OmniaScience

Journal of Industrial Engineering and Management
JIEM, 2021 – 14(2): 250-268 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423
https://doi.org/10.3926/jiem.3182

Supply Chain Integration within Mass Customization: Tactical Procurement, Production and Distribution Modeling

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Received: April 2020
Accepted: November 2020

Abstract:

Purpose: The actual market characteristic oriented toward customers' requirements compels decision-makers to foresee customization abilities. Mass customization represents a valuable approach to combine customizable offers with mass production processes. From a supply chain standpoint, this paper attempts to develop an integrated procurement, production and distribution modeling to describe the generated framework structure formulation within tactical decision planning level.

Design/methodology/approach: The paper provides a mixed integer linear programming model of a three echelon supply chain illustrated from the automotive industry with (a) customers: Original Equipment Manufacturers (OEMs) identified as leaders and (b) first-tier supplier: wiring harnesses manufacturer (c) second-tier suppliers: raw material suppliers, identified as followers. The model formulation is depicted through dyadic relationships between stakeholders considering the specific operation enablers of the environment such as make to order, modular approach in addition to the corresponding inventory management policy.

Findings: The integrated model is solved by an exact method which illustrates the feasibility of the formulation in addition to the observance of the applied constraints. A sensitivity analysis is performed to highlight the interdependency across some key parameters to provide managerial insights within the studied framework while keeping the optimal solvability of the model.

Research limitations/implications: The limitation of this study is the computational experiment study. An extensive experiment with a real-word case will outline the optimal solvability status of the exact method and the necessity for a performance benchmark through the approximate solving approaches.

Originality/value: The present research aims to contribute as first studies toward mathematical modeling for supply chain decision planning endeavor operating within mass customization business model.

Keywords: tactical integrated supply chain, mass customization, postponement, mixed integer linear programming (MILP)

To cite this article:

Benbouja, M., Touil, A., Echchatbi, A., & Charkaoui, A. (2021). Supply chain integration within mass customization: tactical procurement, production and distribution modeling. *Journal of Industrial Engineering and Management*, 14(2), 250-268. https://doi.org/10.3926/jiem.3182

1. Introduction

Product customization is considered as an important leverage to develop a competitive business strategy towards market trend where customer expectations become more heterogeneous. Within large production context, mass customization strategy combines mass production aspect with customization abilities in addition to the related processes in order to build a customer-based approach (i.e. economy of scale and economy of scope) (Daaboul, Da Cunha, Bernard & Laroche, 2011). Many definitions of mass customization have been proposed in the literature, the main understanding is to provide a custom product according to some specified characteristics for a mass market so as many units of one achieving cost and speed of mass production (Coletti & Aichner, 2011). The deployment of this strategy exhibits the supply chain to an increased complexity. Thus, all stakeholders have to enhance collaboration activities to cope with strategical, tactical and operational changes. Correspondingly, product variety management attempts to outline product and process activities. Offering a large product range compel actors to provide a high responsiveness through flexibility and agility toward the realized dyadic relationships. For instance, many firms provide product configuration abilities to the customers which generate specific design operations as a trigger to the related upstream and downstream processes.

From a supply chain management (SCM) standpoint, firms have to draw an interaction framework for the required mass customization enablers to sustain capability strengthens due to its crucial role within a highly volatile context, particularly with a market demand's timeline that is often tight. The mass customization capability is perceived as the ability to quickly produce a high range of product variety coming from customized offers with a cost nearly to mass production scale through technical and managerial innovations (Tu, Vonderembse, Ragu-Nathan & Ragu-Nathan, 2004). Despite the improvement opportunity that mass customization brings to firms, supply chain actors have to cope with the evolved challenges from product variety. As stated by Jin, Wang, Zhang and Zeng (2019), mass customization is extended to include an efficient operations realization by developing customer value through a dynamic integrated collaborative process. The prevailing elements suggest an information flow integration, supply mode driven by customer demand in addition to dynamic capability development across the actors to ensure a quickly transfer of customer demand through the supply chain. However, a complete pull system adoption for all supply chain functions appears very tough. Correspondingly, the required responsiveness for mass customization capability is based on postponement and modularization, the defined customer order penetration point reveals make to order process for value creation while the global supply chain configuration supports heterogeneous upstream lead time (Ivanov & Sokolov, 2010).

The ultimate success of supply chain depends on the capability to efficiently handle flows through the stakeholders. In this regard, this paper attempts to model the supply chain network operating with mass customization strategy. In fact, an optimization planning model is provided to support decision making with an integrative view of supply chain considering the coordination complexity through dyadic relationships between stakeholders within mass customization context. Thus, the study proposes a mixed integer linear programing model to evoke the tactical supply chain planning interactions' patterns where procurement, production and distribution are considered simultaneously. Hence, the related framework considers an integrated three echelon supply chain with a centralized decision making according to leader and followers interactive's system. To the best of our knowledge, there is a lack of mass customization studies with the perspective of an integrated supply chain mathematical modeling through MILP formulation. The study is inspired by a real-world case from the automotive industry which is oriented towards mass customization, as highlighted by Candelo (2019), the automotive industry behavior has been shifted from homogenous structure towards a customer focus new market. The proposed model incorporates (a) original equipment manufacturers (OEM) (b) first tier supplier: wiring harnesses manufacturer (c) second tier suppliers: raw material suppliers. The OEMs are outlined as leaders due their main trigger role of the supply chain, while the second and third echelons are pointed out as followers.

The remainder of this paper is organized as follows. Section 2 provides an overview of the relevant mass customization literature. The model formulation and the adopted assumptions are described in section 3. Section 4 presents the case study in addition to the results of the computational experiments. A sensitivity analysis with managerial insights is considered in section 5, followed by the conclusion in section 6.

2. Literature Review

Mass customization is a broadly approach that develops a business value creation with a specific focus on customers' requirements of product and service definitions. It has been introduced by Davis on 1989, he indicated that mass customization challenge is to preserve a highest customer service level while proposing an individual treatment for a mass market. It is also defined as a competitive strategy where each customer can fit its own need with a reasonable price (Pine, 1993). In the actual context, companies tend towards customer-based strategies to strengthen their market position. Candelo (2019) provided the new market characteristics that promote the switch from mass production to mass customization argued by three main factors of change, namely, the limits of mass production process which requires stable inputs, reduction of market homogeneity and demand instability, while these elements depict the fundamental of the economy of scale. Thus, the business orientation is shifted from providing low-cost and standardized products to fulfilling customers' needs as an improving market share leverage. In fact, product variety management strategy (PVMS) presents a tradeoff framework between variety creation and supply chain performance to enhance actor's capability through the overall interactions, the purpose is to mitigate the product variety impact on supply chain performance. Besides, PVMS is classified into two classes, namely, product basis and process basis. For instance, Scavarda, Reichhart, Hamacher and Holweg (2010) associated modularity as a product basis design while introducing operations flexibility with postponement concept to support the organizational capability for process basis. Um, Lyons, Lam, Cheng and Dominguez-Pery (2017) introduced a conceptual model to outline the link of supply chain responsiveness and PVMS, it has been emphasized by flexibility on internal operations and agility for external competencies. Afterwards, an overview of the supply chain performance through cost efficiency and customer service level has been provided. According to the studied survey, the results indicate that supply chain flexibility leads to build its agility. Thereupon, from an industrial standpoint, mass customization could be perceived as an operations management perspective due to its impact on the adopted organizational strategies through the supply chain, for example, the rapid and effective integration to record customer requirements and production launch considering delivery time window, building a strong customer relationship with customer-supplier framework for the interactions between supply chain actors (Selladurai, 2004). Zebardast, Malpezi and Taisch (2013) proposed a conceptual framework of the corresponding supply chain with four main clusters, namely, customization level, modularity level, postponement and relationship management that involves actors' integration for decision making. Hence, fostering mass customization capability through the supply chain should be placed alongside with dynamic capabilities such as quick response which is suggested as high agility level. Many factors provoke this organizational structure, especially the delayed customer order decoupling point (i.e. postponement) and the resulted operations' schemes such as make to order policy as it represents the crucial point to launch upstream activities and operate according to the designed supply chain interactions framework. Indeed, manufacturing processes are performed after customers' order reception to cope with the uncertainty and ensure the product content accuracy (Yang & Burns, 2003). Furthermore, modularization approach is closely related to mass customization which allows an efficient organization of complex products and processes. It helps to perform with a more flexibility and quick response according to product variety combination (Peng, Liu & Heim, 2011). To some extent, both postponement and modularization can be adopted to achieve the desired business process of scale and scope since modularity contributes to facilitate postponement (Hsuan Mikkola & Skjøtt-Larsen, 2004). Therefore, the supply chain strength arises from collaborative aspect within a highly volatile environment, and the standalone position will hinder performance. Fogliatto, Da Silveira and Borenstein (2012) pointed out mass customization enablers where supply chain coordination figures among others (e.g. design and product platform, information technologies) as long as they underline the expectation toward customer–manufacturer interaction structure to underline supply chain operations activities. On second thoughts, Maleki and Cruz-Machado (2013) advice that supply chain integration is the underpinning of mass customization to dump as much as possible the generated uncertainty for demand, scheduling and procurement. In fact, the challenge is to adapt the organizational framework between actors accordingly. Different qualitative and quantitative studies have been proposed in the literature as presented in Table 1.

Most researchers focus mainly on studying structural drivers of mass customization at different hierarchical levels. For instance, product design studies and customer-oriented architectures' economic efficiency. Furthermore, from supply chain management dimension, many qualitative studies suggested the importance of supply chain integration to develop mass customization capability. However, the literature does not clearly suggest a quantitative perspective for an integrated modeling approach identifying the interrelated planning interfaces in the context of mass customization. In this field, many research groups tend to propose optimization approaches as decision models in which a specific supply chain functions are studied. For example, inventory planning and safety stock policies for modular product, postponement strategies identification for demand fulfilment and scheduling perspectives. Therefore, the contribution of this work resides in addressing a comprehensive framework through mathematical formulation to simultaneously manage supply chain planning objectives according to the various mass customization underpinnings. To this end, a mixed integer linear programming model for solving an integrated procurement, production and distribution problem is developed taking into account definition of objectives and constraints for flows and capacities coordination between supply chain members.

Paper	Classification	Scope of the study
Tiihonen and Felfernig (2017)	Literature review	Investigate technologies enablers for product definition within mass customization context
Geier and Fleischmann (2013)	Mathematical modeling	Propose a MIP model for demand fulfilment according to assemble to order process after receiving the customized orders, then define the related processing and delivery dates
Mourtzis and Doukas (2014)	Conceptual model	Build a holistic framework resulted from design, planning and control processes for a manufacturing network triggered by product variety and mass customization. It represents a broadly decision-making support for the overall management within strategical, tactical and operational levels
Raza, Haouari, Pero and Absi (2018)	Conceptual model	Investigate integration abilities of mass customization with industry 4.0 concept according to a conceptual model while adding customer involvement on its pillars (i.e. smart product, smart machine and technology workers support)
Shahzad and Hadj-Hamou (2013)	Mathematical modeling	Propose a MILP for a logistic network according to a multi-stage, multi-period, multi-product and multi-objective to build an optimization decision support model for market analysis. In fact, incorporate the generic-bill-of-product (GBOP) influence on the generic-supply-chain-structure (GSCS)
Tokman, Beitelspacher, Liu, and Deitz (2011)	Conceptual model	Develop a capability framework toward mass customization while adopting supply chain management practices. It has been proven through the realized survey that collaborative scheduling and forecast allow lead time decrease which positively impact the mass customization capability and support customer focus
Liu, Shah and Schroeder (2010)	Conceptual model	Develop a theoretical basis to highlight the positive relationship between efficient management of demand and supply uncertainty on mass customization ability. According to the realized survey, this link has been validated. In fact, make to order and postponement policies could be adopted to mitigate demand uncertainty while trust based with suppliers and lead time reduction contribute to fix supply uncertainty
Lai., Zhang, Lee and Zhao (2012)	Conceptual model	Explore the influence of supply chain integration on mass customization capability, the considered core elements are internal, customer and supplier integration
Paul, Tan and Vakharia (2015)	Mathematical modeling	Propose a stock level optimization for modules which constitute an end product assembled according to the selected options. Stochastic modeling has been adopted to define potential combination
Merle, Chandon, Roux and Alizon. (2010)	Conceptual model	Investigate a broadly tool to assess the perceived value from mass customization by the customers where it has been split into two structures: mass customization product value and co-design process value
Xu, Landon, Segonds and Zhang (2017)	Mathematical modeling	Propose a decision support model to ensure the optimization between economy of scale and scope considering customer preferences and the related marginal profit in the objective function
Hernández, Olivares-Benítez and Zuñiga (2015)	Mathematical modeling	Develop a safety stock model for modular product architecture that involve part commonality and substitutability factors

Table 1. Mass customization literature review

3. Model Description

In this section, we present the supply chain model formulation. The study is based on a three-echelon supply chain with leader and followers basis operating in the automotive industry (i.e. manufacturing plants). The supply chain's leader is the OEM (i.e. customer) and both remain stages are considered as followers, namely, (a) first tier supplier: wiring harnesses manufacturer and (b) second tier suppliers: subset of upstream raw material's suppliers as shown in Figure 1. The supply chain model will consider a set of OEMs in order to reflect as much as possible a general framework and keep the possibility for potential adoption of such structure. Moreover, the business strategy of the supply chain is evocated toward mass customization. Hence, the concerned product features are based on customization abilities afforded to the consumer (e.g. by a configurator) which generates a specific product, in addition to mass production capability through the supply chain. In this study, the focus is on the first-tier supplier operations, the choice is motivated by its major processing function within the supply chain according to its role of the first interface with the OEMs.

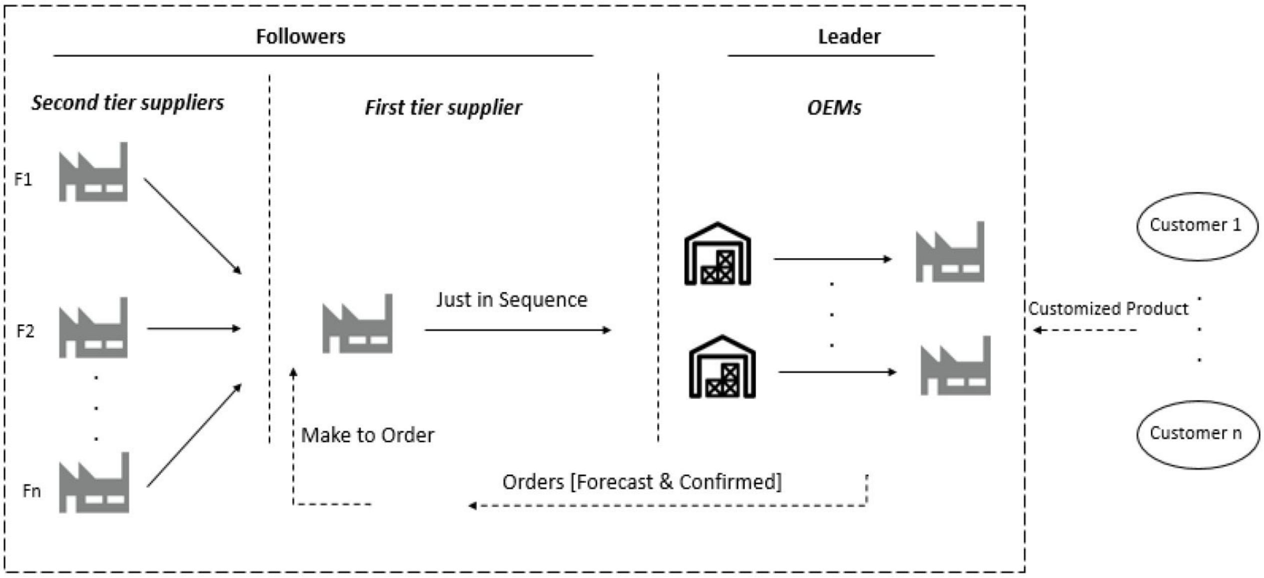

Figure 1. Supply chain structure

Hence, the organizational business traits are based on postponement strategy to shape the interactions between actors where the decoupling point position (i.e. order penetration point) is very close to customers. This core basis behavior of customer orders drives the dimensional function between the OEMs and the first-tier supplier according to make to order process. In this sense, manufacturing activities will be launched after order reception dotted as confirmed demand. Whereas, the restricted lead time for delivery and the characteristic of wire harnesses' bill of material which generates an extended supplier range, compel the first-tier supplier to ensure procurement process based on previously shared demand forecasts from OEMs. While adopting a product configuration system, the product structure within customization process is reflected by modularity abilities, which is the definition adopted for the PVMS first class. It is assigned through basic module and optional modules. The product cluster contains a mandatory basic module which provides common features in addition to a set of optional modules according to customers' requirements. In this case, each product (i.e. wire harness) is dedicated to a specific car, which is the trigger of the make to order approach and the related planning specifications. Thus, once the order is received by the first-tier supplier, the timeframe reactivity becomes crucial and any disruption on the internal operations could highly impact the OEM vehicle's sequencing, which generates a defined lead time to respect in order to avoid any special highly cost actions. This product variety aspect gives back much more complexity on the related systems. For this reason, in real production environment, the logistic window addresses three main timeframe stages as described in Figure 2 (i.e. total time in production plant, total transport time, safety stock). The key figure outlines that in spite of disruptions, it is mandatory to preserve just in sequence deliveries (i.e. according to make to order), which led to highly cost expected solutions (e.g. premium freight). The mentioned product safety stock represents a very tight buffer level which is not designed to cover a large horizon demands as it is performed from specific and confirmed orders. As mentioned previously, the studied supply chain provides forecasted demand for procurement process and confirmed demand for production. In fact, the option preferences for optional modules are handled according to penetration rates for each module, they are provided to assess the percentage of products that will include this option. This approach is considered as OEMs' expectations shared previously with the manufacturer to drive customer demand behavior.

The purpose of this paper is to perform a quantitative model of an integrated supply chain. Thus, a tactical operations model is proposed through a mixed integer linear programming with integrated production, procurement and distribution decisions. In fact, collaboration endeavor is intended to serve the egalitarian organizational relationships to enhance mutual interactions driven by stakeholders' condition consideration for an overall supply chain performance (Gölgeci, Murphy & Johnston, 2018). The objective is to minimize the total cost while balancing demand fulfillment and supply chain capacities over a defined planning horizon. Hence, contractual elements between actors are depicted through constraints. It involves material flows as input and output for supply and demand as well as the corresponding information flow. Products' manufacturing within mass customization requires a traceability upon demand reception, so that material movement can be controlled too.

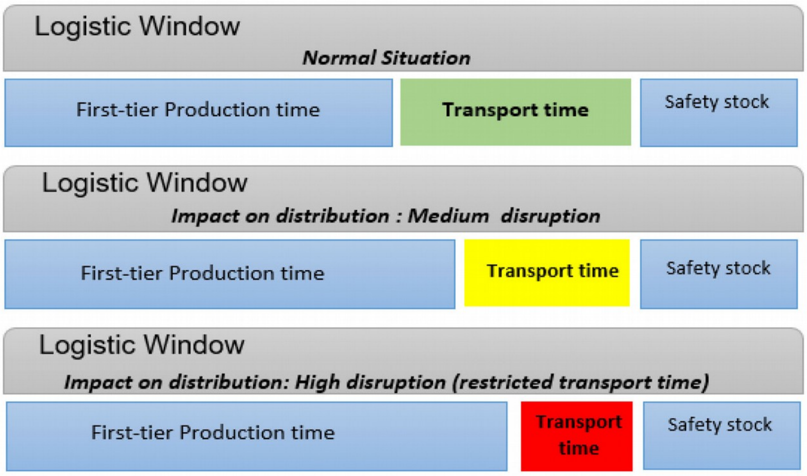

Figure 2. Mass customization logistic window

The considered model in this paper is based on a number of assumptions as described below:

Model assumptions:

- Customer demand between the OEM and the first-tier supplier is managed through confirmed and forecasted demand
- Production is performed according to OEMs confirmed demand
- Customer demand is generated with serial numbers for each product during each period (e.g. at the period t=1, demand of product "p" from OEM "o" is 5, then we will get 5 serial numbers from 1 to 5, each one represents the chosen set of modules by the customer)
- The products content in terms of optional modules is set with penetration rates for each period. The number of the orders that include an optional module is equal to the penetration rate
- Lost sales are not allowed. The unsatisfied demands during a period are qualified as backorders, their production is performed during the next period
- The product inventory value is based on an average cost for each product p, independently of its content
- Module cost is calculated from the bill of material content (i.e. cost of each component)
- Production cost is an aggregation of the produced modules (i.e. cost of each produced module)
- Logistics flow is ensured by 3PL provider, each delivery has a fixed cost. No capacity hurdle is concerned
- Production capacity hurdles are contractual between stakeholders

- Vendor managed strategy is adopted between the first-tier supplier and OEMs. Production is sent to advanced warehouses (AW) and shipped to OEMs
- The advanced warehouses charge an inventory holding cost. It is under the first-tier supplier responsibility. Each advanced warehouse is affected to one OEM
- The level of the required raw materials is assessed through an order-up to level strategy (base stock) over supplier's lead time horizon
- The adopted inventory policy is (s,S), however, the allowed period for replenishment from second tier suppliers is pre-defined
- Uncertainty on the received raw material quantity and the delivered products is not considered
- The backorder cost is considered in the objective function

The Table 2 presents the notations used for model formulation.

Indexes and sets			
$t \in T$	Set of time period	$p \in P$	Set of product families
$o \in O$	Set of customers (OEM)	$m \in M$	Set of modules
$s \in S$	Set of serial numbers	$f \in F$	Set of raw material suppliers
$c \in C$	Set of raw material	$v \in V$	Set of advanced warehouses

Parameter	
Sales	
$DR_{o,p,t}$	Real demand of product p received from customer o in period t
$DF_{o,p,t}$	Forecasted demand of product p received from customer o in period t
$D^{min}_{o,p,t}$	Minimum demand quantity contracted with customer o of product p in period t
PR_m	Penetration rate of the module m
$PSF0_{o,p,s,t}$	Auxiliary parameter = 1 to activate the serial number s of the forecasted demand from customer o of the product p at period t
$PSF1_{o,p,s,m,t}$	Auxiliary parameter = 1 to activate the module m that belongs to serial number s of the forecasted demand from customer o of the product p at period t
$PSR0_{o,p,s,t}$	Auxiliary parameter = 1 to activate the serial number s of the real demand from customer o of the product p at period t
$PSR1_{o,p,s,m,t}$	Auxiliary parameter = 1 to activate the module m that belongs to serial number s of the real demand from customer o of the product p at period t
Production	
$BO0_{o,p,s}$	Initial backorder level of product p with serial number s of the customer o
$BOC_{o,p,s}$	Backorder cost of product p with serial number s of the customer o at the period t
$IHPS_{o,p,t}$	Inventory holding cost of product p of the customer o in period t in the manufacturer
$IPS0_{o,p}$	Initial inventory level of product p of the customer o at the manufacturer plant
$PQ^{max}_{o,p,t}$	Maximum production capacity of the manufacturer of product p in period t for the customer o
$PQ^{min}_{o,p,t}$	Minimum production capacity of the manufacturer of product p in period t for the customer o
MCS_m	The cost of module m
Procurement	
PC_c	Purchase price of component c

$ICS0_c$	Initial inventory level of raw material *c*
$QFC_{f,c,t}^{\min}$	Minimum contracted demand for raw material *c* from supplier *f* in period *t*
$QF_{f,t}^{\max}$	The maximum capacity of supplier *f* in period *t*
$H_{f,c,t}$	Parameter; 1 if replenishment from supplier *f* of raw material *c* in period *t* is allowed, 0 otherwise
$\alpha_{c,m}$	The needed quantity of raw material *c* in module *m* (Bill of material)
Distribution	
$IHPV_{o,v,p,t}$	Inventory holding cost of product *p* of the customer *o* in period *t* in the advanced warehouse *v*
$CPV_{o,v,p,t}$	Shipping cost of product *p* of the customer *o* to the advanced warehouse *v* in period *t*
$CPO_{o,v,p,t}$	Shipping cost of product *p* from the advanced warehouse v to the customer o in period *t*
$IPV0_{o,v,p}$	Initial inventory level of product *p* of the customer *o* at the advanced warehouse *v*
M	Big Number
Decision variables	
Production	
$XQT_{o,p,s,t}$	Total Produced quantity of product *p* for the customer *o* with serial number *s* in period *t*
$XQD_{o,p,s,t}$	Produced quantity of product *p* for the customer *o* with serial number *s* in period *t* to satisfy demand
$XQB_{o,p,s,t}$	Produced quantity of product *p* for the customer *o* with serial number *s* in period *t* to satisfy backorders
$BO_{o,p,s,t}$	Backorder quantity of product *p* of the customer *o* with serial number *s* in period *t*
$IPS_{o,p,t}$	Inventory level of product *p* of customer *o* in period *t*
$CSD_{c,t}$	Consumption of the component *c* at period *t* from the produced quantity to satisfy demand
$CSB_{c,t}$	Consumption of the component *c* at period *t* from the produced quantity to satisfy backorders
$CST_{c,t}$	Total consumption of the component *c* at period *t*
Procurement	
$ICS_{c,t}$	Inventory level of raw material *c* at period *t*
$BS_{c,t}$	Net required quantity to purchase of raw material *c* at period *t*
$CRQ_{c,t}$	Required quantity assessment of raw material *c* at period *t*
$QS_{f,c,t}$	Purchased quantity from supplier *f* of raw material *c* at period *t*
Distribution	
$IPV_{o,v,p,t}$	Inventory level of product *p* of customer *o* in period *t* at the advanced warehouse *v*
$QV_{o,v,p,t}$	Shipping quantity to the advanced warehouse *v* of product *p* for the customer *o* in period *t*
$QO_{o,v,p,t}$	Shipping quantity to the customer *o* from the advanced warehouse *v* of product *p* in period *t*

Table 2. Model notations

3.1. Objective Function

The objective is to minimize the sum of the total costs related to production, backorders, inventories, and transportation through the supply chain:

$$\begin{aligned} TC = & \sum_{t\in T}\sum_{o\in O}\sum_{p\in P}\sum_{s\in S}\sum_{m\in M} XQD_{o,p,s,t} * PSR1_{o,p,s,m,t} * MCS_m \\ & + \sum_{t\in T}\sum_{o\in O}\sum_{p\in P}\sum_{s\in S}\sum_{m\in M} XQB_{o,p,s,t} * PSR1_{o,p,s,m,t-1} * MCS_m + \sum_{t\in T}\sum_{c\in C} PC_c * ICS_{c,t} \\ & + \sum_{t\in T}\sum_{o\in O}\sum_{p\in P} IHPS_{o,p,t} * IPS_{o,p,t} \\ & + \sum_{t\in T}\sum_{o\in O}\sum_{v\in V}\sum_{p\in P} IHPV_{o,v,p,t} * IPV_{o,v,p,t} \\ & + \sum_{t\in T}\sum_{f\in F}\sum_{c\in C} PC_c * QS_{f,c,t} + \sum_{t\in T}\sum_{o\in O}\sum_{v\in V}\sum_{p\in P} CPV_{o,v,p,t} * QV_{o,v,p,t} \\ & + \sum_{t\in T}\sum_{o\in O}\sum_{v\in V}\sum_{p\in P} CPO_{o,v,p,t} * QO_{o,v,p,t} + \sum_{t\in T}\sum_{o\in O}\sum_{p\in P}\sum_{s\in S} BOC_{o,p,s,t} * BO_{o,p,s,t} \end{aligned}$$

Subject to (1)-(20).

3.2. Production Constraints

Constraint 1 represents the total production quantity through $XQD_{o,p,s,t}$ and $XQB_{o,p,s,t}$ in order to associate production of the confirmed demand and the backorders to fulfill respectively. The product order content is registered according to a defined serial *s* of the product family *p*:

$$XQT_{o,p,s,t} = XQD_{o,p,s,t} + XQB_{o,p,s,t},\ \forall p \in P, t \in T, \forall o \in O, s \in S \tag{1}$$

Constraint 2 ensures the production capacity restriction of the manufacturer:

$$\sum_{s}^{S} XQT_{o,p,s,t} \leq PQ_{o,p,t}^{\max}, \forall o \in O, p \in P, t \in T \tag{2}$$

Constraint 3 describes the received demand production jointly to backorder level during the period, it represents the produced serial numbers and the backorder ones as follows:

$$XQD_{o,p,s,t} = PSR0_{o,p,s,t} - BO_{o,p,s,t},\ \forall o \in O, p \in P, \forall s \in S, t \in T \tag{3}$$

In order to fix the hurdle of backorders. Constraint 4 implies its corresponding level for each period that should be lower than the real demand, it is expressed by:

$$\sum_{s}^{DR_{o,p,t}} BO_{o,p,s,t} \leq DR_{o,p,t},\quad \forall o \in O, p \in P, t \in T \tag{4}$$

The model deems that lost sales are not allowed which tend to perform production of the generated backorder. Therefore, the generated backorders during period *t* are produced during the next one. The adopted constraint is as follows:

$$\mathrm{XQB}_{o,p,s,t} = \mathrm{BO}_{o,p,s,t-1},\ \forall o \in O, p \in P, 1 \leq s \leq \mathrm{DR}_{o,p,t-1}, t \in T \tag{5}$$

Constraint 6 expresses the product inventory balance at the manufacturer plant:

$$IPS_{o,p,t} = IPS_{o,p,t-1} + \sum_{s} XQT_{o,p,s,t} - \sum_{v\in V} QV_{o,v,p,t}, \forall o \in O, p \in P, t \in T \tag{6}$$

3.3. Procurement Constraints

Constraint 7 joints raw material consumption to procurement decision to settle the inventory balance. It considers the inventory levels from the last period in addition to the received quantity minus the consumed level, it is described as follows:

$$ICS_{c,t} = ICS_{c,t-1} + \sum_{f \epsilon F}^{F} QS_{f,c,t} - CST_{c,t}\ , \forall c \in C, t \in T \tag{7}$$

The raw material consumption $CST_{c,t}$ is calculated from both produced partitions $XQD_{o,p,s,t}$ and $XQB_{o,p,s,t}$ according to constraint 8 and constraint 9 respectively. The total consumed quantity $CST_{c,t}$ is represented by constraint 10.

$$CSD_{c,t} = \sum_{o}\sum_{p}\sum_{s} XQD_{o,p,s,t} * \sum_{m} PSR1_{o,p,s,m,t} * \alpha_{c,m}\ , \forall c \in C, t \in T \tag{8}$$

$$CSB_{c,t} = \sum_{o}\sum_{p}\sum_{s} XQB_{o,p,s,t} * \sum_{m} PSR1_{o,p,s,m,t-1} * \alpha_{c,m}\ , \forall c \in C, t \in T \tag{9}$$

$$CST_{c,t} = CSD_{c,t} + CSB_{c,t}, \forall c \in C, t \in T \tag{10}$$

As described previously, the procurement is based on forecasted demand. Within mass customization context, it is considered as main organizational characteristics to allow make to order approach which led to stock positioning with forecasts. From operations standpoint, the manufacturer has to launch production assuming guaranteed in-house raw material availability. The requirement assessment is performed through constraint 11 as follows:

$$CRQ_{c,t} = \sum_{o \epsilon O}\sum_{p \epsilon P}\sum_{s}^{DF_{o,p,t}}\sum_{m \epsilon M} PSF1_{o,p,s,m,t} \cdot \alpha_{c,m}\ , \forall c \in C, t \in T \tag{11}$$

Constraint 12 evaluates the net raw material requirement excluding the available quantity in the manufacturer from the previous inventory level:

$$BS_{c,t} \geq CRQ_{c,t} - ICS_{c,t\text{-}1}\ ,\ \ \forall c \in C, t \in T \tag{12}$$

The policy of the replenishment frequency contracted with suppliers is formulated by constraint 13, the associated reviewing selection is defined by a binary matrix while the purchased quantity variable is activated when the parameter $H_{f,c,t}$ has a true value, i.e.:

$$QS_{f,c,t} \leq M \cdot H_{f,c,t}\ , \forall f \in F, c \in C, t \in T \tag{13}$$

Given these points, the purchased quantity from the raw material suppliers is defined with constraints 14 and 15. The received quantity should be greater than the net raw material requirement with constraint 14 or respect the contractual minimum order quantity aligned previously with suppliers according to constraint 15:

$$QS_{f,c,t} \geq BS_{c,t} \cdot H_{f,c,t}\ , \forall f \in F, c \in C, t \in T \tag{14}$$

$$QS_{f,c,t} \geq QF_{f,c,t}^{min} \cdot H_{f,c,t}\ , \forall f \in F, c \in C, t \in T \tag{15}$$

Constraint 16 represents the maximum restriction aligned with suppliers:

$$\sum_{c=1}^{C} QS_{f,c,t} \leq QF_{f,t}^{max}, \forall f \in F, t \in T \tag{16}$$

However, the inventory level should not decrease under a safety stock threshold. As stated by Brunaud, Lainez-Aguirre, Pinto and Grossmann. (2018), a complete inventory management model is established through the combination of inventory policy and safety stock formulation. For the proposed tactical interactions modeling, the choice of a suitable inventory policy is mandatory to allow a smooth procurement management. At each period, the needed raw material quantity is defined through forecasted demand as well as the safety stock level to maintain for the purpose of bringing back the inventory level to the required one. The studied supply chain exhibits the stakeholders to a guaranteed service level. As mentioned previously, customers demand's assumption is considered as normally distributed each period and *i*.i.d. As presented by Hernández et al. (2015), the safety stock calculation is based on demand variability, in order to give more accuracy, it uses statistical parameters as mean absolute and standard deviations. The structure of modular product is based on a set of modules, each module has a defined bill of material, while product content depends on the chosen module combination. Hence, considering the commonality in modules and component between products, the corresponding mathematical formulation for safety stock is expressed in constraint 17 as follow:

$$ICS_{c,t} \geq K * \left(\sqrt{\sum_{p \epsilon P} \sum_{m \epsilon M} PR_m * \alpha_{c,m} * \sigma_p^2} \right) * \sqrt{LT_c}\, , \forall\, c \in C, t \in T \tag{17}$$

Where *K* reflects a safety factor, it is the inverse cumulative normal distribution coefficient for a target service level. The choice represents the decision makers' willingness to cope with demand variability. Thus, constraint 17 reinforces the raw material inventory hurdle representing the safety stock calculation according to base stock policy.

3.4. Distribution Constraints

Constraint 18 determines the inventory balance at the advanced warehouse. It addresses the deliveries performed for the OEMs in addition to the received ones from the manufacturer. However, a buffer should be kept as aligned between actors, it is represented by a percentage (i.e. β) from the received confirmed demand as stated in constraint 19:

$$IPV_{o,v,p,t} = IPV_{o,v,p,t-1} + QV_{o,v,p,t} - QO_{o,v,p,t}\, , \quad \forall v \in V, p \in P, t \in T, o \in O \tag{18}$$

$$IPV_{o,v,p,t} \geq \beta * DR_{o,p,t}\, , \quad \forall o \in O, p \in P, v \in V, t \in T \tag{19}$$

The delivered quantity to OEMs should be greater than the minimum contracted demand, it is represented by constraint 20:

$$\sum_{v \epsilon V} QO_{o,v,p,t} \geq D_{o,p,t}^{min}\, , \forall o \in O, p \in P, t \in T \tag{20}$$

4. Numerical Example

In this section, an illustration for the described model is performed on a concrete instance to examine the applicability of the proposed model. It consists of 3 OEMs, 3 advanced warehouses and 6 product families with a total of 102 modules. The corresponding modules bill of material encompass an overall of 670 components supplied from 11 raw material suppliers (i.e. second tier suppliers). Each product has a defined set of modules with one basic module, the rest are considered as optional. In order to generate the different configurations for customers' demand, the module handling is performed according to the related penetration rate. For example, if a module has a penetration rate of 80%, it means that it will be generated in 80% of customer demand. The Figure 3 provides an example of customer demand of a product *p* with serial numbers identification. The OEMs affectations to the advanced warehouses in addition to their product is presented in Table 3. It presents also the related modules for each product.

To solve the proposed model, it is supposed that the confirmed and forecasted demands are normally distributed. The uniform distribution is used to generate the other parameters such as penetration rates, capacities in addition to the different costs (i.e. production, shipping and backorders).

OEM	Advanced warehouse	Product	Range of Modules	Basic Module
O1	V1	P1	M01 -> M17	M01
		P2	M18 -> M35	M18
O2	V2	P3	M36 -> M53	M36
		P4	M54 -> M71	M54
O3	V3	P5	M72 -> M89	M72
		P6	M90 -> M102	M90

Table 3. Affectations of OEMs

Due to different possible configurations, the product inventory holding cost at different locations has been set to an average cost. The initial level of backorders and product inventory is set to zero. Like the industrial experiments, due to the variability of the raw material suppliers lead time, it has been assumed that the procurement lead times are constant (i.e. in this case LT=1 period). Besides, the transportation cost between the partners is considered as a fixed one. In order to foster storage at the advanced warehouse, the product holding cost at the first-tier supplier is assumed to be greater than the holding cost at the advanced warehouse. It argues also the necessary just in time deliveries to satisfy and the limited storage level at the first-tier supplier.

According to the raw material safety stock to ensure at the first-tier supplier, the corresponding customer service level in this study has been set to 95% which gives K=1,65. Also, as customers' demand is generated similarly across products, the constraint (17) will get the same standard deviation. Then, the maximum capacity of suppliers is fixed while assessing the bill of materials to infer the most used components and define their respective suppliers. Furthermore, the raw material purchase costs have been generated randomly between 0,05 and 12. Subsequently, they are used to define the modules' costs according to their bill of material. Table 4 provides a summary of numerical input data. The experiment is performed through 10 periods. The model is programmed and solved with GAMS 22.5/CPLEX 12.2 optimization software and all numerical experiments are processed with a Core i5 2.49 GHz computer with 8 GB RAM.

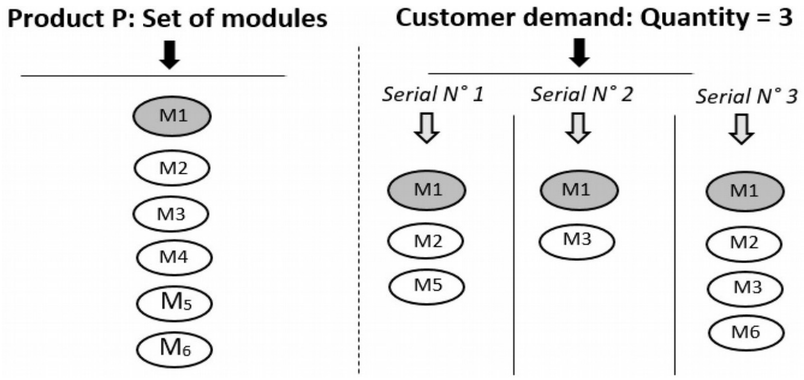

Figure 3. Modular product identification

The computational experiment of the model has been performed through 10 periods. As can be seen in Figure 4, the total supply chain cost is depicted according to the integrated structure adopted for the objective function, namely, procurement, production and distribution, in addition to inventory holding costs. In fact, the inventory holding cost for products at the plant is equal to zero for the global horizon, therefore, it outlines the just in time deliveries trigger required within mass customization context. The significant cost amount is related to raw material holding cost at the plant.

Parameters			
Parameter	**Value range**	**Parameter**	**Value range**
$DR_{o,p,t}$	N(300;100)	$PQ^{max}_{o,p,t}$	U(400;500)
$DF_{o,p,t}$	N(300;100)	$PQ^{min}_{o,p,t}$	U(150;180)
$ICS0_{c}$	U(1500;2000)	$D^{min}_{o,p,t}$	150
PC_{c}	U(0,05;12)	PR_{m}	U(0,05;0,9)
$QFC^{min}_{f,c,t}$	U (700;1000)	$QF^{max}_{f,c,t}$	F1 & F11 = 1 000 000 F2->F10 = 400 000
$BOC_{o,p,s,t}$	5	$H_{f,c,t}$	1
$CPO_{o,v,p,t}$	4	$IHPS_{o,p,t}$	200
$CPV_{o,v,p,t}$	10	$IPV0_{o,v,p}$	0
$IHPV_{o,v,p,t}$	100	$IPS0_{o,p}$	0
$BO0_{o,p,s}$	0	-	-

Table 4. Model Parameters

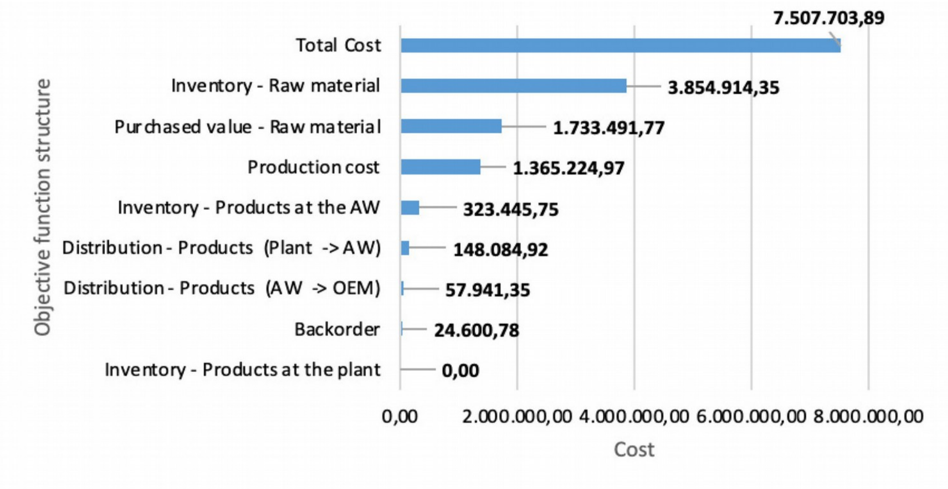

Figure 4. Objective function-Cost summary

The Table 5 represents the generated demand. While Tables 6, 7, 8 provide respectively a summary of the numerical results for the shipped quantity to the advanced warehouses, the shipped quantity to customers, and the product inventory level at the advanced warehouse.

		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
o1	**p1**	307.09	287.72	123.95	299.89	268.46	270.53	186.74	177.56	294.37	314.68
o1	**p2**	239.52	429.41	280.55	377.75	243.31	335.09	236.75	310.86	51.84	349.95
o2	**p3**	360.20	171.90	229.32	147.59	277.62	194.29	160.06	146.03	208.50	240.44
o2	**p4**	228.34	283.38	217.06	275.82	241.83	198.20	208.06	322.90	301.54	238.66
o3	**p5**	449.02	465.82	126.95	418.40	502.03	307.40	202.62	344.84	306.76	193.62
o3	**p6**	369.63	409.72	237.40	206.57	173.35	373.14	321.63	261.84	185.35	278.42

Table 5. Real demand $DR_{o,p,t}$

			t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
o1	**v1**	**p1**	307.00	287.00	123.00	299.00	268.00	193.07	191.92	248.01	173.36	195.15
o1	**v1**	**p2**	239.00	395.76	313.24	263.95	356.05	307.58	218.42	179.69	175.31	209.62
o2	**v2**	**p3**	304.41	204.59	251.00	147.00	199.82	222.32	143.15	147.19	162.50	156.39
o2	**v2**	**p4**	228.00	283.00	217.00	217.90	227.77	205.38	151.97	172.97	268.00	301.00
o3	**v3**	**p5**	449.00	329.29	261.71	408.24	425.45	138.31	409.45	300.16	142.39	255.00
o3	**v3**	**p6**	369.00	409.00	237.00	206.00	173.00	300.69	323.18	212.81	134.70	168.61

Table 6. Shipping quantity from the manufacturer to the advanced warehouse $QV_{o,v,p,t}$

			t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
o1	**v1**	**p1**	245.58	290.87	155.75	263.81	274.28	192.66	208.67	249.85	150.00	191.08
o1	**v1**	**p2**	191.10	357.78	343.01	244.51	382.94	289.23	238.08	164.87	227.11	150.00
o2	**v2**	**p3**	232.37	242.25	239.52	163.35	173.81	238.98	150.00	150.00	150.00	150.00
o2	**v2**	**p4**	182.33	271.99	230.26	206.15	234.57	214.11	150.00	150.00	272.27	313.58
o3	**v3**	**p5**	359.20	325.93	329.48	349.95	408.73	177.23	430.41	271.72	150.00	277.63
o3	**v3**	**p6**	295.07	400.98	271.46	212.17	179.64	260.73	333.48	224.77	150.00	150.00

Table 7. Shipping quantity from the advanced warehouse to customers $QO_{o,v,p,t}$

			t1	t2	t3	t4	t5	t6	t7	t8	t9	t10
o1	**v1**	**p1**	61.42	57.54	24.79	59.98	53.69	54.11	37.35	35.51	58.87	62.94
o1	**v1**	**p2**	47.90	85.88	56.11	75.55	48.66	67.02	47.35	62.17	10.37	69.99
o2	**v2**	**p3**	72.04	34.38	45.86	29.52	55.52	38.86	32.01	29.21	41.70	48.09
o2	**v2**	**p4**	45.67	56.68	43.41	55.16	48.37	39.64	41.61	64.58	60.31	47.73
o3	**v3**	**p5**	89.80	93.16	25.39	83.68	100.41	61.48	40.52	68.97	61.35	38.72
o3	**v3**	**p6**	73.93	81.94	47.48	41.31	34.67	74.63	64.33	52.37	37.07	55.68

Table 8. Product inventory level at the advanced warehouse $IPV_{o,v,p,t}$

5. Sensitivity Analysis and Managerial Insights

A sensitivity analysis is performed to depict the influence of varying different parameters on the solution quality. The purpose is to improve the supply chain performance metrics while keeping the computational solvability and derive managerial insights. Besides, the computational effort is important as much as the size of the formulation. It is worth mentioning that the optimality of the problem solving is achieved starting from some parameters' threshold.

For instance, the parameter $PQ_{o,p,t}^{max}$ represents the available resources according to a defined demand range. Its level illustrates the contracting capacity investment with customers. Thus, 4 instances have been launched with the same demand range while decreasing the capacity level. As a result, the effect of this change has been solved till -20% from the initial capacity as shown in Table 9. The objective function was impacted mainly by backorder level which has been increased by +10,6% as presented in Figure 5 which obviously reports the inverse relation between the maximum capacity and backorder.

Therefore, it is perceived as a potentially useful insight to support decision makers to foster a trade-off level combining the allowed backorder level and maximum capacity effects.

The most important part of the objective function is generated from the raw material inventory holding cost. In spite of adopting a guaranteed service time due to mass customization context with a 95% of service level. The supply operation includes other parameters such as the initial inventory level at the plant, the minimum order quantity represented by the minimum supplier capacity as well as the contracted maximum capacity. These parameters will be decreased gradually to assess the impact on the objective function cost. The Table 10 reports the solving status and the involved parameters for each instance. Notice that percentage decrease is according to the initial level provided by Table 4. The execution time for all presented scenarios in this study is up to 4 minutes.

	$DR_{o,p,t}$ ~ N(300;100)			
$PQ_{o,p,t}^{max}$	-10%	-20%	-25%	-30%
Solving status	Solved	Solved	No solution	No solution

Table 9. Solving status

	$DR_{o,p,t}$ ~ N(300;100)			
	Instance 1	Instance 2	Instance 3	Instance 4
Decrease (%)	-10%	-20%	-25%	-30%
$QF_{f,c,t}^{min}$	*	*	*	*
$QF_{f,c,t}^{max}$	*	*	*	*
$ICSO_c$	*	*	*	*
Solving status	Solved	Solved	Solved	No solution

Table 10. Parameters change and solving status

As shown in the Figure 6, the total cost naturally reduced since the different parts of the objective functions related to inventory demonstrates a general decreasing trend. As a part of this evolution, the adopted inventory policy (i.e. (s,S)) gives much more flexibility for ordering which is mainly required within mass customization context, it is combined to an adaptive safety stock policy to handle demand variability. However, it is perceived that the reported minimum and maximum supplier capacities have a significant impact on the inventory curves and problem resolution, this means the practical application as a guideline with a mandatory consideration of the contracted demand and modules' penetration rates to infer the optimal level. Correspondingly, the product inventory at the plant and the advanced warehouse remain unchanged as well as the total production and distribution costs which demonstrate the maintaining of the operations flow between actors as required. By investigating the results, the structural model network illustrates the interdependency of the decisions. The overall resolution logic of the model is subject to the influence of parameters set. Despite the customers' position as a high influence trigger attribute, the supply chain performance is emerged through a symmetric mechanism of the organizational and operational linkage with mutuality coordination.

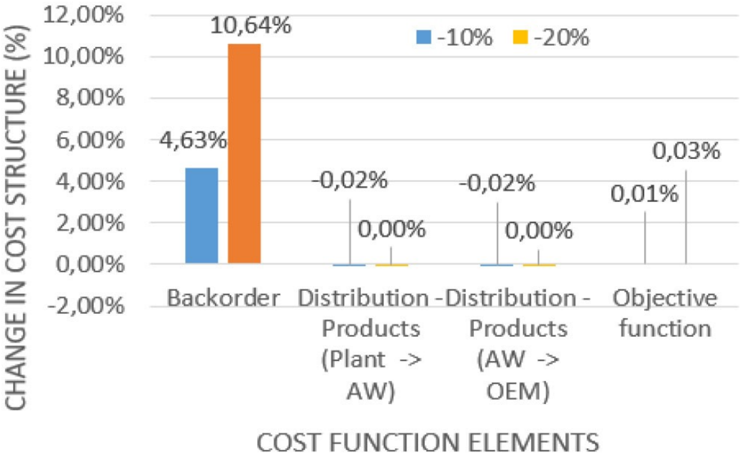

Figure 5. Maximum capacity cost impact

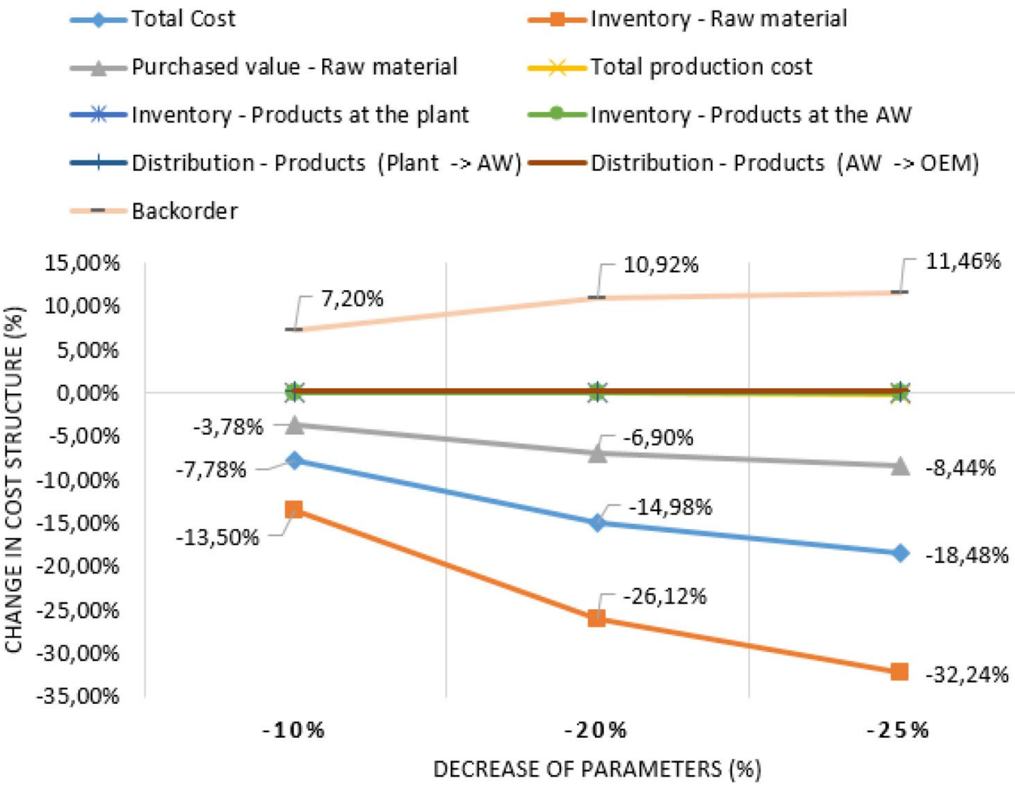

Figure 6. Objective function cost split

6. Conclusion

In this paper, a deterministic mixed integer linear programming model has been developed for a three-echelon supply chain operating through mass customization context. This model is incorporated within a centralized tactical decision making for an integrated procurement, production and distribution activities. The studied supply chain outlines customers (i.e. OEMs) prevailing role as core firms and therefore pointed out as leaders while the first-tier and second-tier suppliers as followers. The related trigger role is emerged from the customization utility associated to products definition. The application of this study is performed according to the automotive supply chain with a focus on the first-tier supplier interactions taking into account the practical conditions for an efficient and cost-effective collaboration endeavor. Hence, the model assumptions have been considered accordingly to describe the pertinent aspects of the interactions between actors and evolve the required capability. For instance, the developed value to customers is characterized with product modularity and this granularity ranges has been handled with serial numbers to drive the related manufacturing and planning activities. Furthermore, raw material inventory assessment is based on the shared forecasts from customers in order to cope with the heterogeneous lead times throughout the supply chain. In fact, the adopted inventory policy is the periodic review (s,S) which is perceived as the most suitable replenishment strategy to enhance flexibility level. The necessity of the guaranteed service time to customers arises a safety stock definition to hinder customer's demand variability, the base stock development has been employed to review inventory levels. A sensitivity analysis on the effect of some parameters on different parts of the total cost was performed at the end.

This study can be expanded in several directions to develop new approaches and face mass customization challenges effectively. It is worthy to run the model with large data set involving further products and modules for an extensive experimental instance, the purpose is to analyze the computational performance of the exact resolution methods and foresee heuristic formulations accordingly. Besides, developing the proposed model to a multi-site formulation is a significant differentiation also for the strategic decision-making level.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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Journal of Industrial Engineering and Management, 2021 (www.jiem.org)