

Chapter 10

Proposing a Tool for Supply Chain Configuration: An Application to Customised Production



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Abstract The full implementation of collaborative production networks is crucial for companies willing to respond to consumer demand strongly focused on product customisation. This chapter proposes an approach to evaluate the performance of different Supply Chain (SC) configurations in a customised production context. The model is based on discrete-event simulation and is applied to the case of supply chain in the fashion sector to support the comparison between mass and customised production. A prototype web-based interface is also developed and proposed to facilitate the use of the model not only for experts in simulation but for any user in the SC management field.

10.1 Scientific and Industrial Motivations, Goals and Objectives

Empirical evidence indicates the growing application of product customization strategies thanks to the possibility to consider the customers' opinion along the production process and realize goods more in line with customer's preferences [1]. It is expected that product customization will increase in the next 10 years by about 30% [2]. Fashion industry, and in particular footwear, appears to have good possibilities in implementing product customization, since Nike and Adidas are working on materials and technologies to support this business model and also small and medium companies are becoming more and more interested in customizing their offer [3, 4]. Moreover, a customized production can be a way to restore the competitiveness of European companies, enabling them to differentiate their offer from mass-productions realized in low-wage countries. However, to realize personalized productions the application

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of advanced production technologies and innovative management practices [5]. This is particularly relevant within the footwear industry in which customer requirements can vary widely in terms for example of fit, colours, functional and aesthetic features [4] along different dimensions like seasons, target groups, and geographical areas.

There are several studies proposing innovative strategies for customization at the company level, but it is still needed to identify the supply-chain implications of customized productions especially in sectors like footwear where production is highly parcelled to many different suppliers and subcontractors, each of them specialised in specific operations. The complexity of the footwear production is given mainly by the high variability of the product and the short life of each model requiring fast changing production systems and flexible production networks [4, 5].

The potential benefits of personalization are based on better adherence to customers' requirements and the resulting customers' satisfaction. Several studies suggest that this strategy may be particularly suitable in highly competitive sectors like fashion industry, where product differentiation is a key factor to compete in the market and achieve a competitive advantage [6]. A company may decide to offer only a few customizable products, or could adopt a fully made-to-measure strategy involving all aspects of its production [7–11].

This chapter proposes an approach to evaluate Supply Chain (SC) performance of customized productions characterized by small-customized orders within the footwear industry. Thanks to a prototype web-based interface, a simulation model evaluates different type of performance indicators like inventory volume, order delivery, product quality for customized (i.e. small production) and traditional collections (i.e. large productions), and quality and delivery time of suppliers [4]. The model is based on deep analysis of historical data from 8 companies to study the common features of their SCs and to define a model that can represent the most critical and important steps in production.

The chapter is organized as follows. Section 10.2 gives an overview of the literature related to SC management for customized production. Section 10.3 presents the proposed approach, whereas Sect. 10.4 presents the details about the simulation model and the scenarios to be evaluated. Finally, Sect. 10.5 discusses the conclusions and future developments.

10.2 State of the Art

Customization strategy should enable a company to provide the right product variety without compromising rapid response to market or impinging upon its need for efficient production [9, 10]. In this way, customization is like mass production of customized goods while needing to find a trade-off between efficiency and flexibility [6, 9, 10, 12, 13]. This issue has been extensively studied from the company's internal point of view by identifying product design aspects (such as modularization and postponement [14, 15]) that can combine the different market demand needs with the production capability of a company [8]. In particular, for what concerns footwear

industry, the development of new customized collections has become a significant challenge, where the desire for style, quality and comfort is very high and is influenced by the customer individual expectations and needs. Several footwear companies have decided to shift from the production of standard products to customization of some product collections for final consumers or for their direct first tier customers (i.e. retailers having direct contact with the final market that are able to specify the type of product customization that will be offered and appreciated within their shops). Therefore, footwear industry has started to create collections that match the stylistic and aesthetic trends of the market, e.g. flash collections characterized by a low number of products compared to traditional collections, produced in compressed lead times and characterized by features based on the specific market requirements [16]. However, an analysis that considers the implication that customization has on the entire SC is still missing and this works aims at filling this gap. Customization remains a real challenge within the footwear sector because of the complexity of the entire production process, which encompasses the assembly of several shoe parts while using different materials and manufacturing technologies and needing the involvement of many SC partners.

In customized contexts, the supply network configuration must be supported by the systemic monitoring of performance indicators [17], in particular of the suppliers' performance, as a way to assure the timing of the delivering process [18]. Therefore, how to physically locate production and manage supplier relationships have become an increasingly important strategic decision as shown both in review [19], in explorative studies [20–22] and quantitative modelling [16, 23–26] to optimize sourcing and production activities.

These strategic decisions become even more critical in case of customized production [27]. An evaluation of inter-company and intra-company performance is required to improve SC capability in order to optimize the use of both resources and suppliers. In particular, the analysis of suppliers' performance leads to understand how the production nodes can be linked in a network, and how they can collaborate to propose new practices that aim at filling the gap between the current performance (in terms of quality and delivery time) and the expected performance targets [28, 29]. However, even though many studies have discussed the need to monitor the performance of each supplier, relatively few attempts have been made to systematically identify how the supplier performance can affect the performance of the entire SC network [30].

10.3 Modelling a Supply Network for Customized Production

Several different aspects need to be taken into consideration to address the product customization issue by adopting a SC point of view. The proposed approach aims to evaluate network configurations over time to understand the organizational

decision-making process, investigate the relations between the actors in the SC and analyse the consistency between the SC coordination model and the decision-making policies [31]. A discrete-event simulation (DES) model was developed to evaluate the performance of supply networks for customised productions in terms of inventory volume and order delivery time for small or large productions. Moreover, the model allows evaluating how the suppliers' performance in terms of quality and delivery time can influence the overall ability of the network to fulfil the customized requests [4, 32].

As explained in [4], discrete-event simulation is chosen because various problems related to SC configurations have already been solved with this technique. For instance, Cigolini et al. [33] employ discrete-event simulation to analyse SC configurations in terms of stocks and stock-out by evaluating if intermediaries influence product cost and quality. Ramanathan [34] implements a simulation method to evaluate the importance of collaboration in a SC, while Bottani and Montanari [35] propose a simulation model to support demand forecast with information sharing mechanisms in a SC. In terms of applying a simulation method in the fashion industry, Zülch et al. [36] employed simulation to examine different scenarios for customised orders in the garment sector, although that model made a comparison at the company level instead of considering the entire SC. This work takes inspiration from the previous approaches in literature to design a simulation model to support the comparison of different SC configurations.

The proposed SC configuration approach was developed for the fashion sector and the structure of the network is based on the experience gained during the analysis of several case studies within the footwear sector [27, 37, 38]. Figure 10.1 represents the network flow where different suppliers collaborate with the focal company (i.e. the shoe producer) by realizing specific components of final products and then by delivering the products to the warehouse of the shoe producer. The shoe producer assigns specific orders to suppliers based on their manufacturing skills after the verification of the specific needs of consumers in terms of stylistic preferences and ordered quantities. Finally, when each product component arrives at the components' warehouse, the shoe producer finalizes the production activities (mainly assembling) and sends final products to warehouse where orders are organized and shipped to customers. As a proxy for the implementation of product customization, the model considers the dimension of the customer order, which can range from the request of a single customized product to a single customized batch and compares these customization possibilities with a production realized with large batches of non-customized products.

The developed model supports the analysis of the impact of changing external parameters (e.g. customer demand, environmental regulations) on business, in particular in relation to the introduction of new product opportunities into their production network. The model mainly targets supply managers who have the possibility to create comparative SC configuration scenarios based on the variations in the suppliers' performance. Some of the variables that are available for the user are the following:

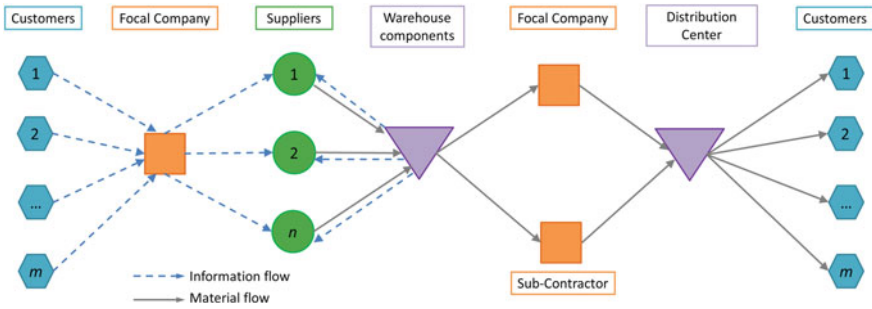


Fig. 10.1 Simplified representation of the network flow

- Activation of suppliers for the specific scenario to be considered.
- Updating their performance according to the data analysed in ERP.
- Implementing different re-order strategy (EOI-Economic Order Interval versus EOQ-Economic Order Quantity).
- Changing the customer order quantity and typology.
- Changing the mix of products to be produced in the considered period and related quantities.
- Changing BOM (Bill of Material).
- Changing initial stock of components in the warehouse.

10.4 Outcomes

This section is organised in three parts: Sect. 10.4.1 describes the developed simulation model, Sect. 10.4.2 presents the software architecture that is behind the web-based user interface and that enables the use of the model also to people not expert in simulation. Finally, Sect. 10.4.3 gives an insight on the experiments carried out to compare different scenarios.

10.4.1 Simulation Model

The optimization of a SC configuration requires first to characterize the *as-is* situation in terms of available suppliers, type of supplied components, type of managed order (small or large quantities) and performance indicators (quality, delivery time for each order).

In this study, we adopt the representation of the supply chain where there are two main flows, goods and order flows. The generic node i ($i = 1, \dots, N$) receives orders from the node $i - 1$ and goods from the node $i + 1$, through transport activities. For each node i , a lead time $L(i)$ includes transport, ordering and warehousing activities. We model the flow of multiple goods, with different BOM and with

different order dimension. Customer demand is a stochastic variable, with normal distribution $N(\mu, \sigma)$.

The proposed Simulation Model evaluates the daily production for a period defined by the user (usually season production of six months or one year). The production mix considers the use of a fixed number of components chosen among the most important for customisation for the specific product. Moreover, the model assumes that a share of the products are produced only by the focal company or by a sub-contractor while the remaining by either the focal company or the subcontractor based on the shortest queue in the production process. The sub-contractor production time includes the extra time required to cover both the time it takes to deliver the components to the focal company and the time it takes to ship the final products. It is assumed that there are two different re-ordering policies (ROP):

- *ROP1*, i.e. the suppliers send the ordered quantity every time it is requested by the focal company.
- *ROP2*, i.e. the components are sent at a fixed time or when the accumulated quantity of re-orders reaches a predetermined value.

The materials are sent to the longest production queue for products that can be produced either by the focal company or by a subcontractor.

One centralised warehouse is located at the focal company site where all suppliers send components for all the product models. When components arrive at the centralised warehouse, they undergo a quality check with an associated processing time. In case of defects, the system sends back the request of a new order to the suppliers to cover the discarded amount. In the *ROP2* policy, since the inventories cover the mean consumption of the supplier lead-time, the re-stocking order will be sent to the suppliers only when the stock reaches the re-order point. This can shorten the delivery time, but requires larger inventories [39]. When the production is completed, all the products are sent to the distribution centre located at the focal company site, which is then responsible for delivering the required orders to the retailers.

Since the proposed Simulation Model adopts a SC perspective, the model is based on the key performance indicators (KPIs) of each supplier in terms of order delivery time and order quality, as suggested in literature [13]:

- $T(i)$, i.e. delivery time of supplier i evaluated as the average time to deliver an order. This KPI is particularly relevant in a customization context because the need to provide the customized product in a short period calls for high flexibility.
- $Q(i)$, i.e. quality of supplier i evaluated as the average percentage of defective pieces for each delivered order. This KPI is also particularly critical in a customization context because consumers willing to pay a higher premium price for customized products do not tolerate defective pieces; defective products create delivery delays due to reworking.

After the definition of the *as-is* situation, different *to-be* scenarios for each network configuration can be defined to analyse the performance of both traditional and customised products. Starting from the collected data, a set of experiments allows to vary from the *as-is* analysis depending on the company's choice, for instance, to

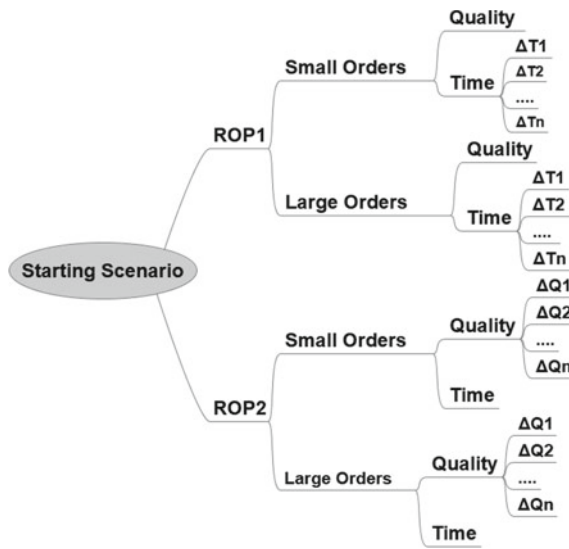


Fig. 10.2 Scenarios according to the chosen variables

collaborate with new suppliers or to outsource specific activities to different suppliers. The simulation runs for each of the *to-be* scenarios along the dimensions represented in Fig. 10.2 (i.e. re-ordering policy order dimension, supplier KPIs) to create different supply chain configurations.

The overall network performance is analysed for each configuration, based on variations in the suppliers’ performance in terms of quality and delivery time. Thus, according to the supply network, different SC configurations are automatically analysed and compared in order to identify the best SC solution. Each network configuration is evaluated based on the following supply chain performance indicators:

- Order Lead-Time (OLT), i.e. the average time window from the issue of the order to the retailer of the focal company until the delivery of products to the customer.
- Inventory Volume (IV), i.e. average amount of inventory in the supply chain.

More details about the development of the Simulation Model can be found in [4].

10.4.2 Software Architecture

The software architecture represented in Fig. 10.3 was designed and implemented to take advantage the Simulation Model presented in the previous section. The architecture consists of the following components: Simulation Model, Simulation Engine, Web Interface, and external data sources.

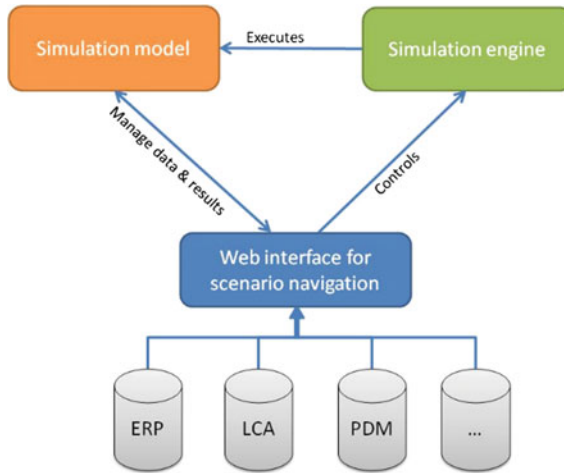


Fig. 10.3 The software architecture

The web interface supports supply chain managers in the use of the simulation model. Indeed, this interface provides an analysis of the *as-is* situation of the SC configuration in terms of type of supplied components, type of orders (small or large quantities, customized orders) and performance indicators (quality, delivery time for each order). Then, using data from external data sources (e.g. ERP, PDM), various *to-be* network configurations can be generated by taking into consideration different combinations for suppliers' performance. For each network configuration, the user can see the impact on the overall network performance.

The generated simulation models are executed by a simulation engine (i.e. SIMIO¹ in this case) and the web interface enables to navigate through the scenarios in a user friendly way. The user can access the models, so that input data can be gathered and the results can be easily visualized and analysed.

The web interface was developed on the Bloomy Decision platform² that is an executive decision platform providing a framework to support *what-if* analysis based on advanced analytics (predictive and prescriptive). The choice on Bloomy Decision is based on the fact that it can tackle complex problems in multi-decision making contexts and exploits data and computation distribution, while managing information with hybrid data structures (SQL, NO-SQL, and Hadoop HDFS techniques).

Moreover, this platform enables multiple users to share input data, models, and calculus engine results. The platform offers the ability to manage simulation and optimization problems, by enabling the user to setup a simulation or optimization model in a guided and structured manner. The web interface enables to control:

- Simulation input data and parameters.

¹<https://www.simio.com>.

²www.act-OperationsResearch.com.

- Creation of simulation scenarios.
- Execution of simulation runs exploiting the SIMIO simulation engine.

The software architecture is based on the web application that manages the data flow feeding the simulation engine (SIMIO) to start the simulation process based on the predefined model. Moreover, the platform enables *what-if* analysis and comparative visualization of simulation scenario results.

After the simulation run, the user can compare different scenarios (up to 5) with different views summarising the results. In particular, the web application provides views on simulation results and scenario comparison. The Simulation view enables to select a scenario and visualize the related results via a graph and a set of tables. For example, in the case of the simulation model described in Sect. 10.4.1, it is possible to control the amount of items assembled by the focal company or by the sub-contractor, the average order lead time, the level of pollution and the final stock of the components. The user can select a scenario and compare it while exploring a table reporting all the evaluated scenarios. The simulation engine dynamically creates a set of bar charts for each control variable, where each graph compares different scenarios in the considered dimensions.

10.4.3 Experiments

The simulation model was tested with data collected from footwear companies by means of interviews and extraction of data from their ERP to have the possibility to make a cross-case analysis on most important practices related to fashion supply management. Data from different sources were aggregated to consider an average value of most important performance indicators.

Table 10.1 summarizes some important data related to the selected companies. It is clear that these companies need to manage orders with large variability (see *Order dimension* column in Table 10.1), requiring them high flexibility in the production process and supply chain.

The initial value of the inventory level is set to an average of 20 orders (both for large and small orders) when the ROP1 policy is adopted and an average of 40 orders when the ROP2 policy is used. Large orders are characterised by a normal distribution $N(800, 20)$, whereas small orders by a normal distribution $N(40, 5)$. The model simulates the daily production for a period of six months. The model assumes that 30% of the products are produced only by the focal company, 30% only by a sub-contractor and the remaining 40% by either the focal company or the subcontractor.

After setting the *as-is* supply chain scenario with the starting figures, the simulation runs are based on the scenarios presented in Fig. 10.2. For each ROP strategy and for each order dimension, the variations in the supplier performance (quality and delivery time) lead to different configurations. Therefore, scenarios are characterized by the improvement in the suppliers performance in terms of either $T(i)$

or $Q(i)$ (i.e. improvement in the delivery time or percentage of defects). Table 10.2 reports the results for 24 scenarios in terms of change in the supply chain IV and OLT. Each scenarios $J_{xy}(s)$ is characterized by x that indicates the order dimension (S =small, L =large), y that indicates the supplier performance improvement (Q =quality, T =time) and s that specifies the magnitude of the improvement ranging from 3 to 18%.

Figure 10.4 puts together all the scenarios from Table 10.2 and shows the two indicators (IV and OLT) considered for SC performance. The results show that, assuming the ROP1 strategy is applied, most of the scenarios with small orders (scenarios $JSQ(s)$ and $JST(s)$) have a large impact on both IV and OLT compared with the scenarios with large orders (scenarios $JLQ(s)$ and $JLT(s)$). Moreover, the improvement in the supplier average delivery time $T(i)$ [scenarios $JST(s)$ and $JLT(s)$] has a greater impact on IV than the improvement in the quality $Q(i)$ [scenarios $JSQ(s)$ and $JLQ(s)$].

Similar results can be obtained for the ROP2 strategy and a more detailed analysis can be found in [4]. Furthermore, as addressed in [40], the simulation model can be integrated with Life-cycle assessment (LCA) analysis to create scenarios where it is

Table 10.1 Master data of companies

Company	Turnover € 2015 ^a	Employees	Seasonal volume ^b	Seasonal n. models	Order dimension ^c	Price range
A	53	230	220	600	10–300	medium/high
B	10	20	150	180–250	80–600	high
C	10	40	37	150–180	50–1500	medium
D	8	40	32	200–300	50–600	medium/high
E	17	100	60	300	10–1000	medium/high
F	6	53	25	40–60	300–5000	medium/high

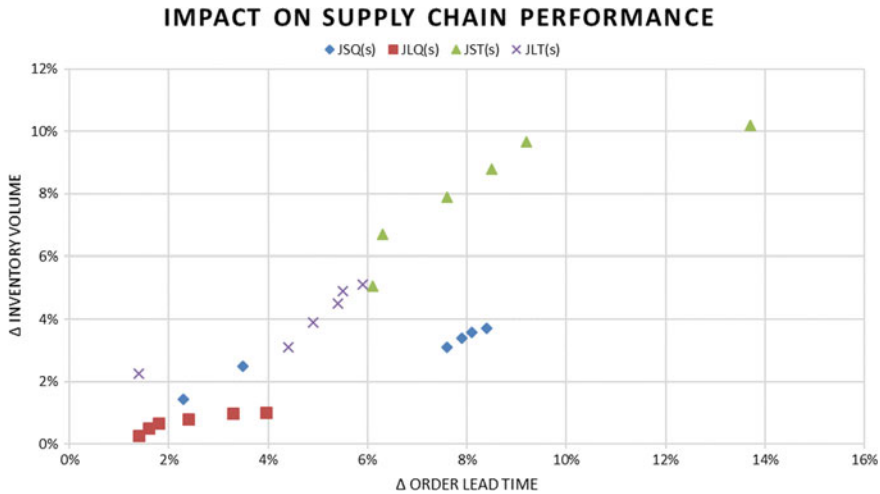
^ain million euro

^bin thousands of products

^cno. of products per order

Table 10.2 Results of the scenarios for ROP1

s	Δ improvement (%)	Δ Inventory Volume (IV) (%)				Δ Order Lead Time (OLT) (%)			
		JSQ(s)	JLQ(s)	JST(s)	JLT(s)	JSQ(s)	JLQ(s)	JST(s)	JLT(s)
1	3	1.4	0.3	5.1	2.3	2.3	1.4	6.1	1.4
2	6	2.5	0.5	6.7	3.1	3.5	1.6	6.3	4.4
3	9	3.1	0.7	7.9	3.9	7.6	1.8	7.6	4.9
4	12	3.4	0.8	8.8	4.5	7.9	2.4	8.5	5.4
5	15	3.6	1.0	9.7	4.9	8.1	3.3	9.2	5.5
6	18	3.7	1.0	10.2	5.1	8.4	4.0	13.7	5.9



the performance in terms of inventory volume and order lead-time. In fact, although the quantitative results of the study are specific to the case of the footwear industry, the presented simulation model can be applied to other companies to compare different production scenarios and evaluate the performance of the SC.

The proposed model could also be improved by including other performance indicators and the variation of exogenous factors, such as demand variability. Changes in the management of orders (e.g. varying when and how customer orders become production orders) could also be considered as a way to improve the scenarios to be considered. Finally, the study could be further deepened by adopting a long-term perspective that investigates the performance trends over a number of years to study SC configurations with a longitudinal perspective.

Further developments can be done to improve the web-interface, to extend the integration of the tool with other databases and to assure a multi-criteria comparison between the scenarios.

During the development of the model, several interactions have been organized with experts at Politecnico Calzaturiero, an organisation representing footwear companies in Veneto Region, to disseminate customisation paradigm and to validate the software prototype.

Finally, the exploitation of the scientific results led to the submission and approval of two European research projects titled DISRUPT (FOF-11, 2016) and NEXT-NET (NMBP-37-CSA). The former deals with the management of the SC, whereas the latter is related to definition of scenarios for SC of the future. Indeed, one important focus will be on new SC models for customization and how technologies can support the process towards customisation.

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