.

In summary, this chapter mainly answered part of the fourth research question (Section 1.4) and the main objective (Section 1.5). The simulation results are in Chapter 8. The discussion on calibration, verification and validation of the developed models is in Section 8.3.1.

Chapter 7 Application of design and analysis of computer experiments (DACE)

7.1 Application of DACE

Chapter 6 focused on developing the MRMM model to enable equitable order allocation based on a single simulation model (Figures 6.32 to 6.34). Yet, the process of running a simulation model necessitates the specification of the independent variables (inputs), controllable factors, uncontrollable factors, and the response (the dependent variables or output). There should also be specifications of the model structure, e.g., *FIFO, LIFO, LAV* and *HAV* (Rossetti, 2016). In comparing the system configurations, specifying the model inputs—variables and/or model structure—thus represents the configuration of the specific system under consideration (Rossetti, 2016). Initial discussion on DACE is in Section 4.11.

DACE is the statistical approach to design experiments and analysing the generated data. DACE is applied to model simulations or computer experiments. Design of the experiments means how and where to collect the data, and the analysis of the experiments is deciding how to analyse the collected data. A lot of the time in the literature DACE has been to create robust designs (Sacks *et al.*, 1989; Kleijnen, 2018). However, the application of DACE to this study was not to create robust designs of the equitable order allocation model. In this study, computer experiments were run and then analysed the generated data through an objective approach. Thus, the focus was mainly the analysis of the generated data to demonstrate the feasibility of allocating orders to several manufacturers given multiple order quantities, parameters, and configurations.

In connection with the primary objective (Section 1.5), it is crucial to investigate the feasibility of allocating bulk orders due to multiple factors and conditions, including different order availability, level of expertise, quality, price, and other vital decision criteria. Could this be performed by computer algorithms, computer simulation software, etc.? Thus, in Section 4.11, the realisation of the feasibility of order allocation virtually across multiple manufacturers working as an extended enterprise suggested the application of DACE. Sufficient information must be generated using the initial computer-simulated model in

Chapter 6. That allows analysing the impacts of several configurations and inputs to investigate the MRMM model's performance under a variety of controlled specifications.

Figure 7.1 depicts the general illustration of the simulation through DACE concepts to execute the feasibility of allocating orders. It is crucial to clarify what this Figure 7.1 for because there are several processes to this figure. Each business partner is allocated based on the cumulative sourcing performance index (Chapter 5). When an order comes in and allocated by deciding which manufacturer manufacture what, the inputs (β_n) are the *order sizes*. The output (response, *R*) of the simulation can be the time taken to manufacture (this is a transfer function aspect), the number of orders distributed equitably, or the total manufactured products across several manufacturers.

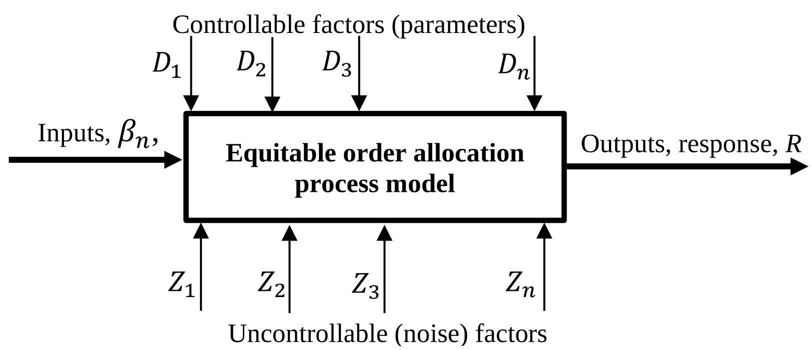


Figure 7.1: The overall illustration of the simulation through DACE concepts.

In Figure 7.1, the controllable factors and uncontrollable factors are the design parameters for the system (simulation). All the controllable factors are things such as manufacturers involved, the quantities that each would manufacture, the information shared, etc. While simulating the model, quantities allocated to each of the manufacturers are controlled for the given simulation. This means the number of retailers and manufacturers can also be controlled. Other controllable parameters are depicted in Figure 7.3. The system also involves noise factors (uncontrollable). The uncontrollable aspects are how much time will take for particular steps. For example, SMV can be treated as noise factors depending on the developed model. However, in this study, SMV was grouped under controlled factors to be altered in the system. Therefore, all these factors should be set up as part of the system (simulation) design. It should also be assumed that some of the noise factors are also modelled using random numbers inside the system.

There are at least two approaches to conduct the simulation. First, by setting specific values, it is normally random, but the values can be chosen before executing the simulation. Then, every time a model is simulated, it generates the same output. The second alternative does not involve fixing values, and thus with the concept of the simulation, the model generates random numbers that give that value for the simulation run. So, by setting the value before running the simulation, there are no uncontrollable factors that do not have values set. All the values for the simulation generate the same output all the time. This approach necessitates changing the values before running another simulation. This is not the most efficient way to conduct it, and the simulation of this study was not performed in this way.

This study was conducted using some stochastic processes to model some of the time taken in the process steps. When an order comes in, the simulation is run with both controllable factors and the uncontrollable parameters set; thus, some random numbers generated during the simulation. The model was simulated for several times depending on the replication length and warm-up period set (Section 6.6). Subsequently, the average of the outputs was taken. These experiments show that given a means to allocate the available order across a cluster of manufacturers the simulation was run to indicate that manufacturers can do it or they cannot do it and even with the variations and fluctuations including the time taken, order size, among other decision criteria, this shows that it would be feasible if they work together.

Experiments generate data to show the feasibility of the order sharing and allocation of working together. This type of simulation cannot be performed in real-life (real-life experimentations) because manufacturers do not do it as it could take an extended period to show such feasibility if there are different order sizes. In this study, the simulation shows that given different volumes, capacities, capabilities, settings, etc., they can work together, or they cannot fulfil the order. For those simulations, the model input is the order sizes. Therefore, the conducted DACE to this study showed the feasibility of the simulations to generate data that shows the feasibility of manufacturers working together: that is the role of DACE. It should be noted that DACE is not verifying nor validating the simulated model. If the approach could have involved the creation of the robust system design, it could have needed the simulations to show the best order allocation, best information-sharing practice, etc., so that the collaboration of manufacturers working together is robust to things uncontrollable such as suppliers' delivery time, a fluctuation processes, etc. But this is a different use of the simulation that helps to generate data that realise the research objective.

In conducting DACE as the classical experimental-design techniques, it is imperative to consider some of the inputs, controllable and uncontrollable parameters. This helps to establish the effects on the outputs after altering the configurations or parameters for several levels. The configurations and parameters are experimental factors, whereby possible levels for each factor are specified. Subsequently, the *Arena Process Analyser* (PAN) tool executes the experiments under the factorial design. For these simulation-based experiments, such a process allows measuring the primary influence (effects) of and the possible interactions amongst the specified input and other parameters on the response (outputs). Unlike most physical or real-life experiments, the process(es) should allow replication of the (entire) factorial experiment to place confidence intervals circa the expected main interactions and effects (Kelton *et al.*, 2004). Also, the statistical design of experiments should involve the process of planning the experiments that allow data collection and analysis processes using suitable statistical approaches, leading to demonstrating the feasibility of allocating orders.

The assumption is that the simulated ordering model takes inputs and generates outputs. Due to that, there are different configurations, and it is thus better knowing the best configurations. Since random variables drive the simulations of the MRMM model; the outputs are thus also random variables. This means that the model has input, controllable and uncontrollable parameters, and it responds in a certain way, i.e. the change in inputs changes responses as well. Here, it is better to model the responses as the stochastic process to find the average, distribution, and variation: this provides a response surface. In that way, the simulation is considered as an object that takes inputs to deliver outputs; thus, generates the function. Instead of having a physical object—order allocation model—the developed MRMM computer model was considered as a 'black box' with inputs and outputs (Figure 7.23). It is not possible to see inside the computer simulation model.

Completion of the above explanations helps to prove that it is feasible for the SMEs to work together on the received orders. The SMEs would need a means of distributing the orders across them in terms of their capacities, the required volume, lead times, etc. Demonstrations of the feasibility is thus a proof of concept. This should be the case mainly when someone gives different order sizes to the developed model, and the model successfully distributes orders across SMEs. The model can also be modified to show through the simulations that it would deliver in time. But in this study 'delivering on time' was not the primary objective. The model should also not only work for just one allocation; it should work for different possible allocations. Given multiple orders and multiple scenarios, the system should thus give potential solutions, or it turns out that there is no possibility of fulfilling the ordered quantities. So, this assures that the system is well developed statistically and functionally.

7.2 Designing and executing simulation experiments

7.2.1 Procedures for designing and executing simulation experiments

Figure 7.2 shows the main procedures followed in conducting computer experiments.

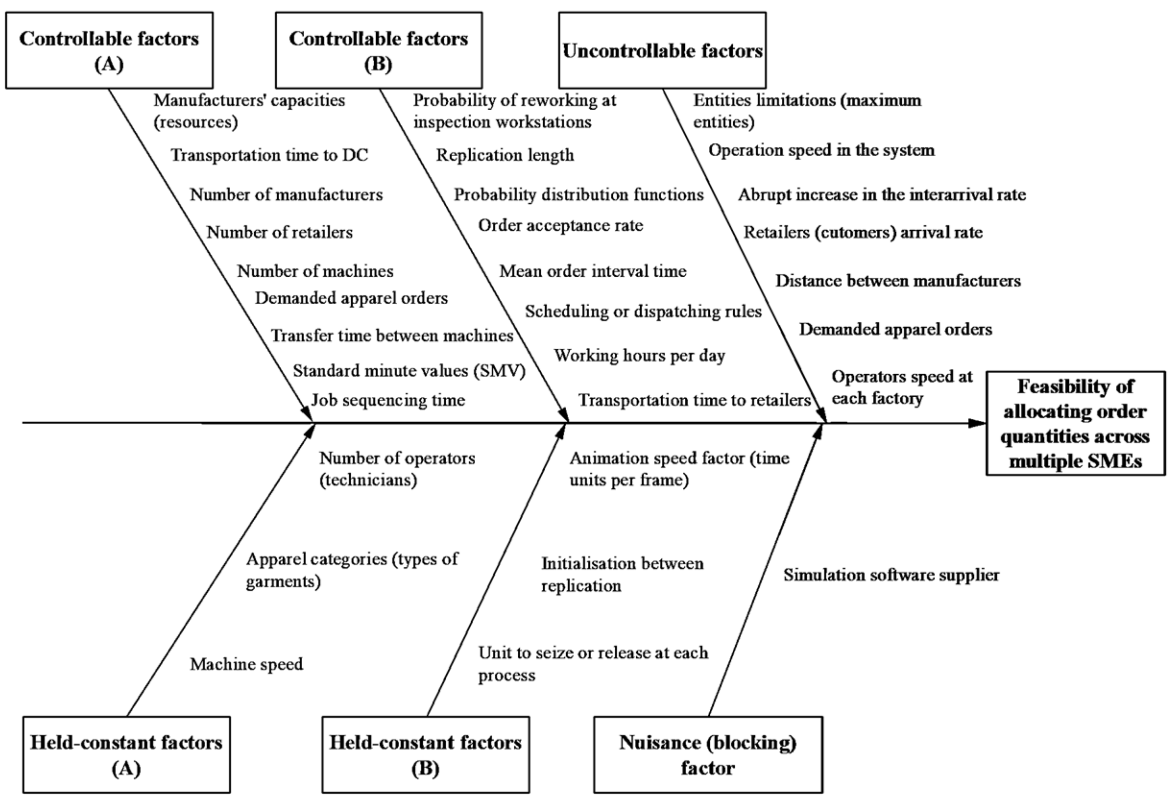
(a) Recognitions and statement of the problem	• It is important to clarify the equitable order allocation model problem that requires the statistical design of experiments.
(b) Choosing the response variables	• The major response variable is confirming the feasibility of allocating bulk orders equitably to several SMEs working collaboratively. This can be measured as the average, standard deviation or both for the studied system.
(c) Selecting suitable factors, levels and ranges	• Mostly, the cause-and-effect, fishbone or Ishikawa diagrams are applied to classify potential design factors or nuisance parameters.
(d) Selecting pertinent experimental design	• This comprises a consideration of the number of replications (sample size), choosing the suitable run order for the experimental trials, and checking whether or not blocking or other randomisation restrictions are considered.
(e) Experimenting	• Experimenting by conducting a few pilot or trial runs whilst observing carefully to ensure that the planned processes are executed successfully.
(f) Statistical analyses	• Conducting statistical analysis of the data by the simple graphical methods or empirical model using an equation derived from the relationship between the targeted vital response and the design factors.
(g) Concluding remarks and recommendations	• State practical concluding remarks. If possible, the follow-up simulation runs and confirmation testing can be conducted to validate the conclusion from the designed or simulated computer experiments.

Note(s): (**b**) and (**c**) can be performed in reverse order or concurrently.
Summarised from Montgomery (2013).
Figure 7.2: Critical procedures for designing and experimenting.

7.2.2 *Choice of factors, levels, and range for executing simulation experiments*

a) Factors selection

In the experimental-design viewpoint, the structural assumptions, input and parameters to create a model are factors while the output performance measures (indicators) are responses (Law and Kelton, 2000; Law, 2015). Factors are mainly categorised as either nuisance or possible design factors: the nuisance factors are further categorised as controllable, noise or uncontrollable factors (Montgomery, 2013). When the nuisance factors are known but uncontrolled in the experiment, the analysis of covariance procedure can be used (Montgomery, 2013). If the nuisance and controllable factors are known, the blocking technique can also be used to eliminate its effect. Within the simulation model, all input factors are controllable. The input parameters are also the *decision variables.* They can be altered with several configurations to confirm, screen, optimise, develop robustness or discovery of something new. Figure 7.3 is the fishbone or cause-and-effect diagram to execute simulation experiments. Table 7.1, likewise, explains some factors from Figure 7.3.



Note(s): A and **B** letters for the controllable and held-constant factors were for the presentation purposes only as a means of reducing the size of Figure 7.3; DC = distribution centre(s).

Figure 7.3: Cause-and-effect diagram for designing and executing experiments.

This study included the collected factors through the interview sessions, document reviews and expert opinions. The reason being that deciding the structural assumptions and experimental factors relies on the specific study's aim instead of the inherent form of the model (Law, 2015). The key response is the total distributed orders (apparel throughput) and the distributed (allocated) orders to each SME given several factors. This is along with the research aim (Section 1.5) — allocating or distributing orders to several SMEs equitably. Many studies focus on controllable factors; nevertheless, some uncontrollable factors should be experimented to establish their influence in the system. For instance, although the abrupt increase of retailers' arrival rate is an uncontrollable factor (Figure 7.3), in real cases, such a factor can create a massive impact: it must be dealt to establish its significance statistically.

Table 7.1: Description of design factors.

S/N	Controllable factors	Description
1	Demanded apparel orders	The order quantities received from five retailers—Rd_1 to Rd_5.
2	Number of manufacturers	SMEs that make apparel or clothes
3	Number of retailers	Enterprises that sell apparel for use rather than for resale
4	Probability distribution functions (PDFs)	The change of the PDFs for the received orders, e.g. Normal, Triangular, Uniform, among other PDFs (Table 3.7).
5	Decision criteria (CSPIs)	In Section 8.2.7, equations 8.1 to 8.7 developed the CSPIs.
6	Standard minute values (SMV)	The time for a skilled operator working at standard performance to perform tasks at the specified process modules (Table 6.3).
7	Machine utilisation	Arena® gives the scheduled and instantaneous utilisation.
8	STD of the processing time at the sewing process workstation	What if the standard deviation of the sewing process or section was increased, decreased, or kept constant?
9	Manufacturers' capacities (resources)	Focuses on establishing the influence on the responses after altering the resources as fixed or based on the schedule scenarios.
10	Dispatching rule (scheduling) or queue-ranking rules	These include FIFO, LIFO, LAV and HAV (Section 6.5.9(c)).
11	Order acceptance rate	Deals with the variable to decide order quantities to accept.
12	Probability of reworking at inspection workstations	Assesses the chance of producing apparel with poor quality which requires to be repaired or reworked.
13	Transfer time between machines	Time to transfer entities from one machine to another.
14	Working hours per day	Initially, SMEs work 16 hours per day (Section 6.6.1).
15	Replication length	Necessary simulation time to assess the modelled system.
16	Transportation time to retailers	Transportation time from the distribution centres to retailers.
17	Transportation time to DC	Transportation time from manufacturers to distribution centres.
18	Mean order interval time	The interval between order arrivals.

b) *Selection of factorial design and levels*

Experimentally, levels are the ranges of variation for the suitable identified factors. Montgomery (2013) suggests the use of two to three-level factorial and fractional designs when improving, troubleshooting, and developing processes and products, especially when factors are quantitative. If both qualitative and quantitative factors are considered, a mixed-level fractional design method should be the better choice. This research considered only quantitative factors, thus resulted in a three-level design. Thirteen crucial factors from Figure 7.3 were considered in the designed computer simulation experiments. The orthogonal array (OA) to execute the feasibility of allocating orders by the simulated model (Figures 6.32 to 6.34) was found to be L_{27} (3^{13}). To replicate this design, three levels were considered: the base level (low) (*level 1*), first alteration (medium) (*level 2*) and the second alteration (high) (*level 3*). Table 7.2 provides the three levels for each factor. It should be noted that in the design of experiments, there is no one agreed standard on naming the levels. Levels should be determined in some sense opposite but with logic. A simple OA layout is depicted in Figure 7.4, while the general OA is in Figure 7.5. Since the factorial design was considered, this thus forms an $L_{27}(3^{13})$ OA. Table 7.3 shows the general layout of the L_{27} OA.

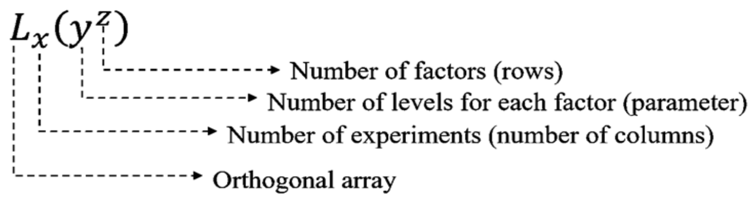
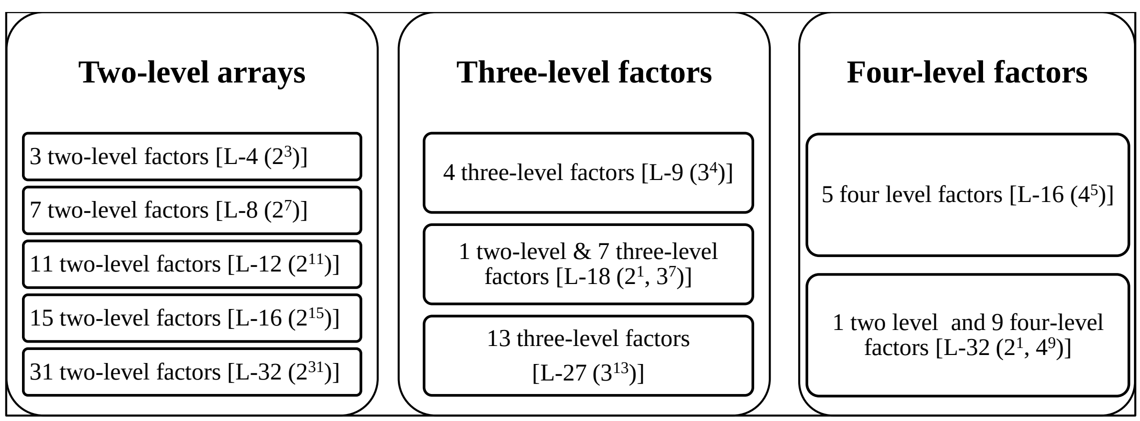


Figure 7.4: Orthogonal array for designing and executing simulation experiments.



Source: (Roy, 2001; Deresse *et al.*, 2020).
Figure 7.5: Commonly used orthogonal arrays with levels.

Table 7.2: The chosen factors, level, and range of inputs and controllable variables (parameters).

Factors and inputs	The defined variables in Arena®	Description of the defined variables	The base level (*Level 1*)	The 1st change (*Level 2*)	The 2nd change (*Level 3*)
A	*vOrderquantity*	Increase of the received orders before being processed	1	1.5	2
B1	$vPIMz_1$	CSPI for the first SME (Mz_1)	23.95%	5%	30%
B2	$vPIMz_2$	CSPI for the second SME (Mz_2)	20.28%	10%	30%

B3	$vPIMz_3$	CSPI for the third SME (Mz_3)	17.86%	15%	5%
B4	$vPIMz_4$	CSPI for the fourth SME (Mz_4)	18.56%	30%	20%
B5	$vPIMz_5$	CSPI for the fifth SME (Mz_5)	19.36%	40%	15%
C1	$vEPA\_Rd_1$	Entities per arrivals (EPA) received from the first retailer.	POIS (114)	POIS (120)	POIS (126)
C2	$vEPA\_Rd_2$	EPA received from the second retailer.	POIS (108)	POIS (126)	POIS (132)
C3	$vEPA\_Rd_2$	EPA received from the third retailer.	POIS (102)	POIS (132)	POIS (138)
C4	$vEPA\_Rd_4$	EPA received from the fourth retailer.	POIS (96)	POIS (138)	POIS (144)
C5	$vEPA\_Rd_5$	EPA received from the fifth retailer.	POIS (90)	POIS (144)	POIS (150)
D1	vMA_Rd_1	Maximum arrivals (MA) to be received from the first retailer.	POIS (342)	POIS (360)	POIS (378)
D2	vMA_Rd_2	MA to be received from the second retailer.	POIS (324)	POIS (378)	POIS (396)
D3	vMA_Rd_3	MA to be received from the third retailer.	POIS (306)	POIS (396)	POIS (414)
D4	vMA_Rd_4	MA to be received from the fourth retailer.	POIS (288)	POIS (414)	POIS (432)
D5	vMA_Rd_5	MA to be received from the fifth retailer.	POIS (270)	POIS (432)	POIS (450)
E	*vOrderAR*	Order acceptance rate	65%	70%	75%
F	*vSeq_time*	Sequencing time to assign the processing time for each process	0.5 second	1 second	1.5second
G	*vMOIT*	Mean order interarrival time	1 day	2 days	3 days
H1	$vTrMz_1$	Transfer time from one machine to another for the 1st manufacturer	1 minute	2 minutes	3 minutes
H2	$vTrMz_2$	Transfer time from one machine to another for the 2nd manufacturer	1 minute	2 minutes	3 minutes
H3	$vTrMz_3$	Transfer time from one machine to another for the 3rd manufacturer	1 minute	2 minutes	3 minutes
H4	$vTrMz_4$	Transfer time from one machine to another for the 4th manufacturer	1 minute	2 minutes	3 minutes
H5	$vTrMz_5$	Transfer time from one machine to another for the 5th manufacturer	1 minute	2 minutes	3 minutes
I	*vPRework*	Probability of a rework in the inspection process	5%	10%	15%
J1	$vTtfmDCMz_1$	Transportation time from Mz_1 to DC	1 day	2 days	3 days
J2	$vTtfmDCMz_2$	Transportation time from Mz_2 to DC	2 days	3 days	4 days
J3	$vTtfmDCMz_3$	Transportation time from Mz_3 to DC	1 day	2 days	3 days
J4	$vTtfmDCMz_4$	Transportation time from Mz_4 to DC	2 days	3 days	3 days
J5	$vTtfmDCMz_5$	Transportation time from Mz_5 to DC	3 days	4 days	5 days
K1	$vTtRd_1$	Transportation time from DC to Rd_1	1 day	2 days	3 days
K2	$vTtRd_2$	Transportation time from DC to Rd_2	2 days	3 days	4 days
K3	$vTtRd_3$	Transportation time from DC to Rd_3	1 day	2 days	3 days
K4	$vTtRd_4$	Transportation time from DC to Rd_4	2 days	3 days	3 days
K5	$vTtRd_5$	Transportation time from DC to Rd_5	1 day	2 days	3 days
L	*vWHPD*	Working hours per day	16 hours	20 hours	24 hours
M	*Num Reps*	Number of replications to run	60	100	140

Note(s): DC = distribution centre; CSPI = Cumulative Sourcing Performance Index; Initial values for factors *C1-C5* and *D1-D5* were computed using equations 6.10 to 6.12. *B1-B5*: level 1 was generated in Table 5.5. *F, J1-J5, K1-J5, K1-K5* and *L* are the assumed factors, which can be altered based on the available actual data.

Table 7.3: The general layout of the L_{27} (3^{13}) orthogonal array for the performed computer simulation experiments.

Experiment	Inputs and factors to set computer simulation experiments													Response values
	A	B	C	D	E	F	G	H	I	J	K	L	M	
Experiment 1	1	1	1	1	1	1	1	1	1	1	1	1	1	R_1
Experiment 2	1	1	1	1	2	2	2	2	2	2	2	2	2	R_2
Experiment 3	1	1	1	1	3	3	3	3	3	3	3	3	3	R_3
Experiment 4	1	2	2	2	1	1	1	2	2	2	3	3	3	R_4
Experiment 5	1	2	2	2	2	2	2	3	3	3	1	1	1	R_5
Experiment 6	1	2	2	2	3	3	3	1	1	1	2	2	2	R_6
Experiment 7	1	3	3	3	1	1	1	3	3	3	2	2	2	R_7
Experiment 8	1	3	3	3	2	2	2	1	1	1	3	3	3	R_8
Experiment 9	1	3	3	3	3	3	3	2	2	2	1	1	1	R_9
Experiment 10	2	1	2	3	1	2	3	1	2	3	1	2	3	R_{10}
Experiment 11	2	1	2	3	2	3	1	2	3	1	2	3	1	R_{11}
Experiment 12	2	1	2	3	3	1	2	3	1	2	3	1	2	R_{12}
Experiment 13	2	2	3	1	1	2	3	2	3	1	3	1	2	R_{13}
Experiment 14	2	2	3	1	2	3	1	3	1	2	1	2	3	R_{14}
Experiment 15	2	2	3	1	3	1	2	1	2	3	2	3	1	R_{15}
Experiment 16	2	3	1	2	1	2	3	3	1	2	2	3	1	R_{16}
Experiment 17	2	3	1	2	2	3	1	1	2	3	3	1	2	R_{17}
Experiment 18	2	3	1	2	3	1	2	2	3	1	1	2	3	R_{18}
Experiment 19	3	1	3	2	1	3	2	1	3	2	1	3	2	R_{19}
Experiment 20	3	1	3	2	2	1	3	2	1	3	2	1	3	R_{20}
Experiment 21	3	1	3	2	3	2	1	3	2	1	3	2	1	R_{21}
Experiment 22	3	2	1	3	1	3	2	2	1	3	3	2	1	R_{22}
Experiment 23	3	2	1	3	2	1	3	3	2	1	1	3	2	R_{23}
Experiment 24	3	2	1	3	3	2	1	1	3	2	2	1	3	R_{24}
Experiment 25	3	3	2	1	1	3	2	3	2	1	2	1	3	R_{25}
Experiment 26	3	3	2	1	2	1	3	1	3	2	3	2	1	R_{26}
Experiment 27	3	3	2	1	3	2	1	2	1	3	1	3	2	R_{27}

Note(s): *A*-*M* are the factors and inputs from Table 7.2; *R* is the response for each experiment.

7.2.3 Conducting design of computer simulation experiments

The chosen factors, level, and range of the inputs and variables (design factors) (Table 7.2) and the orthogonal array layout (Table 7.3) were entered in the Arena® PAN. Figures 7.6 to 7.8 display the result of the process for the controls. The responses were the 'distributed (allocated) orders' to each manufacturer (i.e. SME) and the total order quantities (number out). Arena® generated all performance response values in Figure 7.9 after inputting parameters (Figures 7.6 to 7.8). The first simulation was run in Section 6.5.9 (the MRMM model) before conducting the experiments in Figures 7.6 to 7.8. The question is, how does the system decide what manufacturer gets how many orders? The developed model distributes the received orders (volumes), but the distribution depends on the preliminary information in Sections 5.4.3, 6.5.4 and 8.2.7.

	Scenario Properties				Controls										
	S	Name	Program File	Reps	vOrderquantity	vPIMz1	vPIMz2	vPIMz3	vPIMz4	vPIMz5	vEPA_Rd1	vEPA_Rd2	vEPA_Rd3	vEPA_Rd4	vEPA_Rd5
1		Experiment 1	17 : MRMM	60	1.00	23.94	20.28	17.86	18.56	19.36	114	108	102	96	90
2		Experiment 2	17 : MRMM	100	1.00	23.94	20.28	17.86	18.56	19.36	114	108	102	96	90
3		Experiment 3	17 : MRMM	140	1.00	23.94	20.28	17.86	18.56	19.36	114	108	102	96	90
4		Experiment 4	17 : MRMM	140	1.00	5.00	10.00	15.00	30.00	40.00	120	126	132	138	144
5		Experiment 5	17 : MRMM	60	1.00	5.00	10.00	15.00	30.00	40.00	120	126	132	138	144
6		Experiment 6	17 : MRMM	100	1.00	5.00	10.00	15.00	30.00	40.00	120	126	132	138	144
7		Experiment 7	17 : MRMM	100	1.00	30.00	30.00	5.00	20.00	15.00	126	132	138	144	150
8		Experiment 8	17 : MRMM	140	1.00	30.00	30.00	5.00	20.00	15.00	126	132	138	144	150
9		Experiment 9	17 : MRMM	60	1.00	30.00	30.00	5.00	20.00	15.00	126	132	138	144	150
10		Experiment 10	17 : MRMM	140	1.50	23.94	20.28	17.86	18.56	19.36	120	126	132	138	144
11		Experiment 11	17 : MRMM	60	1.50	23.94	20.28	17.86	18.56	19.36	120	126	132	138	144
12		Experiment 12	17 : MRMM	100	1.50	23.94	20.28	17.86	18.56	19.36	120	126	132	138	144
13		Experiment 13	17 : MRMM	100	1.50	5.00	10.00	15.00	30.00	40.00	126	132	138	144	150
14		Experiment 14	17 : MRMM	140	1.50	5.00	10.00	15.00	30.00	40.00	126	132	138	144	150
15		Experiment 15	17 : MRMM	60	1.50	5.00	10.00	15.00	30.00	40.00	126	132	138	144	150
16		Experiment 16	17 : MRMM	60	1.50	30.00	30.00	5.00	20.00	15.00	114	108	102	96	90
17		Experiment 17	17 : MRMM	100	1.50	30.00	30.00	5.00	20.00	15.00	114	108	102	96	90
18		Experiment 18	17 : MRMM	140	1.50	30.00	30.00	5.00	20.00	15.00	114	108	102	96	90
19		Experiment 19	17 : MRMM	100	2.00	23.94	20.28	17.86	18.56	19.36	126	132	138	144	150
20		Experiment 20	17 : MRMM	140	2.00	23.94	20.28	17.86	18.56	19.36	126	132	138	144	150
21		Experiment 21	17 : MRMM	60	2.00	23.94	20.28	17.86	18.56	19.36	126	132	138	144	150
22		Experiment 22	17 : MRMM	60	2.00	5.00	10.00	15.00	30.00	40.00	114	108	102	96	90
23		Experiment 23	17 : MRMM	100	2.00	5.00	10.00	15.00	30.00	40.00	114	108	102	96	90
24		Experiment 24	17 : MRMM	140	2.00	5.00	10.00	15.00	30.00	40.00	114	108	102	96	90
25		Experiment 25	17 : MRMM	140	2.00	30.00	30.00	5.00	20.00	15.00	120	126	132	138	144
26		Experiment 26	17 : MRMM	60	2.00	30.00	30.00	5.00	20.00	15.00	120	126	132	138	144
27		Experiment 27	17 : MRMM	100	2.00	30.00	30.00	5.00	20.00	15.00	120	126	132	138	144

Note(s): This includes parameters A, B1-B5 and C1-C5 from Table 7.2.

Figure 7.6: Experimental set up controls in conducting computer simulation experiments (Part 1).

Controls													
vMA_Rd1	vMA_Rd2	vMA_Rd3	vMA_Rd4	vMA_Rd5	vOrderAR	vSeq_time	vMOIT	vTrMz1	vTrMz2	vTrMz3	vTrMz4	vTrMz5	vPRework
342	324	306	288	270	65	0.50	1.00	1.00	1.00	1.00	1.00	1.00	95.00
342	324	306	288	270	70	1.00	2.00	2.00	2.00	2.00	2.00	2.00	90.00
342	324	306	288	270	75	1.50	3.00	3.00	3.00	3.00	3.00	3.00	85.00
360	378	396	414	432	65	0.50	1.00	2.00	2.00	2.00	2.00	2.00	90.00
360	378	396	414	432	70	1.00	2.00	3.00	3.00	3.00	3.00	3.00	85.00
360	378	396	414	432	75	1.50	3.00	1.00	1.00	1.00	1.00	1.00	95.00
378	396	414	432	450	65	0.50	1.00	3.00	3.00	3.00	3.00	3.00	85.00
378	396	414	432	450	70	1.00	2.00	1.00	1.00	1.00	1.00	1.00	95.00
378	396	414	432	450	75	1.50	3.00	2.00	2.00	2.00	2.00	2.00	90.00
378	396	414	432	450	65	1.00	3.00	1.00	1.00	1.00	1.00	1.00	90.00
378	396	414	432	450	70	1.50	1.00	2.00	2.00	2.00	2.00	2.00	85.00
378	396	414	432	450	75	0.50	2.00	3.00	3.00	3.00	3.00	3.00	95.00
342	324	306	288	270	65	1.00	3.00	2.00	2.00	2.00	2.00	2.00	85.00
342	324	306	288	270	70	1.50	1.00	3.00	3.00	3.00	3.00	3.00	95.00
342	324	306	288	270	75	0.50	2.00	1.00	1.00	1.00	1.00	1.00	90.00
360	378	396	414	432	65	1.00	3.00	3.00	3.00	3.00	3.00	3.00	95.00
360	378	396	414	432	70	1.50	1.00	1.00	1.00	1.00	1.00	1.00	90.00
360	378	396	414	432	75	0.50	2.00	2.00	2.00	2.00	2.00	2.00	85.00
360	378	396	414	432	65	1.50	2.00	1.00	1.00	1.00	1.00	1.00	85.00
360	378	396	414	432	70	0.50	3.00	2.00	2.00	2.00	2.00	2.00	95.00
360	378	396	414	432	75	1.00	1.00	3.00	3.00	3.00	3.00	3.00	90.00
378	396	414	432	450	65	1.50	2.00	2.00	2.00	2.00	2.00	2.00	95.00
378	396	414	432	450	70	0.50	3.00	3.00	3.00	3.00	3.00	3.00	90.00
378	396	414	432	450	75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	85.00
342	324	306	288	270	65	1.50	2.00	3.00	3.00	3.00	3.00	3.00	90.00
342	324	306	288	270	70	0.50	3.00	1.00	1.00	1.00	1.00	1.00	90.00
342	324	306	288	270	75	1.50	1.00	2.00	2.00	2.00	2.00	2.00	95.00

Note(s): This includes parameters D1-D5, E, F, G, H1-H5 and I from Table 7.2.

Figure 7.7: Experimental set up controls in conducting computer simulation experiments (Part 2).

Controls											
vTtfmDCMz1	vTtfmDCMz2	vTtfmDCMz3	vTtfmDCMz4	vTtfmDCMz5	vTtRd1	vTtRd2	vTtRd3	vTtRd4	vTtRd5	vWHPD	Num Reps
1.00	2.00	1.00	2.00	3.00	1.00	2.00	1.00	2.00	1.00	16.00	60
2.00	3.00	2.00	3.00	4.00	2.00	3.00	2.00	3.00	2.00	20.00	100
3.00	4.00	3.00	3.00	5.00	3.00	4.00	3.00	3.00	3.00	24.00	140
2.00	3.00	2.00	3.00	4.00	3.00	4.00	3.00	3.00	3.00	24.00	140
3.00	4.00	3.00	3.00	5.00	1.00	2.00	1.00	2.00	1.00	16.00	60
1.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	20.00	100
3.00	4.00	3.00	3.00	5.00	2.00	3.00	2.00	3.00	2.00	20.00	100
1.00	2.00	1.00	2.00	3.00	3.00	4.00	3.00	3.00	3.00	24.00	140
2.00	3.00	2.00	3.00	4.00	1.00	2.00	1.00	2.00	1.00	16.00	60
3.00	4.00	3.00	3.00	5.00	1.00	2.00	1.00	2.00	1.00	20.00	140
1.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	24.00	60
2.00	3.00	2.00	3.00	4.00	3.00	4.00	3.00	3.00	3.00	16.00	100
1.00	2.00	1.00	2.00	3.00	3.00	4.00	3.00	3.00	3.00	16.00	100
2.00	3.00	2.00	3.00	4.00	1.00	2.00	1.00	2.00	1.00	20.00	140
3.00	4.00	3.00	3.00	5.00	2.00	3.00	2.00	3.00	2.00	24.00	60
2.00	3.00	2.00	3.00	4.00	2.00	3.00	2.00	3.00	2.00	24.00	60
3.00	4.00	3.00	3.00	5.00	3.00	4.00	3.00	3.00	3.00	16.00	100
1.00	2.00	1.00	2.00	3.00	1.00	2.00	1.00	2.00	1.00	20.00	140
2.00	3.00	2.00	3.00	4.00	1.00	2.00	1.00	2.00	1.00	24.00	100
3.00	4.00	3.00	3.00	5.00	2.00	3.00	2.00	3.00	2.00	16.00	140
1.00	2.00	1.00	2.00	3.00	3.00	4.00	3.00	3.00	3.00	20.00	60
3.00	4.00	3.00	3.00	5.00	3.00	4.00	3.00	3.00	3.00	20.00	60
1.00	2.00	1.00	2.00	3.00	1.00	2.00	1.00	2.00	1.00	24.00	100
2.00	3.00	2.00	3.00	4.00	2.00	3.00	2.00	3.00	2.00	16.00	140
1.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	16.00	140
2.00	3.00	2.00	3.00	4.00	3.00	4.00	3.00	3.00	3.00	20.00	60
3.00	4.00	3.00	3.00	5.00	1.00	2.00	1.00	2.00	1.00	24.00	100

Note(s): This includes parameters J1-J5, K1-K5, L and M from Table 7.2.

Figure 7.8: Experimental set up controls in conducting computer simulation experiments (Part 3).

	Scenario Properties				Responses					
	S	Name	Program File	Reps	Total produced quantities	Distributed orders to Mz1	Distributed orders to Mz2	Distributed orders to Mz3	Distributed orders to Mz4	Distributed orders to Mz5
1		Experiment 1	17 : MRMM	60	118534	18258	13627	14785	15471	14170
2		Experiment 2	17 : MRMM	100	63755	10680	7976	8636	9054	8271
3		Experiment 3	17 : MRMM	140	35203	6326	4720	5105	5344	4900
4		Experiment 4	17 : MRMM	140	137304	4466	13401	35733	8928	26774
5		Experiment 5	17 : MRMM	60	103721	3623	10876	29068	7248	21800
6		Experiment 6	17 : MRMM	100	55098	2071	6198	16537	4122	12384
7		Experiment 7	17 : MRMM	100	171974	33512	5589	16740	33520	22322
8		Experiment 8	17 : MRMM	140	71878	15087	2518	7543	15089	10083
9		Experiment 9	17 : MRMM	60	71626	16138	2694	8037	16119	10729
10		Experiment 10	17 : MRMM	140	54778	8536	6350	6895	7228	6602
11		Experiment 11	17 : MRMM	60	137870	23099	17242	18691	19574	17912
12		Experiment 12	17 : MRMM	100	102932	18504	13787	14944	15655	14323
13		Experiment 13	17 : MRMM	100	71696	2333	6993	18644	4668	13966
14		Experiment 14	17 : MRMM	140	160346	5580	16701	44559	11134	33408
15		Experiment 15	17 : MRMM	60	71953	2700	8098	21597	5404	16183
16		Experiment 16	17 : MRMM	60	35267	6880	1141	3439	6868	4580
17		Experiment 17	17 : MRMM	100	153176	31945	5334	15951	31908	21277
18		Experiment 18	17 : MRMM	140	63936	14394	2395	7194	14388	9580
19		Experiment 19	17 : MRMM	100	71769	11187	8347	9033	9461	8655
20		Experiment 20	17 : MRMM	140	71815	12021	8986	9719	10186	9339
21		Experiment 21	17 : MRMM	60	172187	30896	23058	24974	26130	23968
22		Experiment 22	17 : MRMM	60	63800	2067	6225	16583	4148	12469
23		Experiment 23	17 : MRMM	100	35469	1241	3740	9926	2490	7442
24		Experiment 24	17 : MRMM	140	156338	5842	17525	46717	11683	35039
25		Experiment 25	17 : MRMM	140	103031	20120	3348	10047	20107	13393
26		Experiment 26	17 : MRMM	60	54541	11442	1917	5735	11437	7625
27		Experiment 27	17 : MRMM	100	135869	30521	5094	15232	30511	20343

Figure 7.9: The generated responses after simulating computer experiments in Arena®.

7.3 Results and analysis from the designed and executed simulation experiments

7.3.1 Statistical analysis of the conducted experiments

Figure 7.10 displays the Column chart type, which compared the replication values of the response—the produced quantities—for the 21st experiment. Similarly, Figure 7.11 displays a 3D line chart, which compares the average values of a response, i.e. the distributed apparel orders amongst SMEs, across all twenty-seven experiments. The results indicated that the 24th experiment, followed by the 14th experiment for the third manufacturer had the maximum distributed orders.

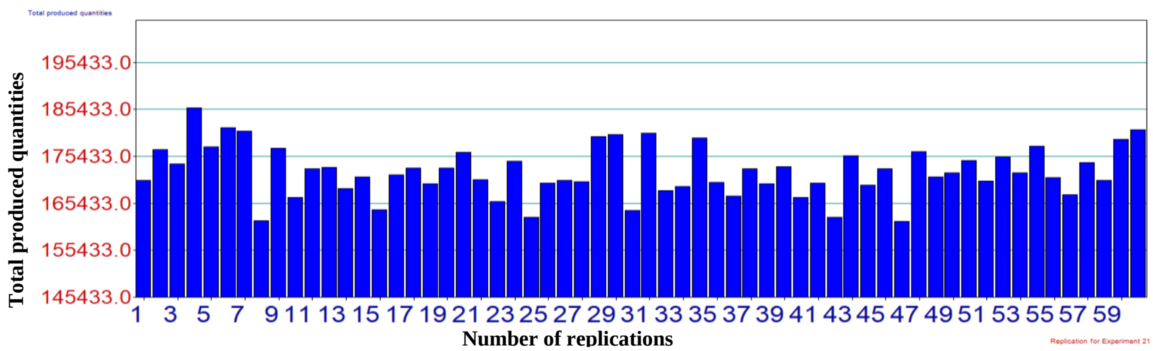


Figure 7.10: Individual experiment chart of the total order quantities processed after setting the experiment.

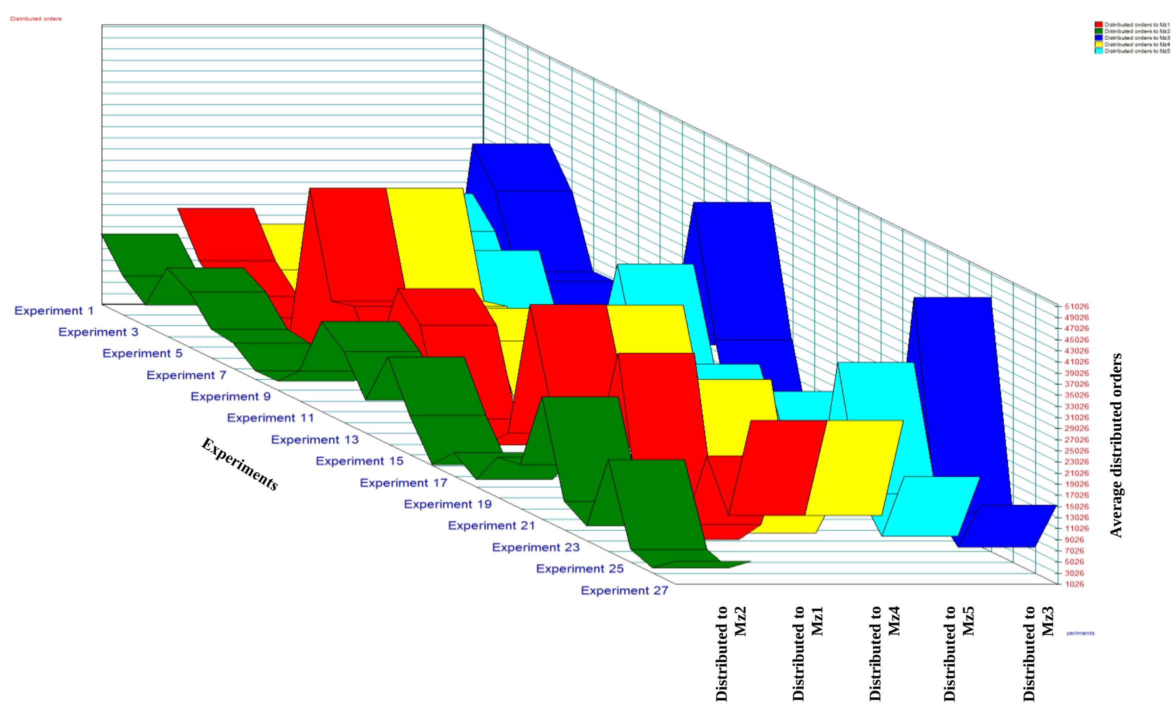


Figure 7.11: The 3D line chart for the conducted simulation experiments.

Figures 7.12 and 7.13 show the values of the produced quantities and the distributed orders, respectively, using Bar charts. For Figure 7.12, identifying the best experiment can be chosen based on the bigger-the-better or the smaller-is-better. Experiment 21 is the best one with over 180,000 items, i.e. using the bigger-is-better category (Figure 7.12).

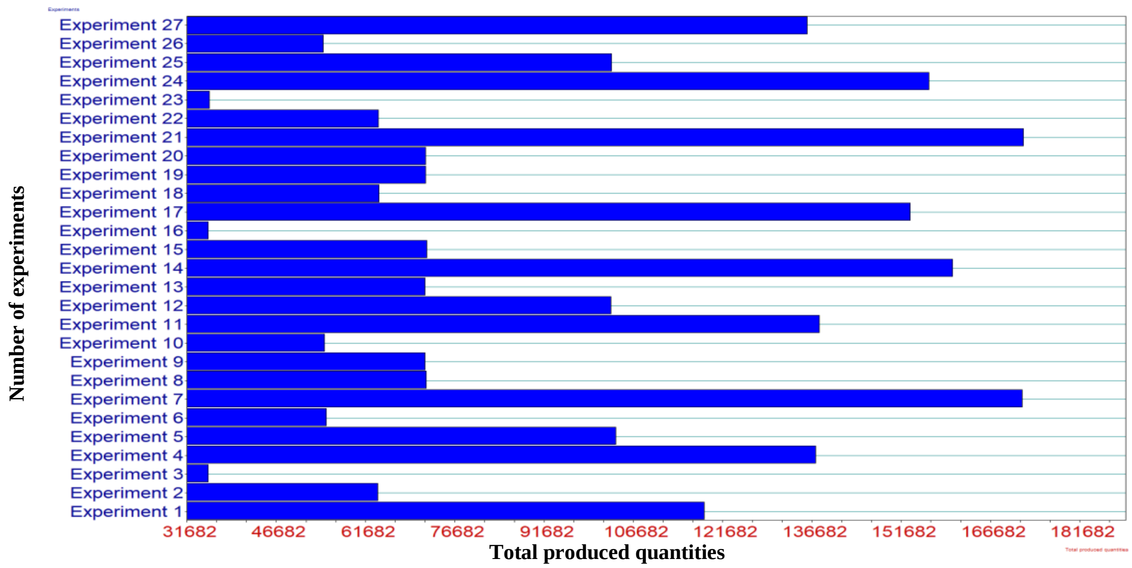


Figure 7.12: A Bar chart displaying multiple comparison results for the produced quantities for all experiments.

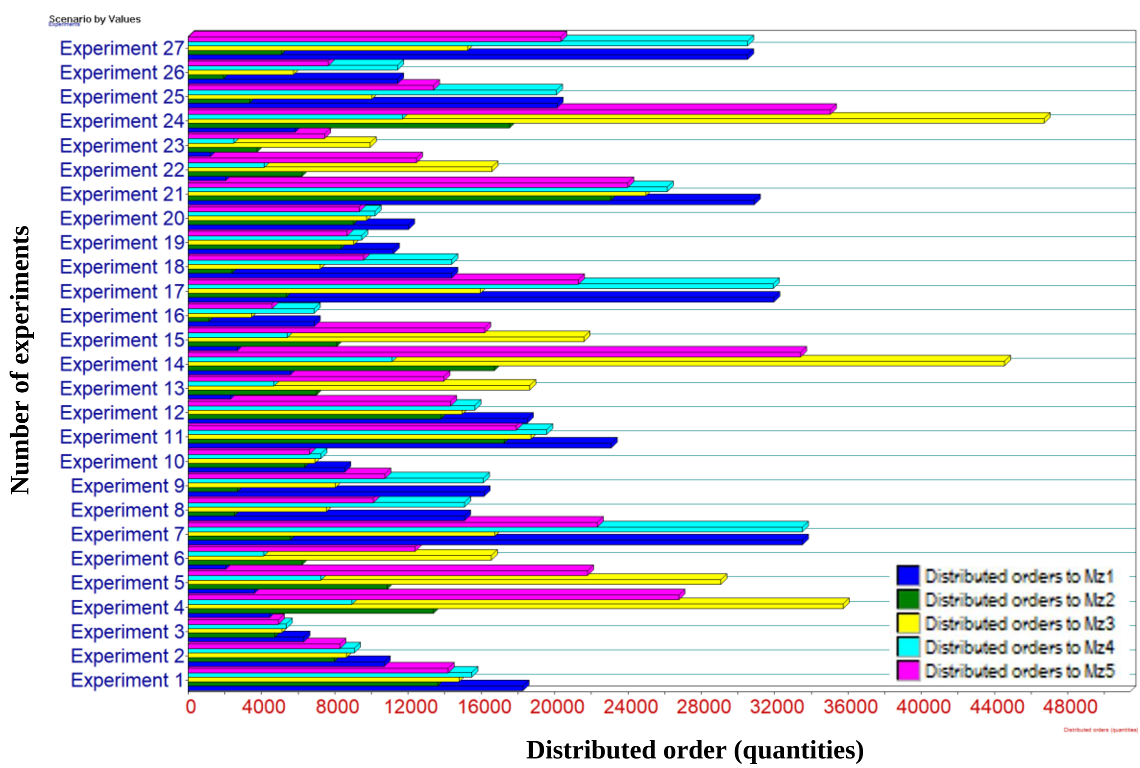


Figure 7.13: A Bar chart displaying multiple comparison results for the distributed quantities for all experiments.

Figure 7.14 displays the 3D line chart's results showing multiple response values of the distributed orders to several SMEs against the considered replications. The displayed results were due to the compared average values of the multiple responses across many controls as applied to the conducted 27 simulation experiments. On average, Mz_1 was allocated more quantities than other manufacturers. The displayed results are for the 21st experiment.

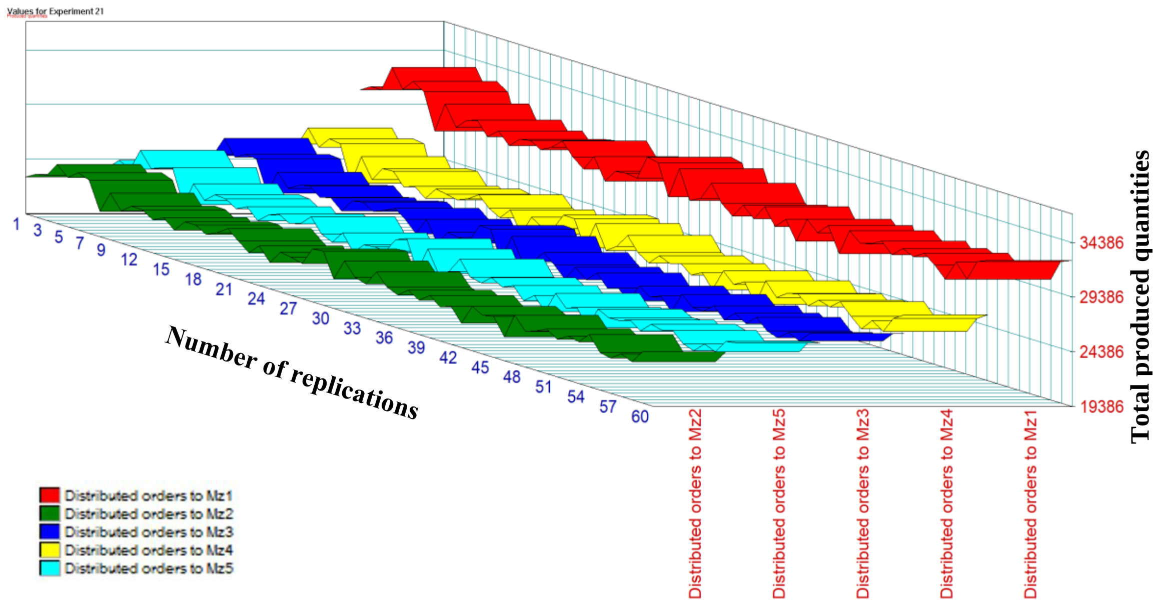


Figure 7.14: The 3D line chart displaying multiple responses values against the number of replications, showing the values for experiment 21.

In the simulation, there should always be differences in the generated responses. Due to that, performing the standard ANOVA tests of the developed differences in means cannot be much meaningful on its own. In statistics, one-way ANOVA is a method that compares means of at least two samples. Among other functions, conducting ANOVA assesses whether enough samples are taken to detect the differences in the means (Rossetti, 2016). Since DACE aimed to execute the feasibility of allocating orders due to multiple parameters and input(s); ANOVA was thus performed to check the data means, interactions between factors and main effects for the entire simulation experiments of the MRMM model.

The main effects plots were generated to analyse how one or more factors influenced the response. For instance, it was interesting to assess the results through ANOVA, specifically on how the considered factors (e.g. *CSPIs* and *EPA*) influenced the total produced order quantities. Figures 7.15 and 7.16 display the main effects plots for the CSPIs ($vPIMz_1$ to *vPIMz*5) and 'Entities Per Arrival' factors (*vEPA_Rd1* to *vEPA_Rd*5), respectively. The main effects can also be assessed for the other factors shown in Figures 7.6 and 7.7. In Figure 7.15, the main effects plots indicate that $vPIMz_1$ (level 3), $vPIMz_2$ (level 3), $vPIMz_3$ (level 1), $vPIMz_4$ (level 2) and $vPIMz_5$ (level 1) are related with the produced quantities. For Figure 7.16, the highest produced quantities were influenced at level 3 for $vEPA\_Rd_1$ to $vEPA\_Rd_5$. This is proportionate to the real scenario, that is, whenever retailers order huge volumes of apparel, that increases the number of the produced quantities.

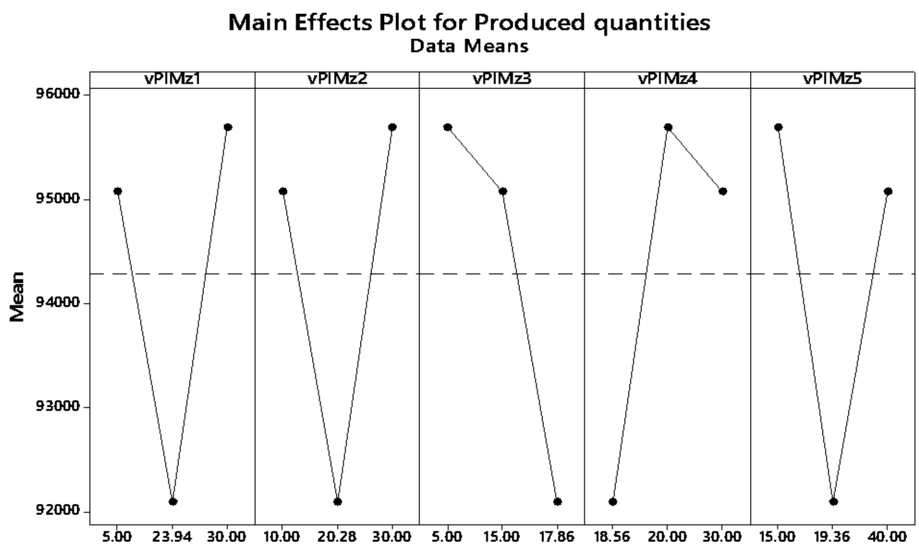


Figure 7.15: The main effects plots of the CSPIs in the total produced order quantities.

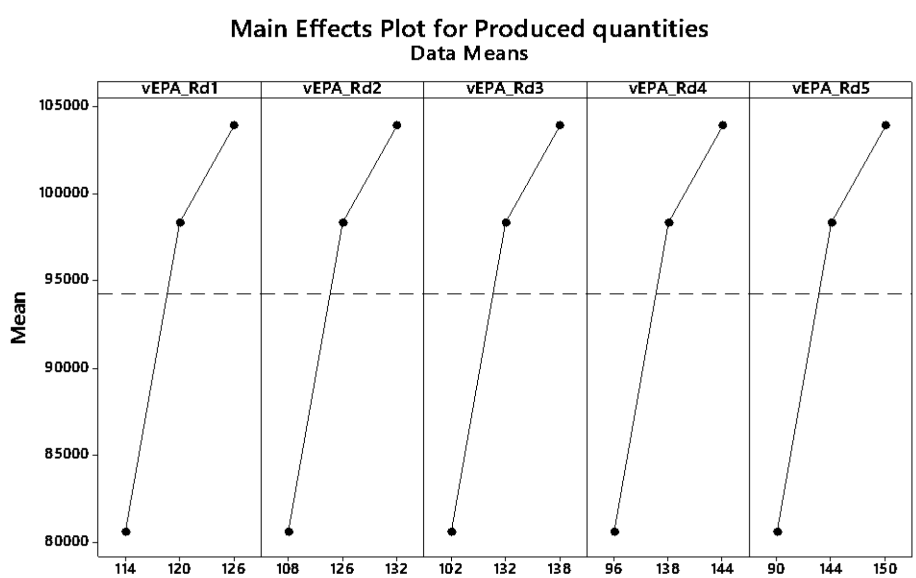


Figure 7.16: The main effects plots of the entities per arrivals from each retailer on the produced quantities.

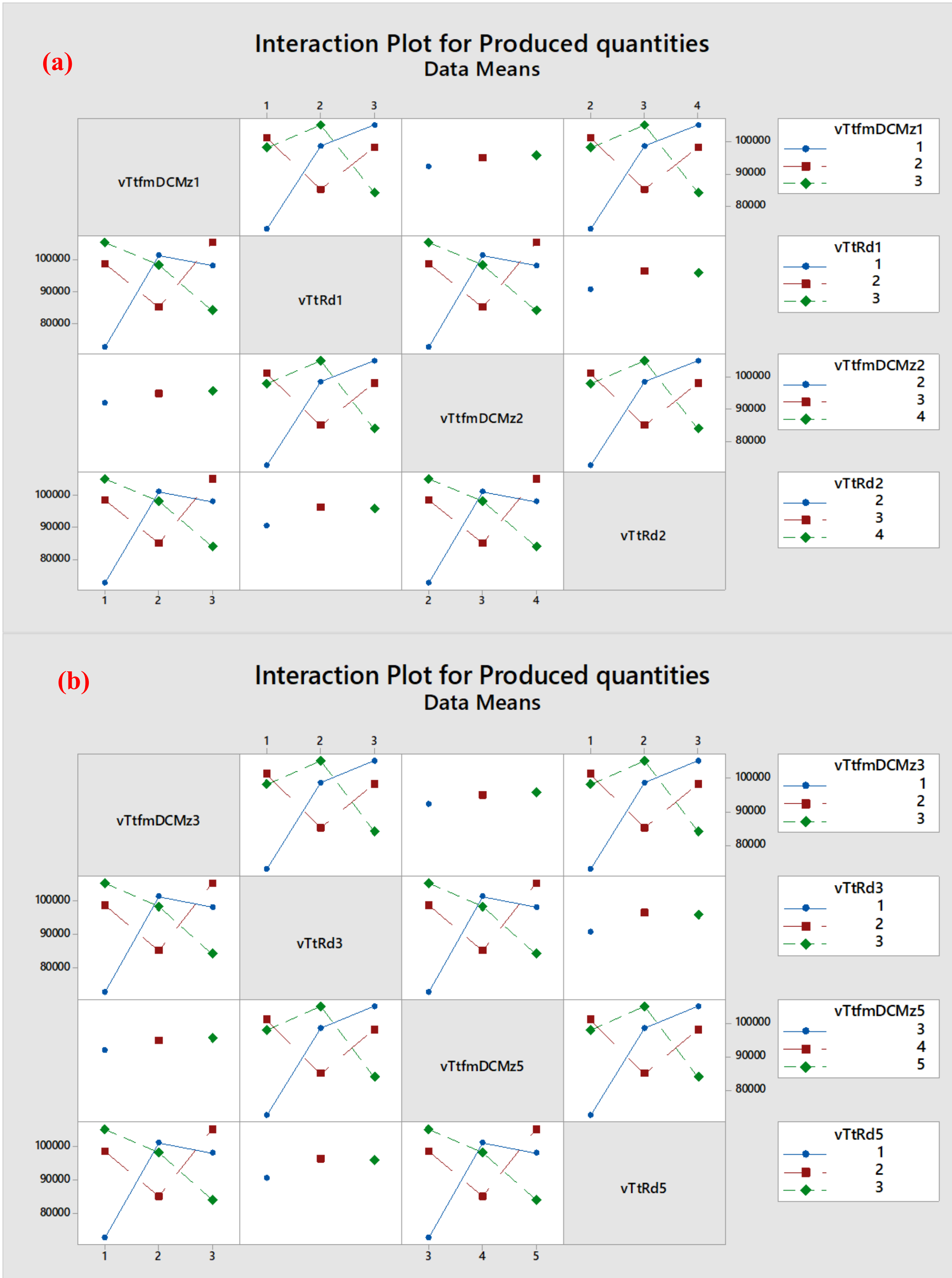
Although Figures 7.15 and 7.16 show the main effects of individual factors, to have a better conclusion, it is imperative to evaluate statistical significance through the ANOVA table. DACE was not performed to choose the most robust factors. For this study, the plots provide data means, and the 'data means' show a general concept concerning the most influential factors and levels. Generally, it is vital to use factorial plots to create the relationships between the response and the used variables in simulation experiments.

Further analysis was achieved through interaction plots to show how the relationship between one factor and the generated response relied on the value of the second control factor. Figure 7.17 shows the interaction plots of the transportation time from manufacturers to DC ($vTtfmDCMz_1$ to $vTtfmDCMz_5$) and the transportation time from DC (distribution centres) to retailers ($vTtRd_1$ to $vTtRd_5$) in relation to the produced apparel quantities. The produced apparel quantities were recorded after being dispatched to specific retailers.

Figure 7.18 shows means for the levels of CSPI factors ($vPIMz_1$ to $vPIMz_5$) and a separate line for each level of EPA ($vEPA\_Rd_1$ to $vEPA\_Rd_5$) factors. Figure 7.19, likewise, shows an interaction plot of the produced entities (throughput) with the entities per arrivals (first retailer) and maximum arrivals (first retailer), for the fourth and fifth manufacturers.

Therefore, through Figures 7.17 to 7.20, it is possible to assess the drawn lines to understand how the interactions affect the relationship between the controlled factors and the particular response. If there are parallel lines in Figures 7.17 to 7.20, that means there is no interaction between the specific factors and the response. On the contrary, for all non-parallel lines, this displays interactions. Since there are more non-parallel lines in Figures 7.17 to 7.20, it proves the greater strength of interactions between the distributed orders to manufacturers and the CSPIs and entities per arrivals from retailers.

Generally, the majority of the factors interact at each level. The factors description is in Table 7.2 and Figure 7.3. To further conclude whether the control factors are significant, this thus requires conducting suitable ANOVA tests and assessing the statistical significance (Section 7.6). For this study, Figures 7.17 to 7.20 aimed at showing the effects.



Note(s): (a) the transportation time from manufacturers (vTtfmDCMz1 and vTtfmDCMz2) against the transportation time from DC to retailers (vTtRd1 and vTtRd2); (b) the transportation time from manufacturers (vTtfmDCMz3 and vTtfmDCMz5) against the transportation time from DC to retailers (vTtRd3 and vTtRd5).

Figure 7.17: The interaction plots of the produced apparel quantities.

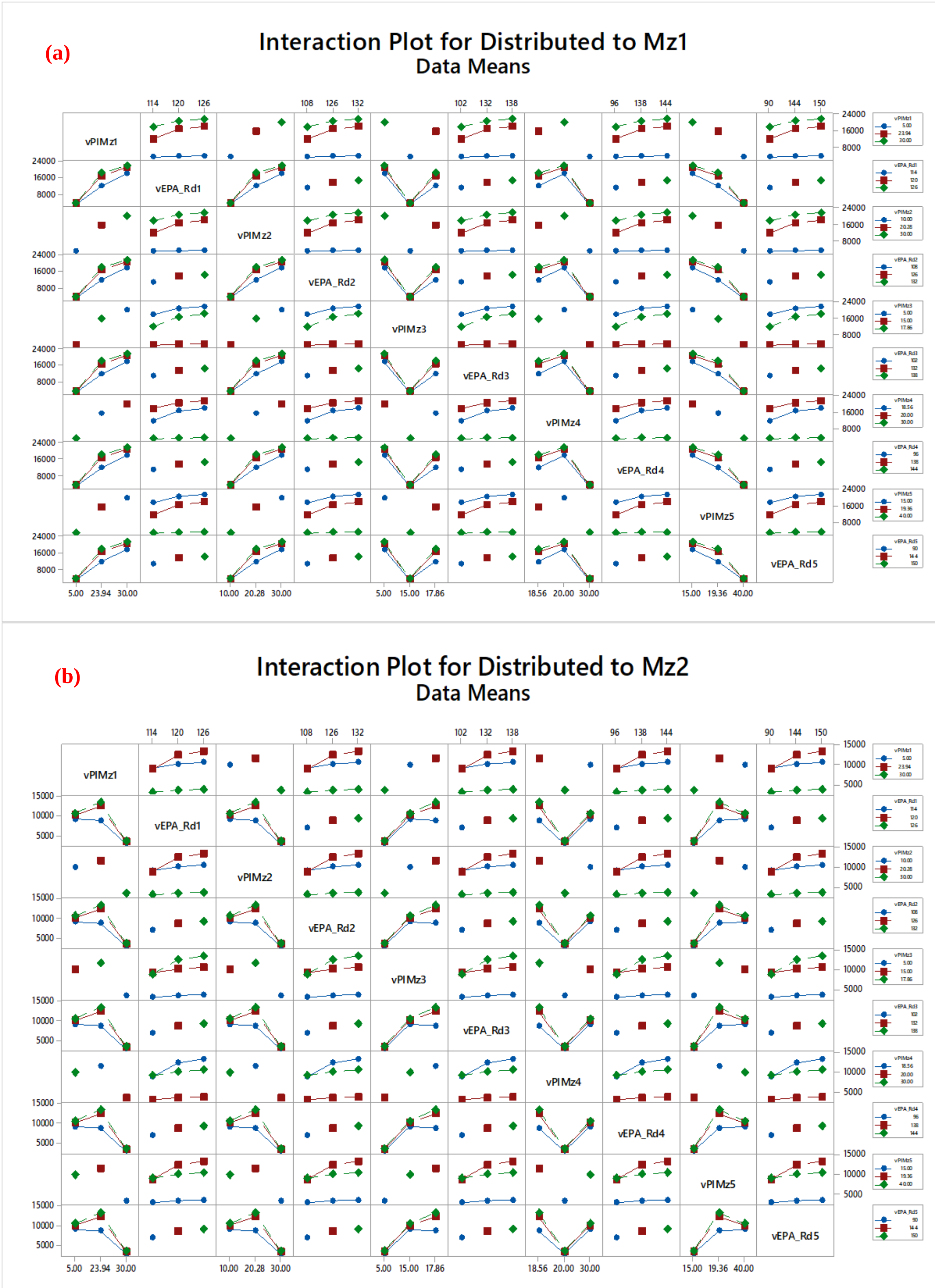


Figure 7.18: The interaction plots of (*a*) the distributed entities to the first manufacturer and (*b*) the second manufacturer against the entities per arrivals and the CSPI factors from each retailer.

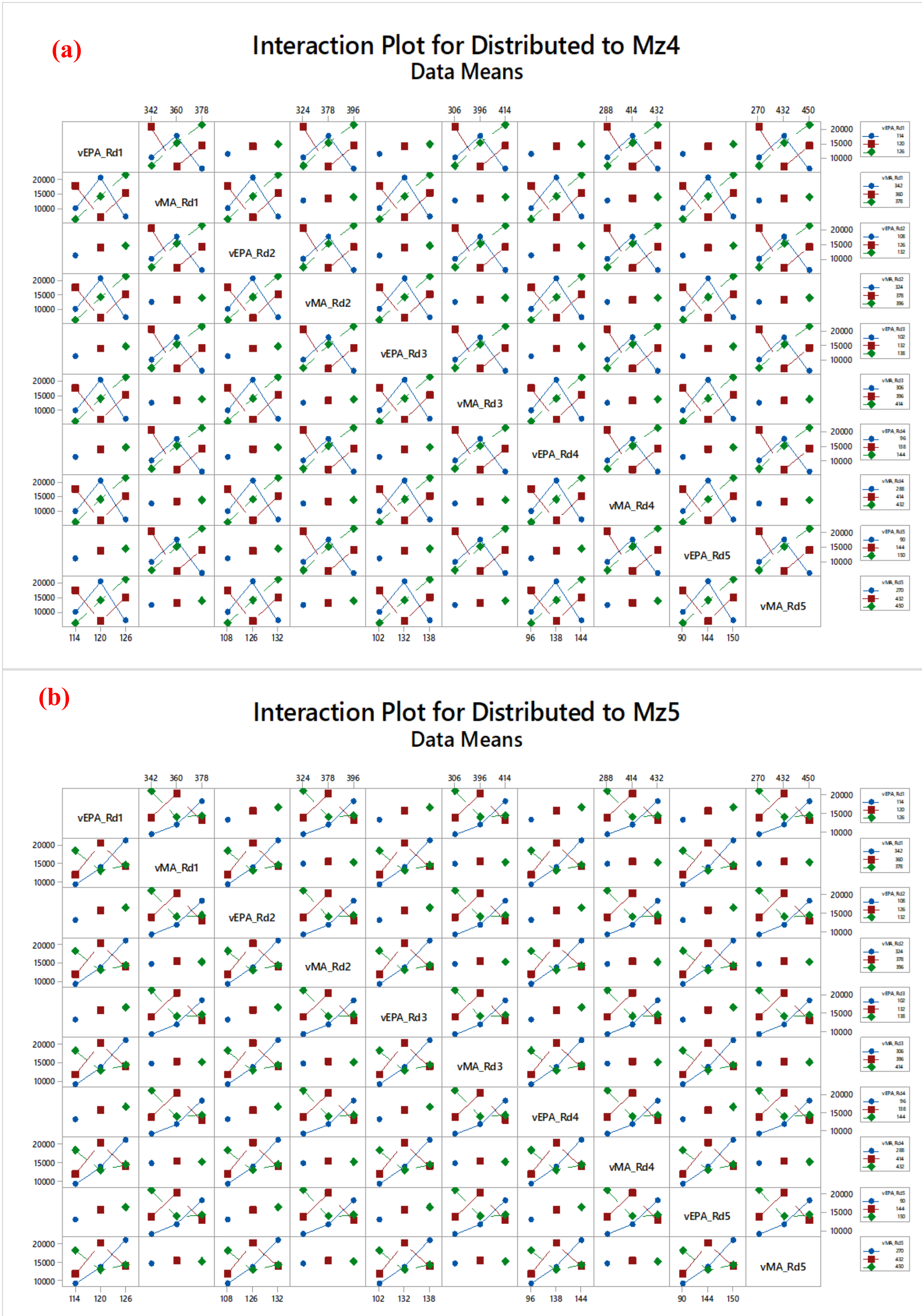


Figure 7.19: The interaction plots of the distributed entities to the (*a*) fourth and (*b*) the fifth manufacturers against the EPA and the maximum arrival factors from each retailer.

Figure 7.20 displays an interaction plot of the produced entities (throughput) with the entities per arrivals (first retailer), maximum arrivals (first retailer), order acceptance rate and the CSPI factors for the first SME. All the four controllable factors proved to have greater strength of the interaction because there are more non-parallel lines in Figure 7.20.

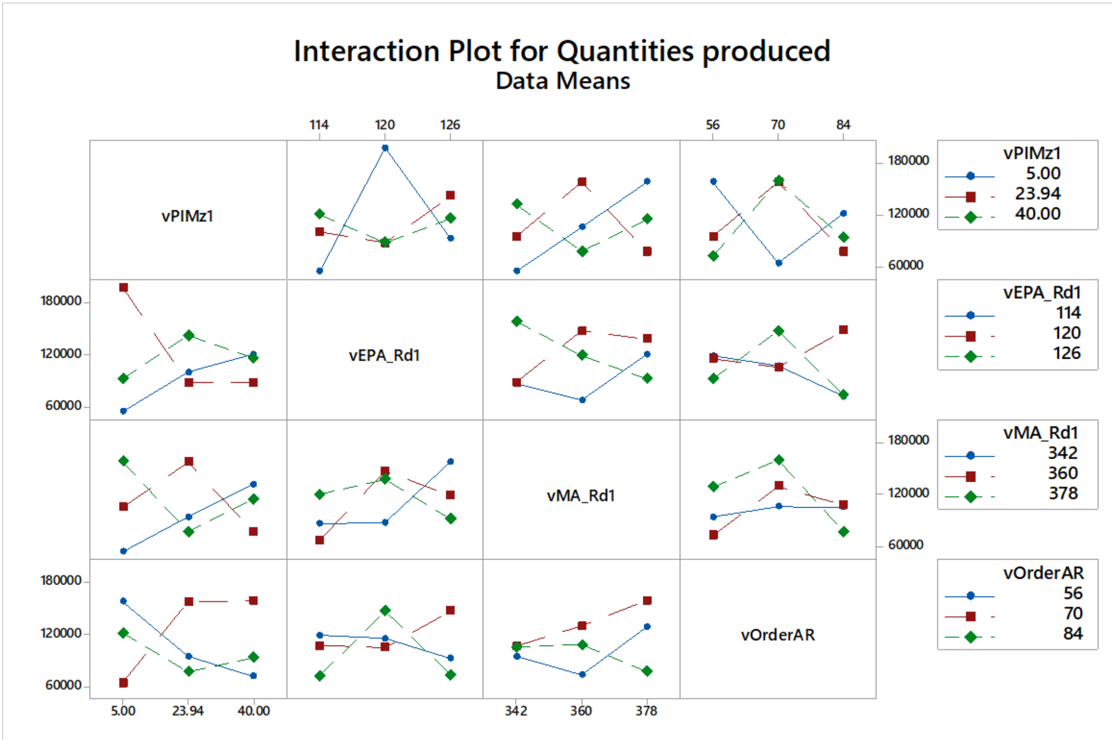


Figure 7.20: The interaction plot of the produced entities (throughput) with the entities per arrivals (first retailer), maximum arrivals (first retailer), order acceptance rate and the CSPI factors for the first SME.

Further analyses were performed through a One-Way ANOVA for several factors in determining the data means differences of factors and response, i.e. the produced entities (throughput). Figures 7.21 and 7.22 illustrate the One-Way ANOVA generated interval plot, boxplot, an individual value plot and residual plots, of the produced quantities against the mean order interarrival time (*vMOIT)* and the sequencing time (*vSeq_time*), respectively. In the plots of Figure 7.21 (a)-(c), the lowest mean for *vMOIT* is at level 3, while the highest is at level 1. Similarly, from Figure 7.22 (a)-(c), the lowest mean for *vSeq_time* is at level 1, while the highest is at level 3. From all plots in Figures 7.21 and 7.22, it is not easy to determine whether any differences are statistically significant: establishing the statistical significance thus requires assessing the confidence intervals for the differences of means. Section 7.6 discusses hypotheses testing.

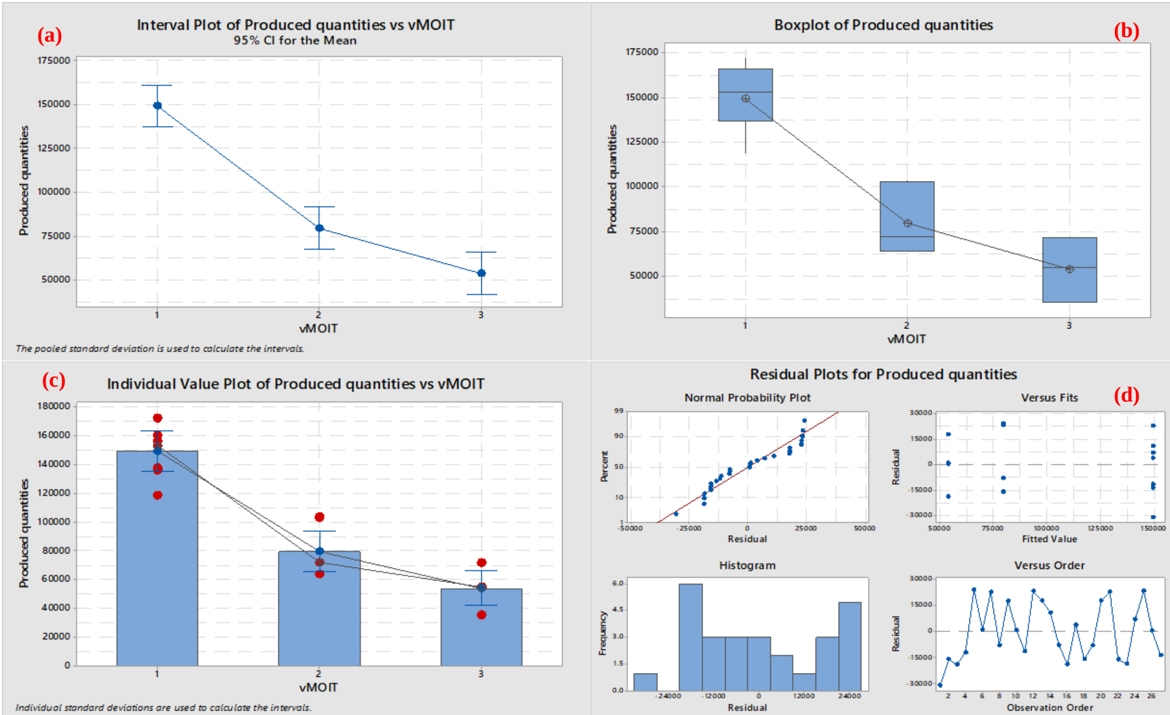


Figure 7.21: The One-Way ANOVA generated (a) an interval plot, (b) the boxplot, (c) an individual value plot and (d) residual plots of the produced quantities against the mean order interarrival time factors (*vMOIT*).

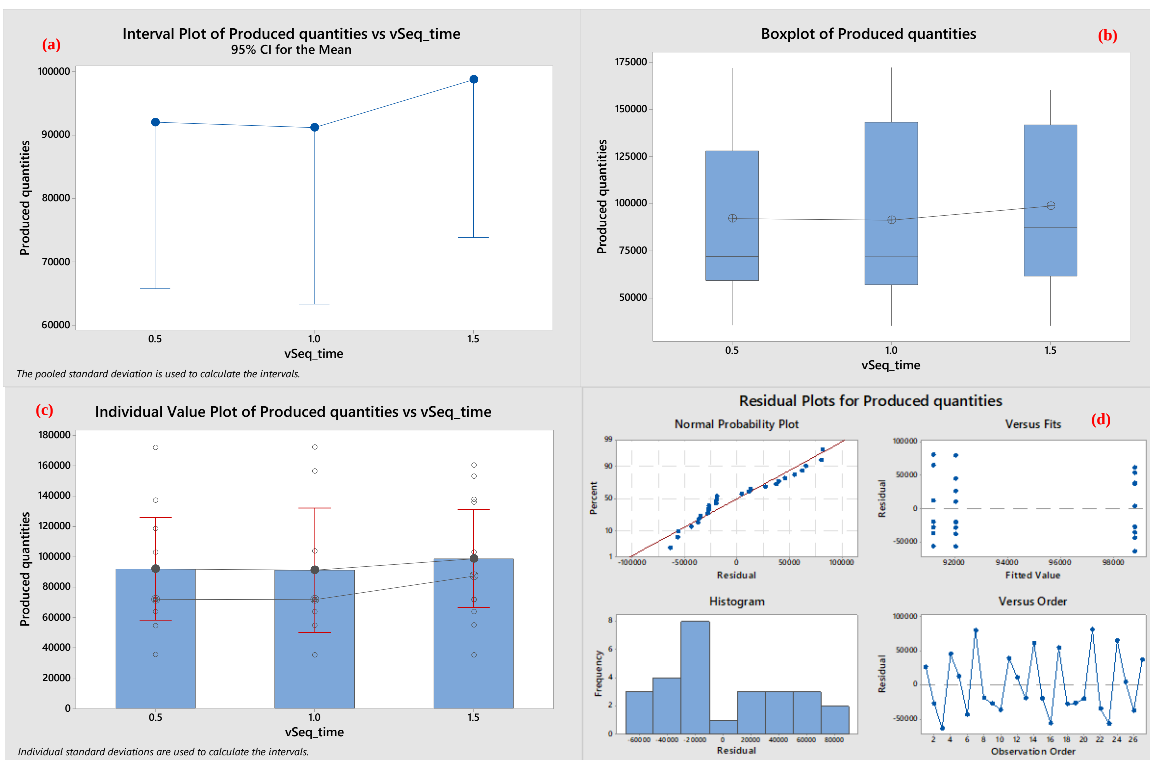


Figure 7.22: The One-Way ANOVA generated (a) an interval plot, (b) the boxplot, (c) an individual value plot and (d) residual plots of the produced quantities against the sequencing time to assign the processing time for each process time factors (*vSeq_time*).

7.3.2 Response surface and metamodels of the simulation experiments

Further evaluations for the conducted experiments (Figures 7.6 to 7.8) were performed using the response surface and metamodels. Response surface plots considered contour and surface plots only. For the response surface, simulation is considered as a function. The developed system (Figures 6.32 to 6.34) has inputs and outputs. The system has parameters which are easy and not easy to control, and it has noise as well. To generate the outputs for a particular scenario or an experiment, the system is assumed to be a function. Ideally, the function is an algebraic model of the simulation model. It is often referred to as a metamodel.

Equation 7.1 illustrates a simple linear model as a straight-line equation with one input. R represents the dependent variables (outputs or response); β_0 represents the intercept; β_1 is the coefficient (slope); and ε is the error or disturbance term. Some of the assumptions for the simple linear regression model include the mean of each error term is zero; the errors are independent of each other; each random variable (error term) follows an approximately normal distribution; the variance of the error term, δ_{ε}^{2}, is the same for each value of D *(factors)* (Kvanli *et al.*, 1996). It is also possible to establish the interrelationship between two or more responses, or dependent and independent variables.

$$R = \beta_0 + \beta_1 D + \varepsilon \qquad (7.1)$$

The dependent variables can be categorical or continuous variables. The *continuous variables* have an infinite number of values between any two values. Such variables can be time, date or numeric. Examples of the continuous variables include the time payment at which apparel order is received, length of the date since the day of completing preliminary procedures for manufacturing apparel, the weight of the fabric used in the textile industry, the distance between industries (from the concept of geographical proximity), time for order completion, etc. For *categorical variables*, these are the finite number of distinct groups or categories. These variables include apparel material type, payment method for the received clothes, among others. Similarly, *discrete variables* are numeric variables whose values are generated by counting. Examples of these variables comprise the number of complaints from retailers, the number of apparel defects, the number of collaborating partners, etc.

Experiments in this study included an analysis of the effects of more than two factors (Figures 7.6 to 7.8). This required performing the factorial design. The effects of the considered factors (Figure 7.3) influence the change in the response generated by a change in the level of each factor (Table 7.2). So, this usually is termed as the 'main effect' because it is the fundamental factor of interest in the particular experiment (Montgomery, 2013). If the considered factors are quantitative, thus, the multiple linear regression model showing the possible interaction can be generally illustrated by equation 7.2 (Figure 7.1). Equation 7.2 computes the estimated response values while the original simulated experiments before applying DACE are the observed response values.

$$R = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_2 D_1 D_2 + \cdots + \beta_n D_n D_n + \varepsilon \qquad (7.2)$$

Whereby *R* represents dependent variables, response, measured variable, regressed variable, criterion variable and observation: outputs; β_0 represents an intercept while the βs are the coefficients of the regression model; D_1 and D_2 are explanatory or independent factors coefficients which are not inputs; $D_1 D_2$ shows the interaction between D_1 and D_2, and ε is the error term, random error, or disturbance term. Some of the assumptions for the multiple linear regression model include: errors are (statistically) independent; and errors follow a normal distribution, centred at zero, with common variance, δ_ε^2 (Kvanli *et al.*, 1996).

So, due to the study's nature and aim, equations 7.1 and 7.2 were not applied to execute the feasibility of order allocation because the equations are for the *linear regression model*. Equations 7.1 and 7.2 can be applied when modelling the response as a linear combination of the control factors with some random elements. The regression model can be performed by simulating for a specific replication length with all the controllable factors set and uncontrollable factors modelled for a given order size as an input. The coefficients could be generated from the linear regression. Then, based on a certain order size subject to the given control factors, the linear regression could assist in predicting the distribution of order sizes to a cluster of manufacturers. But this is not in line with the research objective of this study.

In this study, the *function* is unknown in the conducted experiments. DACE considered the computer simulation model as a *black box* (Figure 7.23) as opposed to a *white-box* approach:

only the outputs and inputs are studied and analysed. In computer simulation view, a "black-box view of a simulation model observes the inputs and outputs of [a] simulation model, but not the internal variables and specific functions implied by the simulation's computer modules" (Kleijnen, 2015, p.24). Equation 7.3 shows the general concept (Kleijnen, 2015).

$$R = f(\beta_n, r_0) + \varepsilon \tag{7.3}$$

where $f(.)$ means the mathematical transfer function completely specified by the simulation package, which comprises inputs β_n, output R, and pseudorandom number seed r_0.

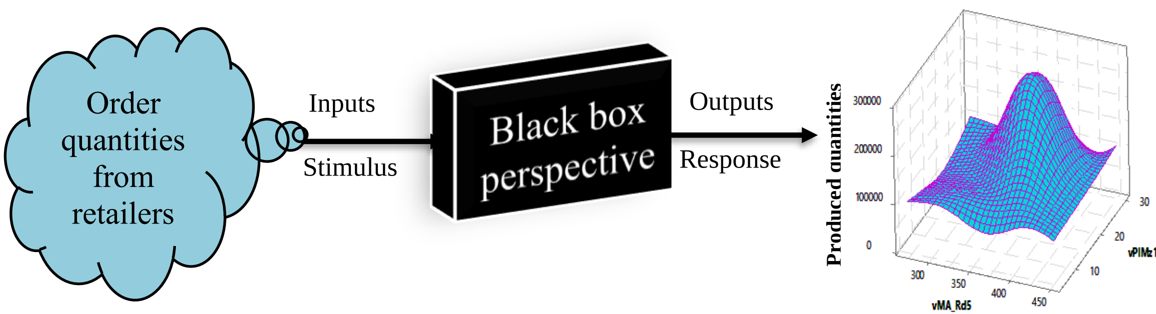


Figure 7.23: The overall illustration of a black box concept through DACE.

The response surface was created that relates to the amount of each of the design parameters. In Figures 7.24 to 7.27, the generated data were used to approximate the response surface function, $f(.)$: showing the direction and magnitude of the responses. Development of such plots helps to know the required change for some parameters to generate optimal responses. The predicted responses for the DACE included the distributed orders to each manufacturer and the produced order quantities at the end of the simulation run. The assessment assists in studying the behaviour of the response surface, especially when changing some inputs and parameters slightly without rerunning the actual simulation program.

Figure 7.24 shows the surface plots, which assessed the relationships between the response (produced order quantities) against orders per arrival and the maximum order arrival. Figure 7.24(a)-(f) shows how the increase in *EPA* and *MA* influenced the surging of the produced quantities. Considering that the surface plot mainly illustrates the magnitude and direction, thus, from Figure 7.24(a)-(f), all factors are proportional to the generated response meaning that the increase of any of the factors can increase the magnitude of the response.

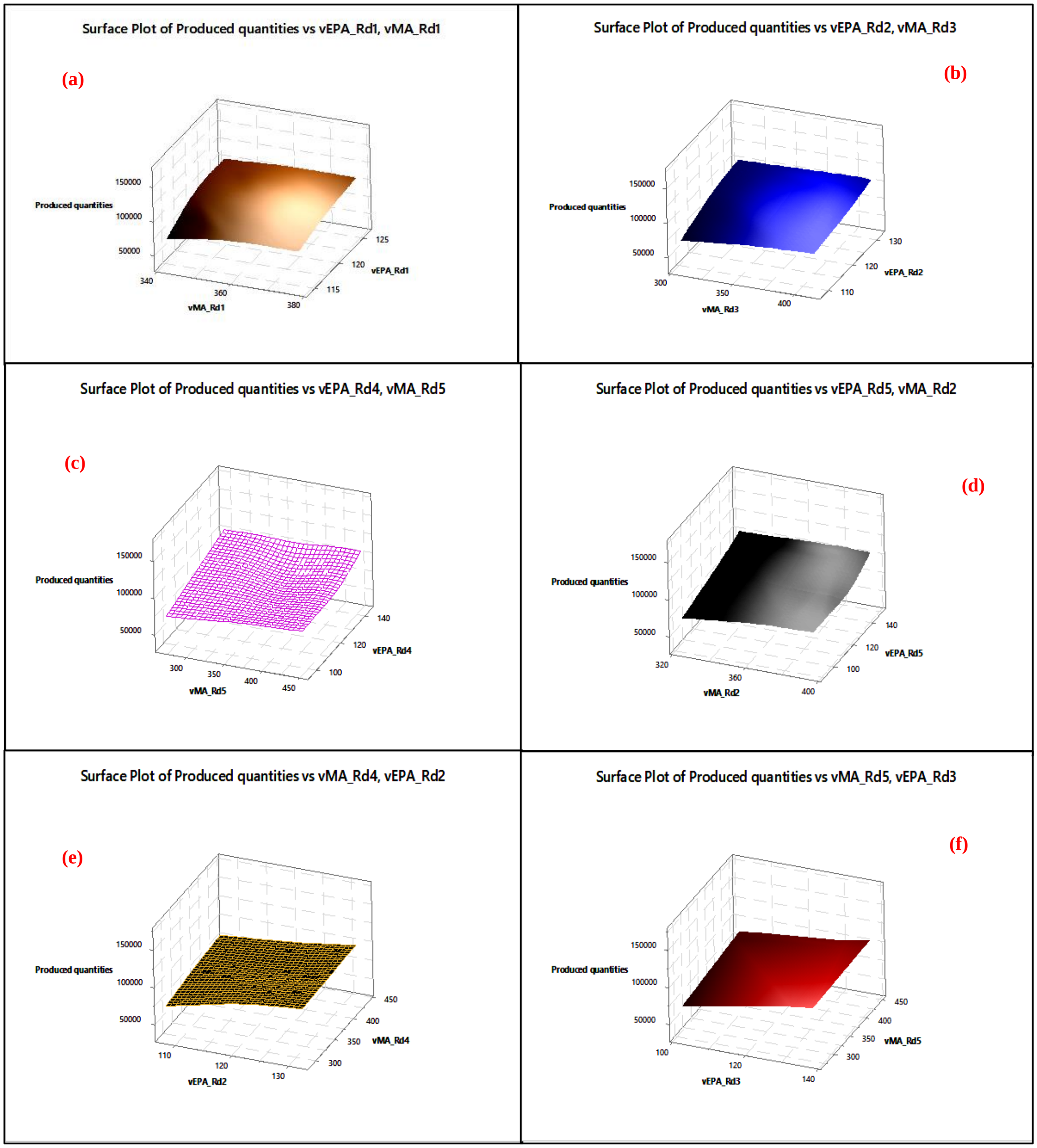


Figure 7.24: The 3D surface plots which assessed the relationships between the response against orders per arrival and the maximum order arrival.

Figure 7.25(a)-(f) illustrates the 3D surface plots, which examined the relationship between the response variable (*Z-axis*) and two predictor variables (*X and Y-axis*) by viewing a 3D surface of the predicted response. To demonstrate this, the surface plot was generated for the distributed order quantities, as the response, against the order acceptance rate (*vOrderAR*) and the mean order interval time (*vMOIT*). The variables, *vOrderAR* and *vMOIT*, indicate the direct and inversely proportional relationship between the distributed quantities for each manufacturer with these variables, respectively. For example, the short mean order interval time increases the distributed orders positively.

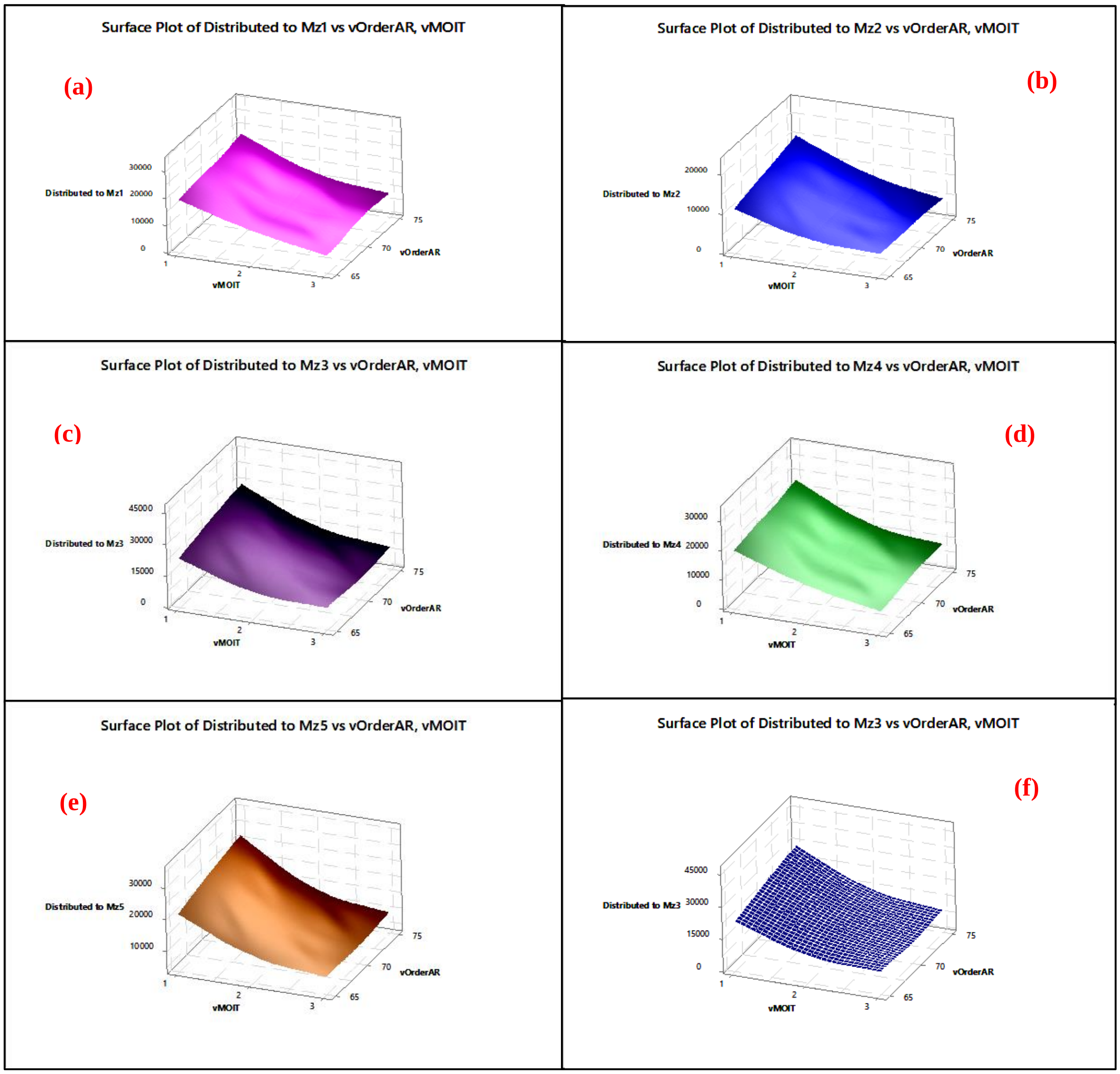


Figure 7.25: The 3D surface plots which assess the relationships between the response (*distributed order quantities*) against *vMOIT* and *vOrderAR* variables.

Figure 7.26(a)-(f) shows the surface plots which assessed the relationships between the response against CSPIs—$vPIMz_1$ to $vPIMz_5$—and the maximum order arrival (*MA*). Figure 7.27 shows the contour plots which examined the relationship between the response variable (*Z-axis*) and two predictor variables (*X and Y-axis*) by viewing discrete contours of the predicted response. Contrary to the 3D surface plots, the response values in the contour plots are displayed in the 2D plane. All variables in Figure 7.27 indicate positive relationships.

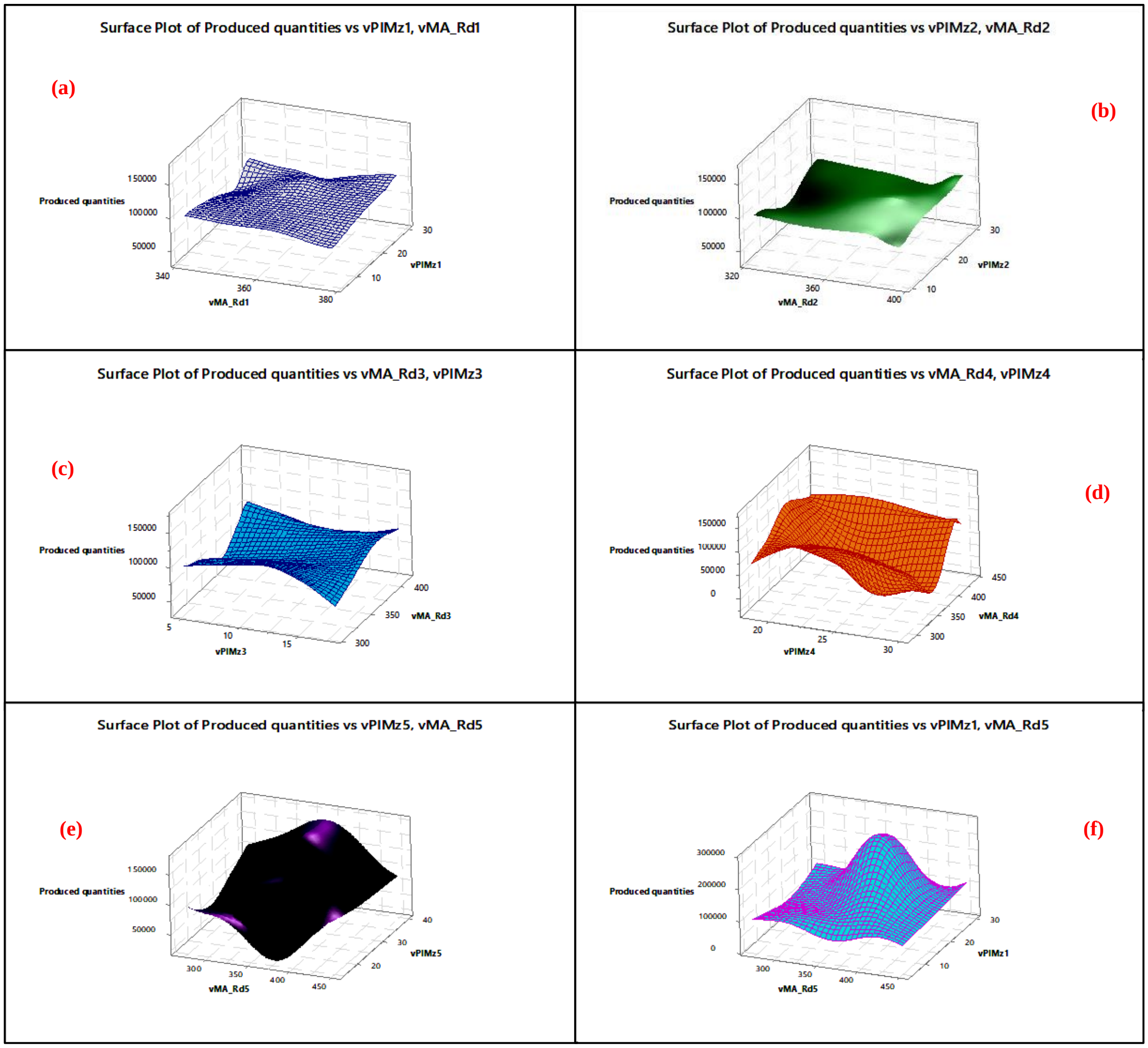
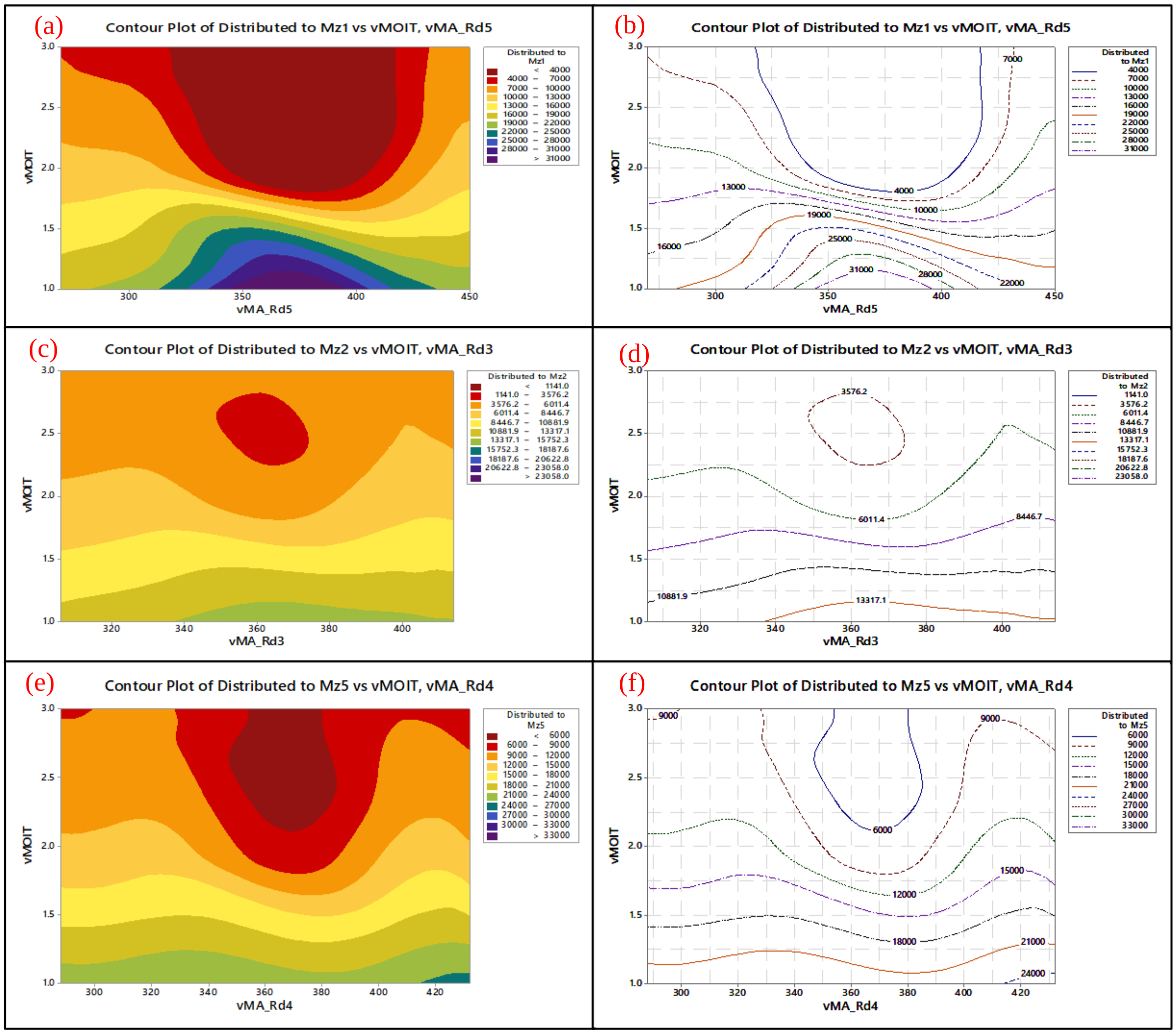


Figure 7.26: The 3D surface plots which assessed the relationships between the response (*produced order quantities*) against *vMA_Rd*$_{1\text{-}5}$ and *vPIMz*$_{1\text{-}5}$.

Generally, the response surface modelling is a key benefit of having developed a simulation model like the one in Figures 6.32 to 6.34. Because by giving such a system to a group of companies, they would want a big simulation system. Companies could work according to the proposed system for an order size of, e.g. 50,000. The companies would want to know the time it would take for them to process the order sizes subject to some parameters. Subsequently, by assigning the order size as an input, the system should assist in generating results, including the distributed orders corresponding to the number of firms. As a result, this could be a transfer function for the companies. The input parameters need to be the volume of the order and the available capacity together with other parameters to the manufacturers. Because then, such parameters would relate to all illustrated parameters in Figure 7.1. Availability of the response function for allocating orders assists manufacturers from not rerunning many simulations. The model should be able to perform the allocation based on the available parameters. Therefore, this is a potential future work (Section 10.4).



Note(s): (a), (c) and (e) display areas while (b), (d) and (f) display the contour lines of the contour plots.
Figure 7.27: The contour plots which assessed the relationships between the distributed order quantities against the mean order interval time and maximum order arrival.

7.4 Testing the model feasibility of executing the order allocation processes

Additionally, Section 7.4 demonstrates order variation through DACE. This also tests the model's feasibility of executing bulk order sizes. That is, given multiple orders and multiple scenarios, the MRMM model, should provide a feasible solution or indicate whether it is not possible to fulfil orders. To perform this, the received order size from the first retailer (Rd_1) was initially considered to execute the baseline results because this was the actual data. To test the possibility of the MRMM model executing any order size, three scenarios were defined (Table 7.4). Since each manufacturer cannot process orders to infinity, the maximum order arrivals (*MA*) had to be set with reference to the first retailer's (Rd_1) order size. The order size is actual data gathered from Rd_1 as it always orders from Mz_1.

Table 7.4: Testing the feasibility of executing any order size.

Description of the variables to test the feasibility of executing any order size	Initial average order size per year (A)	The base level for order size	Percentage of change	Altered first average order size per year (B)	First change	Altered second average order size per year (C)	Second change
EPA received from Rd_1	43,200	POIS (120)	± 5%	41,040	POIS (114)	45,520	POIS (126)
EPA received from Rd_2	45,520	POIS (126)	± 10%	38,880	POIS (108)	47,520	POIS (132)
EPA received from Rd_3	47,520	POIS (132)	± 15%	36,720	POIS (102)	49680	POIS (138)
EPA received from Rd_4	49680	POIS (138)	± 20%	34,560	POIS (96)	51840	POIS (144)
EPA received from Rd_5	51840	POIS (144)	± 25%	32,400	POIS (90)	54,000	POIS (150)
MA from Rd_1	129,600	POIS (360)	± 5%	123,120	POIS (342)	136,080	POIS (378)
MA from Rd_2	136,080	POIS (378)	± 10%	116,640	POIS (324)	142,560	POIS (396)
MA from Rd_3	142,560	POIS (396)	± 15%	110,160	POIS (306)	149,040	POIS (414)
MA from Rd_4	149,040	POIS (414)	± 20%	103,680	POIS (288)	152,820	POIS (432)
MA from Rd_5	152,820	POIS (432)	± 25%	97,200	POIS (270)	162,000	POIS (450)

Apart from setting the data presented in Table 7.4, testing the possibility of executing several order sizes can be set using data in Table 7.5. The given information in Table 7.5 must be quantified in proportion or numerals so that to be executed in the Arena® software. For example, *smallest* can be equated to 5% of the required order size; *small* (15%), *medium* (20%), *large* (25%), and *largest* can be equated to 35% of the required order size. These percentages can then be entered into Arena® to evaluate the possibility of allocating apparel entities successfully.

Table 7.5: Options for testing the possibility of executing any order size.

Manufacturer	**Scenario 1**	**Scenario 2**	**Scenario 3**
Mz_1	Smallest	Largest	Medium
Mz_2	Small	Large	Largest
Mz_3	Medium	Medium	Small
Mz_4	Large	Small	Smallest
Mz_5	Largest	Smallest	Large

Figures 7.28 to 7.30 indicate three levels of order distribution for the five SMEs working collaboratively. The three levels tested for include when the received orders and the maximum orders are in low (*base level*), medium (*first change*) and high (*second change*) levels. Figures 7.28 to 7.30 aim to show the feasibility of allocating (distributing) across several SMEs. Since these results are the order quantities, this thus requires rounding to the nearest integer numbers; for example, the average order size for the output 'Distributed to Mz_1' should be rounded to 33,665 items (Figure 7.28).

Output	Average	Half Width	Minimum Average	Maximum Average
Distributed to Mz1	33665.17	200.30	32043.00	35175.00
Distributed to Mz2	25099.39	155.13	23581.00	26260.00
Distributed to Mz3	27226.07	160.77	25670.00	28542.00
Distributed to Mz4	28523.12	164.28	26872.00	29934.00
Distributed to Mz5	26132.36	151.22	24714.00	27464.00

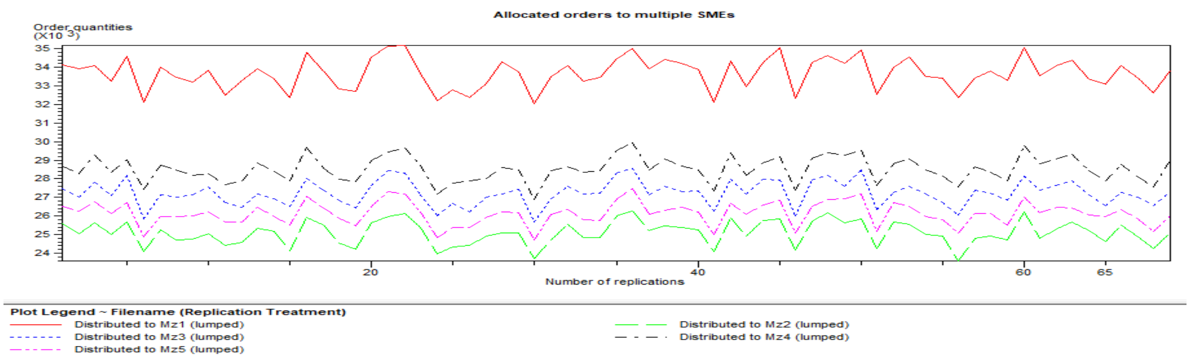


Figure 7.28: Plot showing the distributed orders from the initial (base level) average order sizes. Mz_1 to Mz_5 are the five manufacturers (SMEs).

Output	Average	Half Width	Minimum Average	Maximum Average
Distributed to Mz1	4114.39	24.63	3904.00	4371.00
Distributed to Mz2	12345.32	60.81	11650.00	12891.00
Distributed to Mz3	32904.62	152.67	31341.00	34194.00
Distributed to Mz4	8223.20	45.68	7638.00	8599.00
Distributed to Mz5	24660.14	107.92	23482.00	25538.00

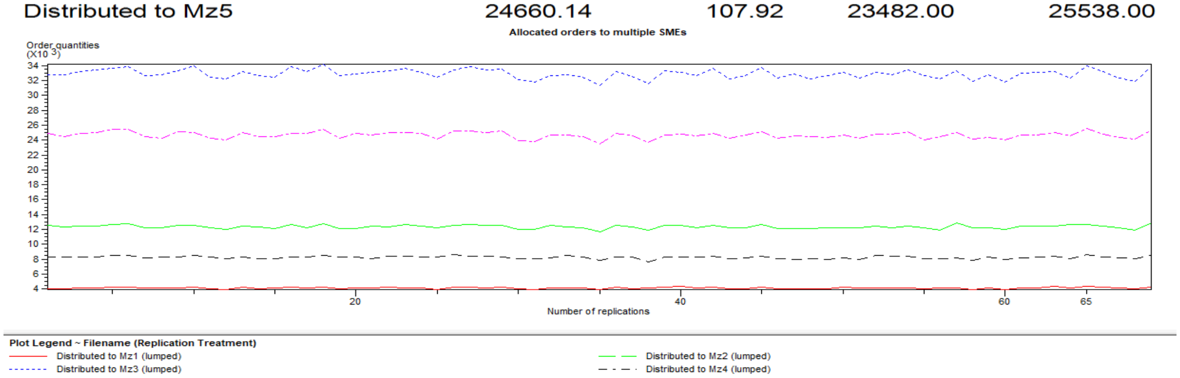


Figure 7.29: Plot showing the order distribution from the first altered average order sizes. Mz_1 to Mz_5 are the five manufacturers (SMEs).

Output	Average	Half Width	Minimum Average	Maximum Average
Distributed to Mz1	60358.80	315.23	56169.00	63739.00
Distributed to Mz2	7543.52	46.24	7010.00	8039.00
Distributed to Mz3	22622.72	130.23	21029.00	24009.00
Distributed to Mz4	45242.00	247.83	41971.00	48206.00
Distributed to Mz5	15080.46	83.15	13809.00	15877.00

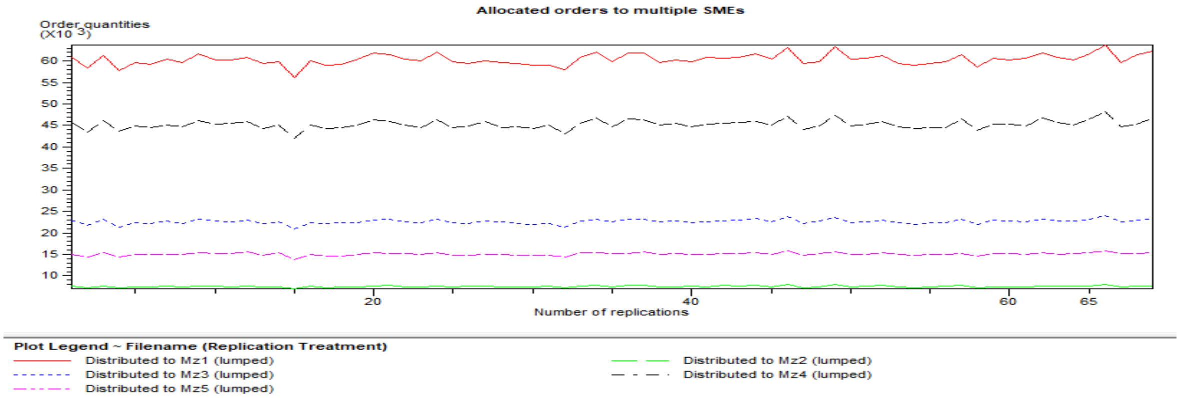
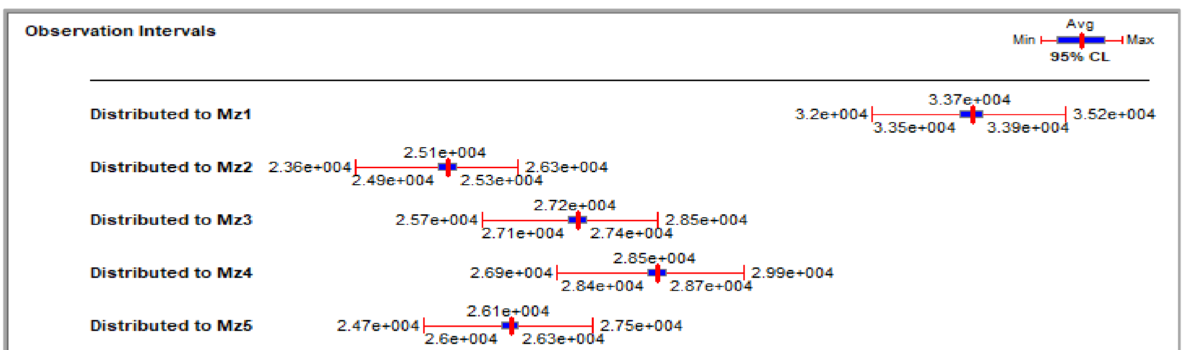


Figure 7.30: Plot showing the order distribution from the second altered average order sizes. Mz_1 to Mz_5 are the five manufacturers (SMEs).

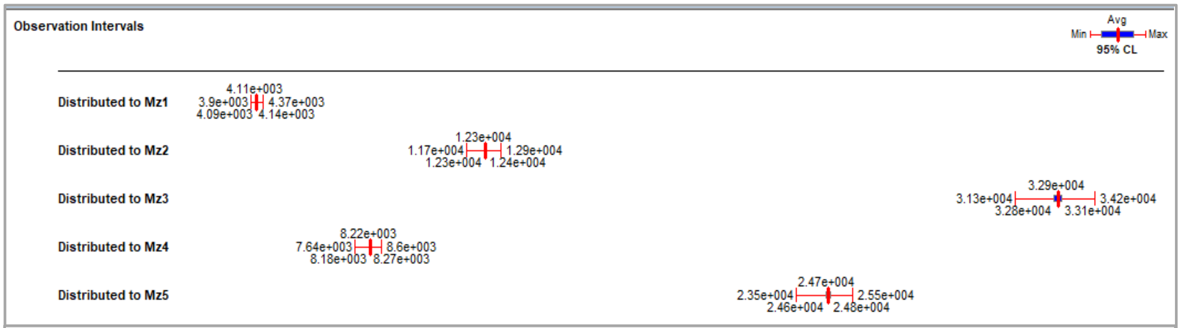
Figures 7.31 to 7.33 show the Classical Confidence Interval on Mean (CCIM) which includes an average, half-width, STD, minimum and maximum values. The Arena® *Output Analyser* tool generated the results through the inputs from Table 7.4. The confidence coefficient was set to 0.95, resulting in 95% confidence intervals. Three levels—low, medium, and high—were considered for the classical CI on mean graphical displays. Figure 7.31 indicates that the distributed orders for Mz_1 are not aligned with the distributed orders to Mz_2 to Mz_5. For Figure 7.32, the observed intervals are not aligned similar to Figure 7.33.



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Distributed to Mz1	3.37e+004	828	199	3.2e+004	3.52e+004	69
Distributed to Mz2	2.51e+004	641	154	2.36e+004	2.63e+004	69
Distributed to Mz3	2.72e+004	664	160	2.57e+004	2.85e+004	69
Distributed to Mz4	2.85e+004	679	163	2.69e+004	2.99e+004	69
Distributed to Mz5	2.61e+004	625	150	2.47e+004	2.75e+004	69

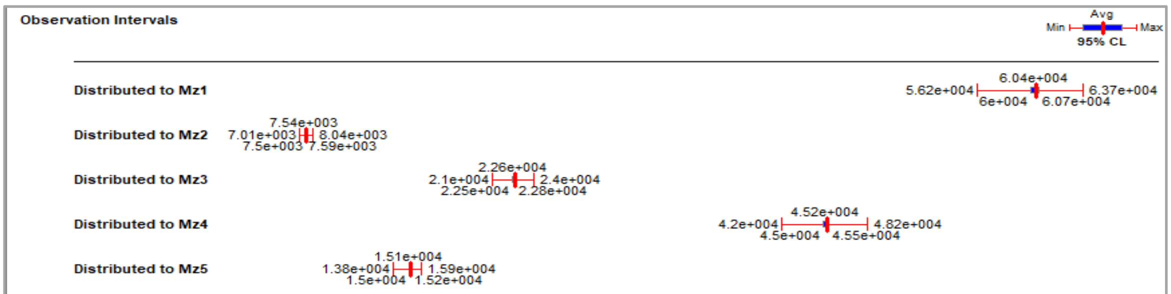
Figure 7.31: The CCIM for the baseline scenario (level 1) of the ordering process in the MRMM model.



Classical C.I. Intervals Summary

ENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
stributed to Mz1	4.11e+003	102	24.4	3.9e+003	4.37e+003	69
stributed to Mz2	1.23e+004	251	60.4	1.17e+004	1.29e+004	69
stributed to Mz3	3.29e+004	631	152	3.13e+004	3.42e+004	69
stributed to Mz4	8.22e+003	189	45.3	7.64e+003	8.6e+003	69
stributed to Mz5	2.47e+004	446	107	2.35e+004	2.55e+004	69

Figure 7.32: The CCIM for the first scenario (level 2) of the ordering process in the MRMM model.



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Distributed to Mz1	6.04e+004	1.3e+003	313	5.62e+004	6.37e+004	69
Distributed to Mz2	7.54e+003	191	45.9	7.01e+003	8.04e+003	69
Distributed to Mz3	2.26e+004	538	129	2.1e+004	2.4e+004	69
Distributed to Mz4	4.52e+004	1.02e+003	246	4.2e+004	4.82e+004	69
Distributed to Mz5	1.51e+004	344	82.5	1.38e+004	1.59e+004	69

Figure 7.33: The CCIM for the second scenario (level 3) of the ordering process in the MRMM model.

7.5 Sensitivity analysis

Sensitivity analysis assists in measuring the effect of small alterations to critical parameters to the developed MRMM model. The Arena® software executes sensitivity analysis using the Arena® *Process Analyser* (PAN) tool. PAN tool focuses on the post-model development phase. It enables the evaluation of alternatives that are obtainable through the execution of diverse simulation model scenarios (Kelton *et al.*, 2004). This means a comparison should be made by comparing the generated outputs from the validated model, which are established on several model independent variables (inputs). PAN should be conducted once the model has run to completion; and when the model has been configured appropriately, verified, and validated. Three terms are essential in executing the PAN, i.e. scenarios, responses, and controls. When controlling the responses by reducing the number of inputs which have less impact on the generated outputs, this becomes the *sensitivity process*.

The aim of conducting a sensitivity analysis helps in twofold: to measure the impact of small variations on crucial input parameters; and to see if the expected direction of modification in the response (independent variable) is accomplished (Rossetti, 2016). An equitable order allocation model needs to be analysed. In conducting sensitivity analysis, several parameters should be investigated in combination with other parameters; this thus requires several experiments to run (Rossetti, 2016). From sensitivity analysis, all the insignificant factors should be dropped out. Then, the sensitivity process would come up with the reduced model that enables to dictate the impact on the response due to the reduced inputs. Ultimately, this becomes a *robust design*. The next step is looking at the area of robust design, whereby the key factors must be selected. A lot of the time in the literature DACE has been to create robust designs (Sacks *et al.*, 1989; Kleijnen, 2018). But, the application of DACE to this study is not to create robust designs of the equitable order allocation model. Creation of an equitable order allocation which is robust should forge a potential future work (Section 10.4).

Section 7.4 involved testing the feasibility of executing any order size. In Table 7.4, the effect of small alterations to critical parameters was tested to the developed MRMM model. The conducted simulation experiments in Section 7.2 also involved altering the parameters. So, the conducted experiments prove that the developed model (Figures 6.32 to 6.34) is statistically significant to execute order allocation equitably across a cluster of SMEs. Despite all changes of variables, there are no variables dropped to create a robust system.

7.6 Hypotheses and/or propositions

7.6.1 Overview

In computer simulation experiments, both propositions and hypotheses can be formulated. Hypothesis refers to the formulation of a concession to a particular scientific conjecture, question or idea to empirically establish its validity (Montgomery, 2013). Any hypothesis must be tested to provide the comparison of two major formulations of the statement on objective terms. In a nutshell, a hypothesis is a technique of statistical inference which deals with quantitative data. Hypothesis testing leads to statistical decision making (Altiok and Melamed, 2007). On the contrary, the proposition is a qualitative one. Proposition also deals with scientific concepts and be stated whether true or false if it refers to the observed phenomena. For hypothesis, there are variables to be assigned. The theoretical proposition should be expressed as a hypothesis that can be empirically tested. Research can have a scientific proposition and/or hypothesis. According to Clay (2018), both hypotheses and propositions help in formulating a likely answer to a specific scientific question.

What are the hypotheses relating too? In this study, the hypothesis can be for simulations or business scenarios. Initially, the hypotheses were developed for the performed simulations; however, from the simulation perspective, it is possible to expand them into the business points of view. To perform hypothesis tests, the assertion to be tested is known as the *null hypothesis*, mostly written as H_o. In this study, H_o characterises what is being claimed after running the set simulation experiments in Figures 7.6 to 7.8. The opposite of H_o is the *alternative hypothesis* (H_A). Testing a hypothesis provides the decision rule on selecting H_o or H_A (Kelton *et al.*, 2004). Normally, an analyst cannot be 100% right on what to choose between H_o or H_A. According to Rossetti (2016), a *Type I Error* happens if H_o is true to be selected, yet an analyst rejects it in favour of H_A and *Type II Error* happens if H_A is really the true one yet the analyst fails to reject H_0.

7.6.2 Methods for testing hypothesis in Arena®

Arena® software comprises tools that execute hypothesis testing. If there are the generated inputs, the testing can be performed using the Arena® *Input Analyser*, which has in-built methods such as the *Kolmogorov-Smirnov* and the *chi-square tests* (Law and Kelton, 2000; Kelton *et al.*, 2004; Rossetti, 2016). Such methods generate fitting input probability distributions for the generated inputs. For this study, since the hypothesis testing is for the generated responses after setting the controllable factors (Section 7.2); the Arena® *Output Analyser* is thus the best in-built tool to test the generated MRMM model's data. The *Output Analyser* tool has in-built methods to make multiple comparisons in ANOVA. The methods include Turkey, Scheffé and Bonferroni: these methods are also available in Minitab®. For the exported data, the testing can be performed externally.

Usually, from the generated sample data, the hypothesis testing can be calculated based on the difference between means, chi-square, *z*-score, *t* statistics, the difference between proportions, among other many statistical analysis methods. So, if the *p*-value > α, then accept H_o; and if the *p*-value ≤ α, then reject H_o and accept H_A: this means that H_o is rejected when the *p*-value is smaller than the alpha level. Statisticians usually choose significance levels such as 0.10, 0.05 or 0.01, whereby any value between 0 and 1 is appropriate to be considered as the decision-making point of reference. For this study, the considered confidence interval is 95% to which the rejection of the H_o is when *p*-value ≤ (α = 0.05). The 95% confidence interval was selected based on the in-built value for the Arena® software. Arena® generates results by assuming that 95% of all the repeated replications of the sample mean are within the interval sample average (mean) plus-or-minus half-width.

7.6.3 Hypothesis testing processes and the formulated hypotheses

Hypothesis testing involves at least four significant steps: first, stating the hypothesis to be tested; second, formulating an analysis plan; third, analysing the corresponding sample data as per the established plan; and fourth, evaluating and choosing the hypothesis carefully by either rejecting or accepting the H_o, based on the generated results of the analysis.

Eight hypotheses were formulated to validate the developed model, as follows:

***H1**: The cumulative sourcing performance indices (CSPIs) do not affect the total produced apparel orders (volume).*

There are five manufacturers—Mz_1 to Mz_5; each manufacturer thus had to be rated based on its performance rating (Section 5.4.3). *H1* was further categorised to five sub hypotheses — $H1_a$ *to* $H1_e$ (Figure 7.34).

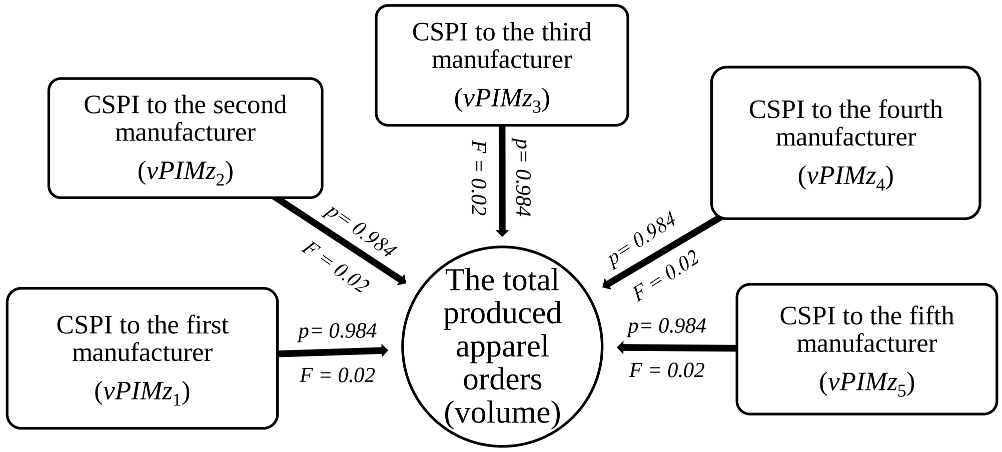


Figure 7.34: The *p*-values and *F*-values for testing the influence of CSPIs to the total produced apparel orders.

From the results in Figure 7.34, the null hypothesis states that the CSPIs do not affect the total produced apparel orders (volume). Since the *p*-value (0.984) is greater than the significance level of (α = 0.05), the H_o is accepted. Hence, CSPIs do not influence the total produced apparel orders.

H2*: The cumulative sourcing performance indices (CSPIs) do not affect the distributed apparel demanded orders (volume).*

In Section 5.4.3, a collection of the performance criteria from all participating SMEs were gathered and ranked. In this study, the overall performance given multiple criteria is what is referred to as CSPIs. The CSPIs are essential when a group of companies works together, precisely in order to be allocated orders equitably. Each SME should be allocated corresponding to its CSPI. Thus, the hypothesis is on testing statistically on how the CSPIs affect distribution across several participating entities. With this, it is a bigger picture of the simulated model. It thus requires to be broken into smaller hypotheses to enable testing. The testing helps to check whether the simulation and data support it or does not support it—null hypothesis and alternate hypothesis.

H2 is made up of sub-hypotheses: since there are several formulated hypotheses, they come together to prove the *overall result.* Figure 7.35 illustrates the hierarchical structure of the CSPIs for the five manufacturers—Mz_1 to Mz_5. Table 7.6 depicts the results of Figure 7.35.

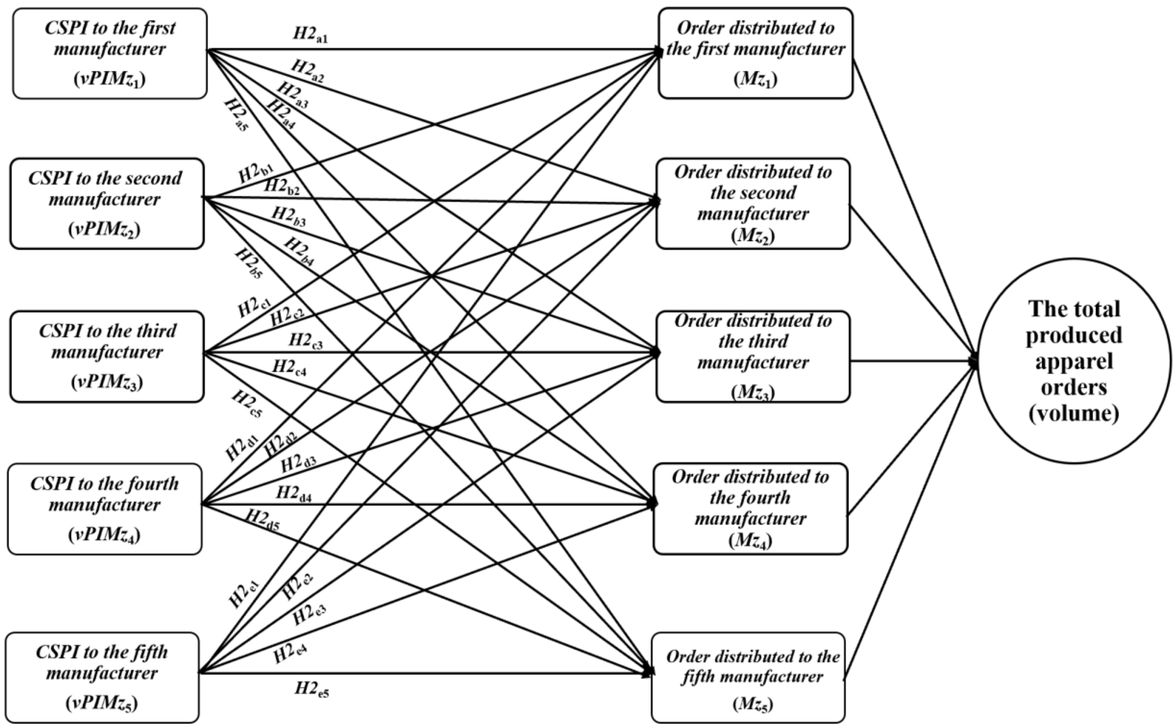


Figure 7.35: The hypothesis relationship for testing the influence of CSPIs on the distributed orders across a cluster of manufacturers (SMEs)—Mz_1 to Mz_5.

Table 7.6: Obtained parameters for hypotheses (*H2*) assessment.

Sub hypotheses	***F*-values**	***p*-values**	**The outcome of the assessment**
$H2_{a1}$	12.65	0.000^{**}	Reject H_0; accept H_A
$H2_{a2}$	8.35	0.02^{**}	Reject H_0; accept H_A
$H2_{a3}$	9.11	0.001^{**}	Reject H_0; accept H_A
$H2_{a4}$	8.06	0.002^{**}	Reject H_0; accept H_A
$H2_{a5}$	2.76	0.083^{*}	Accept H_0; reject H_A
$H2_{b1}$	12.65	0.000^{**}	Reject H_0; accept H_A
$H2_{b2}$	8.35	0.02^{**}	Reject H_0; accept H_A
$H2_{b3}$	9.11	0.001^{**}	Reject H_0; accept H_A
$H2_{b4}$	8.06	0.002^{**}	Reject H_0; accept H_A
$H2_{b5}$	2.76	0.083^{*}	Accept H_0; reject H_A
$H2_{c1}$	12.65	0.000^{**}	Reject H_0; accept H_A
$H2_{c2}$	8.35	0.02^{**}	Reject H_0; accept H_A
$H2_{c3}$	9.11	0.001^{**}	Reject H_0; accept H_A
$H2_{c4}$	8.06	0.002^{**}	Reject H_0; accept H_A
$H2_{c5}$	2.76	0.083^{*}	Accept H_0; reject H_A
$H2_{d1}$	12.65	0.000^{**}	Reject H_0; accept H_A
$H2_{d2}$	8.35	0.02^{**}	Reject H_0; accept H_A
$H2_{d3}$	9.11	0.001^{**}	Reject H_0; accept H_A
$H2_{d4}$	8.06	0.002^{**}	Reject H_0; accept H_A
$H2_{d5}$	2.76	0.083^{*}	Accept H_0; reject H_A
$H2_{e1}$	12.65	0.000^{**}	Reject H_0; accept H_A
$H2_{e2}$	8.35	0.02^{**}	Reject H_0; accept H_A
$H2_{e3}$	9.11	0.001^{**}	Reject H_0; accept H_A
$H2_{e4}$	8.06	0.002^{**}	Reject H_0; accept H_A
$H2_{e5}$	2.76	0.083^{*}	Accept H_0; reject H_A

Note(s): ** the alternative hypothesis is accepted and * the null hypothesis is accepted.

***H3**: Replication length does not influence the throughput of products.*

***H4**: Mean order interarrival time (vMOIT) does not influence the total distributed orders across a cluster of SMEs.*

***H5**: Transfer time (vTrMz$_1$ to vTrMz$_5$) between machines to process items does not influence the total produced apparel orders (volume).*

***H6**: The sequencing time to assign the processing time for each process does not affect the distributed apparel demanded orders (volume).*

***H7**: The transportation time from DC to retailers (Rd_1 to Rd_5) affects total distributed orders.*

***H8**: The transportation time from manufacturers to DC affects total distributed orders.*

Table 7.7 shows the obtained *p* and *F* values for assessing hypotheses, specifically for *H3* to *H8*. For *H3* to *H8,* refer to Tables 7.1 and 7.2 for the description of each considered factor.

Table 7.7: Obtained parameters for hypotheses (*H3* to *H8*) assessment.

Hypotheses	**Hypotheses for assessment**	***F*-values**	***p*-values**	**Outcomes of the assessment**
H3	Replication length does not influence the throughput of products.	0.02	0.985*	Accept H_0; reject H_A.
H4	Mean order interarrival time (*vMOIT*) does not influence the total distributed orders across a cluster of SMEs.	72.83	0.000**	Reject H_0; accept H_A.
H5	Transfer time between machines to process items does not influence the total produced apparel orders (volume).	0.04	0.959*	Accept H_0; reject H_A.
H6	The sequencing time to assign the processing time for each process does not affect the distributed apparel demanded orders (volume)	0.08	0.927*	Accept H_0; reject H_A.
H7	Transportation time from DC to retailers (Rd_1 to Rd_5) does not affect total distributed orders	0.04	0.959*	Accept H_0; reject H_A.
H8	The transportation time from manufacturers to DC does not affect total distributed orders.	0.01	0.985*	Accept H_0; reject H_A.

Notes: ** the alternative hypothesis is accepted; * the null hypothesis is accepted and DC = distribution centres.

The discussion of the results in Table 7.7 is in Section 9.2.5. All the generated experimental results generally indicate that the proposed and developed MRMM model to allocate (distribute) orders are statistically significant equitably. The results in Figures 7.10 to 7.26 indicate that the developed model in Figures 6.32 to 6.34 is a good approximation of the physical system of allocating (distributing) orders to a cluster of SMEs working collaboratively. Therefore, the results from DACE prove the successful demonstration of the feasibility of allocating orders equitably to a cluster of SMEs working collaboratively. Experiments show that it would be feasible if manufacturers work together. Further discussion on the hypotheses results is in Section 9.2.5.

An interesting question can be: how can retailers know whether manufacturers can fulfil their order sizes? This is because the information shows that manufacturers work together effectively to meet the orders. The simulated model was developed in consideration of logical assumptions on the shared information, including the number of hours available, and other necessary manufacturing details.

Also, the research question for this study focused on whether it is feasible for the manufacturers to work together by sharing orders, sharing information, etc. So, since the developed model considered time available for the manufacturers and other essential resources, thus it is a feasible way that manufacturers can fulfil orders by working together. Working together should involve information sharing at the computing cloud waiting for the virtual factory to optimise and allocate orders equitably.

Chapter 8 Qualitative and Quantitative Results and Analysis

8.1 Introduction

This chapter summarises the results for the conducted interview sessions, survey, Likert scale ranking results (qualitative data) and the initial modelling and simulation (quantitative data). Other results and analysis are presented in Chapter 7 for the performed computer simulation experiments (Section 7.2.3) and the testing of hypotheses (Section 7.6). Therefore, the quantitative results presented in Chapter 8 are for the initial simulations (Chapter 6) before conducting DACE (Chapter 7).

8.2 Results from qualitative data

8.2.1 Participants' response rate

The purposive sampling technique was applied to recruit participants (both retailers and manufacturers within the UK). Firstly, at least sixty-four retailers and manufacturers from the T&A industry were contacted with at most three reminder emails as per the University of Manchester research ethics guidelines. The response rate was 15.6% (10 firms). Among these, two firms participated fully in this study, including those listed in Table 8.1. Other eight firms indicated time constraints among the mentioned reasons for not participating. Secondly, during the Make it British exhibition event, at least thirteen firms discussed with the researcher and provided their responses although they requested to be under the 'non-disclosure category'. Five firms among the thirteen firms ranked their firms using the Likert scale tool (Appendix E). Their responses assisted in generating results in Table 8.2.

Table 8.1 summarises the participants' characteristics: UKR1 and UKR2 belong to the same company, but the interview sessions were conducted to different participants. Their valuable contributions were the inputs in simulating some processes, including the creation of incoming apparel orders (Sections 6.5.4 and 6.5.9). Appendices A to D comprise a list of guideline information used for this study. The UKR1 has a sales capacity of £20 to £25 million per week and the average order size of 7,600 to 14,400 per season. These records are the held stock in the distribution centre before restocking. UKR1 deals with womenswear, lingerie, menswear, girls, homeware, school uniforms, among others. The company sells basic core products and fast fashion, schoolwear, among other apparel items. This company is more of a mid-market brand, i.e. the so-called 'value retailer' as it offers products at an affordable price [UKR1].

Table 8.1: Participants summary.

Company (code)	Experience	Category
UKR1	35 years	Retailer
UKR2	35 years	Retailer
UKM1	109 years	Manufacturer

8.2.2 What is an extended enterprise within the Industry 4.0 perspective?

This study primarily answered the first research question: *what is an extended enterprise (EE) within the Industry 4.0 perspective?* This question explored the meaning of an EE, and how does it exist. Similarly, the question explored the benefits of developing the concept of an EE on simplifying order placement by retailers within the T&A industry. It is an Industry 4.0 era whereby numerous sectors are gradually transforming. In order to answer this question, a qualitative approach through documentary reviews, semi-structured interviews, questionnaires, and observational techniques gathered required data and/or information. Initially, two approaches assisted in identifying a list of prominent retailers and manufacturers. Firstly, by attending a Make it British exhibition event to meet several garment manufacturers, sample makers and retailers at the Business Design Centre, London in the UK on 29th and 30th May 2019. Secondly, through secondary data, including reports and websites, it assisted in identifying a list of several manufacturers or suppliers (Appendix F) and reputable retailers within the UK (Table 2.1, Sections 2.2.3 and 2.3).

Subsequently, Sections 2.6 and 2.9 briefly discussed the general meanings of an EE and Industry 4.0 concepts, respectively. Industry 4.0 is an ongoing integration of digital or smart technologies to enhance improved process efficiency and advanced decision-making processes across several sectors. The characteristics of Industry 4.0 includes technologies such as smart factory, predictive maintenance, autonomous robots, smart manufacturing (manufacturing 4.0), connected enterprise, internet of things (IoT), augmented reality, dark factories (lights out-manufacturing), 3D printing, big data and predictive analytics, computer simulation, vertical and horizontal systems integration, computing cloud, cyber-physical systems (CPS), additive manufacturing and the internet of everything (Mussomeli *et al.*, 2015; Gerbert *et al.*, 2015; Erol *et al.*, 2016; Sniderman *et al.*, 2016; Sanders *et al.*, 2016; Leech *et al.*, 2017; Taifa *et al.*, 2019; 2020b). This research was located in the Industry 4.0 context. The characteristics of Industry 4.0 that triggered the work undertaken include the virtual factory, computing cloud, vertical and horizontal systems integration of SMEs, connected enterprises and computer simulation. This study thus fits in the Industry 4.0 context. As digitalisation initiatives are increasing, the transformation should not be only around executing more and improved technologies; it should also encompass digital congruence—linking SMEs workers, tasks, culture and structure (Kiron *et al.*, 2016).

It was found that Textile 4.0 (Chen and Xing, 2015), Fashion 4.0 (Bertola and Teunissen, 2018) and Apparel 4.0 (Gökalp *et al.*, 2018) are interpretation and application of Industry 4.0 within the T&A sector. Both empirical and theoretical studies suggest the potential of renovating supply chains through the Industry 4.0 concepts. Despite that Industry 4.0 began back in 2011; still several of Industry 4.0's technological innovations are yet to be fully realised in numerous manufacturing factories (Strange and Zucchella, 2017), including the apparel industry.

> "(Textile sector) is lagging behind other sectors [in terms of technological innovation]" [UKR1].

This research mainly aimed to digitalise the DSC for UK apparel manufacturing regarding order distribution processes. The digitalisation was about enabling an equitable order allocation across a cluster of SMEs working as an extended enterprise. In connection with this study, the digitalised models needed to allocate orders from retailers to manufacturers require Industry 4.0-related concepts. Both retailers and manufacturers need advanced systems. For example, UKM1 stated that firms are willing to adopt a technological change regarding an ordering process aspect and equitable order allocation amongst the SMEs.

> "[…] yes, we are willing to adopt new technology which helps order processing" [UKM1].

This thus indicates the need for digitalising an equitable order allocation process. However, the results show that the UK apparel sector has not yet fully digitalised its order allocation system. Digitalisation is part of Industry 4.0-related concepts. UK manufacturers have already embraced some basic technologies; for example, the UKM1 responded that:

> "We have a digital system for order swatches which we are looking to develop further for production orders."

UKM1 receives orders through emails. Also, UKM1 has never thought to equitably distribute its orders as it does not receive bulk orders. The problem is not only to the manufacturer's side but also to the retailers' side. UKR1 responded that this sector is lagging behind other sectors.

> "From a technical point of view, we use the likes of BV. To show up reports of factories, we collect all information from our suppliers. So, anytime we have access, it is one source of information, so [that] we can go, and we can have a look where our factories stand. Internally we have a system called WEB PDM. [BV is an international certification agency]. Generally, PDM is used for the technical team to input size specifications, specs on the products, [etc.], and web PDM is also accessible by the suppliers and the rest of the business [partners]."

Although academics, institutions, organisations, major consultancies, and governments, are continually discussing digitisation, digitalisation, and digital transformation in connection to Industry 4.0, yet the T&A Industry lags behind as its firms still operate with unadvanced systems to some extent. For example, through the interview sessions at UKR1, it was stated that the company still uses some '*basic old school packages or software*' which are not competitive, something which slows the company's business. The UKR1 explained that web PDM:

> "[…] it is quite a basic old school package. So, when I was in the industry for many years this was the revolutionary package, and we did not have email addresses, we did not have spreadsheets, [Microsoft®] Excel. WEB PDM is an old school package."

The company (UKR1) is aware of the current digitalisation, and understands the system from its competitors as the UKR1 stated:

> "[..] there is a new product life cycle management (PLM) package. Some of our big competitors use PLM because it is far more advanced. Within PLM, you get many masters (…) that is from strategy design to the meetings selecting your fabrics,

> approving your samples. You get to the stage where a safety board, then shows you whether the delivery is going to be on time. The PLM package gives you end to end activities. That is what companies use now, and all partners get access to it. We are not there yet, and we slow business."

The results further indicate that in the future, digitalisation would potentially boost the T&A sector within the UK, e.g., UKR2 stated that:

> "[…] yes, digitalisation will play a big part in the way we move stuff. From the [UKR2's company] point of view, there are so many manual processes that we do. UKR2 personally can visualise robots, but we do a work-based system. We use scanners to track the items, but we have not tried RFID in the store. Hopefully, in future, we should have more automation in the warehouse as well. For dispatching, we track through the scanner movement."

This probably shows the digitalisation viewpoint to this vital sector, which requires revitalisation to compete with foreign companies, including China, Bangladesh, and Turkey. UKR1 indicated that lack of digitalised systems slows their business.

The above-explained results from UKR1, UKR2 and UKM1, indicate the available gap in the T&A sector explicitly on the digitalisation perspective. In connection to theoretical underpinnings, the T&A sector, especially for the SMEs, do not receive sufficient orders in order to earn higher profits. One of the approaches is an extended enterprise (EE) concept. The EE concepts in conjunction with the virtual factory, vertical and horizontal system integration, and information sharing systems, could assist in sustaining the SMEs over a more extended period through consistent manufacturing capacity fulfilment at a break-even level as a minimum. An EE is suggested to address tremendous competition within enterprises that look to address several challenges (Jagdev and Browne, 1998; Babenko, 2020). One of the benefits of working collectively as an EE is an execution of order allocation equitably. However, the key question on this should be, is the extended enterprise competitive on the global market? Are there other benefits from acting as a large virtual enterprise which allows competition? What makes an EE viable for the companies to get involved in that kind of business relationship? These are crucial questions within an EE.

Firstly, working collaboratively requires advanced information-sharing systems to enable both asynchronous and synchronous communication within the collaborating firms. So, working as an EE assists SMEs' survival over a long period if business opportunities are shared across the well-established systems equitably. Secondly, this study focused on equitable order allocation amongst SMEs to ensure their survival over an extended period. So, for SMEs which are constrained with their small sizes, low capabilities and capacities to secure bulk orders, working collaboratively as an EE could thus assist them to form a large virtual enterprise which can compete similar to large enterprise which is not collaborating with other enterprises. So, SMEs can be assisted to secure enough orders that help to utilise their capacities and capabilities, thus gaining competitive advantage through collaborative supply chains. Third, working collaboratively can also help in the global market if a group of SMEs can secure enough orders and execute within the required lead time as retailers are looking for a quick response. Initially, a cluster of manufacturers, e.g. SMEs, working collaboratively to secure orders may not compete fully with other well-established large manufacturers. But forming a large virtual enterprise, over a long period could compete in securing orders, and such firms could survive as their resources would not remain idle.

The underpinnings indicate that the global market is now facing tremendous competitive pressures (Jagdev and Browne, 1998; Babenko, 2020). This is due to the need for high innovation and creativity, quick response, customised products and/or services, among other factors. So, due to Industry 4.0 concepts, there should be simplification in addressing some of the challenges in the generic supply chains. Industry 4.0 as it is related to digitisation, digitalisation, and digital transformation, comprises advanced technologies which assist in improving information sharing and integrating all business operations. For the enterprises to respond to the current challenges in the Industry 4.0 perspective, this requires firms to collaborate closely as an EE for the entire supply chain. As this research focused on illustrating the feasibility of allocating orders across a group of manufacturers, yet it was not explored whether working collaboratively is also feasible on legal responsibilities and financial aspects for companies including SMEs within the T&A industry.

In today's business, micro, small, medium, and large enterprises are encouraged working synergistically. Such collaboration is associated with the extended enterprise framework that necessitates enterprises working as a single virtual entity, and this works much better for micro, small and medium-sized enterprises. Enterprises need digitalised supply chain models to realise the influence of extended enterprise framework through Industry 4.0 concepts. However, the digitalisation to enhance collaboration must be enabled by advanced information sharing secured platforms. The supply chain model can be for sharing (allocating) received orders from customers, e.g. apparel orders from retailers, raw materials from several tiers, and the like, depending on the business nature.

Figure 8.1 illustrates the conceptual (diagrammatically) with collaboration and information sharing enabled relationships amongst SMEs that work synergistically. Each enterprise can decide to either work individually (though not encouraged in today's business nature) or work collaboratively as an EE. This means the collaborating companies—SME_1 to SME_n—can have the universal virtual factory (for decision making) and share pertinent information to enable them to achieve their operations.

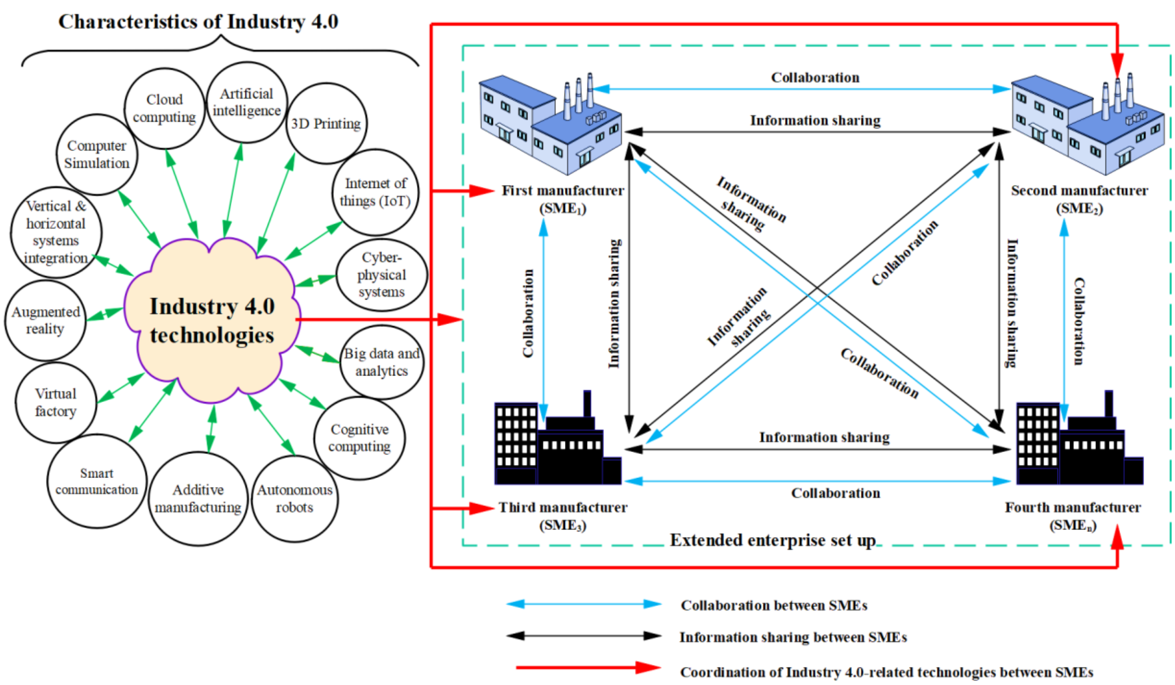


Figure 8.1: The concept of Industry 4.0 to enhance collaboration and information sharing platforms in an extended enterprise.

8.2.3 Scenarios of the apparel distribution systems (order allocation processes)

a) A scenario of the ordering systems

In order to develop an equitable order allocation model, it was crucial to understanding the current ordering processes. Through interviews sessions, it was established from the UK apparel retailers that they use two main options to place orders. First, the retailer can order directly from the manufacturer (supplier or SMEs); second, it is through agents as an indirect approach (Figure 8.2). The interviewed retailer prefers a direct approach to place orders.

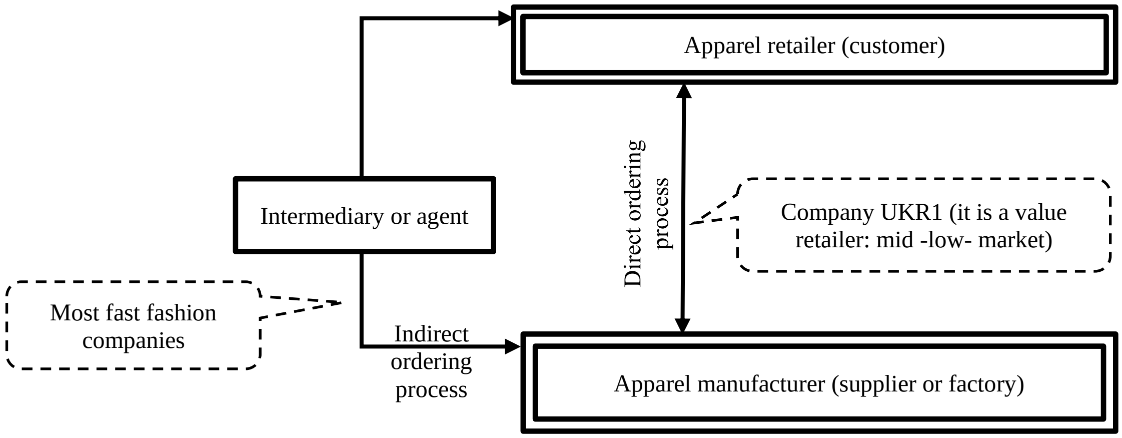


Figure 8.2: Direct and indirect business ordering process model for the T&A sector.

From the retailer's viewpoint, the ordering process is as follows:

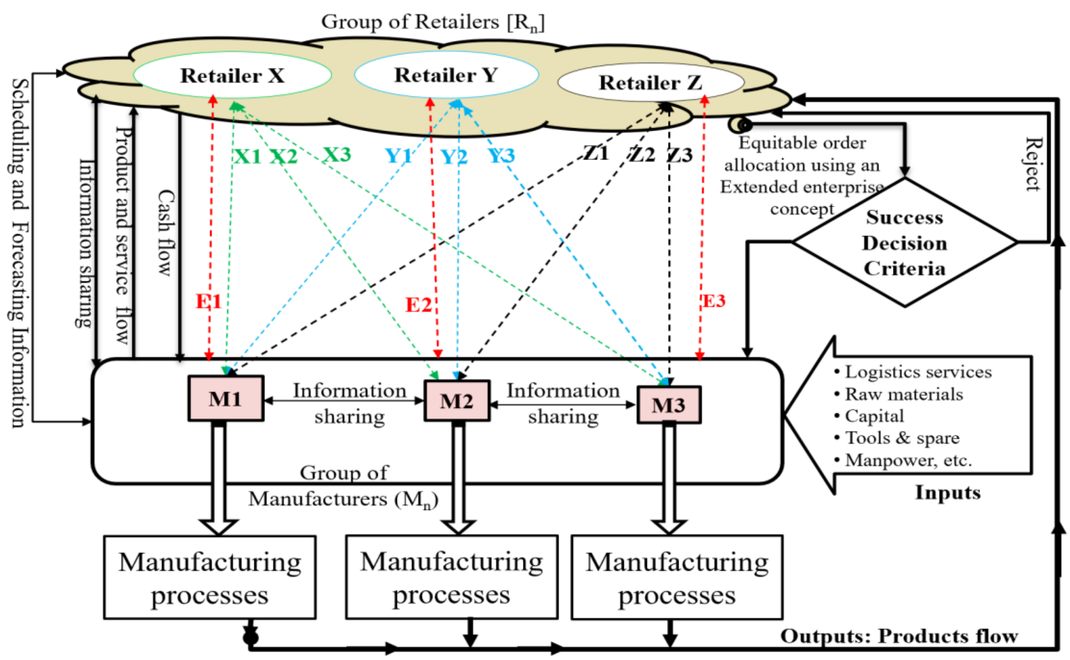
> "[…] there are various ways. It could be the team [at the head office] (..) come up with the concept. [If] we want a collection of dresses, etc., then we come up with product specifications, then we will look at the suppliers to work with. That supplier—let us say China or Turkey or whoever (...). Then, they will say to send technical specifications, and then they will say to produce that sample to that specs, or the other options we might go to the showroom and pick from the showroom and say make me a dress or a supplier might come in and present lots of different options. That is the starting point. The next point is that we go to the next step of approvals of prototypes. Then once we say yes, that is what we want, after that we approve fabrics. Once it is approved, it goes to Web PDM (Product Data Management). The technology and designers, all group. So, stage one is what design you want. Stage two lead us to the approval process. Stage three what is the quantity we want to go with, when do we want to come in, and that is when they start working with a range planner and put all this information which raises the purchase order. They [then] give the delivery date (the lead time), and that is a kind of inception approval and then to market" [UKR1].

It was interesting to know whether there is a system or tool which helps companies to make a follow-up of the placed orders. UKR1 responded that appropriate system:

> "[…] would be a PLM (product life cycle management), PLM would do all that. PLM is a system where you can put your technical criteria; you can put your suggestions, [etc.] Here we can put basic information on WEB PDM. Range planner has all the information about quantities, etc. There are various options. So, there is no one 'product life cycle management' system from product inception to delivery to market. It is fragmented into different forms" [UKR1].

Thus, this shows how the ordering process at UKR1 is not yet fully digitalised. Much of the ordering processes involve manual interventions.

Figure 8.3 proposed a conceptual framework of an extended enterprise for ordering options. Thus, by having an EE, it explicitly recognises a single-stage and several companies doing the same things as a collective recognised company. For example, the presence of five SMEs making jackets, jeans, among others, can be enabled to secure bulk orders as an EE. If retailers order 40,000 jackets and if such orders are collectively allocated across a list of collaborating SMEs; here, the manufacturers behave as a single virtual entity in an extended enterprise. This makes an example of the horizontal distribution. In an EE framework, the manufacturer in the manufacturing-centred EE should establish strong and long-standing relationships with crucial retailers (Browne and Zhang, 1999). Like other Industry 4.0-enabled technologies, the EE concept needs information-sharing practice which is developed with extensive use of IT to support manufacturer-retailer integration. The EE concept should be explored jointly with horizontal integration aspects. So, an EE needs strong business relationships for all the firm's departments. Also, procurement and engineering operations, and the commercial relationship must advance for a longer period (Stallkamp, 2005).



Note(s): Manufacturing processes include designing, pattern creation, grading, spreading, cutting, sorting or bundling, sewing/stitching, inspection, ironing and finishing, packing and labelling; ***E1*** to ***E3*** = Each retailer orders to a group of manufacturers working as an extended enterprise; ***X1*** to ***X3***, ***Y1*** to ***Y3*** and ***Z1*** to ***Z3*** = retailers ***X***, ***Y*** and ***Z***, respectively, order traditionally to distinct manufacturers (***M1*** to ***M3***).

Figure 8.3: The proposed conceptual framework of an extended enterprise for ordering options.

b) *Apparel orders' rejection rate*

Generally, not all the ordered products are accepted. To prove this, the proportion of rejection experienced when ordering within the UK and overseas is circa 70%. This information was used in Section 6.5.9(b), mainly for Figure 6.18.

> "yes [not all orders are accepted], (..) at the inception stage, we might tell them here are our 10 garments, and these are 10 ideas, and they (manufacturers) might be able to achieve 7 of them which is 70%. I think it is around the industry standard, which is around 70%. We should aim for 90%, but on average, it is around 70%" [UKR1].

c) *Mean order interarrival time (MOIT)*

The ordering process cannot be uniform to all UK retailers. However, at least from the UKR1, it was found that the company classifies its ordering process into three seasons: spring, summer, and winter, which further lead to three main phases. This information was used in Section 6.5.9(a). MOIT information was also configured to illustrate the feasibility of allocating orders through DACE concepts in Chapter 7.

> "[…] we have two to three phases within summer for fast fashion, and if it is not fast fashion, we can have one or two phases. Therefore, it depends on the season, but between that, we can check in the stock, and we can see that we want a certain dress, so on suddenly we can raise an order. [Sometimes] they all (suppliers) know that we want, e.g. 2000 [apparel] in January and 5000 in May. Sometimes if we want to lower a stock, we can use RFID to check the stock" [UKR1].

d) *Distribute, divide, or split the order size to different manufacturers*

Although the fundamental aim was on enabling an equitable order allocation (distribution) to SMEs, it was also essential to know whether the UK retailers also distribute their orders. This can happen when a retailer decides to split its orders to multiple suppliers or manufacturers. Retailers would like to split if they are testing targeting to obtain the best manufacturer(s).

> "[…] we would generally [do so]. If we think about negotiations of prices, they book the capacity, book the production line, and let us say I have got 20000 garments; it is very rare to split it. You would [wish to] split if you are testing. For example, you want to make a new dress. You would say that let go in Turkey, and it is quick, they are capable of making it, if that works it becomes more successful, we pay a bit more for making it in Turkey, we then go to the Far East to get a lower price. We had an experience of splitting them in the previous where we had to move the fabric to another factory. That does not do good business" [UKR1].

e) Company certifications or audits does the UK firms comply with

Both manufacturers and retailers should be fully certified and audited by national and/or international authorised companies or bureaus. To collaborate in an extended enterprise system, it is crucial to work with a company which is fully accredited in that business to abide by the legal and law issues and other CSR related aspects. UKR1 responded regarding ethical compliance and companies' certifications that:

> "[..] we have ethical compliance, and we have technical compliance. So, ethically factories need to prove that they are socially compliant, and they need to present what we call a SMETA report. The SMETA report has to pass, and it needs to be registered to a website called BV (Bureau Veritas). So, they need to present on the website, and that shows that they are ethically compliant. Until the ethics and compliance, we won't proceed. Then the next route is, they have to show that they are technically capable. And technically capable [means the suppliers should] present a technical report. So, the technical report could be an audit of myself or one of my colleague's carried out in order to audit the pass or fail operation of the factory. If they fail, they are not technically compliance, and if passed means they are technically compliance. And what we do if myself or one of my colleagues can carry out an audit, we will contact some textiles, and they are called STS (Sustainable Textile Solutions) and BV (Bureau Veritas). Then we will do a technical audit report again, and they will need to send us results. If they are showing non-compliance in any of our requirements, we will give them a corrective action plan. They will have to go away after picking the non-compliance, and we give them a time frame whereby we will make a follow-up audit to fix and ensure compliance. If there are safety issues compliance, we will not proceed. So, SMETA is the main issue of the ethical side" [UKR1].

SMETA is "one of the most widely used ethical audit formats in the world. SMETA is an audit methodology, providing a compilation of best practice ethical audit techniques. It is designed to help auditors conduct high-quality audits that encompass all aspects of responsible business practice, covering Sedex's four pillars of labour, health and safety, environment and business ethics."[16]

Regarding ISO 9001, this is a technical requirement and is much based on the quality management aspects. The quality standards must be followed for all collaborating factories. If SMEs have no such standards, retailers look for other manufacturers who have quality standards as per ISO. Dealing with SMEs may be challenging for them to adhere to ISO

[16] Sedex Members Ethical Trade Audit (SMETA) available at: https://www.sedexglobal.com/smeta-audit/ (accessed 7 May 2019).

standards. Most of the factories have their systems. The results from the UKR1 indicate that their primary focus is not on ISO 9001; the company insists on the company's technical audit compliance, STS, BV compliances, etc. ISO 9001 ensures that companies can produce quality products which are compliant with international standards. There are other examples of certifications, for example, since the 2013 Dhaka garment factory collapse (also referred to as the Rana Plaza collapse or the 2013 Savar building collapse), due to structural failure that injured around 2500 people and resulted to 1,134 death:

> "[..], so a quota has been set up in Amsterdam [The Netherlands]. Our company is much sensitive around the structure of the building, the electrics [checking whether it] is safe; it is a safe environment to work in, etc. So, [manufacturers] have to show certification, and if they do not have, we will not work with them. The most important thing for this company is safety, safety, safety. If they cannot conform to safety, our company will not even look for technical capability" [UKR1].

f) Lead time in the UK apparel industry

This research explored the lead times within the UK. The results indicate that the lead time varies depending on the product, company, technology, number of workers, order quantity, the distance between manufacturer and retailers, etc. For example, UKR1 reported that:

> "[..] recently explored a new fashion model. This model started in Leicester, UK. From the day we had a meeting with a supplier (or manufacturers) to look at the products they can produce to be in the store is three weeks. This is a fast-fashion model, that is, from inception to delivery to market. Normally fast fashion is around 6 weeks. Mostly, the fast fashion products are from Turkey. We generally talk for an average of 12 weeks for a normal call." UKM1 similarly indicated that the lead time is "4 weeks for cloth dyed from undyed stock; 12 weeks for cloth woven to order [and] 1 day for stock bought from finished stock."

8.2.4 Decision criteria

To digitalise equitable order allocation processes, it is essential to have the critical success decision criteria from both the UK apparel manufacturing (SMEs) and retailers. In line with Figure 5.6, the cost criterion is not a dominant factor in today's business. Theoretical underpinnings' results show that retailers have been considering cost as the key criterion to decide the right supplier (manufacturer). However, nowadays, cost (price) is no longer a dominant factor. The UKR1 responded that:

> "[…] hundred per cent (100%) [yes]" cost is no longer the key criterion. "[For our company], cost just has to come into it because we cannot go to a factory producing high-quality fabrics premium with top the range; also automated production facilities

we will not be able to satisfy our customers' demand. [Our firm] is doing really well, it has a really good framework, of course, we know it has good quality standard products at an affordable price. You might go to one of our big retailers, and they do not have quality, [instead, they are focusing too much on] price. Within the garments, there are threads; there are components, are they all tested? [Our company] tests everything. We ensure quality. So, we would not say that you forget about quality, forget about safety, forget about compliance, and look at the price. That is not our ethos at all."

The research also aimed to establish and support the afore-explained problem statement (Sections 1.3 and 2.13) that probably orders sharing is not yet practised within the sector. At least thirty-three decision criteria that are crucial in selecting the suitable manufacturers were established (Figures 5.6 and 5.7). UKM1 answered the question regarding 'order sharing or dividing practices or experience between different manufacturers (if any)' that "*We do not share order information.*" However, UKM1 shared other information. UKM1 said, "*We supply our commission weaver [to] make details for our products, and we discuss and share information with our finishers to create the handle of our clothes.*" UKR1 also reported that the T&A sector would generally wish to have such a system which can enable equitable order allocation. UKR1 further explained that "*we had an experience of splitting them in the previous where we had to move the fabric to another factory*."

Firms are nowadays ensuring slavery is absent from modern apparel businesses: this is essential as it forms part of the corporate social responsibility model. It was found that UK retailers are following procedures to eradicate any form of slavery from their suppliers or manufacturers. Retailers help to eradicate and/or plummet modern slavery practices in the T&A business.

> "[…], our company considers modern slavery issues in ethical compliance. It is a 100% important aspect to consider when it comes to [workers] salary, [long working] time or hours, women involvement and [children involvement] in their business. Safety, safety, safety is the key consideration to whomever we work with" [UKR1].

8.2.5 Standard allowable minutes (SAM)

An apparel firm undertakes several processes. All processes require processing time, i.e. SAM. Does the company have a database regarding the duration of executing each stage, e.g. cutting, sewing, inspection, finishing, among others? This question was important to get inputs to develop the MRMM model (Figures 6.32 to 6.34), specifically for manufacturing apparel products (Figure 6.26). The results indicate that there are no databases for SAM or SMV data amongst SMEs. This was proved by UKM1 who stated that "*no [we do not have SMV data], but we monitor, some jobs take longer than others, which are determined by the cloth.*" To develop the MRMM model, SAM data had to be summarised from secondary sources: from Brother Industries (1995) (Table 6.3). More data contributed by other researchers are in Table 6.2. This study utilised the data in Table 6.3.

8.2.6 Equitable allocation of the manufactured products at distribution centres

The other area explored in this study was the distribution centres. The study mainly discussed the order allocation to manufacturers. However, the study found that distribution centres for retailers with multiple stores require an equitable allocation system. The results suggest that when SMEs have multiple manufacturers with distribution centres that consolidate the manufactured products from SMEs, they should probably have an equitable order allocation system as well. UKR2 was asked: '*how do you allocate or distribute your received product from manufacturers?*' The response was:

> "[…] the merchandise from the head office will allocate the products amongst the stores. So, all stores will be graded. The highly graded stores will get most of the products. Depending on the regions, that is the item which sales best, they will be distributed that way. So, in advance, once receiving the goods, we allocate to the store. What store requires what items. The first ratio packs will be fully packed boxes with different sizes: small, medium, large, and extra-large size. All items received come as replenishment in the system."

UKR2 was further asked on whether they compare their selling performance measures to allocate new items. This was based on the response that the received orders are distributed based on what stores require what items. UKR2 replied that the storerooms are small, and the company does not want to overcrowd the storerooms. Keeping the items in the stores would later force them to make sales. So, the firm tries to keep the stock-flow as quick as possible. Moreover, the current distribution centres face challenges regarding advanced technologies. UKR2 stated that:

> "[this is a] good question, I think in some warehouses people would pick stuff [apparel products] through pen and paper. So, if they want something, they have to locate it on paper. In the UKR2's warehouse, they would require allocating in the system provided

that they are pre-scanned. We cannot send someone to go and locate it. If it reaches a point to get a product from the store, we have a problem to allocate it. They (workers) perform a walkaround which we call 'manual revise'. So, we pick it out from the store, and then we invoice once it is picked out. Therefore, all processes are manually performed. When there are tiny products, the picking process consumes much time because we must pick and check the label, tag, among others."

Factories need to improve workforce productivity through advanced technologies. For example, the factories should install a real-time locating system, mobile computers, RFID technology, tablets, barcode scanners, speciality printers, and much more. Without such tools, working collaboratively might fail as much of the processes within the factories must share information, including the order size, produced quantities, among others.

8.2.7 SMEs ranking results using Likert scale method

The Likert scale tool (Section 4.6a) ranked five SMEs, as shown in Section 5.4.3. Table 8.2 presents a summary of the scores for all the five apparel SMEs. The results were generated through the use of Appendix E and the compilations of Table 5.4.

Table 8.2: A summary of the Likert scale's scores for all the five SMEs.

Category	Weight	Criteria		Weight	Scores for SME_1 to SME_5					Manufacturers (computed scores)				
					1	2	3	4	5	SME_1	SME_2	SME_3	SME_4	SME_5
FLP	0.1	FPO		1	4	2	5	4	3	0.40	0.20	0.50	0.40	0.30
IBPP	0.35	QLT	QA	0.05	2	4	3	2	5	1.22	1.21	0.93	1.09	1.06
			QP	0.05	2	3	3	2	5					
			QC	0.15	3	4	2	5	2					
		DLV	LS	0.05	4	2	2	1	3					
			LT	0.15	3	2	2	4	2					
		PRC	SP	0.1	3	4	3	2	3					
			OC	0.05	3	4	3	3	2					
		PFC	MC	0.06	4	4	4	3	3					
			MQ	0.06	4	4	4	3	3					
		TEC		0.13	5	4	3	3	4					
		MO		0.1	5	3	2	2	3					
		FLE		0.05	2	4	3	4	4					
CRP	0.3	GEL		0.4	5	3	2	3	3	1.26	0.96	0.66	0.72	0.96
		PH		0.2	4	3	2	1	4					
		SER		0.2	4	3	2	3	3					
		RPI		0.2	3	4	3	2	3					
ILOP	0.15	PCE		0.2	4	3	3	2	2	0.60	0.51	0.44	0.39	0.41
		ICS		0.4	3	4	3	3	2					
		CPP		0.3	5	3	3	2	4					
		LRL		0.1	5	3	2	4	3					
CSR	0.1	MSIs		0.5	5	5	4	5	5	0.45	0.45	0.40	0.45	0.45
		ENV		0.5	4	4	4	4	4					
Total scores	1			5						3.93	3.33	2.93	3.05	3.18

Note(s): See Table 5.4 for the full form of the given criteria and categories of the Balanced Scorecard.

To select the values shown in Table 8.2 requires the rating processes of the CSDCs (Figures 5.6 and 5.7) with the corresponding justification by equations 5.1 to 5.13. The ranking processes for each decision criterion were performed by five firms' representatives during the Make it British exhibition in London. This was vital to develop the computer simulation model, then allocate orders corresponding to firms' scores. For the experiment reasons, the total scores for each manufacturer (TSEM) shown in Table 8.2 can be used to either allocate bulk orders equitably or input the scores in the designed computer simulation modelling in Arena® (Section 6.5.9). For DACE execution, the scores were altered in Table 7.2.

The total scores for each manufacturer in Table 8.2 were used in equations 8.1 to 8.7. Alteration of these scores can be performed based on the rating processes of the distribution criteria for the collaboration of virtual entities through an extended enterprise. Ideally, the lower the TSEM, the poor performance is for the specific SME. SMEs should perform better for each decision criterion to be rated high and finally to secure more bulk orders equitably.

The Cumulative Sourcing Performance Index (CSPI) on allocating, distributing, dividing, or sharing the received apparel orders for all SMEs was calculated using equation 8.1. Based on the results shown in Table 8.2, the CSPI for the first manufacturer ($CSPI_{SME1}$) secured a share of 23.94%, $CSPI_{SME2}$ (20.28%), $CSPI_{SME3}$ (17.86%), $CSPI_{SME4}$ (18.56%) and $CSPI_{SME5}$ (19.36%) by using equations 8.2 to 8.6, respectively. To further exemplify the scenario, the retailers' entries of 50,000 shirts were manually shared by using equation 8.7 as follows: 11970 shirts to SME_1, 10140 shirts to SME_2, 8930 shirts to SME_3, 9280 shirts to SME_4 and 9680 shirts to SME_5.

$$CSPI_{SMEi} = \left[\frac{TSEM_{SMEi}}{TSEM_{SMEi} + TSEM_{SMEj} + TSEM_{SMEk} + TSEM_{SMEl} + TSEM_{SMEm}}\right] \times 100\% \qquad (8.1)$$

Where *i*, *j*, *k*, *l*, *m* = the five apparel manufacturers (SMEs): SME_1 *to* SME_5, respectively.

$$CSPI_{SME1} = \left[\frac{3.93}{3.93 + 3.33 + 2.93 + 3.05 + 3.18}\right] \times 100\% = 23.94\% \qquad (8.2)$$

$$CSPI_{SME2} = \left[\frac{3.33}{3.93 + 3.33 + 2.93 + 3.05 + 3.18}\right] \times 100\% = 20.28\% \qquad (8.3)$$

$$CSPI_{SME3} = \left[\frac{2.93}{3.93 + 3.33 + 2.93 + 3.05 + 3.18}\right] \times 100\% = 17.86\% \qquad (8.4)$$

$$CSPI_{SME4} = \left[\frac{3.05}{3.93 + 3.33 + 2.93 + 3.05 + 3.18}\right] \times 100\% = 18.56\% \qquad (8.5)$$

$$CSPI_{SME5} = \left[\frac{3.18}{3.93 + 3.33 + 2.93 + 3.05 + 3.18}\right] \times 100\% = 19.36\% \quad (8.6)$$

$$Order\ distribution\ (allocation)\ to\ SME_1 = \frac{23.94}{100} \times 50000 = 11{,}970\ shirts \quad (8.7)$$

However, an assumption for such order distribution works well when manufacturers are working as an extended enterprise. The ranking of CSDCs is an input process to the modelling and simulation processes in Section 6.5.9. Some modifications were also performed in the developed system; however, all inputs from Table 8.2 were fundamentally imperative in accomplishing the initial equitable order allocation processes in Section 6.5.4.

8.2.8 Potential techniques, tools, and management software

The third research question was on ‘what are the potential techniques, tools, and management software required in transforming the apparel sector and how to evaluate those techniques, tools, and software?’ This question was answered mainly in Chapter 3 (modelling and simulation method overview). Documentary review, expert judgement approach and checklist established the vital decision support tool. Firstly, three potential approaches that could have tackled this research were discussed: real-life experimentations (RLE), mathematical modelling (MM) and computer modelling and simulation (CMS). CMS was found to be the appropriate approach for this research (Sections 3.3 and 3.4).

Secondly, through the CMS approach, there are several simulations approaches such as discrete-event simulation (DES), system dynamics simulation (SDM), virtual reality-based simulation (VRS), agent-based simulation (ABS), gaming-based simulation (GBS), continuous simulation and Monte Carlo simulation (Section 3.4). DES was thus suggested to be applied to determine the feasibility of allocating orders equitably across a group manufacturer working as a single virtual entity.

Thirdly, there are several decision support tools or software applications and techniques required to digitalise the distribution process(es). This research systematically assessed several software packages, including FlexSim®, Arena®, Simul8®, AnyLogic®, Enterprise Dynamics®, Simio®, ProModel®, SAS® Simulation Studio and Witness Simulation®, whereas the potential software packages for solving the identified problem include Arena®, Simul8® and FlexSim® (Figures 3.2 to 3.4, and Tables 3.3 to 3.5). Among the three, the prominent discrete-event simulation software is Arena®.

8.3 Results from modelling and simulation of the MRMM model

8.3.1 Calibration, verification, and validation of the developed models

The fourth research question was on 'how to develop, verify, validate and illustrate the feasibility models for the UK apparel manufacturing (SMEs) regarding the processes of distributing (sharing) orders equitably? What worth this question is: does the T&A sector need the digitalised models? What are the criteria and evidence to prove the practicability of the developed models? How can the developed models be validated to be worth an implementation in the UK and elsewhere?

Due to the need of transforming the T&A industry, it was found that the sector needs digitalised models or systems. Both the interviews and theoretical underpinning results established the need for advanced models, especially for order securing and distribution should bulk orders be directed to the SMEs. Chapter 6 developed equitable order allocation while Section 4.11 and Chapter 7 demonstrated the feasibility of allocating orders equitably across several SMEs, given multiple configurations, parameters, and orders.

Equitable order allocation models, i.e. SRSM (Figure 6.6), SRMM (Figure 6.7), MRSM (Figure 6.8) and MRMM (Figures 6.32 to 6.34), were developed with much focus placed on the MRMM model. The realistic scenarios to model could have been the SRSM, SRMM and MRSM despite that the MRMM may be the most challenging. However, for multiple retailers to collaborate, this can happen, for example, when retailers would want to meet or exceed the minimum order quantities (MOQ) to place orders from the manufacturers (suppliers) as the majority have their well-defined MOQ. Similarly, achieving to model the MRMM scenario makes it easy to alter the model when requiring executing the SRSM, SRMM and MRSM because all the three scenarios are the subset of the MRMM scenario. However, the MRMM scenario also involves multiple retailers placing order independently, meaning that a group of manufacturers could receive multiple orders placed independently from several retailers. When questioned to retailers on the possibility of collaborating with other retailers to order quantities, they have not ordered collaboratively due to their experience in the business meaning that they are having long term relationship with several manufacturers (suppliers) who can handle their orders independently.

The verification process deals with the design (development) phases of a model. Verification provides a contrast of the established conceptual models with the used Arena® software. In more colloquially, the verification process involves debugging the developed model. Development of the MRMM model followed standard procedures on approaching the simulations, which included literature background and rigorous development approach. Therefore, model verification was performed by following the model design processes. Having established all models, their behaviour was visualised and rigorously checked to find out whether both models behave as the real situation.

For the model validation, this study executed model development to simulate processes. The processes information and/or data were collected from the industry, from literature, from partially related working models, and discussed with people from the industry who indicated that the followed procedures are fairable representation of the processes. For example, before developing the model, the processes involved in manufacturing apparel, the order processing procedures and several inputs were contributed by experts both from the field and the industry. So, the developed model is an actual representation of the physical processes which was confirmed. Although there is no prototype that was developed as that was out of scope for this study (Section 1.7), the components of the models were validated by drawing from literature, taking process maps from existing mapping literature sources, and actually talking from the industry which contributed how they order from their suppliers. The industry shared their information on how they interact with each other, what is the limit of the shared information, and they indicated the willingness in implementing an equitable order allocation system should multiple orders be directed to them. Face validation was also performed: the model validity was achieved by discussing with the experts. So, there is full confidence for the developed model because the process steps, the applied information, order sizes, interarrival time used, probability distribution functions used, etc., are all validated.

The next important thing is calibrating the developed model to a specific manufacturer. This can be accomplished by determining, for example, how long certain processes take, what are the typical order sizes, among other vital information. The calibration processes can also involve standard minute values for all the manufacturing processes. Nevertheless, the developed model(s) was not calibrated to simulate from any specific manufacturer, and this is a separate issue from both the verification and validation processes.

Furthermore, illustrating the practicability of the developed models was performed in Chapter 7. After utilising DACE concepts, the generated experimental results generally indicate that the proposed and developed MRMM model to allocate (distribute) orders are statistically significant equitably. Therefore, the results from DACE prove the successful demonstration of the feasibility of allocating orders equitably to a cluster of SMEs working collaboratively.

8.3.2 Equitable order distributed results from the Arena® software

Section 6.5.5 highlights four key performance indicators (KPIs) for the simulated MRMM model (Figures 6.32 to 6.34). These include the distributed bulk orders, the manufacturing (production) throughput time, resource utilisation and the total produced quantities. Arena® version 16.00.00 generates results consisting of the half-width (HW), average, maximum average, minimum average, maximum values, and minimum values. The average conveys the central value in a set of the gathered results: it is computed by dividing the total values in the set by their specific numbers. HW indicates the runtime confidence intervals by the performed 69 replications. The half-width in the ‘Arena® report’ can be presented, as shown in Figure 8.4 (Kelton *et al.*, 2004).

When Arena® indicates the **insufficient** results	• Means the model has run with insufficient data which can help to compute the half-width (HW) accurately. Usually, the model requires large samples which are normally distributed to display the HW; else, the results show insufficient at the column of the HW. Increasing the simulation time corrects the problem.
When Arena® indicates the **correlated** results	• Means the model has run with data which are not independently distributed. Increasing the simulation time corrects the problem.
When Arena® presents a specific **value**	• Means 95% of all the repeated 69 replications of the sample mean are within the interval sample average (mean) plus-or-minus the HW.

Figure 8.4: Categories of the commonly generated half-width results through Arena®.

This research digitalised the DSC for UK apparel manufacturing, mainly in enabling SMEs to secure enough orders from the British retailers through an equitable order allocation model. Figure 8.5 depicts the distributed orders to SMEs for a specific time.

(a)

Output	Average	Half Width	Minimum Average	Maximum Average
Distributed to Mz1	33261.65	178.05	31696.00	35008.00
Distributed to Mz2	24809.55	132.48	23760.00	25981.00
Distributed to Mz3	26905.94	142.53	25793.00	28334.00
Distributed to Mz4	28245.78	152.81	26769.00	29669.00
Distributed to Mz5	25810.25	134.58	24543.00	27106.00

(b)

(c)

Note(s): (a) The distributed quantities to five manufacturers. (b) Histogram showing the distributed quantities. (c) The plot for the distributed quantities for the entire simulation run time.

Figure 8.5: Executed order distribution (order sharing) process for the MRMM model.

Figure 8.5(a) was generated through the Arena® summary report after the initial simulations (Figures 6.32 to 6.34); for Figure 8.5(b), the results were generated using the Microsoft® Excel version 2016 after exporting the results, and for Figure 8.5(c), the results were generated by the Arena® Output Analyser tool: these are amongst the key findings of this study. The HW in Figure 8.5(b) is small compared to other results, thus indicating that the precision is good.

Results in Figure 8.5 were generated based on a single simulation, i.e. before conducting alternatives. For the several configurations, such processes were executed in Chapter 7. DACE generated essential data to execute the feasibility of allocating multiple order sizes equitably given multiple configurations, inputs, and factors. The experimentation was successfully performed, as for all set scenarios, the system statistically managed to allocate orders equitably. Also, the results in Figure 8.5 bridge the identified research gap that simulation of order distribution was not available, as highlighted by Medvedev *et al.* (2019).

From Figure 8.5, precisely for the quantities distributed to Mz_1, the quantities are averaged to 33261.65 with 178.05 as the HW. This should thus be written as 33261.65 ± 178.05 [33439.70, 33083.60], and can be interpreted as the displayed results are correct by a 95% confidence interval. Since there is no half an apparel, thus precisely it is 33262 ± 178 [33440, 33084]. The maximum and minimum values are 31690 and 35008, respectively, for the first manufacturer. Likewise, the HW results show that this interval of 178.05 is minimal compared to the average value at the centre (33262). Therefore, precision is excellent. If the HW could be almost the same with the mean (μ), that could imply that the precision was not good; the number of replications thus had to be increased. It should also be noted that the results generated from several runs (number of replications) are 'normally' distributed. Noting that apparel products cannot be half a product, this necessitates rounding to the nearest integer using Mathematical function in Arena® developed as an expression, i.e. ANINT (..). Therefore, the distributed products are either an integer or near to the integer.

Retailers (Rd_1 to Rd_5) may be dealing with different apparel categories, which can include basic, fashion or fast fashion (Table 6.7). One of the assumptions stated is that for the demonstration purposes, initially, all retailers request similar apparel. The classification of clothes (apparel) ordered can be referred from Figure 2.1 or Figure 6.12 (the frequently purchased clothes by women and men in the UK between 2015 and 2018). Arena® generated results depicted in Figure 8.6: this illustrates the distributed orders of Figure 8.5(a)-(c), whereby the specified apparel categories are correctly classified as well. The marked ones in Figure 8.6 are for the first manufacturer; others can thus be interpreted similarly. The apparel preferences can be altered based on the specifications of each retailer when applying the model. Orders preferences can be executed using the DECIDE module in Figure 6.22.

Number Out	Average	Half Width	Minimum Average	Maximum Average
Apparel Orders	198083.33	980.86	187508.00	206014.00
Jeans Mz11	11499.36	66.43	10671.00	12130.00
Jeans Mz21	9732.19	51.38	9153.00	10153.00
Jeans Mz31	8535.16	49.45	8033.00	9022.00
Jeans Mz41	8888.22	49.66	8386.00	9346.00
Jeans Mz51	9251.90	53.49	8762.00	9774.00
Shirt Mz13	7440.13	45.78	7020.00	7822.00
Shirt Mz23	6305.41	37.73	5979.00	6742.00
Shirt Mz33	5522.14	32.95	5193.00	5880.00
Shirt Mz43	5731.22	33.60	5424.00	6093.00
Shirt Mz53	5995.25	35.78	5560.00	6302.00
Skirt Mz14	5189.42	32.81	4858.00	5442.00
Skirt Mz24	4396.42	28.06	4139.00	4625.00
Skirt Mz34	3851.43	22.83	3514.00	4068.00
Skirt Mz44	4019.32	26.26	3801.00	4314.00
Skirt Mz54	4175.22	29.74	3914.00	4509.00
Trouser Mz12	9378.04	59.73	8768.00	10044.00
Trouser Mz22	7911.93	47.87	7269.00	8320.00
Trouser Mz32	6970.03	39.63	6536.00	7320.00
Trouser Mz42	7237.99	42.96	6739.00	7739.00
Trouser Mz52	7556.55	41.95	6983.00	7983.00

Apparel products for the first

Figure 8.6: Categorised apparel types (entities) for the five manufacturers.

8.3.3 Resources utilisation for the machines and operators

Arena® provides scheduled and instantaneous utilisation (Figure 8.7). Sewing Mz_1 to Sewing Mz_5 represent the five sewing workstations for the first to the fifth manufacturer, respectively. Resources process incoming entities (orders): entities can be delayed; delayed and released; seized and delayed; or seized, delayed, and released, depending on the purpose of the defined resource(s). In this study, all resources seize, delay, and release all the received entities. Apparel manufacturers (Mz_1 to Mz_5) process the received orders through the resource utilisation. The resources in Arena® were defined in Figures 6.29 and 6.30. The resources can be defined as *Fixed Capacity* or *Based on Schedule*: since the resources differ between manufacturers, this study defined resources based on the latter category. Further detailed discussion on these results is in Section 9.2.2.

Time Persistent	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
SU Sewing Mz1	1.0024	0.00	0.9689	1.0039	0.00	1.0270
SU Sewing Mz2	0.3373	0.00	0.3042	0.3717	0.00	1.0000
SU Sewing Mz3	0.4650	0.00	0.4203	0.5064	0.00	1.0000
SU Sewing Mz4	0.6055	0.01	0.5493	0.6660	0.00	1.0032
SU Sewing Mz5	0.4771	0.00	0.4319	0.5291	0.00	1.0118

Figure 8.7: The scheduled utilisation (SU) for the five SMEs.

8.3.4 Manufacturing (production) throughput time:

Figure 8.8 depicts the manufacturing (production) throughput time. It is an aggregate time used by each category of the apparel product in the manufacturing process. The received apparel orders were distributed into specific categories—jeans, shirts, trousers, skirts for Mz_1 to Mz_5. The production times are essential as they help to estimate the total waiting time for the order: such results can thus inform the SMEs of the required lead-time.

Entity

Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Jeans Mz11	27341.70	1,302.96	13118.29	38770.47	1156.53	113439.90
Jeans Mz21	6530.10	7.62	6462.68	6584.01	316.18	34311.32
Jeans Mz31	4656.61	6.27	4589.68	4711.39	238.26	29333.80
Jeans Mz41	4795.23	6.90	4723.31	4888.41	291.42	31467.53
Jeans Mz51	4794.86	6.43	4739.33	4873.77	252.30	32221.94
Shirt Mz13	27341.36	1,297.72	13152.48	38619.80	1315.57	111807.83
Shirt Mz23	6548.97	11.67	6428.88	6650.79	310.08	32793.67
Shirt Mz33	4657.22	9.02	4573.07	4740.96	212.05	33141.40
Shirt Mz43	4809.63	8.37	4731.67	4911.16	303.03	30464.36
Shirt Mz53	4804.33	8.46	4700.13	4898.13	296.88	27726.51
Skirt Mz14	27341.34	1,299.88	13179.98	39151.08	888.67	110256.74
Skirt Mz24	6558.77	13.11	6443.39	6722.59	402.37	37348.36
Skirt Mz34	4682.02	8.73	4598.33	4761.78	298.48	30681.66
Skirt Mz44	4829.59	10.44	4748.12	4904.91	349.60	31126.86
Skirt Mz54	4817.10	11.15	4669.17	4971.47	353.89	34074.76
Trouser Mz12	27335.28	1,296.78	13201.82	38635.78	1162.22	111812.90
Trouser Mz22	6556.79	8.99	6467.71	6663.76	348.89	39112.08
Trouser Mz32	4673.08	9.01	4582.02	4778.10	278.57	31313.52
Trouser Mz42	4819.80	7.09	4758.44	4894.06	306.98	32751.03
Trouser Mz52	4808.52	6.50	4739.22	4879.44	268.39	33663.16

Apparel products for the fifth manufacturer

Figure 8.8: The manufacturing throughput time for the MRMM model.

From Figure 8.8, precisely for the total time of 'Jeans' for the fifth manufacturer (*Mz_5*), the average time is 4794.86 with 6.43 as the HW: this should thus be written as 4794.86 ± 6.43 [4801.29, 4788.43], and can be interpreted as the displayed results are correct by a 95% confidence interval. The maximum and minimum values are 32221.94 and 252.30, respectively, for the 'Jeans' product of the fifth manufacturer. Similarly, the HW results show that this interval of 6.43 is minimal compared to the average value at the centre (4794.86). Therefore, precision is excellent. The marked ones in Figure 8.8 are for the fifth manufacturer; other results can also be interpreted similarly.

Despite that this research chiefly illustrated the feasibility of digitalising equitable order allocation of the secured orders to several manufacturers, it was significant to generate the manufacturing (production) throughput time for all critical operations designed. Arena® also gives statistics on the 'value-added time per entity (VATPE)', 'wait time per entity (WTPE)' and 'total time per entity (TTPE)'. Figures 8.9 and 8.10 display the total time per entity in minutes: in both figures, the sewing workstation consumes a large amount of time because, in an actual scenario, it involves several steps than other processes during apparel manufacturing (Collins and Glendinning, 2004). In Figures 8.9 and 8.10, the TTPE includes the VATPE and WTPE: Mz_1 to Mz_5 stand for the first to the fifth manufacturer, respectively.

SMV or SAM data to manufacture garments were extracted from Brother Industries (1995) (Table 6.3). SMV data illustrate VATPE, WTPE and TTPE: other non-value-added processes are also included for the WTPE, e.g. an entity waiting for scheduling or assignment processes. From Figures 8.9 and 8.10, Mz_1 to Mz_5 are the five apparel manufacturers. In Figure 8.9, the 'Back body process workstation Mz_1' processed each entity for the average of 3.0191 minutes as TTPE without any half-width value. The minimum and maximum average values are 2.9794 and 3.0639 minutes, respectively, for the 'Back body process workstation Mz_1' of the first manufacturer. Also, the minimum and maximum values are 0.068 and 24.9329 minutes, respectively. Other results in Figures 8.9 and 8.10 can be interpreted similarly. These results in Figures 8.9 and 8.10 are essential as they show the total amount of time needed for apparel to pass through a manufacturing process(es) after being equitably distributed to specific manufacturers (Mz_1 to Mz_5). The simulation of apparel manufacturing included part process, front process, back body process, collar process, sleeve process, facing process, back body lining process, front body process, cuff process, body lining process, sewing process, inspection and finishing process workstations. Each specified process workstation with the corresponding time of the apparel category requires raw materials and other accessories to be converted and processed, respectively, into the finished apparel. However, the simulation in Figures 6.32 to 6.34 considered CMT, thus excluding the initial procedures and raw materials conversion to manufacture apparel.

Values Across All Replications

MRMM Model

Replications: 69 Time Units: Minutes

Process

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Back body Process Workstation Mz1	3.0191	0.00	2.9794	3.0639	0.06802833	24.9329
Back body Process Workstation Mz2	2.9488	0.00	2.9118	2.9890	0.07396820	23.5053
Back body Process Workstation Mz3	2.9611	0.00	2.9199	3.0082	0.07893095	22.4267
Back body Process Workstation Mz4	2.9033	0.00	2.8551	2.9341	0.05965768	24.8689
Back body Process Workstation Mz5	2.9624	0.00	2.9185	3.0112	0.05536323	22.5061
Body Lining Process Workstation Mz1	4.0953	0.00	4.0891	4.1013	3.8608	12.2549
Body Lining Process Workstation Mz2	4.1437	0.00	4.1386	4.1506	3.9116	9.7118
Body Lining Process Workstation Mz3	4.1934	0.00	4.1880	4.1998	3.9136	10.6097
Body Lining Process Workstation Mz4	4.4618	0.00	4.4544	4.4713	4.2216	11.3278
Body Lining Process Workstation Mz5	4.0257	0.00	4.0188	4.0315	3.7912	10.8011
Finishing Process Workstation Mz1	0.1681	0.00	0.1674	0.1689	0.00	0.7666
Finishing Process Workstation Mz2	0.1713	0.00	0.1706	0.1721	0.00	0.7086
Finishing Process Workstation Mz3	0.1711	0.00	0.1702	0.1719	0.00	0.7360
Finishing Process Workstation Mz4	0.1921	0.00	0.1897	0.1939	0.00	1.4016
Finishing Process Workstation Mz5	0.1711	0.00	0.1703	0.1719	0.00	0.6096
Front body Process Workstation Mz1	4.1337	0.01	4.0460	4.2441	1.1817	49.1287
Front body Process Workstation Mz2	4.0245	0.01	3.9611	4.1268	1.2057	42.1205
Front body Process Workstation Mz3	3.9796	0.01	3.9262	4.0414	1.1461	37.9228
Front body Process Workstation Mz4	4.1469	0.01	4.0771	4.2153	1.2422	37.9428
Front body Process Workstation Mz5	7.3120	0.06	6.7299	7.9050	0.9769	129.58
Inspection Process Workstation Mz1	0.1667	0.00	0.1660	0.1674	0.00	0.5221
Inspection Process Workstation Mz2	0.1672	0.00	0.1665	0.1680	0.00	0.6967
Inspection Process Workstation Mz3	0.1668	0.00	0.1662	0.1674	0.00	0.5051
Inspection Process Workstation Mz4	0.1916	0.00	0.1894	0.1936	0.00	1.5136
Inspection Process Workstation Mz5	0.1669	0.00	0.1660	0.1674	0.00	0.6523

Figure 8.9: Total time per entity at each manufacturer's workstation (part 1).

Replications: 69 Time Units: Minutes

Process

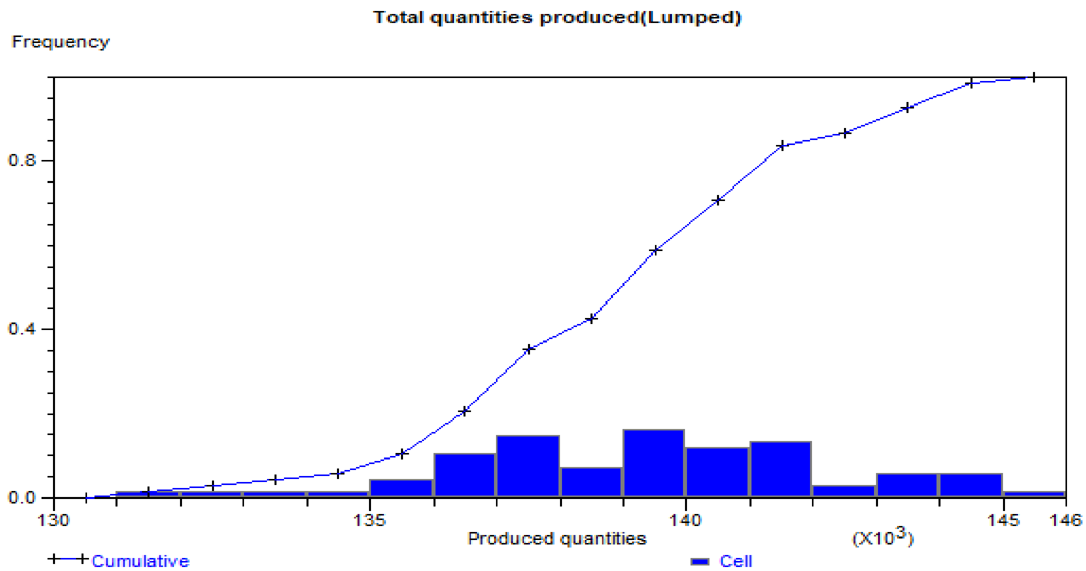
Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Packaging Process Rd1	2.0943	0.00	2.0683	2.1268	0.00000062	29.0140
Packaging Process Rd2	2.0607	0.00	2.0235	2.0990	0.00000221	26.5094
Packaging Process Rd3	2.0633	0.00	2.0167	2.0943	0.00000100	28.8983
Packaging Process Rd4	2.0708	0.00	2.0345	2.1057	0.00000056	34.6001
Packaging Process Rd5	2.0671	0.00	2.0380	2.1030	0.00000012	31.7235
Parts Process Workstation Mz1	8.1815	0.05	7.8065	8.6693	2.1068	113.07
Parts Process Workstation Mz2	7.1112	0.03	6.8033	7.4907	2.0971	77.9011
Parts Process Workstation Mz3	6.7092	0.02	6.4647	6.9763	2.1564	67.3526
Parts Process Workstation Mz4	6.7963	0.02	6.5664	7.0287	2.1446	76.2600
Parts Process Workstation Mz5	6.9493	0.03	6.7227	7.3624	1.9280	91.1244
Sequence Assign Process Mz1	3.2251	0.02	3.0684	3.3628	0.00000000	60.0362
Sequence Assign Process Mz2	3.2357	0.01	3.1026	3.3640	0.00000001	60.0193
Sequence Assign Process Mz3	3.2177	0.02	3.0326	3.3792	0.00000000	60.0311
Sequence Assign Process Mz4	3.2151	0.01	3.0781	3.4081	0.00000001	60.0354
Sequence Assign Process Mz5	3.2149	0.02	3.0438	3.4040	0.00000001	60.0188
Sewing Process Workstation Mz1	19504.27	1,280.92	5542.79	30845.69	0.03769791	51512.11
Sewing Process Workstation Mz2	32.5025	0.69	25.5670	39.3196	0.00	322.30
Sewing Process Workstation Mz3	18.3334	0.33	16.2886	24.0999	0.00	430.49
Sewing Process Workstation Mz4	40.1727	1.63	26.4475	62.4789	0.00	1204.42
Sewing Process Workstation Mz5	32.6009	0.43	28.2068	37.2527	0.00	490.15
Sleeve Process Workstation Mz1	1.1678	0.00	1.1661	1.1696	0.9343	3.2265
Sleeve Process Workstation Mz2	1.0843	0.00	1.0827	1.0860	0.8459	3.1324
Sleeve Process Workstation Mz3	1.0842	0.00	1.0826	1.0858	0.8506	2.8305
Sleeve Process Workstation Mz4	1.1176	0.00	1.1162	1.1201	0.8711	2.7253
Sleeve Process Workstation Mz5	1.1844	0.00	1.1821	1.1861	0.9548	2.8606

Figure 8.10: Total time per entity at each manufacturer's workstation (part 2).

8.3.5 Total produced apparel orders.

The shown model in Figures 6.32 to 6.34 was run. On average, the total produced apparel orders are 199,477 units with an HW of 980.86 for a one-year production period. The minimum and maximum averages are 187508 and 206014, respectively. Also, Figure 8.11 shows a generated Histogram through the Arena® *Output Analyser* tool for the total produced quantities from the simulated MRMM model. The graph shows the cumulative results. Based on Figure 8.11, the percentage for the produced orders by five manufacturers was 86.76%, and this per cent gives quantities between 143,000 and 144,000, which required 59 replications on average. All other data can be interpreted similarly.



Histogram Summary
Total quantities produced(Lumped)

Cell	Cell Limits From	Cell Limits To	Abs. Freq. (Time) Cell	Abs. Freq. (Time) Cumul.	Rel. Freq. Cell	Rel. Freq. Cumul.
1	-Infinity	1.31e+005	0	0	0	0
2	1.31e+005	1.32e+005	1	1	0.01471	0.01471
3	1.32e+005	1.33e+005	1	2	0.01471	0.02941
4	1.33e+005	1.34e+005	1	3	0.01471	0.04412
5	1.34e+005	1.35e+005	1	4	0.01471	0.05882
6	1.35e+005	1.36e+005	3	7	0.04412	0.1029
7	1.36e+005	1.37e+005	7	14	0.1029	0.2059
8	1.37e+005	1.38e+005	10	24	0.1471	0.3529
9	1.38e+005	1.39e+005	5	29	0.07353	0.4265
10	1.39e+005	1.4e+005	11	40	0.1618	0.5882
11	1.4e+005	1.41e+005	8	48	0.1176	0.7059
12	1.41e+005	1.42e+005	9	57	0.1324	0.8382
13	1.42e+005	1.43e+005	2	59	0.02941	0.8676
14	1.43e+005	1.44e+005	4	63	0.05882	0.9265
15	1.44e+005	1.45e+005	4	67	0.05882	0.9853
16	1.45e+005	+Infinity	1	68	0.01471	1

Figure 8.11: A histogram for the total produced quantities from the MRMM model.

In summary, Chapter 8 presented the qualitative results and the generated results from initial simulations of the MRMM model (Figures 6.32 to 6.34). Sixty-nine replications were set to run the developed model by using the Arena® simulation software version 16.00.00 (academic licence). Since the SRSM, SRMM and MRSM models are the subsets of the MRMM; the results are thus for the MRMM model only. To generate the results for the SRSM, SRMM and MRSM models require modification for both the retailer(s) and the manufacturer(s). Arena® software generates several results categories; this chapter only summarised the results for the stated KPIs (Section 6.5.5). The results for the application of DACE to this study should be referred from Chapter 7. Further discussion on these results is in Chapter 9.

Chapter 9 Discussion

9.1 Introduction

This chapter discusses arguments on the generated results, analysed results, and general research perspectives. The discussion focuses on the equitable order allocation results, related studies, resource utilisation, decision criteria, hypotheses tests, quality indicators of models, qualitative data results, the model execution processes, the main users of the developed model, and practical, managerial, and theoretical implications.

9.2 General discussion on the generated results

9.2.1 Equitable order allocation results and digitalisation

The most significant results for this study rely on the developed and simulated MRMM model (Figures 6.32 to 6.34) together with the experimental setup and responses (Figures 7.6 to 7.9): DACE application to this study. The experimental setup is also referred to as parametric analysis (Altiok and Melamed, 2007). These findings (Chapters 7 and 8) close the gaps which were identified by Medvedev *et al.* (2019) and Di Pasquale *et al.* (2020), among others, regarding order allocation studies. Also, the order allocation models with consideration of multiple retailers, multiple manufacturers (SMEs) together with multiple settings extend studies that focused on multiple retailers to a single manufacturer, single retailer to multiple manufacturers or vice versa (Kawtummachai and Hop, 2005; Guo and Li, 2014; Islam *et al.*, 2017). Among the studies that considered multiple retailers with multiple manufacturers includes the study by Xiang *et al.* (2011; 2014). Xiang *et al.'s* (2014) research acknowledged that several studies that executed order allocation considered the allocation problem as the deterministic optimisation process based on the commonly referred to as 'traditional decision criteria' such as cost (price), delivery, quality and suppliers' capabilities. Thus, the generated results in Chapter 7 through the application of DACE considered stochastic processes to model some of the time taken in the process steps. This also closes the gap of solely focusing on deterministic processes in distributing orders.

Other studies examined the distribution of the manufactured products from the manufacturers to the retailers contrary to the distribution process as part of sharing, dividing or allocating orders: such research include the studies by Karbasian *et al.* (2008) and Kumar *et al.* (2015). In much of the literature, the order allocation studies applied mathematical modelling approaches (Guo and Li, 2014; Scott *et al.*, 2015; Islam *et al.*, 2017; Gören 2018) contrary the used methodology for this study: a computer simulation approach.

SMEs face challenges in utilising their manufacturing capacities and capabilities due to lack of enough secured apparel orders, among other reasons. Their limitation in size makes them not able to compete enough to secure enough orders from large retailers (CSWEF, 2015; Brill *et al.*, 2019). Through this study, the results (Figures 7.28 to 7.30, 8.5 and 8.6) indicate that working jointly as a cluster of entities dictates the SMEs to distribute or allocate the received orders equitably amongst themselves. Bulk orders can be secured because a cluster of SMEs working jointly can make them work as a single large manufacturer virtually: this can thus enable their long-term survival in the current competitive manufacturing environment. Working jointly is an opportunity for UK SMEs because large retailers prefer working with "fewer, more efficient, larger suppliers and factories" (CSWEF, 2015, p.27) or ordering from oversea firms (Brill *et al.*, 2019). Working as a single virtual entity can also assist in having a large firm recognised form of representation. CSWEF (2015) highlights that several UK SMEs are not integrated into existing forms of representation. Thus, the findings of this study which emphasise on working collaboratively with a recognised enterprise may close such a gap which emphasise collaboration amongst a cluster of SMEs.

Working as an EE could also allow the large retailers to place bulk orders to SMEs with confidence that as a group, the SMEs can manufacture as per the specifications without extending the lead time. Traditionally, the T&A sector faces a long lead time (Al-Zubaidi and Tyler, 2004; Tyler *et al.*, 2006; Berg *et al.*, 2017), something which can make some retailers import their products due to the long lead time. For example, Tyler (2008) emphasises that supply chains should enhance responsiveness by finding optimal approaches to reduce lead times. Thus, by having the digitalised model, which is successfully validated statistically to allocate orders amongst SMEs, could thus reduce the lead time because SMEs could work jointly on all the secured orders. Considering the ultimate goal of digitalising equitable order allocation process; digitalisation, on its own, is thus acknowledged to facilitate the lead time reduction (Schlaepfer *et al.*, 2015; Wee *et al.*, 2015; Berg *et al.*, 2017).

There are great relationships amongst the generated results from the initial simulations of the MRMM model (Figures 6.32 to 6.34) with the results in Figures 7.28 to 7.30 (DACE). The distribution processes show excellent trends in the generated results because the results are proportional to the considered inputs in developing models. For example, the results in Figures 8.5 and 8.6 show direct proportional results when compared with results in Figures 7.28 to 7.30: the results through DACE (Chapter 7) conform with the initial generated results (Figures 8.5 and 8.6). The results indicate that when given multiple orders with multiple scenarios, the developed MRMM model provides potential solutions or turns that there is no possibility of fulfilling the received orders. To validate such a situation, three conditions were set in Section 7.2.2—low, medium, and high placed orders—with many controllable factors (Figure 7.3 and Table 7.2). Initial order sizes were collected from the UK retailer. In simulating the model, FIFO was considered as the queue-ranking rule. In Section 6.5.9, four 'queue-ranking rules'—FIFO, LIFO, LAV and HAV—were discussed. LIFO is also called LCFS (last come, first served) and FIFO is FCFS (first come, first served) (Altiok and Melamed, 2007). So, the application of DACE to this study provides a potential solution(s) on enabling equitable order allocation in an extended enterprise framework. Also, although the study was not the longitudinal one, still the discrete-event modelling can execute longitudinal effects, including proving how a cluster of SMEs would perform for over a year. This is only possible after executing the verified and validated model. The model can be altered for the initial provided inputs and replication length to fit the required time.

The application of DACE to this study contributes probably to a new insight on illustrating computer simulation for the order allocation processes in a cluster of SMEs working collaboratively. This is because hardly any study that addressed the order allocation problem applied DACE. For example, Chen *et al.* (2014) applied Least-square curve-fitting analyses to illustrate the model fitness; Scott *et al.* (2015) applied the decision model in a real industry; Xiang *et al.* (2014), Islam *et al.* (2017) and Gören (2018) all performed a sensitivity analysis. Overall, the use of DACE substantiated to probably make a timely contribution given policy interest in the digital economy in all phases of the manufacturing industries.

From the DACE processes in Figures 7.6 to 7.9, the model proves to allocate orders across a cluster of SMEs equitably. Previous studies did not allocate orders in a cluster of manufacturers, suppliers, or vendors in consideration of an extended enterprise context (Kawtummachai and Hop, 2005; Karbasian *et al.*, 2008; Xiang *et al.*, 2014; Islam *et al.*, 2017; Gören, 2018), among others. To develop a model, some initial data were gathered from the UK retailer and manufacturer (Section 8.2), while other realistic assumptions were stated to finalise modelling and simulation processes (Section 6.5.9). If bulk orders are placed to an SME, it is probably hard to process all orders on time. This occurs when multiple retailers place orders to a single manufacturer—the MRSM model (Figures 6.3 and 6.8). However, when a cluster of SMEs works jointly, it can process quickly to meet retailers' lead time. A similar observation was made by several researchers that examined the significance of an extended enterprise (Owen *et al.*, 2008; Spekman and Davis, 2016) and Collaboration Design Method (Kazantsev *et al.*, 2019). Ideally, working as an EE facilitates capacity and capability utilisation, resource utilisation, shorter lead times, customer satisfaction, improved service levels, cost reduction, stronger information-sharing practice, technologies sharing and clearer responsibility divisions amongst business partners (Jagdev and Browne, 1998; Browne and Zhang, 1999; Owen *et al.*, 2008; Spekman and Davis, 2016).

UK apparel manufacturing SMEs, similar to other manufacturing industries, need orders to increase their profits. Lack of sufficient secured orders forces their resources to remain idle, thus making a massive loss to their factories. Other problems include wages reduction and working time reductions as workers can be sent home unwillingly due to lack of orders or sufficient orders in the UK (CSWEF, 2015). For example, CSWEF (2015, p.33) in its UK study found that 75% of their respondents did not "work the same number of hours every day, the same number of days every week or the same number of hours every week. Nor do they have fixed starting and finishing times." This was due to lack of orders and large fluctuations of the secured orders by UK apparel manufacturers. In the long run, many SMEs cannot sustain their business if retailers could keep importing massive products: thus, could lead to the closure (liquidation) of the firms (Taifa *et al.*, 2020c).

The next important aspect is, for example, by speaking to SMEs and demonstrating to them that if they work together, they can get bigger order sizes and will be a better concept for them. Ideally, companies would be happy with such information. Nevertheless, the key concept should be how would they work together, considering that manufacturers (SMEs) have different availability, capabilities, and other preferences. Therefore, it is vital demonstrating how manufacturers can work together with excellent partnerships. The critical thing should be about gathering data from simulations: such simulations are experiments. Experiments were thus designed in an objective way to collect the needed data to explore different order allocations in multiple approaches. Using DACE concepts (Chapter 7), this study chiefly designed experiments to explore how different order sizes allocation works and how to gather pertinent data. Thus, what information or data required, what level of information needed to work on, what are the required experimental setup, what analyses required, among other relevant aspects: this is what DACE was for this study.

Simulating designed experiments can be used in multiple approaches. Simulating a model generates data. When generating data from the simulations, data can be applied in different ways. Data can be used to compare with reality, i.e. testing the model accuracy, which is model validation. Simulations can also be used to generate data that would predict times taken for the values that were simulated. Simulation can also be used to see how the setting of different design parameters can create a more robust system for the uncontrollable values perhaps by setting certain variables higher because some of the fluctuations in times do not have the same impact. This study applied simulation data to provide information or data to show the feasibility of working together and allocating orders equitably. Previous studies did not apply computer simulation approach to illustrate the feasibility of working together in a cluster, how to generate data and how orders can be allocated (distributed) equitably through DACE (Kawtummachai and Hop, 2005; Karbasian *et al.*, 2008; Xiang *et al.*, 2014; Chen *et al.*, 2014; Kumar *et al.*, 2015; Islam *et al.*, 2017; Gören, 2018). Unlike most of the previous order allocation studies, this study bridges that gap of demonstrating feasibility.

Moreover, the results in Figures 7.24 to 7.27 showed the generalisations amongst the results because the generated data through computer simulation experiments established the approximated response surface function. The response surface—surface plots and contour plots—were generated without any known function as the simulated model had to be considered as a black box (Kleijnen, 2015) which comprises inputs, parameters and noise factors. The equations for non-complicated systems form a metamodel which can be easily written and used to forecast other factors. Still, the generated results (Figures 7.24 to 7.27) are much noteworthy as they estimate the response surface of the MRMM model. The surface of the distributed orders and the total produced quantities can be estimated as the plots display the direction and magnitude of the responses. So, the generation of such plots helps to identify the required changes for some parameters to generate optimal responses. If an analyst would need to perform further analyses, the assessment of the models' behaviour of the response surface, can thus be performed by altering some inputs and factors slightly without rerunning the actual simulation program in Figures 6.32 to 6.34. An increase in any of the factors increases the magnitude of the responses.

Although the study generated validated vital findings, the results were not applied in any industry because an implementation was out-of-scope for this study (Section 1.7). However, considering that the data deployed are realistic as the majority of them were gathered from the T&A industry, and all assumed data were considered with logic and valid reasons, it is still statistically significant that it is feasible to place an order and equitably allocate to all collaborating partners based on their performance ratings.

Moreover, although the model (Figures 6.32 to 6.34) was statistically validated to allocate orders equitably, yet without a collaborative approach amongst SMEs, nothing much significant can be achieved. Similar viewpoints were indicated by Owen *et al.* (2008) who emphasised having "collaborative innovation throughout the extended enterprise"; Erol *et al.* (2010) emphasised having collaborative network; and Spekman and Davis (2016) highlighted both intra and inter-organisational collaborations. For the 21st Century, firms require digitalised business tactics which are supported by information sharing practice (Cheng and Wu, 2005; Du *et al.*, 2012; Lotfi *et al.*, 2013; Kumar *et al.*, 2017). In the digital era, firms should cooperate by sharing information without violating intellectual property rights, security, trust issues, among other critical agreements.

Obviously, not necessary that all collaborations can be successful as Spekman and Davis (2016, p.45) stated that "cooperation is a necessary but not sufficient condition." Firms must willingly share their details on the computing cloud, including their capacities and capabilities, among other factors (Du *et al.*, 2012; Lotfi *et al.*, 2013). The external integrated systems with the cloud (virtual factory) should rank each firm for equitably allocating orders.

The emphasis is on information sharing practice which must be an IT-enabled system. Historically, managers are sceptical about sharing details with their business partners due to concerns about risks, privacy, competition, costs to run some sophisticated information sharing systems, security, complexities, etc. (Baihaqi and Sohal, 2013; Tran *et al.*, 2016). Continuation of scepticism on sharing information within the T&A sector will disadvantage execution of an equitable order allocation model. Sharing information needs commitment from retailers and SMEs to have mutual and genuine useful collaborations. Partnerships need trust to each partner, effective interaction to solve ethical compliance aspects as currently ethical issues are prioritised in sourcing both domestically and internationally (Benstead *et al.*, 2018). Certainly, it is logical that the execution of an equitable order allocation is not 100% feasible, but for bulk orders, the developed approach is essentially needed.

In the developed MRMM model (Figures 6.32 to 6.34), together with all the gathered information, it is statistically significant that the execution of an EE is possible and has a significant influence in increasing the manufacturers' survival. Also, the impact on enabling collaboration and integration in securing apparel orders from retailers in the digital transformation can be measured based on how coordination and control are affected. For example, information sharing is acknowledged to be one of the key enablers in this matter; though, the same requires more visibility, information security, trust and transparency to develop the long term positive collaborative relationships, both vertically and horizontally (Kaipia and Hartiala, 2006; Du *et al.*, 2012; Baihaqi and Sohal, 2013; Wang *et al.*, 2014).

Additionally, for decades now the world population increases more similar to a linear trend rather than exponentially for many countries (Roser *et al.*, 2013), including the UK: this may certainly lead to huge demand increases in apparel products made in the UK and elsewhere. Considering that SMEs have not fully utilised their capacities and capabilities (Kazantsev *et al.*, 2019), such a scenario should lead the way in grabbing the opportunity of manufacturing in the future, specifically for small batching manufacturing and sustainable products. SMEs, meanwhile, should have the right technology, including Industry 4.0 (digitalisation)-enabled technologies. Eventually, the right workforces to operate the entire sector are also needed. Having the right digitalised technology, including the digitalised equitable order allocation system, is not enough to revitalise the apparel sector. It is crucial to emphasise working as a cluster of SMEs who can collaborate; nevertheless, missing the right technology would lead to failure in meeting the lead-times (quick response) to retailers which could increase importation of products. Digitalisation concepts through Industry 4.0 viewpoint, mainly in today's business competition, should also persuade companies (SMEs) to reconsider their supply chain plans, policies, approaches, and vision to delve into the newly available opportunities that require working jointly. Although digitisation, digitalisation, and digital transformation concepts are now essential for securing competitive advantages; SMEs need to prioritise having implementable and robust strategies that can help in realising working jointly. It might be short-sighted thinking that IT-enabled systems alone might renovate the apparel sector's supply chains: research background emphasises having suitable plans, policies and strategies must also be prioritised for SMEs that expect to achieve the success of the digital transformation and collaboration (Kane *et al.*, 2015; Kazantsev *et al.*, 2018).

9.2.2 Resource utilisation results

The developed computer simulation model executed resource utilisation results. For example, the instantaneous utilisation (IU) and scheduled utilisation (SU) provide useful information (Figure 8.7) based on several conditions and purposes. In Arena®, if the manufacturers' resources remain fixed for the entire simulation time, thus the IU and SU reports would be the same: it means that for the considered resources, none of them is in an inactive or failed state at any point during the simulation. In this study, the IU statistics illustrated how busy are the used resources for the entire simulation time. Based on Figures 8.9 and 8.10, the sewing process took an extended period more than other processes: this report thus highlighted the SU results at each manufacturer's workstation. The IU statistics can be interpreted on how busy the resources are only if the Arena® system includes the schedule, which is attached to the utilised resources. The schedule is for the capacities of the resources, as shown in Figure 6.29. The IU and SU can be useful knowing how busy the deployed resources are, and also can help for the recruitment processes (staffing) if some workstations are over utilised beyond the required capacities. The results can also indicate the need to increase the load to the underutilised workstations. Therefore, the IU and SU are vital in line balancing of the manufacturing processes, mostly the assembly or the sewing processes which require many workforces.

In Figure 8.7, the SU for the first manufacturer (Mz_1) exceeds 1, while normally, the utilisation should not exceed 1. According to Kelton *et al.* (2004), SU exceeds beyond 1 when there is, e.g. 8-hour run time and the resource (e.g., an operator or a machine) is scheduled to be available for only the first 4 hours. Now, for example, if the resources were assigned at time 0 to process entities with duration 5, thus, at time 4, the capacity of the resource would be reduced to 0, but the resource would remain assigned until time 5. So, this would report the SU, which exceeds 1. Thus, the IU and SU would be 0.625 and 1.25, respectively.

9.2.3 Decision criteria discussion

In Chapter 5, the literature focused on information sharing practices and the required decision criteria. The critical success decision criteria (CSDCs) were essential to enable the ranking processes of SMEs. A list of CSDCs was developed through the interview inputs (Section 8.2.4) and the methodological decision analysis model (Figure 5.5). The developed CSDCs (Figures 5.6 and 5.7) are of practical significance as both retailers within the T&A sector and other firms can employ the same when ranking their suppliers. This enables them to know their suppliers, primarily when their suppliers work synergistically.

The study also found one of the interesting factors within sourcing networking: modern slavery (contemporary slavery) (Section 8.2.4). Equitable order sharing amongst a cluster of SMEs working as a single virtual entity involves firms of different organisational culture and principles. It is sometimes likely that one of the collaborating firms to have unethical operations, something which can include modern slavery practice. In avoiding this, people in business are now under necessary high pressure, both from law enforcers and the society, that such practices must be eradicated in the (entire) supply chains. For example, the UK government is one among the leading countries that enacted the law, which requires retailers to include ‘modern slavery statement’ on their websites (Benstead *et al.*, 2018; Benstead, 2018). The statement should indicate whether companies are aware of modern slavery issues and what are the taken practices or procedures to eradicate these unacceptable practices within supply chains. The law is for all business entities, including the T&A sector. Modern slavery should be handled with other environmental concerns under sustainability tenets, including social and economic issues. Therefore, managers from many firms can employ the developed CSDCs with a slight modification, mostly those working domestically as the study aimed at allocating orders within the domestic supply chain. For the international sourcing and order allocation would need further research on the CSDCs. Nevertheless, the model remains the same as it allows altering the inputs corresponding to the industry using it. Researchers can also use the established CSDCs when applying mathematical methods and other simple approaches to execute supplier selection processes. Also, the interview inputs from UKR1 revealed that such criteria are crucial in today's business nature.

The digitalisation of the order distribution models is essential for the SMEs as it enables capacity utilisation for all business partners of the specific extended enterprise. Through digitalisation, it is expected that digitalisation in the T&A sector would change the present and future business perspectives in the following aspects: the creation of the decentralised decision-making support (Garay-Rondero *et al.*, 2019); to create automated assistance and support, achieve greater cost optimisation, accuracy and productivity, flexibility, and speed (Berg *et al.*, 2017); to create information transparency (Bertola and Teunissen, 2018); interoperability: a system's ability to utilise and exchange information acceptably (Hofmann *et al.*, 2011; Erol *et al.*, 2010; Ślusarczyk *et al.*, 2019), among other many benefits. The developed, verified, and validated model helps to create digitalised order allocation systems for the SMEs to distribute orders equitably while the retailers, likewise, can rank and select the suitable manufacturers through the established CSDCs (Chapter 5).

Executing sourcing decisions in the T&A industry regarding the sourcing and manufacturing locations are dynamic and complicated because of several CSDCs, including the trade-off between lead time and cost factors (Benstead, 2018). Many factories are gradually reshoring their manufacturing operations domestically (Benstead, 2018). Reshoring drivers include competitive priorities; infrastructure-related issues (to avoid or overcome complexity related to machinery, materials, labour and site); cost-related issues (if offshore operations involve hidden or unexpected higher costs); and risk, ambiguity and ease of doing business (Benstead *et al.*, 2017). Reshoring processes might not be successful for many SMEs; but, working as an EE can enlarge their sizes. This study also emphasised on information-sharing practices, which are embodied with transparency (Lotfi *et al.*, 2013; Wang *et al*., 2014). A checklist for the collaborating firms was created to assist retailers and SMEs in assessing their potential business partners before creating long-term collaboration (Table 5.3).

9.2.4 Related studies discussion

Many studies focused on information sharing practice, collaborating without compromising the security and intellectual properties rights, among other concerns (Du *et al.*, 2012; Tran *et al.*, 2016). The results from the conducted interviews emphasised information sharing despite that the sector lags regarding digitalisation. Similarly, hardly any study distributed the received orders in an EE framework. For example, the available studies researched on an order distribution (e.g. Zhang *et al.*, 2002; Xiang *et al.*, 2014; Scott *et al.*, 2015; Renna and Perrone, 2015), mainly on the distribution related to delivery or supply of the finished apparel to wholesalers, retailers or end customers. Unlike such studies, this study thus bridges that gap through the developed models which can be used in an EE.

Moreover, the fewer studies looked at distributing the finished products involved one manufacturer to multiple suppliers, wholesalers, or customers (Kawtummachai and Hop, 2005; Xiang *et al.*, 2011) or a single manufacturer to multi-retailers (Islam *et al.*, 2017). Other studies focused on the manufacturing phase, and this includes many studies in areas like line balancing of the sewing processes. For instance, Kursun and Kalaoglu (2009) simulated the production line of apparel manufacturing using Enterprise Dynamics® for the sewing line. Güner and Ünal (2008) performed the discrete-event modelling for the apparel factory using the Arena® version 7.0 simulation package, specifically for the sewing processes of the t-shirts. Medvedev *et al.* (2019) also conducted a comparative analytical study of suitable intelligent systems and methods for assigning orders. Their findings show that information systems for order allocation were not available despite the presence of other several systems for similar tasks (Table 2.4). Simulation models were not also found for distributing orders (Medvedev *et al.*, 2019). Thus, this study also bridges such a gap by developing simulation models that potentially allocate bulk orders equitably. The developed computer simulation model initially included five retailers and five manufacturers; meaning that the model works for multiple retailers, multiple manufacturers under multiple settings for several products (Figures 6.32 to 6.34).

9.2.5 Discussion of the hypothesis testing

Based on the first hypothesis (*H1*), the results in Figure 7.34 indicate that the null hypothesis (H_0) is accepted. *H1* states that the cumulative sourcing performance indices (CSPIs) do not affect the total produced apparel orders (volume). H_0 is accepted because the *p*-value (0.984) is greater than the significance level of α = 0.05. This is true because the CSPIs only assist in distributing the received orders from retailers across a cluster of collaborating SMEs. Since all the initial accepted orders must be processed; irrespective of the rating for any SME, the total produced apparel orders thus should remain constant. Conversely, from the second hypothesis (*H2), H_0* for the majority of the CSPIs was rejected, thus dictating accepting the alternative hypothesis (H_A). Thus, the CSPIs affect the distributed apparel demanded orders (volume). *H2* is in connection with the main objective of allocating orders across several collaborating manufacturers (Section 1.5). It is thus hypothetically proven that the CSPI of each firm affects the quantities of the received orders to be allocated.

From Table 7.7, since the *p*-value (0.985) > *α-value* (0.05) for *H3, H_o* is thus accepted: the replication length does not influence the throughput of products. For *H4*, since the *p*-value (0.000) ≤ α (0.05), thus the H_o is rejected, and H_A is accepted: the mean order interarrival time (*vMOIT*) influences the total distributed orders across a cluster of SMEs. This means that the shorter the *vMOIT,* the more the total distributed orders. For example, if retailers could be ordering at least every month from the SMEs, amongst the participating SMEs could each secure enough apparel orders provided there are enough orders. However, since the model allows multiple retailers to upload their orders, that creates an opportunity for the average *vMOIT* to be shortened. For *H5*, the transfer time between machines cannot impact order distribution to SMEs. But if the distance is too long to the extent of spending much time, for a vast volume of apparels can result in longer lead time.

For *H6*, since the *p*-value (0.927) > α (0.05); the H_o is thus accepted, and H_A is rejected (Table 7.7). This means the sequencing time to assign the processing time for each process does not affect the distributed demanded orders. From Figures 6.32 to 634, sequencing processes for each process occurs after accomplishing the allocation process (Figure 6.20). *H7* looked at the transportation time from distribution centres (DC) to retailers (Rd_1 to Rd_5)

on whether it does not affect total distributed orders. Similarly, *H8* tested whether there is no relationship between the transportation time from manufacturers to DC and the total distributed orders. For *H7* and *H8*, the H_o for each hypothesis was accepted (Table 7.7). In the business context, *H7* and *H8* can only affect the delivery time of the manufactured products rather than the distributed orders. The longer the transportation time, the longer the lead time. This can thus disappoint retailers who would wish to get their orders quickly.

Furthermore, it is possible testing on the influence of the standard deviation (STD) of the processing times (SMV) for the undertaken processes in Figures 6.32 to 6.34 with regard to the total produced apparel orders (volume). The contributions of the SMV or SAM data are depicted in Figure 8.6: the results depict the aggregate time used by each category of the apparel in the manufacturing processes. The incoming apparel orders were distributed into specific categories—jeans, shirts, trousers, and skirts—for Mz_1 to Mz_5. Only four apparel categories were considered for illustration purposes. However, many clothes can be used depending on the need. From Figure 6.20, the received orders from the DECIDE module are jeans, trousers, shirts, and skirts, with the distributions of 34.3%, 28.0%, 22.2% and 15.5%, respectively. The distribution in terms of percentage can be altered based on the received orders' specifications from each retailer. The DECIDE module executed the specifications of each apparel category (Figure 6.22).

Table 6.3 depicts the average (mean) data for the processing times of each apparel. However, in Arena®, processing time data were entered as *Normal* distribution functions. The NORM comprises the mean (μ) and STD (σ). Statistically, the STD is a measure which shows the variation of a set of values. For this study, the value is 'time factor' for each process within Arena®. By setting a high STD, it means the values are widely spread over a larger range, while a low STD, implies that the values are near to the *mean* of the values. An alteration of the STD can be performed to analyse the influence of STD in the generated results. Thus, testing the influence of STD in the developed model could have helped to establish the relationship for small and large deviations for the distributed orders and produced quantities. For example, in the business context, for a smaller order size (e.g. 500 orders), there is not any big impact that could be noticed on the produced volumes, but for a bigger order size (e.g. 10,000), an impact could be experienced. If there is a broader STD, the impact can be noticed for the lead time of the production rather than the throughput (volumes) to be produced. This means, no matter how big STD is, the SMEs can still produce any order size; the time can still be affected. In the business context, this is actually useful for the firms to know so that they can inform their customers—retailers—on any anticipated delay for their order size as the result of how large the STD is. Therefore, from the business viewpoint, this is really useful as small changes can have a big impact and be translated into business decisions. The small changes on the STD do not impact on the ability to produce but can have a big change and rapidly on time to produce a large order size.

9.2.6 Quality indicators of the developed model

Indicators for the quality of a simulation model design are essential (Balci, 2015). The developed models (Figures 6.32 to 6.34) thus should further possess at least five dimensions to enable smooth retailing in an agile manner, as stated by Gligor (2013): these include the following. First, *accessibility*: for all collaborating factories, there should be an easy way of accessing relevant data, but all data must be well secured to protect unauthorised access. This is possible through an effective information sharing practice amongst firms. Second, *alertness*: it is an ability to detect threats, changes, and opportunities quickly. Digitalised systems or models should be either in-built with or attached with sub (auxiliary) systems which can provide information to the users of the particular systems. It is mandatory for this dimension as it can help easy protection of the relevant data should there be any threat. For the opportunity, there should be an easy way of discussing the available opportunity to secure it as one way of enabling manufacturers' survival. Third, *decisiveness*: it is an ability to make decisions resolutely, i.e. wilfully, convinced or in a satisfactory manner. Fourth, *swiftness*: it is an ability to implement the generated decisions. When developing a virtual networking model for order sharing, it is vital to implement particular decisions quickly: this helps to enable business partners to accrue the benefits. An early implementation of decisions also supports monitoring and evaluation of the developed models. Fifth, *flexibility*: this is an ability to adjust the range of tactics and operating of the developed systems. Models require inputs to obtain outputs. The developed models should allow a high range of flexibility; however, there must be a limit to which flexibility cannot be performed.

9.2.7 Qualitative results on contemporary issues

Qualitative results through interview sessions indicated the concern on ethical compliance. For example, the UK retailer indicated that there is a need for auditing the factories' buildings. The pointed reference case was the 2013 Dhaka collapsed garment factory which killed over 1,134 factory workers. For this study, the collaboration through an extended enterprise aims at enabling equitable order allocation amongst the participating factories. However, retailers should show concern for the workers who make clothes.

Although SMEs may have fewer buildings; retailers should still audit their factories, mainly looking for structural failure, safety precautions, fire systems, electric, etc. The technical capability auditing should be performed after observing and/or auditing the factories premises.

It is challenging if retailers can order their products through email, phone calls or through the computing cloud. However, if there is a long term collaboration, the retailers are expected to have a scheduled auditing visit to ensure the safety of their products, the safety of the factories' workers, etc., as compliance towards social aspects: one of the three sustainability tenets. Having digitalised system that enables working as a single virtual enterprise should involve and force factories to upload their structural audit reports to the cloud or their websites so as both retailers and other collaborators can access such critical information in today's business frameworks.

Furthermore, due to the contemporary issues concerns, including environment and modern slavery; collaborating factories are nowadays required to indicate whether they are aware of these issues and how they are eradicating them. Measures on stopping modern slavery issues must be clearly followed as the society is facing these challenges. Also, environmental concern is one of the biggest challenges the world is facing. Industrialisation is the primary cause of environmental pollution. The UK has several SMEs: each one should set priorities on plummeting environmental pollution. The T&A sector being one of the major industries with high wastes; the sector thus requires strict measures to combat the same.

9.3 Discussion of the execution processes for the developed model

Figure 9.1 is the schematic diagram that shows how an execution process for the virtual distributed manufacturing network can be performed. Figure 9.2 illustrates the proposed series of interactions between the components of the execution cycle for Figure 9.1.

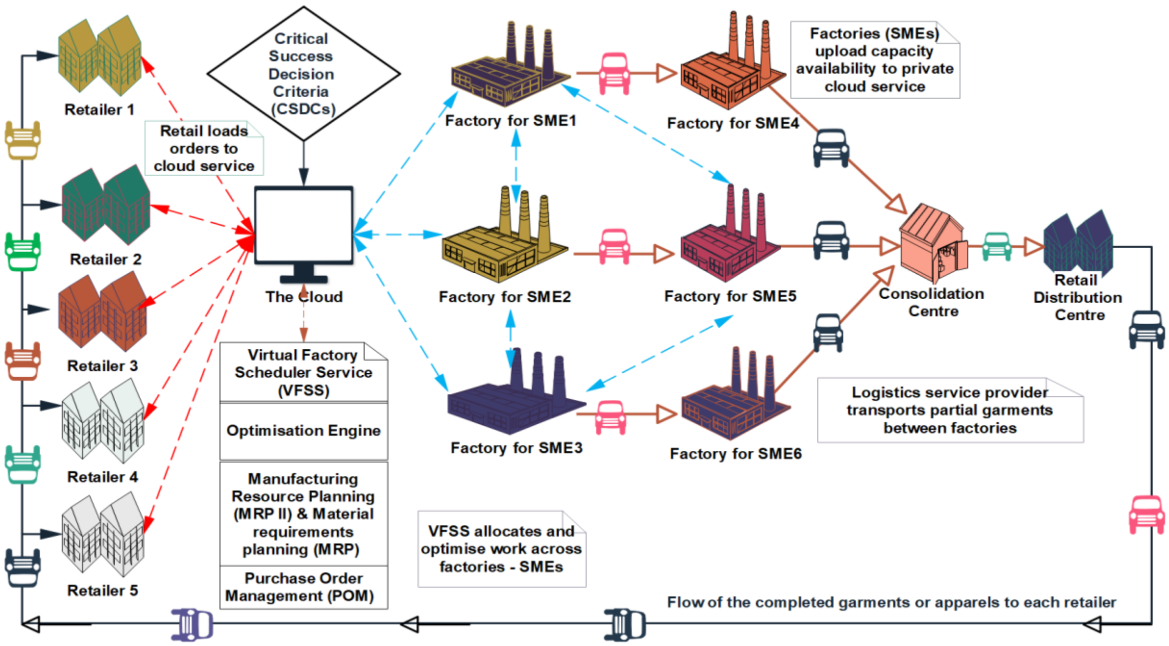


Figure 9.1: The multiple retailers to multiple manufacturers framework of the core concepts and relationships.

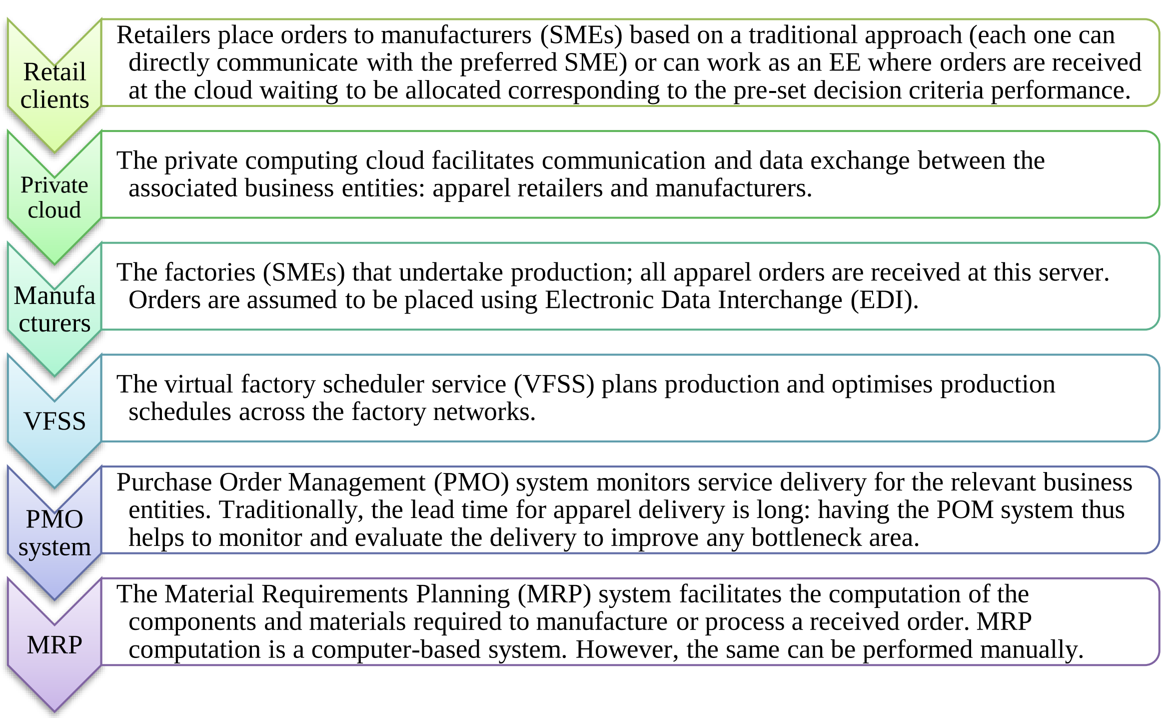


Figure 9.2: The series of interactions between parts of the execution cycle.

The VFSS execution process can be elaborated as follows:

a) The execution cycle begins when a retail client uploads a production order request to the computing cloud. The production order includes a specification of the apparel product that allows the VFSS and participating apparel factories to calculate work content.
b) Participating factories monitor the cloud postings; once identifying an order which they can complete, or partially complete, they then post a bid for that order in the form of the amount of capacity they can provide.
c) The virtual factory scheduler monitors the cloud; when sufficient bids have been posted (or there is a time-out), the scheduler executes a procedure that first generates a set of competing production plans then applies an optimisation algorithm that selects the best production plan according to multi-objective criteria. The best solution is uploaded onto the cloud for the factories to review.
d) If the firms accept the schedule, this must be signalled to the VFSS, which updates the PMO system that informs the retailer. If the firms reject the schedule, an alternative schedule should be made subject to the new constraints and the provided preferences by the factories.

9.4 The main users of the developed models

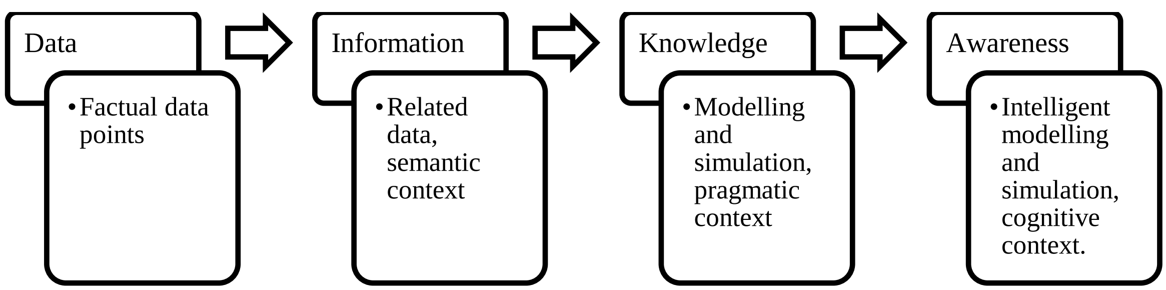
Initially, the targeted users of the developed models were the apparel manufacturers (SMEs). All models are developed as retailers to manufacturers and not vice versa. However, it does not mean that retailers would not benefit from the developed model. The major aim was to assist SMEs that on their own, would not secure enough orders from British retailers. Having a virtual manufacturing network model thus enables them to secure orders collaboratively.

Also, through observation and interview sessions at retailers, specifically, from their 'distribution centres', it was found that retailers distribute apparel products to several stores within the UK without any appropriate digitalised system. This implies that retailers also need a digitalised system to allocate their products equitably to their stores within their geographical coverage. Retailers allocate products based on experience and look at the stores which have been performing better in the past. Despite that retailers are progressing in allocating their finished products, but all processes are heavily manually handled.

Furthermore, in some countries, including the UK, the users can be a well-established institution, organisation or a network that unites manufacturers and retailers. For example, if institutions like the UKFT and 'Make it British' can be enabled to have such a digitalised model which works efficiently and effectively, it can help them to coordinate several SMEs who are currently struggling in this business. Considering that the UKFT is the most inclusive British fashion and textile network; such a network could persuade SMEs to form genuine and mutually beneficial collaborations. However, this does not prevent many SMEs who have potential to collaborate by themselves to use such a system.

9.5 Practical, theoretical, and managerial implications

This research provides potential solutions on allocating orders equitably to a cluster of SMEs working as a single virtual enterprise. The contributions through computer modelling and simulations can be summarised based on the well-known value chain proposed by Ackoff (1989) in chronological order of magnitude (Rowley, 2007; Tolk, 2013). Figure 9.3 highlights the contribution of data, information, knowledge, and awareness.



Note(s): DIKA = **D**ata, **I**nformation, **K**nowledge, **A**wareness.
Source: Adapted from Ackoff (1989).
Figure 9.3: The value chain and intelligent modelling and simulation applications through the DIKA levels.

Theoretically, the study generated factual data required to initiate digitalisation of an equitable order allocation. Such data alone has only limited value. Raw and unprocessed data exist, and data can only serve syntactical issues. SMEs have the potential of securing orders to fill the existing gaps in a befitting manner. The data were generated in connection to the gathered information from willing companies which indicated how digitalisation is highly required in the T&A sector. There is also a contribution to knowledge and methodology through the performed modelling and simulation phases. The modelling and simulation followed the Pragmatism philosophy, which deployed a mixed-methods approach. The study results, including the generated models, should provide awareness to industries and other related experts on the need for having digitalised models (systems). The knowledge is contextual, synthesised, and actionable to stakeholders. Regarding the awareness, this requires understanding, integrating and thinking strategically (Balci *et al.*, 2017).

SMEs in several countries, including the UK, are lagging in embracing Industry 4.0 concepts. Several studies focused mostly on automating manufacturing systems. Hardly any research focused on enabling equitable order allocation to enable SMEs to work as a large firm through the EE framework. This research provides essential rethinking on creating virtual factories that allocate bulk orders to a cluster of SMEs working jointly. The study also contributes to theory through the created simulation models as part of the methodology.

The study likewise discussed DACE concepts. Although DACE is a longstanding research area; hardly any research on the extended enterprise framework applied DACE concepts to illustrate the feasibility of allocating orders equitably given multiple configurations, inputs, and factors. Chapter 7 discussed DACE despite a lack of any system to compare with: this thus serves as a theoretical implication in academia fields. DACE was conducted using some stochastic processes to model some of the time taken in the process steps. When an order comes in, the simulation is run with both controllable factors and the uncontrollable parameters set; thus, some random numbers generated during the simulation. Experiments show that given a means to allocate orders across a cluster of manufacturers the simulation was run to indicate that manufacturers can perform it or not perform it; and even with the variations and fluctuations including the time taken, order size, among other criteria, still it would be feasible if they work together.

Figure 9.4 illustrates the general conceptual framework for all four models. For example, if a single retailer has small order size, ordering from a single SME can be a suitable decision; thus, the SRSM model is the result. If a single retailer has a bulk order size, ordering from multiple SMEs (manufacturers) can be a suitable decision, leading to the SRMM model. In the situation when multiple retailers could willingly order from a single manufacturer

(SME), leading to the MRSM model, this is most challenging provided that the multiple retailers have a large order size. The suitable model to overcome some weaknesses of the above models is the MRMM model which can probably ensure achieving quick response if the order size is large. Ideally, the MRMM model works only if the collaborating SMEs can share information and digitalise their systems to fulfil retailers' requirements. Therefore, the MRMM model is the appropriate model that can suit different scenarios of securing orders to ensure long-term manufacturers' survival.

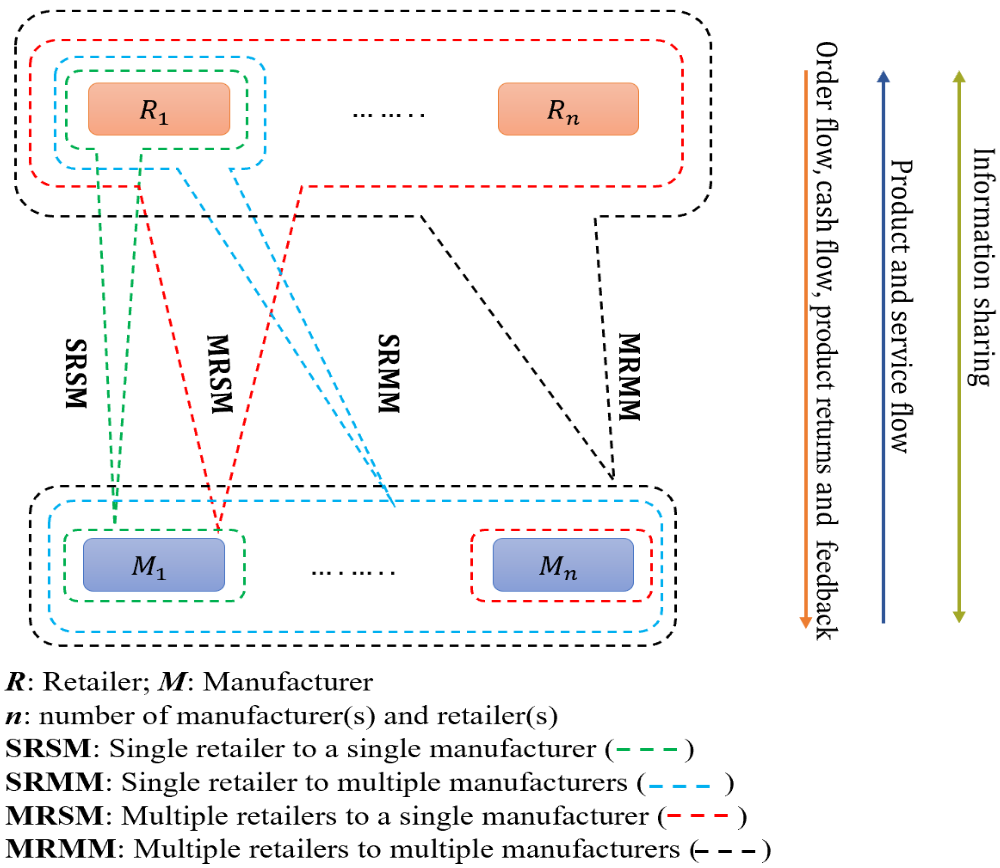


Figure 9.4: The general conceptual framework of the retailer(s) to the manufacturer(s).

In summary, this chapter discussed the generated results, specifically on the KPIs (Section 6.5.5). Some of the interview results were also discussed, such as modern slavery and CSR issues. The other crucial results discussed include the hypotheses testing results, CSDCs and quality indicators of the developed model. The study indicates essential execution processes of equitable order allocation through EE conceptual frameworks. Finally, Chapter 9 discussed the primary users of the developed models, the practical, managerial, and theoretical implications.

Chapter 10 Conclusions, Recommendations and Future work

10.1 Conclusion

This research mainly developed a novel equitable order allocation model to ensure manufacturers' survival over an extended period through consistent SMEs' capacity fulfilment at a break-even level as a minimum. The broader contextual question was on how an equitable order distribution, sharing, dividing, or allocation system can be digitalised for UK apparel manufacturers (SMEs). However, the driving research question focused on establishing whether it is feasible for a group of UK apparel manufacturers (SMEs) to work together by equitably allocated or distributed multiple orders. Therefore, achieving the illustration of the feasibility of equitable order allocation answered whether it is feasible to have digitalised infrastructure (systems) that would support a cluster of SMEs to work collaboratively. In order to achieve the research aims, four specific objectives were considered and accomplished pragmatically.

The first objective explored an extended enterprise (EE) within the Industry 4.0 perspective. Here, the research defined an EE concept within the Industry 4.0 context and how an EE exists. Then, stated the benefits of developing the concept of an EE on simplifying order placement by retailers. It is an Industry 4.0 era whereby numerous sectors are slowly transforming. Thus, the first objective question thus explored the meaning of an EE, and how does it exist. In order to achieve this objective, a qualitative approach through documentary reviews, semi-structured interviews, questionnaires, and observational techniques gathered required data and/or information. Initially, two approaches assisted in identifying a list of prominent retailers and manufacturers. Firstly, by attending a 'Make it British' exhibition event to meet several garment manufacturers, sample makers and retailers at the Business Design Centre, London in the UK on 29th and 30th May 2019. Secondly, through secondary data, including reports and websites, it assisted in identifying a list of several manufacturers (Appendix F) and reputable retailers within the UK (Table 2.1, Sections 2.2.3 and 2.3).

Subsequently, Sections 2.6 and 2.9 briefly discussed the general meanings of an EE and Industry 4.0 concepts, respectively. It was found that the characteristics of Industry 4.0

includes technologies such as smart factory, predictive maintenance, autonomous robots, smart manufacturing (manufacturing 4.0), connected enterprise, internet of things (IoT), augmented reality, dark factories (lights out-manufacturing), 3D printing, big data and predictive analytics, computer simulation, vertical and horizontal systems integration, computing cloud, cyber-physical systems (CPS), additive manufacturing and the internet of everything. This research was located in the Industry 4.0 context, and the characteristics of Industry 4.0 that triggered the work undertaken include the virtual factory, computing cloud, vertical and horizontal systems integration of SMEs, connected enterprises and computer simulation. Finally, this research developed the conceptual model with collaboration and information sharing enabled relationships amongst SMEs that work synergistically (Figure 8.1). Similarly, proposed a conceptual framework of an EE for ordering options (Figure 8.3). Each enterprise can decide to either work independently or work collaboratively as an EE. It was also found that both retailers and SMEs need digitalised systems to compete effectively. However, the results show that the UK apparel sector has not yet fully digitalised its order allocation system.

The second objective established appropriate critical success decision criteria (CSDCs) in digitalising the domestics supply chain in terms of an equitable order allocation for the UK apparel manufacturing. This objective was achieved through interview sessions to retailers, and a methodological decision analysis model. In particular, Figure 5.6 depicts a Pareto chart generated by Minitab® version 18 to identify primary decision criteria (representing 80% of the criteria reported in academic literature) from 2012 to 2019. The results were systematically compiled from the T&A industry only. The decision criteria are much crucial amongst apparel retailers and apparel manufacturers. This research thus established pertinent decision criteria that can be used by several industries in executing equitable order allocation for sourcing domestically (Chapter 5). The established CSDCs include quality, delivery, price or cost, production facilities, technical capability, financial position, management and organisation, CSR, environmental factors, performance history, repair service, IT and communication, procedural compliance, labour relation record, geographical location, reputation and position, flexibility or diversification, modern slave issues, collaborative or partnership, green (eco-design) product and production, sustainable capability, customer satisfaction and impression, responsiveness, training (continuous improvement), operation controls, relationship with retailers, warranties and claim policies, R&D and innovation, and packaging ability.

Moreover, for the proposed critical decision criteria to enable equitable order allocation, the inclusion of the related environmental factors and modern slavery practice is crucial as these issues are vital for all enterprises. Ensuring slavery is absent from modern apparel businesses is essential as this forms part of the corporate social responsibility model. The three tenets—economic, social, and environmental—are fundamentally essential to drive better collaborations. There is high pressure from several governments, law enforcers and society regarding these factors. This thus also forms probably a new insight when collaborating with other enterprises to secure orders. When retailers rank suitable manufacturers, they should consider such factors for protecting society and environment as a whole. There are several theoretical and empirical studies but mostly look at ranking supplier selection with fewer factors: in those studies, the environmental factor is mostly discussed whereas fewer studies incorporated modern slavery concern in ranking their suppliers.

The third objective proposed and evaluated the potential techniques, tools and management software application(s) required in transforming the domestic supply chain for the UK apparel manufacturing. This objective was answered mainly in Chapter 3. Documentary review, expert judgement approach and checklist established the vital decision support tool. Initially, three potential approaches that could have tackled this research were discussed: real-life experimentations, mathematical modelling and computer modelling and simulation (CMS). CMS was found to be the appropriate approach for this research (Sections 3.3 and 3.4). Then, through the CMS approach, there are several simulations approaches such as discrete-event simulation (DES), system dynamics simulation, virtual reality-based simulation, agent-based simulation, gaming-based simulation, continuous simulation, and Monte Carlo simulation (Section 3.4). DES was thus suggested to be applied to determine the feasibility of allocating orders equitably across a group manufacturer working as a single virtual entity. Finally, there are several decision support tools or software applications and techniques required to digitalise the distribution process(es). This research systematically assessed several software packages, including FlexSim®, Arena®, Simul8®, AnyLogic®, Enterprise Dynamics®, Simio®, ProModel®, SAS® Simulation Studio and Witness Simulation®, whereas the potential software packages for solving the identified problem include Arena®, Simul8® and FlexSim® (Figures 3.2 to 3.4, and Tables 3.3 to 3.5). Among the three, the prominent discrete-event simulation software is Arena®.

The fourth objective focused on developing, verifying, validating, and illustrating the feasibility for the UK apparel manufacturing (SMEs) about the processes of distributing (sharing) orders equitably using DACE concepts. The conducted interview sessions and the theoretical orientation indicated that the T&A sector needs the digitalised models. To achieve this objective, four feasibility models were developed: SRSM, SRMM, MRSM and MRMM. Since the later model covers the rest; verification and validation were thus executed for the MRMM model only. The model included the well-developed decision criteria together with the Arena® version 16.00.00 as a tool to execute the task. DACE was also applied to this study to illustrate the feasibility of allocating orders equitably. The statistical evidence thus shows that the model is worth to be applied in the UK and elsewhere with further modifications to fit the need. So, achieving the illustration of the feasibility of equitable order allocation answers whether it is feasible to have digitalised infrastructure (systems) that would support a cluster of SMEs to work together.

Bulk order distribution to a cluster of SMEs (manufacturers) working collaboratively as a single virtual entity can be performed traditionally. Nevertheless, the traditional methods are probably insufficient to meet Industry 4.0-related advancement technologies and conceptual frameworks which require working digitally. Theoretical underpinnings show that the UK apparel sector has probably not fully digitalised its equitable order distribution (sharing) system as to compliance with Industry 4.0. To bridge such a gap, the performed theoretical background firstly suggested an appropriate approach to digitalising the apparel order allocation system. The computer simulation approach was thus found to be one of the best methods which can enable digitalisation of the DSC for UK apparel manufacturing. The digitalisation was about enabling SMEs to secure orders from the British apparel retailers that on their own would not secure orders through an extended enterprise framework. Distribution was about enabling an equitable order allocation, sharing, or dividing among the SMEs to ensure the apparel manufacturers' survival over a longer period through consistent manufacturing capacity fulfilment at a break-even level as a minimum.

To adopt the correct methodology, pragmatism was found to provide a methodological stance that allows mixed-methods investigation. Pragmatism is an advanced philosophical framework for the computer simulation-based approach. This research thus deployed a computer simulation approach through the Arena® simulation software version 16.00.00 to develop the discrete-event simulation model. The model was simulated for 50,000 minutes (~ 834 hours) as a warm-up period and ~ 4,992 hours (299,560 minutes) as the steady-state period: making a total simulation runtime of 349,560 minutes for 69 replications per year. The MRMM model was successfully developed, verified, and validated (Figures 6.32 to 6.34). While further improved digitalisation models may be necessary to establish the full Industry 4.0 framework in the future, the currently developed model provides statistical evidence that the equitable order allocation (distribution) process is possible. The MRMM model would provide a new digitalised technique for allocating apparel orders, precisely after developing the digitalised equitable order allocating system.

The model might also provide proper production planning and scheduling (sequencing) services for developing a virtual distributed manufacturing network for UK apparel manufacturing (SMEs). The MRMM model indicates how the distribution of apparel orders can be managed digitally. A sample of five retailers and five manufacturers (SMEs) was involved virtually: the bulk demanded orders (volumes) were allocated (distributed) across them. The order sharing process amongst the five manufacturers was executed by considering the established decision criteria in Section 5.4. The MRMM model development processes were successfully performed, followed by the verification processes. Verification related to an evaluation of the transformational accuracy and answered the question of whether the model was created in the right way: 'have I built the model in the right way?'

Next was the validation processes which checked whether the developed model was right. The question asked was: 'have I built the right simulation model?' To confirm the feasibility of allocating orders, DACE was conducted by setting thirteen controllable factors (Section 7.2.2) and running with twenty-seven simulation experiments — $L_{27}(3^{13})$ OA (Section 7.2.3) — to generate results through the Arena® PAN tool. Both Arena® PAN and Minitab® software analysed the generated data through several charts, graphs, interaction plots, main effects plots (Section 7.3.1), response surface and contour plots (Section 7.3.2). A collection of controllable factors (parameters) were selected to develop logical, valid, and reasonable conclusions on the MRMM model. Some hypotheses were further developed and tested as part of the applied DACE to this study (Section 7.6). The results from the developed model indicate that a cluster of SMEs can be allocated bulk orders in an EE framework to utilise their manufacturing capacities and capabilities. This thus would enable a smooth retailing between retailers and the small, independent apparel factories (SMEs). Such models are also expected to be vital support in creating an alignment of the multi-sites production processes to enable a virtual factory. The virtual factory can be established with sufficient capacity to service the retail demand in an agile manner.

The experimental setup through DACE is one of the significant parts of this study. Several studies that allocated orders, specifically using Mathematical algorithms for a single supplier with retailers, applied sensitivity analysis as the major technique when confirming or showing the models' feasibility. In contrast, this study conducted a classical experimental design with thirteen controllable factors. The design of experiments is not a challenging scenario in other studies that involved optimisation and robust design. However, hardly any study performed DACE to confirm the feasibility of allocating bulk apparel orders equitably to a cluster of manufacturers working in an extended enterprise set up.

10.2 Contributions to knowledge and methodology

Contributions to knowledge can differ from field to field. In some fields, producing an artefact, for instance, the developed simulation models in this research (Chapter 6), may imply a considerable contribution. Nonetheless, for this study, the contribution included the thinking beyond the production of the artefact. In engineering fields, there can be a proof of concept or a proof of application. Therefore, the contributions of this research are as follows:

a) *Development of the conceptual framework and the digitalised model for industries working as an extended enterprise to enhance equitable order allocation processes.*

i. The first insight relates to how different blueprint systems (models) were developed to enhance apparel order distribution (sharing) across several manufacturers (SMEs) working as a single virtual entity. The developed models show that it is feasible working as an extended enterprise. This follows under the 'proof of concept' aspect because the models were developed by linking the field of this research—engineering field. Afterwards, the generated blueprint (models) of the system illustrates the feasibility of allocating (distributing) the received apparel orders equitably, and models were linked with both synthetic and actual industrial related data to show the possibility of performing distribution. This proved to be the logical way of approaching the identified problem(s) in Section 1.3.

Thus, this research illustrated 'decision science', which from this research viewpoint proves to be one of the contributions to knowledge. The study discussed what was needed and how to approach it. Should there be somebody rigorous to follow this study, it would require testing the model using industries' real data to validate what the model captures and how the model works. The developed models are part of contributions due to the following reason(s). The problem area and the challenges related to it were looked at. Then, in researching, the gap and the need for this study were both identified as well. Next, formulated the requirements for the system to address, scoped it, modelled the system, and systematically tested with different scenarios to show that this as the concept works, and this as the concept, proposes the solution for the current problem. Notwithstanding the contributions found in this study, the system was not tested in a real-life scenario. There is a room for improvement as further explained in Section 10.4. Despite that some of the real data, e.g. capacities for SMEs, order sizes for all industries, and the like, were not gathered; the developed blueprint, however, gives way forward for future researchers who might integrate the developed model to suit their needs and capture all actual data ready for implementation. Of course, implementation was not within the scope of this study. The scope is, there is a small collection of SMEs who work together as a single virtual enterprise; the SMEs could take the order as a collective entity and distribute it among themselves. They could then take advantage of the business opportunities that they cannot take advantage of individually. Formerly, this could be modelled as many orders received from many retailers to many manufacturers (SMEs). Instead, the problem was thus solved by considering many SMEs working as a single virtual entity to prove how feasible it is through a simulation approach.

ii. The second insight is on the use of simulations to support this idea of distribution (Chapter 6): on its own, it is the contribution to methodology, that is even before looking at the responses and testing the developed system. To understand the concept, the research examined the problem from scratch. That is, by studying many orders coming from a single retailer to a single SME, many orders from a single retailer to many SMEs, many orders from many retailers to a single SME, and the most critical was many orders from many retailers to a collective number of SMEs working as a single virtual entity. There is a great opportunity in the developed model, specifically the multiple orders from multiple retailers to multiple SMEs (manufacturers), as this provides an in-depth insight into Industry 4.0-related concepts. The developed models can allow the small-scale production units to fill in the gaps in their existing production schedules and ultimately to ensure full utilisation of their assets over time.

    Ideally, it can be better to test and implement this system physically, but that would require a long time. For a longitudinal study, implementation can be possible as well. This study also deployed realistic data because the majority of them were gathered from pertinent companies. The companies shared their information on how they interact with each other, what is the limit of the shared information, and they indicated the willingness in implementing an equitable order allocation system should multiple orders be directed to them. Even though the involved companies were not asked to place orders using this system, it is still statistically significant that it is feasible to place orders and equitably allocate to all collaborating partners based on their performance ratings.

iii. The third industrial and academic impact is on the performed design and analysis of computer experiments (DACE) to illustrate the feasibility of allocating orders by the developed model. This is also a contribution to methodology. It is always challenging to confirm the feasibility of a newly developed model through simulations. The theoretical underpinnings showed that researchers have always found it challenging when dealing with the newly developed system, provided that there is no existing system's performance to compare with. To bridge this gap, in Section 4.11 and the entire Chapter 7, DACE was discussed and performed, respectively, with great success. DACE for the MRMM model was conducted through simulation experiments that involved several selected parameters (Sections 7.2 to 7.6). Therefore, having managed to apply DACE's techniques successfully to the newly developed system (Figures 6.32 to 6.34), this proves to be an additional contribution to methodology. Both academicians and industries who apply simulation approaches in tackling related problems could use it with further modification to the performed procedures.

iv. The fourth insight is on the developed critical success decision criteria (Section 5.4) and the determined KPIs: order distribution (allocation), manufacturing (production) throughput, resources utilisation, and the total produced quantities (Section 8.3).

v. A further contribution is based on the assumptions and simplifications in the developed model. As this research embraced several logical and valid assumptions, these are acknowledged as they assisted in developing a novel approach.

b) Contribution to knowledge through the publication processes

This thesis, on its own, is one of the additional literature materials for the imminent researchers in the related fields. In addition to this thesis, four publications were made by reputable publishers, i.e. Emerald, IEEE, Taylor & Francis and Inderscience, as follows:

a) **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Computer modelling and simulation of an equitable order distribution in manufacturing through the Industry 4.0 framework*", 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE), IEEE, 12-13 June 2020, Istanbul, Turkey (Appendix H) (https://doi.org/10.1109/ICECCE49384.2020.9179275).

b) **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Towards a digital revolution in the UK apparel manufacturing: An Industry 4.0 perspective*", Industry 4.0 – Shaping the Future of the Digital World, in Bartolo, P., Silva, F., Jaradat, S. and Bartolo, H. (Eds.), 1st ed., Taylor & Francis, 2nd International Conference on Sustainable Smart Manufacturing (S2M 2019), Manchester, UK (Appendix I).

c) **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (In press 2020), "*Enabling manufacturer selection and an equitable order allocation amongst textiles and apparel manufacturers*", International Journal of Management and Decision Making, Inderscience (Appendix J) (https://doi.org/10.1504/IJMDM.2021.10032107).

d) **Taifa, I.W.R.,** Hayes, S.G. & Stalker, I.D., (2020), "*Development of the critical success decision criteria for an equitable order sharing for an extended enterprise*", The TQM Journal, Emerald, Vol. 32 No. 6, pp. 1715–1742, (Appendix G). (https://doi.org/10.1108/TQM-05-2019-0138).

10.3 Recommendations

The developed virtual feasibility networking model for enabling securing and distributing orders equitably from British retailers by SMEs requires policy or agenda that can help its sustainability. This study discussed the concept of Industry 4.0 for the initial processes of receiving and allocating orders within the T&A sector, precisely amongst the SMEs. Nevertheless, the full utilisation of the Industry 4.0 concept which signifies a policy initiative targeting digitisation of production processes should be researched and be implemented along the entire value chain of supply chains. It is statistically significant that the digitalisation of the received orders can ultimately lead to the effective performance of the whole collaborating partners (SMEs). Successful enhancement of digitalisation in the T&A sector for the UK applied to both individuals within the sector, companies, organisations and even the government, should involve all stakeholders, as all have a significant role to play.

10.4 Limitations and possibilities for further research

Although equitable order allocation models were successfully developed, there are limitations encountered during the execution process(es) of this research. Some of the limitations are excellent future research opportunities, including the following:

a) This study is the top-down approach as the received orders are distributed amongst several SMEs based on the pre-identified decision criteria. Another way would be to build the supply chain: the bottom-up approach. For example, if an order comes in, e.g. 50,000 shirts, one will look at all items by finding the supplier of fabrics, zip, threads, and other related accessories. In this case, it is vital to break down the shirts to determine the inputs. Then, to identify and assess the available manufacturers by checking their capacities, capabilities, etc., to meet retailers' needs. So, this recommends future work.

b) Given the exploration, understanding and how the apparel sector is now and given the generated research results, what can be digitalised? How can this sector be supported digitally? What soft issues, e.g. trust and relationship, as these cannot be utilised easily? So, such questions inform future researchers on what else needs to be executed. Soft constraints are not feasible in the current simulation. Due to such constraints, it is not 100% feasible that an equitable order allocation could be digitalised. There could be a group of SMEs that works jointly for a while who would rely on digital technology that allocates the order. Firstly, they would need to have confidence in this current technology and experience of using it for a while. Secondly, they would need to have confidence in the partners. However, what if new partners join the cluster: this thus results in soft constraints issues. Nevertheless, that is out-of-scope for the undertaken research because that is not what was explored. Also, there are things like reviews from social media, a friend of friends in business, etc.: such issues can be further explored digitally in a cluster of SMEs as part of equitable order allocation criteria.

c) Creation of a *robust design* to allocate order equitably: a lot of the time in the literature DACE has been to create robust designs. However, the application of DACE to this study was not to create robust designs of the equitable order allocation model. So, the creation of an equitable order allocation robust system should forge a future work.

d) The developed model was not calibrated from any specific industry; it is recommended that in the future, the decision tool (software) should be developed to incorporate all computations and simulations performed in this study. This would need first to develop a robust design of the model and work as a multidisciplinary with the inclusion of computer programming experts and industry experts to come up with the decision tool. This research could help a cluster of SMEs work jointly by giving them some confidence on how they will meet different orders by first of all calibrating the simulation with each of the manufacturers. Then use the calibrated models to create a response function where manufacturers could just put the available order sizes and be allocated orders equitably.

e) There is little readily available data on SMV for the entire apparel manufacturing processes, specifically for the CMT category, thus dictating the use of synthetic data. Also, many studies focused on sewing processes, and they cover a few apparels.

f) The developed CSDCs are pertinent for sourcing domestically. International CSDCs, e.g. free trade or trade regulations, political stability, international business paradigms, etc., were not considered as this study focused on SMEs within the UK.

g) Despite the contributions made to knowledge and methodology through the developed novel approach of equitably allocating orders to multiple SMEs, this study encountered limitations of the UK and ethical restrictions which hampered focus on Tanzania. Initially, the plan was to have a comparative study that could have involved both Tanzania and the UK T&A industries. However, due to ethical restrictions, the study only utilised data from the UK. Due to difficulties in recruiting UK T&A firms, enough data were not obtained, thus dictating the use of synthetic data for some processes. Considering that the study deployed a computer simulation approach, the obtained findings still proves to be able to achieve the four objectives in Section 1.5.

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Appendix

A. Interview questions to manufacturers

Three groups of information were collected from SMEs (manufacturers). Such information included companies' details (*Category I*), general information about the produced products (*Category II*), and detailed questions regarding the ordering processes (*Category III*).

Category I: Preliminary information

The following details were requested for future contact with companies (none of the below information was [will be] directly mentioned in the thesis, report, or other associated publications).

Item	**Reply**
Company Name	
Telephone Number	
E-mail	
Year Established	
Company Address	
Website	
Other social media for the company	
Company location	

Category II: Questions about the company/firm/industry

1. Type of products being produced by this company (e.g. basic garments, fashion, fast fashion, others)
2. Manufacturing experience (in years)
3. Production capacity per week
4. Industry certifications or audits does a firm comply with
5. Quality control philosophy/approach
6. Types of available machinery
7. Information technology facilities/systems available
8. Number of employees

Category III: Detailed questions to apparel manufacturers

1. Does the company know/have a list of the key textile/garment/apparel manufacturers within the UK?
2. What is the current ordering process which is followed by retailers and other potential customers?
3. To what extent has the company digitalised its ordering process?
4. What are the problems associated with the ordering process(es)? (if any)
5. Apparel order allocation/sharing/dividing practices/experience between different manufacturers (if any).
6. The digitalisation of the ordering process: does the company perform equitable order allocation (sharing or dividing) among other SMEs? If not, what can be the key requirements in facilitating the same?
7. What are the major decision criteria for retailers to consider or ask before placing their orders with your company/firm?
8. Order arrival rate: what is the average received order quantities per a certain period at this company: daily, weekly, monthly, quarterly, semi-annually, or annually?

9. What are the accepted minimum order quantities (MOQs) required at this company (i.e. daily, weekly, monthly, quarterly, semi-annually, or annually)?
10. What is the maximum arrival rate can a firm make per given time?
11. What are the manufacturing processes? (Flowchart is much required)
12. An inspection process: having manufactured the required products, what are the inspection procedures does the company follow?
13. What is the rejection rate during the inspection process of the final apparel/garment products? (say per batch, per week, month, or anyhow the company classifies)
14. Standard allowable minutes (SAM) for each process: an apparel firm requires to go through different processes/phases. Does the company have a database regarding the duration of executing each stage/phase, e.g. cutting, sewing, inspection, finishing, packing, and dispatching, etc.?
15. What are the average lead times? (specify the product)
16. Are there other problems regarding the ordering process(es) for your company which requires further research?
17. Apparel/textile factories are still lagging behind in terms of digitalisation, what can be the techniques, approaches, tools, etc. required to transform this sector *(in your opinions)*?
18. There are models developed in facilitating equitable order allocation (sharing or dividing) among other SMEs. How can the same be validated?
19. To what extent is your company willing to adopt a technological change regarding an ordering process aspect and equitable order allocation (sharing or dividing) among other SMEs?
20. How many companies/firms can you allow collaborating with yours in sharing the received apparel orders to help other SMEs secure orders?
21. Information sharing practice: does your company share [full or some] information with other manufacturers/factories? Explain.
22. Could you provide general remarks about this project/research, if any, please?

B. Interview questions to retailers

Three groups of information were collected from retailers. Such information included companies' details (*Category I*), general information about the produced products (*Category II*), and detailed questions regarding the ordering process (*Category III*).

Category I: Preliminary information

The following details are requested for future contact with the company (none of the below information was/will be directly mentioned in the thesis, report, or other publications). These include: Company name, telephone number, e-mail, year established, company address, website, other social media for the company, company location

Category II: Questions about the company/firm/industry

1. Type of products being sold by this company (e.g. basic garments, fashion, fast fashion, others)
2. Retailing experience (in years)

3. Sales capacity per week
4. Company certifications or audits does a firm comply with
5. Information technology facilities or system available
6. Number of employees

Category III: Detailed questions to apparel retailers

1. What are the lead times they can (retailers) wait for each order size?
2. How do they decide a firm to manufacture their orders? (what are the decision criteria in choosing/selecting/evaluate appropriate manufacturer)
3. What is the ordering process?
4. What is the average order size?
5. Number of products required to be on hand or on order at any reordering point
6. Amount of time between orders
7. The time between order placement and when a product is ready for the sales floor
8. Number of products required to meet unanticipated sales for avoiding stock out
9. Do they distribute/divide/split the order size to different manufacturers?
10. Any other ordering issues.

C. Performance attributes for the decision-making process

Please put a Tick (√) corresponding to *Yes*, *Partially*, *No* or *Not sure* column: these provide the deciding points for working as an extended enterprise.

Attributes	**Description**	**Yes**	**Partially**	**No**	**Not sure**
Materials flow	Do they share scheduled information about receiving the raw materials?				
Production	Do they share technologies used to manufacture the products?				
Design	Do they share information regarding the design exercise?				
Engineering changes	Does the company share information on any adjustment which can affect existing products?				
Collaborative forecasts and plans	Are there any tools for predicting the productions and sales as the means of reducing the Forrester effect (Bullwhip effect)?				
Product quality	Do they meet the retailers' quality specifications?				
Production Cost	Are the retailers happy with the production costs?				
Order entry	Do they have an online order entry system?				
Order tracking	Do they track the shared orders?				
Price	Do they discuss the product prices?				
Shipping and billing	Are they willing to share on how to ship the orders to the retailers?				
Delivery schedule	Do they meet the delivery schedule commitment?				
Delivery speed	Does the manufacturer respond quickly to the placed orders?				
Flexibility	Are they flexible in case of the variation of the retailers' orders?				
Accuracy	Do they receive correct or precise information from the retailers?				
Completeness	Do they get complete information from the retailers?				
Reliability	Do they get trustworthy or consistent information?				
Adequacy	Are they satisfied with the information they get from the retailers?				
Availability	Do they have available products for any demand at any time?				
Dependability	Are they on time in manufacturing the apparel products?				
Reliability	Are they able to continue working at an acceptable quality level (AQL)?				
Timeliness	Do they meet the production schedule?				
Internal and external connectivity	Do they have good connectivity amongst themselves, i.e. within the companies' departments and with their external partners?				
Relevance	Do they make related products for the retailers' needs?				
Accessibility	Are they reachable by the retailers all over?				
Credibility	Do both partners believe and trust the information being shared?				
Frequency	Do they update their information frequently?				
Resources	Do they have enough machine capacity?				
	Capacity variance: is there any variation in their capacity?				

	Do they have enough manpower?				
	Do they have enough raw materials?				
	Do they have enough machines?				
Retailing	Do they use sales forecast techniques?				
	Do they perform the Cross-selling and up-selling?				
	Do they follow the “Make to order (No stock company)” approach?				
	Do they follow the “Make to stock (Cloth stock company)” approach?				
	Do they sell to a wholly-owned chain of stores?				
	Do they sell to the independent retailers of the varying types?				
	Do they sell to the large independent chain stores or mail orders?				
	Do they sell to the Wholesalers?				
Retailer linkages	Does the company discuss orders problems with their retailers?				
	Do they have continuous improvement programmes due to the feedback (comments) from the retailers?				
	Do retailers get involved in making plans or goals?				
	Are the retailers aware of the production capacity of the company?				
	Do they get informed if the production schedule is changed?				
Level of Information: involvement	Is there any proprietary information-sharing practice?				
	Do they get information about the production capacity?				
	Do they share information about the “Technology know-how”?				
Support Techniques or Tools	Do they use EDI, POS or POP (point of purchase), and RFID technologies?				
	Do they use e-mails, fax, etc. to get their orders?				
	Do they use Phones to get their orders?				
	Do they use a traditional way, i.e. face-to-face meetings, to get their orders?				

D. Distribution centre (DC) at the retailer’s site

1. How do you allocate or distribute your product received from manufacturers?
2. What are the criteria mostly used to allocate orders?
3. What are the key processes to distribute the products?
4. How long does it take to complete one entire distribution process? (lead time at DC)
5. Do you have an automated distribution system?

   “The automated replenishment or distribution system is now a standard part of the management information system of most large fashion retailers. These systems, whilst generally described as ‘automatic’, in reality, need a great deal of regular human intervention to ensure that the system replenishes logically and sends out just the right amount of stock. The system basically works by deducting the individual size/colour sales each week from the stock that the shop started with at the beginning of the week, usually referred to as the opening stock” (Jackson and Shaw, 2001, p.143).

6. Do you have the delivery or commitment schedule? This a regularly updated document which is kept in a computer format. It allows senior management and the buying and merchandising team to see clearly what is to be delivered into the ‘Distribution Centre’ or warehouse on a daily, weekly, and monthly basis. If this system is not available, how do you check the updated information as distribution continues?
7. Do you think ‘digitalisation’ will potentially boost the textiles and apparel sector within the UK in the future? How?
8. Are there any other digitalised system(s) at your DC?
9. What are the challenges regarding advanced technologies that your DC is facing?

E. Likert scale questionnaire summary to rank manufacturers

Critical success decision criteria (CSDCs)		**Description**	**Apparel manufacturers' (SMEs) performance scores**	**Score**
Financial position (FPO)		Relates to whether the firm has sufficient and stable capital flows. Relates also to the terms for payment.	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Quality (QLT)	Quality assurance (QA)	Quality assurance aspects at the company	Excellent (5), good (4), fair (3), poor (2), very poor (1), and not performed (0)	
	Quality Planning (QP)	Quality planning aspects at the company	Excellent (5), good (4), fair (3), poor (2), very poor (1), and not performed (0)	
	Quality control (QC)	Quality control aspects at the company	Excellent (5), good (4), fair (3), poor (2), very poor (1), and not performed (0)	
Delivery (DLV)	Logistics (LS)	Relates to logistics aspects of transporting the manufactured apparel.	Excellent (5), good (4), fair (3), poor (2), very poor (1), and not effective (0)	
	Lead time (LT)	*Very poor* for a total order lead time of more than 60 days (1); *poor* for a total order lead time of 35 to 60 days (2); *fair* for a total order lead time of 30 to 35 days (3); *good* for a total order lead time of 25 to 30 days (4); and *excellent* for a total order lead time of 20 to 25 days (5).	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Price/cost (PRC)	Selling prices (SP)	The selling prices of the apparel products	Extremely high prices (5), high prices (4), acceptable prices (3), low prices (2), and very low prices (1),	
	Ordering cost factor (OC)	It is about the ordering cost factor. It was considered whether the company uses EDI in simplifying the ordering processes.	Excellent (5), good (4), fair (3), poor (2), very poor (1) and not available (0),	
Production facilities and capacity (PFC)	Types of machinery	The types of machinery available such as cutting, spreading, sewing equipment, among others	Excellent (5), good (4), fair (3), poor (2), very poor (1), and not effective (0).	
	Minimum order quantities (MQ)	*Extremely high* (5): there are no MQ; very high (4): runs only large order quantities; *high* (3): runs medium to large order quantities (wholesalers); *acceptable* (2): runs small to medium order size; *satisfactorily* (1): runs small order size only.	Extremely high (5); very high (4); high (3); acceptable (2); satisfactorily (1)	
Technical capability (TEC)		The physical infrastructure and workforces' skills to manufacture apparel.	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Management and organisation (MO)		The ability to deal or control the workforce and factory's facilities and assessing commitment level	Very high (5), high (4), acceptable (3), poor (2), and very poor (1)	
Flexibility (FLE)		How the firms can manage the demand uncertainty, the production changes, product style or volume changes, both predicted and unpredicted.	Excellent (5), good (4), fair (3), poor (2), and very poor (1).	
The geographical location (GLE		The geographical location of manufacturers (SMEs)	Very close proximity (5), close proximity (4), far (3), and very far (2)	
Performance history (PH)		Concerns the history of the manufactured apparel	Excellent (5), good (4), fair (3), poor (2), very poor (1), and new firm (0)	
Services (SER)		In general, it concerns the way SMEs serve retailers.	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Reputation and position in the industry (RPI)		Reputation and position in the industry	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Procedural compliance (PCE)		Very poor (1): an SME does not have any certification document; poor (2): an SME is a member of the UKFT; high (3): either ISO 9000 or the UKFT certifies the SME; very high (4): ISO 9000 and the UKFT certify the SME.	Very high (4), high (3), poor (2) and very poor (1)	
IT and communication systems (ICS)		Assesses the availability of ICT infrastructures	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Collaborative or partnership planning (CPP)		Collaborative or partnership planning	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Labour relation and training (LRL)		Labour relation and training	Excellent (5), good (4), fair (3), poor (2), and very poor (1)	
Modern slavery issues (MSIs)		Assessing the extent to which the particular factory avoids modern slavery issues and how they comply with other social-related business ethics standards and code of conduct in their entire production.	Very high (5), high (4), fair (3), poor (2), and very poor (1)	
Environmental concern (ENV)		to what extent does the firm take actions regarding environmental issues.	Very high (5), high (4), fair (3), poor (2), and very poor (1)	

F. Some of the UK clothes or apparel manufacturing companies

Company	Descriptions/Type of product(s)	Location	Websites
City Threads Ltd	Produces samples and small dockets to clients in the UK	Barking	http://citythreadsltd.business.site/
All-In-One Company	Produce clothes and services to start-ups	High Market Ashington	https://www.the-all-in-one-company.co.uk/
Angelina Studio	Pattern cutting and sampling – full CMT – small production runs; member of the UKFT	Passey Place, London	http://www.angelinastudio.co.uk/
Hawthorn International	T-shirts, polo shirts, hoodies and sweatshirts, sweatpants, jeans and denim products, a casual jacket and underwear	The City, London	www.hawthornintl.com
Abraham Moon and Sons	Manufacture luxurious woollen fabrics for furnishings and fashion.	West Yorkshire	https://www.moons.co.uk/
Golden Touch	Produces clothing for top high street brands; all jobs	Barking	https://www.gtcclothing.com/
Made In Manchester	Produces clothes and textile products	Manchester	www.madeinmanchester.co
Bruntwood Europe Ltd	Polo Shirts, Hoodies, Sweatshirts, Polar Fleece, Sweat Jacket, T-Shirts, Rugby Shirts, etc.; process any size of orders	Hinckley	www.bruntwoodclothing.co.uk
Appareltasker	Garment manufacturing services	London	https://appareltasker.com/
The Sewing Unit	Small run garment production for independent boutiques and new designers	Pembroke	N/A
Pro Sampling Limited	Toiles, fittings, sample making, alterations, CMT, small to medium production	Stratford, London	www.prosampling.co.uk
C. Weed Clothing Manufacturers	Manufacture woman's, men's, and children's clothes; No minimum order quantities	Launceston	www.c-weed.co.uk
Studio MasaChuka Ltd	CMT; pattern cutting and sampling; No minimum volume required	Stratford, London	www.masachuka.com
Sewport	Clothing manufacturer; Small & large runs	London	www.sewport.co.uk
Aristo Fabrics Limited	Produce high quality knitted fabrics	Leicestershire	http://www.aristofabrics.com/
Needle N Thread Studio	Pattern cutting, bespoke sewing, e.g., wedding gowns, sewing and pattern cutting classes, sample making, clothing manufacturing, leather jackets manufacture. No order is too small.	Whitechapel, London	www.needlenthreadstudio.co.uk
Face of London Fashion Manufacturing Limited	Womenswear, children's wear, menswear, stretch, suiting, delicate fabrics and luxury.	Leyton, London	www.faceoflondon.co.uk
StitchLand UK	Men, ladies, and children's wear; any order	London	www.stitchland.co.uk
White Horse General UK Limited	T-shirts, Shirts, Silk Cotton Sarees; Industrial Garments - Nurse and doctor garments, Chef garments and factory Uniforms. Small and large runs	Watford	www.whitehorselimited.com
Unlimited Fashion	"Sampling and production for high-end luxury designer collections as well as bespoke theatrical costumes". Runs individual and medium quantity production.	New Southgate, London	www.unlimitedfashion.co.uk
Lovell Workwear UK Ltd	Manufactures uniquely designed Aprons and Smocks	Cardiff	www.lovellworkwear.com
F Chand Co Ltd	Supply CMT or fully factored garments	Smethwick	www.fchand.co.uk
Lonastyle Ltd	Clothing manufacturing for gents and ladies; make any quantity orders	Edmonton, London	N/A
AIM Athleisure	Manufacture high-quality women's and men's active-wear, lounge-wear and gym-wear	Newcastle upon Tyne	https://aimathleisure.com/
Runway Clothing Manufacturer	Provides full CMT service for small to medium production runs along with bespoke sampling and pattern cutting services.	Haggerston, London	N/A
AE Sewing Machines	Manufacture women and men country wear.	Midlands	https://www.aerotradeltd.com
Mutiny Co	Design and manufacturing industry.	Edmonton, London	N/A
Ella	CMT	Whitechapel	N/A
ALM-Tradings	Productions of knitted garments; a variety of woven items	Burnley	N/A
WisemanClothing -	Gives toiling and sampling to manufacturing	Tottenham, London	www.wisemanclothing.com
ThreadNeedle Manufacturing	Cater for all samples and size runs.	Haringey, London	N/A
Footprint Uniforms	Fire cadet and school uniforms, sportswear and leisurewear	Crownhill, Plymouth	www.footprintuniforms.co.uk
Eden Studio	Satins, silks, chiffon's, etc; small volume production	London	www.edenstudiolondon.com

Sew Inn Hub	Silks, denim, cotton, jerseys, leather, wool, & polyester fabrics; runs small productions	Woolwich, London	N/A
X S Media and Design	Gothic wedding dresses	Nottingham	www.mentalxs.com
Logo N Stitch	Workwear, corporate wear, sportswear, women's workwear, t-shirts, personalised brand wear and embroidery	St. Leonards-on-sea	www.logo-n-stitch.co.uk
TideSamples	Sample making; produce small runs	Haringey, London	tidesampleslondon.freeindex.co.uk
Flannel Clothing	Shirts, jacket, dresses, joggers	Cardiff	www.flannelclothing.com
London Tradition Ltd	Pea coats as well as Duffle coat, raincoats, and quilts	Hackney, London	www.londontradition.com
Sheepland	Sheepskin Booties, Slippers, Handmade Katrina Sheepskin Slippers and Moccasin slippers (Small, Medium, or Large)	Barton St. David, Somerton	www.sheepskin.co.uk
Exclusive Designs	Womenswear, menswear, and Children's; manufacture 50,000 pieces per week	Leicester	www.exclusive-designs.co.uk
Alcurt Textiles Ltd	Clothing and Curtains, alterations and repairs, Embroidery service and uniforms manufacturing; run big and small orders	Manchester	N/A
Triple L	Accessories and latex garments; deal with individuals, small and medium-size	Potters Bar	www.triplel.co.uk
Alexanders of Scotland	Produce quality woollen fabrics for furnishings and fashion	Mintlaw Scotland	https://alexandersofscotland.com/
First Clothing Leeds Ltd	CMT; serves small shops and large retailers	Leeds	www.firstneatclothing.co.uk
KidsWholesaleClothing.co.uk	Baby blankets, baby t-shirts and bibs, hoodies blank and printed; no minimum order quantities	Leicester	www.kidswholesaleclothing.co.uk
Josery Textiles Ltd	Manufactures fabrics and knitted trims from cotton/polyester and cotton yarns; all order size	Hucknall, Nottingham	N/A
Leilin Ltd	Manufacture dresses, skirts, blouses, trousers, corporate and casual wear, jackets, evening dresses, cocktail, modern classic; all order size. Produce 100,000 garments per year.	Romford	www.leilin.co.uk
Richard Sexton & Co	Jumpers, hats, cardigans, slippers, jackets, scarves, rugs, belts, throws, etc. (wholesaler)	Clapham, Lancaster	www.glencroftcountrywear.co.uk
AbiandAyse studios	Womenswear; small run production	Stevenage	
Elegant Designs Ltd	Ladies wear for premium high street brands	Nuneaton	www.elegantdesigns.ltd.uk
iQ Printwear	Polos to aprons, t-shirts to hoodies,	Manchester	N/A
Fashion Capital/ Fashion Enter	Production and sampling	Haringey, London	www.fashioncapital.co.uk
Hanna Boutique	Clothing manufacturing industry; takes small and large amounts of orders	Forest Hill, London	www.hannaboutique.com
T.G. Bros Limited	Yarns and ladies clothing; all order sizes	Coventry	tgbrosgroup.com
Garment Technology International Limited	Uniform clothing and workwear; all order sizes	Milton Keynes	N/A
Baileyfreer	Ab wear, nightwear, incontinence wear, bridal and prom dresses, Bespoke clothing	Loughborough	www.baileyfreer.co.uk
Point 3 Manufacturing CIC	Clothing sourcing and manufacture in small runs	Consett	www.point3manufacturingcic.com
NMK Text & Leather Ltd	T-shirts, Polo and sweatshirts, jeans, tank top, suits, chino, dress, trouser	Dartford	www.nmktextandleather.com
Fascin Style	Children's and men wear, hats, womenswear, gloves, scarves; runs a minimum of 300 pieces per design	Hurlingham, London	www.fascins.co.uk
Rism Ltd	Womenswear; flexible order range	Leicester	www.rismltd.co.uk
Project MOQ	Sewing services; produce for individuals and businesses	Croydon	N/A
Banned t/a Alternative Wear	Clothes and design for Pin Up, Goth, Rockabilly, Steampunk, Street Wear, nautical (wholesale company)	Whitechapel, London	www.bannedapparel.co.uk
Polka Style Ltd	Bespoke clothes for women and men; run small to medium productions	Watford	www.polkastyle.co.uk
Suede Design Centre	Design and manufacture leather garments	Stratford, London	leathermaker.yolasite.com
Designs Alike Ltd	Sportswear: tracksuits, onesies, hoodies, dancewear, rugby shirts, football kits, and T-bag tops; no minimum order policy	Portsmouth	www.designsalike.co.uk
Elusive	T-shirts, jeans, jackets, skirts, and shorts	Newport	www.elusivesurf.com
Splash Innovations	Manufactures aprons	Par	www.splash-innovations.co.uk
Marinz Fashion	Non-woven, Woven and knit products; produce a large range of non-garment or garment products	Aberdeen	www.marinzfashion.com

Threegdevelop Ltd	T-shirt for men and women (wholesale)	Eastcote	www.threegdevelop.com
London Contour Experts	Creates lingerie, activewear and swimwear	Wimbledon	N/A
Fuller Fillies Ltd	Design or manufacture plus-sized rider wear for ladies who ride horses.	Fitzwilliam, Pontefract	www.fuller-fillies.co.uk
Dennys Uniforms	Chefs wear, Le Chef and front of house uniforms, Catering clothing; any order size	Leatherhead	www.dennys.co.uk
Lara Wear Ltd	Creates long or short series for men, children, and women; manufacture 25,000 units per month.	London	www.garmentproduction.co.uk
Lily Ltd	Produces woven garments (wholesale)	Leicester	N/A
NC23 Ltd	Women's wear; runs a small collection	Crofton Park	N/A
Tiger Global Ltd	Provides outsourced production service; runs low to middle volume	Southgate, London	www.worldinnovators.com
De La Creme	High street fashion jackets and coats; runs for market traders and wholesale buyers	Leyton	N/A
D & M Fashions (Scotland) Ltd	Manufacture gents and ladies wear; runs low to high volume	Alloa	www.dmfashions.co.uk
New Model UK	Leisurewear, sportswear, schools, cleaners, nursing homes, car park attendants, hotels and catering sector, and workwear	Wolverhampton	www.newmodeluk.com
Substance Over Style T-Shirts	Handmade silkscreen art prints and t-shirts	London	N/A
Article 10	Manufacture jerseywear, t-shirts, sweatshirts hoodies	Leicester	http://www.article-10.com/
Private Manufacturing	Make the clothing based on samples, images, photos, sketches, drawings from 1 piece to 200.	Acton, London	N/A
Hall U.K. (Manufacturing) Ltd	CMT from 50 garments per style (Men's wear, Ladies wear, and children's wear)	Handsworth, Sheffield	www.hallukmf.co.uk
Mountain Method Ltd	Manufacture clothes and supplies waterproof clothing.	Millom	www.mountain-method.co.uk
Bespoke Clothing Solutions	Supplies bespoke apparel to suit any budget	Oldham	N/A
Gees Active	Bespoke skating, Gymnastic, Artistic & Dancewear; runs for retailers and wholesalers	Swindon	www.geesactive.co.uk
Mahq Apparel Ltd	Menswear, ladies wear; make all order sizes	Manchester	
White Pilot Shirts	Pilot Uniform Shirts (women and men)	Wembley	www.WhitePilotShirts.Com
DNA Manufacturing Ltd	Men and ladies Blazers, hoodies, T-shirts, sweatshirts, dresses and skirts Joggers; run smaller to larger order sizes	Ashland, Milton Keynes	www.dnamanufacturing.co.uk
Tk Clothing	School and work wear, children's garments, ladies and men's fashion, heavy-duty covers and bags, surf wear; runs small bespoke or large orders	Cullompton	N/A
Arenco Ltd	Uniforms, fashion wear, formal wear, corporate wear; minimum of 50 pieces	Leyton, London	N/A
Brodwaith	CMT; runs small and large quantities	Gaerwen	www.brodwaith.co.uk
Midland Trade & Commerce	Clothing manufacturer line of work; handle different order sizes	East Acton, London	N/A
Creative Fashion Services	Trousers, jackets, dresses, blazers, skirts, coats, tops, wedding bridesmaid dresses	Peckham, London	N/A
Klassic Clothing Ltd	Full CMT; no minimum order requirements	Hounslow	www.klassicclothing.com
J&A Fashion Ltd	CMT; small to medium quantities	Dagenham	N/A
Pattern Cutter UK Ltd	Design, development, and production	Dunfermline	www.patterncutteruk.com
BJS Support Ltd	Ladies, Men's and Children's clothing	Broadway	N/A
The Sampling Unit Ltd	Manufacture of Designer Clothing for women/men; Production Capacity: 300/400 units/month; No minimum order	Finsbury Park, London	thesamplingunit.co.uk
Michelsons Of London Ltd	Neckwear and accessories	Sittingbourne	www.michelsons.com
Childrens Suits UK	Children's partywear; runs all order sizes	Ilford	www.childrenssuits.co.uk
MSN Equine	Bespoke products for the horse rider, and home; runs small order size	Stow Park, Lincoln	N/A
Toumaziandco	High-end clothing manufacturer and runs a small production,	Finsbury Park	N/A
Rifraf Clothing	Woven and knitted fabrics	Leicester	N/A
UK Sample Room	Coats, skirts, trousers, and jackets, dresses; can make up to 200 bespoke samples and sealers per week	Tottenham, London	N/A
Robert J Hughes	CMT	Enfield	N/A
Hamedson Enterprise Ltd	Jeans and t-shirts	Manchester	N/A
Atelier Creative	Offers first patterns, toiles, and grading	Sheffield	N/A
Excel Apparel Ltd	Childrenswear, men's and women's	London	www.excellondon.co.uk
Bramble	CMT and runs	Leyton	N/A
Mokon Fashion Studio UK	CMT and small to medium production	London	N/A
Stock Solution (Global) Ltd	Manufactures clothes	Leeds	http://www.stock-solutions.co.uk

Uniflo Ltd	Dress sampling, skirts, trousers, pleated garments and CMT; 100-1000 orders/week	Tottenham, London	N/A
The Reprocessing Ltd	Clothing and footwear	Hyde	www.trclimited.co.uk
Michaeladressmaking Ltd	Sample, patterns and clothing manufacture; runs small order size	Shepherds Bush	N/A
Agartom Ltd	Design, sample making, toiles and production	Tottenham	N/A
Chic Ciclistas -	Rainwear	Cambridge	N/A
Fielding & Nicholson Tailoring -	Tailoring service; produce to individuals	Whitechapel, London	www.fieldingandnicholson.com
La Ferro	Special occasions, evening, bridal, cocktail, dancewear and plus size; no minimum order required	Kingston upon Thames	www.dresssamplemaking.com
K K Wear	Jackets; member of the British Clothing Companies; runs larger order sizes	Wolverhampton	www.kkwear.co.uk
Lynx Marketing Services Ltd -	Weft knitted fabrics; runs small to large order quantities	Pinxton, Nottingham	www.lynxmarketingservices.co.uk
Pattern Cutter Creative Clothing	Pattern cutting and garment making; runs a wide range of work	Waltham Abbey	www.creative-pattern-cutter.co.uk
Moville Clothing Co. Ltd	Clergy clothing, barrister shirts and blouses, salon wear, school uniforms, work wear, health & beauty wear, pyjamas and nightwear	Londonderry	www.movilleclothing.com
Tanya Dimitrova Fashion Studio	Men and women's clothing, bridal and grooms wear couture.	London	www.tanyadimitrova.com
ME Clothing	Handmade childrenswear; small order sizes	Penzance	www.meclothing-shop.co.uk
Tigon Sports Ltd	Combat gear (MMA Shorts, Weightlifting Straps, Boxing Gloves, focus pads, Hoodies, Curved Thai Pads); runs small to large order quantities	Bristol	www.tigonsports.com
Magzs Group	Sportswear; runs small to large order quantities	London	www.magzs.co.uk
Grade House Ltd	Womenswear, childrenswear menswear, sportswear, maternity, plus size	Wembley	www.gradehouseltd.com
Merox Screenprint & Embroidery	Embroidery and screenprint; runs all order sizes	Bournemouth	www.merox.co.uk
MPC Embroidery Limited	Embroidery decoration; runs small to large order quantities	Glasgow	N/A
Sean Pounds Tailoring	Bespoke suits and clothing; runs smaller and bigger sizes	Northampton	www.seanpounds.co.uk
Aklah Clothing	Ladies polo shirt; runs for wholesalers and retailers	Malton	N/A
Handmade by Aggie	Make clothes, bridal, soft furnishing alterations, kilted skirts, curtains making, men's and kids kilts	Livingston	N/A
Wear UK Ltd	Ladies clothing; runs a large or small order	Stalybridge	wearuk.co.uk
Yoyo Children's Wear	Children's clothing; runs small order	Rawcliffe, Goole	www.yoyochildrenswear.com
About You Fashion	High street fashion branded ladies clothing	Atherstone	N/A
Hotcouture Mitrani Yarden	Freelancer fashion designer and pattern maker.	Nottingham	www.mitraniyarden.com
STC Custom Teamwear	Sportswear (rugby shirts, netball dresses, hockey kits, basketball vests and cricket whites)	Stowmarket	www.stc-teamwear.com
China 2 West Ltd	Product design, manufacturing management and quality control	Chantry, Frome	www.china2west.com
Death Wish Clothing Limited	T-shirts, snapbacks, hoodies, and long sleeves	Bracknell	N/A
S.A.M. Creations	Sampling and CMT; run a small production	Lewisham, London	samcreationsyk.wix.com/tailor
IC Glamour	Designer clothing and accessories	Ilford	icglamour.com
Moguland Garment Ltd	Ladies dresses, Ladies playsuits, women's tops, crop tops, women skirt and bottoms	Manchester	N/A
Kids and Co Wholesale	Baby and children's wear; runs a wholesale clothing	Leicester	www.kidsandcowholesale.co.uk
ASG Europe	Bespoke luggage, bags and accessories; runs small production orders	Witham	www.asggroup.net
Starline Trading Ltd	Beachwear, Lingerie Sets, Burlesque or Retro Costume, Nightwear or Clubwear, Gothic clothing; no minimum order quantities policy	Clapham Common, London	www.starlinelingerie.com
Impact Trading (UK) Ltd	Clothes for schools, workplaces, sports clubs, zoos, charities, etc.	Milton Keynes	www.impacttrading.co.uk

Note(s): N/A stands for Not available

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G. First publication by Emerald publisher

Taifa, I.W.R; Hayes, S.G & Stalker, I.D., (2020) "*Development of the critical success decision criteria for an equitable order sharing for an extended enterprise*" The TQM Journal, published by Emerald, Vol. 32 No. 6, pp. 1715–1742, (Appendix G). (https://doi.org/10.1108/TQM-05-2019-0138).

The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/1754-2731.htm

Development of the critical success decision criteria for an equitable order sharing in an extended enterprise

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Received 17 May 2019
Revised 9 September 2019
13 November 2019
Accepted 30 December 2019

Abstract

Purpose – This study identifies and ranks the appropriate critical success decision criteria (CSDC) for the bulk order distribution (sharing) amongst multiple manufacturers (suppliers) working as an extended enterprise (EE).

Design/methodology/approach – The study deploys a qualitative approach to generate the appropriate decision criteria. The balanced scorecard and Pareto's chart (using Minitab® version 18) were used for gathering and analysing the pertinent criteria.

Findings – The process of evaluating and selecting the right manufacturers is essential. Manufacturer (supplier) selection is no longer decided solely based on cost/price criterion; currently, the quality and delivery criteria prevail. Additional incorporated criteria include price/cost, technical capability, production facilities and capacity, customer satisfaction and impression, geographical location, management and organisation, financial position, environmental concern, performance history, repair service, information technology and communication systems, procedural compliance, labour relation record, reputation, flexibility or diversification, attitude, operating controls, business desire, packaging ability, past business records, trust and loyalty, training aids, complaint handling service, warranties and claim policies, reciprocal arrangements, research and development and innovation, modern slavery concern, sustainable capability, collaborative/partnership and responsiveness. The study proposed a conceptual framework of an EE alongside how manufacturers working as a single virtual entity can consider the supply chain operations reference (SCOR®) model.

Research limitations/implications – The identified CSDC are suitable for order allocation to domestic manufacturers. The deployed approaches could be extended to the mixed and quantitative approaches for increasing the generalisability.

Originality/value – The study establishes the pertinent CSDC that are important to execute equitable order distribution to manufacturers in an EE framework.

Keywords Decision-making, Extended enterprise, Supply chain operations reference model, Buyer-supplier relationships, Small to medium-sized enterprise, Balanced scorecard

Paper type Conceptual paper

1. Introduction

Most retailers source from a mix of suitable manufacturers (vendors or suppliers). In doing so, this becomes one of their most strategic and critical activities. Retailers conduct supplier selection and evaluation processes (SSEP) – as they have to deal with sourcing and supply of products from many vendors (Wu, 2009a; Mavi *et al.*, 2016). Such a process not only benefits retailers but also enhances customer satisfaction (Li and Zabinsky, 2011). Conversely, the

The TQM Journal
Vol. 32 No. 6, 2020
pp. 1715-1742
© Emerald Publishing Limited
1754-2731
DOI 10.1108/TQM-05-2019-0138

We hereby acknowledge for all the funding from the UK Government through the provision of the Commonwealth Scholarship [TZCS-2017-720].

H. Second publication by IEEE publisher

Taifa, I.W.R., Hayes, S.G. & Stalker, I.D., (2020), "*Computer modelling and simulation of an equitable order distribution in manufacturing through the Industry 4.0 framework*", 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE), IEEE, 12-13 June 2020, Istanbul, Turkey, pp. 1-6. (https://doi.org/10.1109/ICECCE49384.2020.9179275)

Proc. of the 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE)
12-13 June 2020, Istanbul, Turkey

Computer modelling and simulation of an equitable order distribution in manufacturing through the Industry 4.0 framework

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***Abstract*— An Extended enterprise (EE) is a comprehensive conceptual framework that facilitates firms' working synergistically. Through the Industry 4.0 framework, large orders from retailers can equitably be distributed (assigned) to small and medium-sized enterprises (SMEs). This paper reports research on modelling and simulation processes for distributing (allotting) apparel orders to a cluster of SMEs in an extended enterprise framework. The distribution processes discussed in this study are mainly on allocating, sharing or dividing order quantities among collaborating business entities within an EE framework. The study employed Arena software as one of the discrete-event simulation software packages to illustrate the distribution processes of order quantities, particularly when many retailers request apparel quantities from many manufacturers. Through an EE framework, firms can gain competitive advantages by strengthening their supply chain partnerships. Several activities need to be controlled and monitored by any virtual factory scheduler service, which distributes and optimises bulk orders amongst manufacturers.**

Keywords—order distribution, Industry 4.0, extended enterprise framework, apparel manufacturing, modelling and simulation

I. Introduction

Small and medium-sized enterprises (SMEs) contribute massively to the United Kingdom (UK) economy [1, 2]. The UK is one of the leading European countries that together manufacture about three-quarters of the total textiles and apparel (T&A) sector's commodities [3]. Other countries include France, Italy, Germany and Spain [3]. In Europe, the T&A sector is supported by the SMEs; for example, more than ninety per cent of the total employees are from enterprises with less than fifty workers [3]. Within the UK, the sector comprises more than 84% of micro-size and 15% of SMEs [4]. In the UK, large firms with over 250 workers comprise less than 1% [4]. This motivates a need to focus on SMEs because they manufacture around sixty per cent of the total value-added output [3]. The UK Fashion & Textile Association (UKFT) highlights the dominance of micro-businesses and SMEs, and eighty-five per cent of firms have fewer than ten workers [5].

Although the sector is of much importance to the UK, still it lags other sectors in digitalising its (entire) supply chain. This might also be because the T&A sector is amongst one of the most complex and dynamic sectors when it comes to manufacturing processes and business models. This complexity can be observed in how manufacturers (suppliers) secure orders throughout the life cycle of an apparel product. Recent technological advancements reveal the potential to reduce complexity by utilising a digitalisation framework within an extended enterprise where SMEs work collaboratively as a single virtual entity. Thus, textiles and apparel companies, similar to other manufacturing industries, should invest in Industry 4.0, together with all essential technology enablers, to transform their ordinary factories to the smart ones [6].

Apparel manufacturing is lagging behind several sectors when it comes to digitalisation concepts [7, 8]. The sector is made of dynamic and complex supply chains. A key competitive area is fulfilling orders for retailers: the sector comprises many SMEs that must continually secure orders from retailers to survive. SMEs are small in size and struggle to compete with large independent apparel manufacturers in several countries; to respond to this, one option is for SMEs to collaborate with other related firms as an extended enterprise [9]. SMEs have resources, e.g. machines, factories' buildings and workers; thus, a lack of sufficient order quantities results in underutilisation of these resources, which over an extended period could lead to the closure (*liquidation)* of the factories.

In this digitalisation era, one approach can be to collaborate and work as a single virtual factory—an extended enterprise (EE)—where firms bid for orders from retailers via digitalised systems, which then equitably allocates orders secured. The resulting virtual partnership is an EE of sufficient size to compete with large factories. This study lays out a fundamental framework to realise an equitable distribution of multiple orders to a group of collaborating manufacturers. The computer model enables SMEs' survival by helping in securing orders via an Industry 4.0 framework. To realise this, three aims are as follows:

a) To explore the conceptual models for equitable bulk order distribution in apparel manufacturing.
b) To simulate a computer model that executes equitable order distribution through the Industry 4.0 framework.
c) To propose the extended enterprise framework for executing equitable bulk order distribution.

The UK Government funded this research through the provision of the Commonwealth Scholarship [TZCS-2017-720].

978-1-7281-7116-6/20/$31.00 ©2020 IEEE

I. Third publication by Taylor & Francis publisher

Taifa, I.W.R; Hayes, S.G & Stalker, I.D., (2020), "*Towards a digital revolution in the UK apparel manufacturing: An Industry 4.0 perspective*", Industry 4.0 – Shaping the Future of the Digital World, in Bartolo, P., Silva, F., Jaradat, S. and Bartolo, H. (Eds.), 1st ed., Taylor & Francis, 2nd International Conference on Sustainable Smart Manufacturing (S2M 2019), Manchester, UK, pp. 3-8.

Industry 4.0 – Shaping The Future of The Digital World – da Silva Bartolo et al. (eds)

Towards a digital revolution in the UK apparel manufacturing: An industry 4.0 perspective

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ABSTRACT: The study explores the potential for developing a virtual distributed manufacturing network for UK apparel manufacturing using a simulation approach for small and medium-sized enterprises (SMEs). The digitalisation is on enabling an equitable order allocation system (sharing or dividing) amongst the SMEs to ensure the apparel manufacturers' survival. The solution provides a potential model for proper production planning and scheduling service in developing strong networks. For the scheduling service, the SMEs are required to upload available capacity to the private cloud server, retailers load orders to cloud services, and the virtual factory scheduler service (VFSS) allocates and optimises work across factories. This study gives an overview of using mixed methods. Arena® software, together with the synthetic data, were utilised to simulate a model for a single retailer to multiple manufacturers. Thus, through the simulation approach as a component of Industry 4.0, it is possible to perform order allocation equitably.

1 INTRODUCTION

1.1 *Research background*

The UK textile industry was the leading industry for the first industrial revolution (late 18th century). In 1784, the first mechanical weaving loom was invented. Since then, much has been discovered. People are now applying the fourth industrial revolution concepts - Industry 4.0 – which began in 2011. Since the 1970s to the mid-2000s, the UK textiles and apparel (T&A) experienced a difficult period where many job opportunities and the domestic production vanished, and the country witnessed high importation of apparel products (Jones & Hayes 2004), mainly from China, Turkey, Bangladesh (Turker & Altuntas 2014), etc. The T&A sector needs revitalisation to benefit much from the digitalisation, which has both tangible and intangible benefits to manufacturers and retailers (Küsters, Praß, & Gloy 2017). In the business context, digitalisation is the use of information technology and digital media to develop a business process. Such a transitioning process in this sector can lead to Textile 4.0 (Chen & Xing 2015). The transformation can be either for all phases, i.e. design, manufacturing, distribution and sales, or to the ordering process. Thus, manufacturers need orders from retailers, both domestically and globally, to increase profits.

The UK T&A sector has both large manufacturers and SMEs. For large manufacturers, there is more possibility of securing orders easily from British retailers on their own, and possibly, they can run production without collaborating with others. Yet, for the SMEs, many of them are of low capacity that cannot enable them to secure orders from retailers on their own. This requires SMEs to work as an extended enterprise (EE) to obtain orders. To do so, SMEs need a virtual distributed manufacturing network that can assist in competing profitably with the foreign manufacturers who have advantages of highly containerised distribution networks, cheap land or renting cost, cheap raw materials, and cheap labours compared to the UK. Thus, the management for the UK SMEs needs to offer a quick response to highly volatile customers' apparel orders in season.

1.2 *Research motivation*

The UK T&A sector requires a quick decision for it to remain competitive in the market. The nature of its business outlook needs that both manufacturers and retailers must collaborate to tackle the routine nature of intense competition and continuously evolving scenario (Lectra 2018). Lectra (2018) further states that this sector needs a fully digitalised system. The digitalisation is needed for the conceiving process, designing and transfer process before enforcing for more technical development. Lectra (2018) states further that there is a need for having well-interlinked supply chain partners. It is thus correct that "fashion is now rapidly becoming a predominantly digital industry – one where huge volumes of data, digital collaboration, online social interaction, digital marketing, and e-commerce come together to create and sell a physical product to a digital-native demographic" (Lectra 2018, p.3). Still, the sustainability of the T&A sector will depend on the members' willingness and commitment as digitalisation needs collaboration in an extended enterprise. So, there is a need for having a bigger picture of effecting digitalisation in apparel

J. Fourth publication by Inderscience publisher

Taifa, I.W.R., Hayes, S.G. & Stalker, I.D., (Accepted 2020), "*Enabling manufacturer selection and an equitable order allocation amongst textiles and apparel manufacturers*", International Journal of Management and Decision Making, Vol. X, No. Y, pp.xxx–xxx. (https://doi.org/10.1504/IJMDM.2021.10032107)

Enabling manufacturer selection and an equitable order allocation amongst textiles and apparel manufacturers

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Abstract: Small and medium-sized textile enterprises (SMTEs) contribute to the UK economy. Anecdotal evidence indicates that many SMTEs fail to secure enough orders from British retailers. So, this paper reports on the methodological decision analysis model and the qualitative linear weighted point method (LWPM) to develop the pertinent critical success decision criteria and virtually distribute the bulk orders equitably. The relevant decision criteria are stated for the SMTEs. The criteria are crucial as they were consolidated from the textiles and apparel manufacturers only, contrary to other several studies that established generic decision criteria. The criteria consist of corporate social responsibility, economic and environmental factors. The results indicate the opportunity to execute order quantities equitably after having ranked the collaborating SMTEs. LWPM assisted to rank SMTEs in selecting the right manufacturers. Since the criteria are from the SMTEs only; the generalisability of the results to other industries may need further research.