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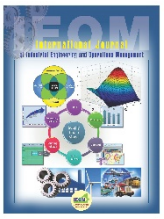

New Framework to Optimise Leagile Supply Chain Design

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ABSTRACT

The literature of Leagile supply chain (LASC) is lacking of the concurrence between supply chain (SC) design and product design, and missing the placement of decoupling point (DP) in the SC design. Therefore, the paper aims at presenting a novel framework to optimise LASC design while fulfilling the aforementioned gaps. The first step utilises Lean tools to identify the optimal architecture of product families through the so-called Leagile bill-of-material in product design. This phrase intends to reduce the storage keeping unit of components (leaner) while increasing their combining ability in a wider range of new products (more agile). Meanwhile, the second stage outlines the preliminary configuration of the future supply chain and transforms it into the Lean system. Next, the supplier network of this chain is matched with the product structure. The last step formulates the issue in one mathematical model to define the optimal LASC's configuration, which includes positioning the best DP in various delivery lead time. In discussing the obtained solutions, the article complements to the theoretical basis by examining the locations of DP corresponding to the product's complexity. The whole framework is illustrated by one specific example and solved by Priority Generic Algorithm Meta-Heuristic, programed with MATLAB.

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1. Introduction

Since the early 1990s, enterprises have witnessed many changes in business environment, which was marked by the saturation of product demand under the impact of mass production and economic globalization. In the meantime, the rapid development of IT increased the power of customers as they could easily compare information about competing products before making a purchasing decision. This, in turn, promoted the tendency of personalization (Jia et al., 2014). To secure this decision in their favor, businesses have to compete on various aspects, such as low prices, diverse goods and swift response time. A survey in furniture industry showed that the last factor comprised to 19% customers' dissatisfaction and 4.29% of whom abandoned their orders (Andreev and Koleva, 2013). In reality, enterprises usually applied well-known strategies like Lean to benefit from cost reduction or Agile to increase the diversity of offered products and responsiveness. Yet, the former is only suitable for standard products while the latter suffers from significant cost. Obviously, the implementation of the sole model seems to be no longer sufficient for the new situation.

Naylor et al. (1999) coined the term "leagility", which combines the two aforementioned paradigms into one through a decoupling point (DP). From Leagile manufacturing, which has recently been reviewed by Virmani, et al. (2018), this concept quickly expanded to the scope of LASC with numerous engineering models. The LASC incorporates Lean Manufacturing (LM) in production and Agile Manufacturing (AM) in distribution (Vollmann et al., 2004). Therefore, the hybrid LASC is believed to be taking advantages of the two original models as well as absorbing the disadvantages of individuals. Currently, LASC is considered to be one of the best alternatives in handling the modern complexities of the market (Chan and Kumar, 2009). A typical success of this model in the automobile industry is described in paper of Goldsby et al. (2006): the base vehicles are fabricated under LM while the AM of customer-specific demands are accommodated at port facilities/dealers where cars can be customized in up to 40 different menus. Yet, based on the bibliometric analysis during 1990–2017of Venkatesh and Bharathi (2018), the publication of LASC in this industry was still very scarce.

Today, LASC is not an option but a necessity (Myerson, 2014). The most important factor to successfully build LASC is effectively positioning DP (Chan and Kumar, 2009). In fact, the placement of DP is very complicated due to the great number of variables involved. Thus, researchers have tried different approaches. Despite of some encouraging results, their shortcomings are numerous. For instance, paper of Saaty (2007) admits that some multi-criteria techniques like AHP or ANP are not easily feasible because of a broad level of experts' participation in decision-making and also the severe limitation of quantitative methods related to plentiful variables included in the strategic decision (Kasperski, 2008). Also, as Vollmann et al. (2004), the position of DP strongly depends on the complexity of the bill of materials (BOM). Lee and Sasser (1995) also "*argued to support a leaner and more Agile supply chain (ASC) by postponing the point of differentiation.*"

One research gap in this domain was given by Sun et al. (2008), who realized the missing of the involvement of product's BOM (in product design) in LASC design. Based on our own review, this gap has yet been fulfilled in the past decade. Another research gap is the lack of DP placement in LASC design. As DP impacts direct LASC configuration, it should be included into SC design stage to orientate the product flows and set up necessary buffer stock. Yet, the previous studies located DP just based on predefined SC structures. Inspired by these, this paper presents one novel quantitative framework of LASC design attempting to bridge the two mentioned gaps by answering three research questions:

1. What is the framework of designing LASC concurring product design and SC design?
2. How to examine the best placements of desirable DPs under different scenarios of LASC design?
3. What are the managerial implications withdrawn from the new framework?

To support this, the following summarizes related background before introducing the procedure in details. The proposed approach is then demonstrated in a numerical example. The following section discusses the management implications while the last part draws the necessary conclusions and makes recommendations for future research.

2. Related Literature Review

The new framework comprises of the four main domains: LM/ Lean SC (LSC), ASC, product design and LASC. This article does not aim to do a comprehensive review of all of them; it attempts to recall the most relevant information, which supports the proposed framework.

2.1. Lean Manufacturing and Lean Supply Chain

Regarding LM, it is a topic of long-standing interest. An exhausted review of Anand and Kodali (2008) enumerates 59 Lean tools/technique used so far. As Lee and Sasser (1995), Lean applications can be extended in the design of process, plant, product and SC. LSC is defined as "an application of LM principles to SC to integrate the activities of all the stakeholders involved in the SC network and provide 'value' to the customers by eliminating wastes"(Anand and Kodali, 2008). Implementing LM in the SC, enterprises can gain competitive advantages from reducing costs, lessening lead time thereby raising service levels. Particularly, LM tools like Geographical Concentration can shape SC structure. Besides, Single Sourcing and The Use of Flat Hierarchy (which refers to minimising the number of organisation levels for decision-making/approvals and number of stages in the SC, Anand and Kodali, 2008) enable to eliminate wastes (nodes or tiers) on SC (Nguyen and Dao, 2016).

2.2. Agile Manufacturing and Agile Supply Chain

According to Sarkis (2001), AM is the combination between a flexible manufacturing system and LM. Agility is defined as "the ability of producing a product in a wide range of cost reduction and high quality of product with short provision time to make special product for each customer" (Gligor and Holcomb, 2012). ASC endeavours to fabricate

a larger variety of interrelated products (Chan and Kumar, 2009). ACS can be obtained by having "design of" the SC holistically and "design for" the SC at the product stage (Dekkers et al., 2006).

2.3. Product Design

Concerning product design, its relationship with SC design gained a lot of attention. The application of LM tool like Platform Commonality in product design results in ASC and reducing inventory of finished goods (Huang et al., 2007). Relevant to this point, Huang, et al. (2005) proposes a generic BOM to manage product complexity by minimising SC total cost (TC) through common platform. The study of Altfeld et al. (2011) realises that automotive industry receives the positive benefits from postponement and Component Commonality. Other LM tools, Modularity ("a process of decomposition or demarcation of the product architecture into sub-assemblies", Anand and Kodali, 2008), and Modular Design, add up the product series and respond quickly to market change (Wang, 2011). Findings of Shamsuzzoha, et al. (2018) highlight that using Modularity, enterprises can reduce lead time, enhance the ability of assembly thereby ameliorating customer satisfaction. Ulrich and Eppinger (1995) assert that "the more modular the product architecture - the greater the opportunities for product customization". Moreover, Standardization, ("the use of standard parts, materials, processes and procedures, thereby avoiding the use of special subcontractors, which are typically used in mass production to supply for general markets", Anand and Kodali, 2008) plays essential role in reducing the complexity of production, lessening the storage keeping unit (SKU), increasing the diversity and customization of products. Additionally, Group Technology proves to be useful in supplier reduction as it "refers to the grouping of similar parts based on similarities in design features or manufacturing processes into part families" (Anand and Kodali, 2008). Also, Pero, et al. (2010) emphasise the importance of matching product architecture with SC. There are two approaches to define the best product family achieving market needs: 1. using generic BOM, in which they are determined to respect assembly constraints; 2. fixed final products but the BOM are more-or-less flexible (Baud-Lavigne, et al., 2012). In short, some Lean tools can boost the agility in SC whereas the matching between product design (through flexible BOM) and LASC design has not been exploited.

2.4. LASC

The characteristics of LASC in comparison with traditional SC, LSC and ASC – were extensively analysed in several studies like Christopher and Towill (2001) and Konecka (2010). They stress that LASC can meet the unstable demands and has the ability to absorb risks throughout the chain. Study of Raj, et al. (2018) proves that the performance of LASC is much higher the one of LSC and ASC. According to Goldsby et al. (2006), LASC results from three outstanding characteristics: 1. mixed-model approach in manufacturing (or Pareto rule), in which 20% of products having stable demands, which contribute to 80% revenue, are produced by Lean; the remaining 80% fewer anticipatory products should be produced in an agile manner; 2. outsourcing temporary capacity to meet the peak/seasonal demand; and 3. postponement or delaying of the final forms of a product until orders are received from customers. The point of postponement is considered as DP.

2.4.1. Decoupling Point

DP is a specific trait of LASC that divides the chain into Lean and Agile processes. As per Basu and Wright (2010), LM can be deployed up to the DP where components and semi-products are fabricated under MTS (make to stock), and from then, AM can be implemented downstream where various products are assembled under MTO (make to order) once orders received. Utilizing DP, firms can offer products with a higher individuality and diversity while reducing the cost of finished inventory goods. To deliver products within an acceptable time, in case the lead time from the market is shorter than the total supply time, enterprises use DP as a buffer stock (Wang, 2011). More explicitly, to compare the two mentioned pipeline times, Rudberg and Wikner (2004) uses ratio S/D (supply lead time/delivery lead time) as the manufacturer's commitment on customer satisfaction. After that, many researchers considered S/D as one important reference to position DP. As Sun et al. (2008), the researchers have attempted to multiply DP in SC to amplify the degree of customization, like Boeing Company has three DPs (Program, 1991).

2.4.2. Decoupling Point Location

DP may be situated in different tiers of SC (Zhang, et al., 2012). This placement can be identified from two main approaches, in which their shortfalls are discussed previously: knowledge-based conceptual model and quantitative model (Jeong, 2011). Naylor et al. (1999) succeed in applying market knowledge to define DP while Ebrahimiarjestan and Wang (2017) formulate a mathematical model to find the best DP respecting three aspects: 1. minimization of production cost; 2. reducing delivery time to the customer; and 3. maximization of customer satisfaction. The common point among quantitative-approach papers is to categorize the MTO and MTS criteria before identifying (semi)

components belonging to these processes (Goldsby et al., 2006; Sun et al., 2008). It is noted that these studies just develop their models based on the assumption that the SC has been designed with pre-defined facilities.

Many researchers suggested that DP should be located near the end customers to minimize the delivery time to the customer (Anand and Kodali, 2008; Chan and Kumar, 2009). Results from Hedenstierna and Amos (2011) even affirm that positioning DP far upstream "possible may be ill-advised … as it passes demand variability directly to the physical SC, leading to excessive inventory and capacity requirements". Nonetheless, that is not a sole conclusion as Olhager (2003) indicates that the best place of DP is unstable: it does not permanently fix but can be shifted upstream or downstream when factors like market, product and production change. As per this author, placing DP far upstream can reduce the stock while locating it downstream helps to smoothen the production. The following table summarized elements affecting the location of PD in the chain.

The comprehensive study of Madsen and Mavraj (2015) suggests taking into account three essential categories, namely, market-related factor (delivery lead time, product volume, range, etc.), product-related factors (customization opportunities, product structure, etc.) and production-related factors (production lead time). Supported by the aforementioned findings, this study here introduces one new framework to design LASC. The procedure begins with product-related factors through generating the agility for product family in product design while balancing it with market-related and production-related elements. The framework is presented as follows.

Table 1. Factors influence the placement of DP

Backwards to upstream	Forwards to down stream
High deterioration rate (Jeong, 2011)	Product life cycle decreasing (Jeong, 2011)
Low-frequency demand (Hedenstierna and Ng, 2011)	High-frequency demand (Hedenstierna and Ng, 2011)
	Competitive advantage based on price (Rudberg and Wikner, 2004)
	Competitive advantage are service delivery and accessibility (Shahin and Jaberi, 2011)

3. New Framework of LASC Design

In the typical model of LASC, the LM is implemented in production up to the DP (to cut cost in producing products) and from then the AM is applied through distribution channel (to respond to customisation). In this paradigm, the agility of product is amplified based on the ability of combining standardised modules stored at DP to form the finished goods once orders received. Thus, this paper here begins at product design in order to enhance the combination ability among compatible components in the so-called LA BOM for product families. This step serves as a stepping stone to boost the agility at DP. Meanwhile, the preliminary SC is outlined where its supply side is matched with the product structure. Afterwards, the sketch SC is refined to eliminate waste on its structure. Then the best desirable DP is identified once the configuration of LASC is optimized. Thanks to the application of Lean tools in product design, sourcing design and also SC design, the LM is expanded throughout the whole chain. This article inherits and extends the findings of Nguyen and Dao (2016) which presented the quantitative model to optimize the design of LSC. In particular, the proposed framework of LASC design consists of four main modules: 1. design LA BOM for product families; 2. design preliminary LSC; 3. design supply side; and 4. design LASC (Fig.1).

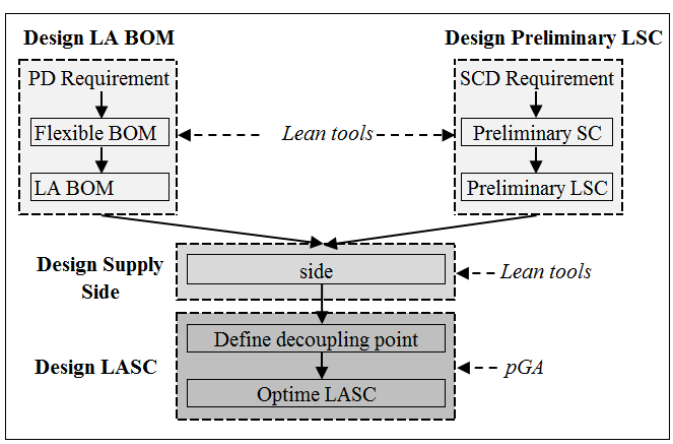


Figure 1. LASC design framework

3.1. Design LA BOM

To begin with, this article delves into the results of Fujita, et al. (2013). These authors emphasize that the selection of components candidates (or BOM) in product design connect directly with the elements of desirable SC; or when the BOM of the product family is modified, it entails a corresponding change in SC's structure. Thus, this step attempts to refine the BOM and transform it into LA BOM by minimizing its SKU (Lean) as well as simultaneously improving the integration among them (Agile). Specifically, the former lessens the number of suppliers while the latter influences the supporting facilities of module assembly and product production (Fig. 2). As a result, the LA BOM impacts both on configuration and performance (like total cost) of future SC.

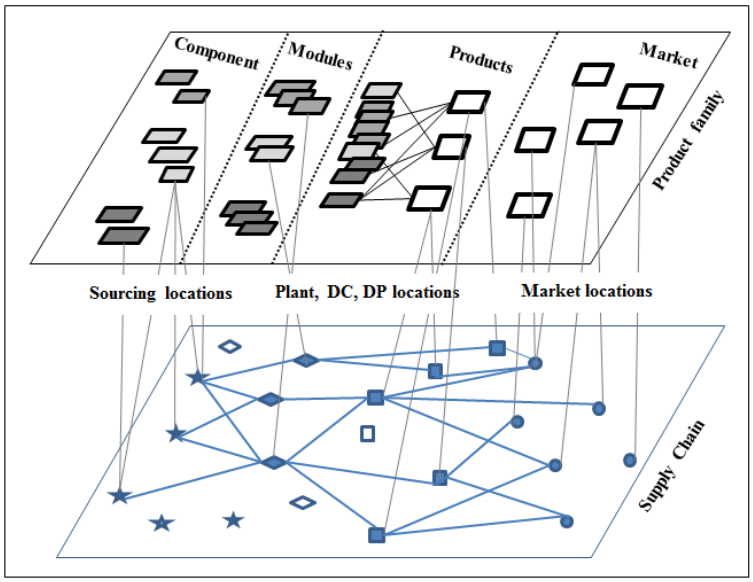


Figure 2. The impact of product family design on LASC design (modified from Fujita et al. (2013))

The ability of combination among components in the product family directly influences the products' diversity. Thus, to boost the capacity of this combination, some mentioned LM tools are applied (Figure 3). First, main suppliers are invited to get involved in the product design process at the very beginning to improve the creativity. Then other tools that can prevent wastage from increasing agility are considered. The BOM of each product is designed based on *Commonality Platform* for the whole product family with some opened options. To reduce the SKU, all flexible BOMs are listed in one master BOM and then refined with *Group Technology* and *Use of Common Parts.* Then, their functions and physical structures in Master BOM are modified or even redesigned under the concepts of *Standardization* and *Modularity* to increase the possible compatibility among them. With the concentration on product-related factors, the base of agility in SC is established. In other words, from each product family, an enterprise can offer a broader range of products, thereby creating greater customization opportunities. The LA BOM obtained is used for LASC design and illustrated in the numerical example in the following sections (Figures 5 and 6)

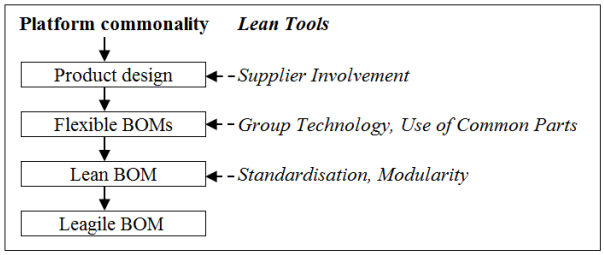


Figure3. The process of generate LA BOM with LM

3.2. Design Preliminary LSC

Assuming that all sufficient information for SC design is available, designers can outline a preliminary fat SC, which in this case – includes 4 potential plants and 7 possible DC. 3 and 5 out of them are selected respectively. From then,

The Use of Flat Hierarchy is implemented to eliminate the waste on fat SC's structure by flattening unnecessarily intermediate tiers in the chain. It is assumed that the preliminary obtained LSC has 4 echelons: supplier, plant, DC and customers (Figure 4).

3.3. Design Supply Side

This step matches LA BOM obtained from product design with a sourcing network of each candidate plant. Particularly, the structure of the draft supply side is evaluated and redesigned to suit the product architecture. In reality, some potential suppliers will provide one component SKU. Under Lean strategy, *Single/Dual Sourcing* is employed based on cost and lead time. Notably, in Lean system, the continuity of product flow is the key factor to maintain production as there are very few inventories (or none at all) to back up for any shortfall. Therefore, suppliers nearby the plants are highly appreciated by *Geographical Concentration*.

3.4. Optimise LASC

PD is the typical characteristics of LASC. To find the best configuration of LASC, the optimal location of DP must be taken into consideration. The issue is formulated into a mathematical model, which satisfies the min SC TC within acceptable delivery lead time. Based on cost point of view, DP should be placed at the nodes where inventory cost and production adjustment/design or Customization cost (Ebrahimiarjestan and Wang, 2017) are more sensitive than the transport cost from and to it. From the lead-time perspective, the placement of this point strives to meet the expectation that the delivery time of final products from this point is shorter than the order time from customers.

3.4.1. Define the Decoupling Point

Before forming the mathematical model, the product's structure of desirable LASC, which comprises from Lean products and Agile products, must be set out. The former is fabricated based on stable demand under LM and sent directly to end customers within the acceptable timeline. Meanwhile, the latter is only shaped from semi-products (or Agile module) stocked at DP where the purchase orders were once received. The inventory of Agile modules is computed to satisfy a pre-defined service level α. In this case, the design and management of SC are more complicated to well support different operations and flows of components of Agile modules and Agile products in front of DP and behind DP.

a. Cost Objective

Both Lean and Agile modules comprise of components in LA BOM and under LM. Potential SC TC includes: 1. *Procurement cost;* 2. *Transportation cost* (from plants to customers for Lean products; between adjacent tiers for Agile products); and 3. *Production Cost* (Fixed cost and Variable cost). In addition, at DP, there exists *Inventory cost* of Agile modules and *Customization cost*. In this case, the inventory decisions are made in advance based on forecasts of uncertain demand based on Single Period Models (Simchi-Levi et al. 2000). The unit costs of LASC are presented in Figure 4.

Where:

S, P, D, C, LC, LP, AC, AM, AP denote for Supplier, Plant, DC and Customer, Lean components, Lean product, Agile components, Agile modules and Agile products

i, j, k, o, Lc, Lp, Ac, Am, Ap, n: index of Supplier, Plant, DC and Customer, Lean components, Lean products, Agile components, Agile modules and Agile products

Binary variables: x_{ji}, x_j, x_k: selection status of suppliers, plants, DC; $x_{jk,}x_{jo}$: transport link; x_{PAm}, x_{DAm}: placement status of DP.

The SC TC elements are:

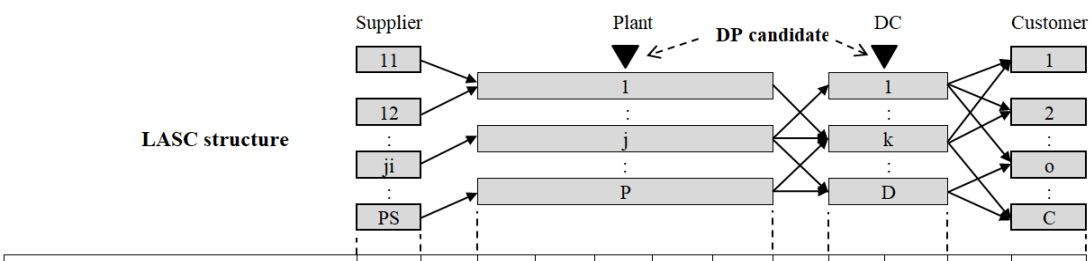
Purchasing cost: $\sum_S \sum_P \sum_{LC} (R_{ijLc} Q_{ijLc} x_{ji})$ (1)

Production cost: $\sum_P \sum_{LP} F_{jLp} x_j + \sum_P \sum_{AM} F_{jAm} x_j \, x_{PAm} + \sum_P \sum_{AP} F_{jAp} x_j \, (1 - x_{jAm}) + \sum_D \sum_{AP} F_{kAp} x_k x_{DAp} + \sum_P \sum_{LP} V_{jLp} Q_{jLp} x_j + \sum_P \sum_{AM} V_{jAm} Q_{jAm} x_j x_{PAm} + \sum_P \sum_{AP} V_{jAp} Q_{jAp} x_j (1 - x_{PAm}) + \sum_P \sum_{AP} V_{kAp} Q_{kAp} x_k (1 - x_{kAm})$ (2)

Transportation cost: $\sum_P \sum_C \sum_{LP} T_{joLp} Q_{joLp} x_{jo} + \sum_P \sum_C \sum_{AM} T_{jkAm} y_{jkAm} x_j x_{PAm} x_{jk} + \sum_P \sum_D \sum_{AP} (T_{jkAp} y_{kAp} x_j (1 - x_{PAm}) x_{jk})$ (3)

Inventory cost: $(H_{jAm} \, I_{jAm} / 2) x_{jAm} + (H_{kAm} \, I_{kAm} / 2) x_{kAm}$ (4)

Customization cost: $\sum_K \sum_{AM} FC_k x_k \, x_{KAm} + \sum_K \sum_{AM} VC_k Q_{kAm} x_{KAm}$ (5)



Products				Lc	Lp	Ac	Am	Ap		Am	Ap		
Purchasing	Unit Cost			R_{ijLc}		R_{ijAc}							
	Quantity parameter			Q_{ijLc}		Q_{ijAc}							
Production	Fixed Cost					F_{jLp}	F_{jAm}	F_{jAp}			F_{kAp}		
	Variable Cost					V_{jLp}	V_{jAm}	V_{jAp}			V_{kAp}		
	Quantity parameter					Q_{jLp}	Q_{jAm}	Q_{jAp}			Q_{kAp}		
Transports	Unit Cost Lean product				T_{joLp}								
	Q'ty Lean product parameter				Q_{joLp}								
	Unit Cost Agile Module								T_{jkAm}				
	Q'ty Agile Module variable						y_{jkAm}						
	Unit Cost Agile product								T_{jkAp}				
	Q'ty Agile product variable							y_{jkAp}					
Inventory	Unit Cost						H_{jAm}			H_{kAm}			
	Quantity						I_{jAm}			I_{kAm}			
Customisation	Fixed Cost										FC_{kAp}		
	Variable Cost										VC_{kAp}		
Binary Variable		x_{ji}		x_j, x_{PAm}					x_{jk}	x_k, x_{DAm}			

Figure 4. Draft LASC and its unit cost

The objective function of LA SC is Z, with Z is Min LASC TC

$$Z = (1) + (2) + (3) + (4) + (5) = \sum_S \sum_P \sum_{LC} (R_{ijLc} Q_{ijLc} + R_{ijAc} Q_{ijAc}) x_{ji} + \sum_P \sum_{LP} F_{jLp} x_j + \sum_P \sum_{AM} F_{jAm} x_j \, x_{PAm} + \sum_P \sum_{AP} F_{jAp} x_j \, (1 - x_{jAm}) + \sum_D \sum_{AP} F_{kAp} x_k x_{DAp} + \sum_P \sum_{LP} V_{jLp} Q_{jLp} x_j + \sum_P \sum_{AM} V_{jAm} Q_{jAm} x_j x_{PAm} + \sum_P \sum_{AP} V_{jAp} Q_{jAp} x_j (1 - x_{PAm}) + \sum_P \sum_C \sum_{LP} T_{joLp} Q_{joLp} x_j + \sum_P \sum_K \sum_{AM} T_{jkAm} y_{jkAm} x_j x_{PAm} x_{jk} + \sum_P \sum_D \sum_{AP} (T_{jkAp} y_{kAp} x_j (1 - x_{PAm}) x_{jk}) + (H_{jAm} I_{jAm} /2) x_{jAm} + (H_{kAm} I_{kAm} /2) x_{kAm} + \sum_K \sum_{AM} FC_k x_k \, x_{KAm} + \sum_K \sum_{AM} VC_k Q_{kAm} x_{KAm} \quad (6)$$

Subject to

Balance between quantities received and amount supplies at each node:

$$\sum_S \sum_{LC} Q_{ijLc} = \sum_C \sum_{LP} Q_{joLp} \, , \forall j \quad (7)$$

$$\sum_S \sum_{AC} Q_{ijAc} = \sum_K \sum_{AM} Q_{jkAm}, \forall j \quad (8)$$

$$\sum_S \sum_{AC} Q_{ijAc} = \sum_K \sum_{AP} Q_{jkAp}, \forall j \quad (9)$$

Satisfy demands from customers:

$$\sum_P Q_{kLp} = D_{oLp}, \forall LP \quad (10)$$

The quantity delivered or received from each node is less/equal to its capacity:

$$\sum_K \sum_{AM} y_{jkAm} + \sum_O \sum_{Lp} Q_{joLp} \leq C_j, \forall j \quad (11)$$

$$\sum_J \sum_{AP} x_{jkAp} \leq C_k, \forall k \quad (12)$$

$$\sum_J \sum_{Am} x_{jkAm} \leq C_k, \forall k \quad (13)$$

Each product has one decoupling point:

$$x_{KAm} = 1 - x_{PAm}, \forall Am \tag{14}$$

Non-negative conditions:

$$x_{ji}, x_j, x_k, x_{jk}, x_{PAm}, x_{DAm}, y_{jkAm}, y_{jkAp} \geq 0 \tag{15}$$

It is noted that the main discrepancy of LASC TC (Eq.6) from normal SC model is the existence of Customization cost that varies depending on the placement of DP (Table 2). From cost standpoint, the placement of DP on plant and DC has its pros and cons on LASC TC. Particularly, locating DP at plants can benefit from available equipment but lose the advantages of inventory and transports cost and vice versa.

Table 2. The impact of DP placement on LASC TC

	DP at Plant	Compare	DP at DC
Inventory Cost of Agile module	x	$\gg$	x
Production Cost at DC	Unchanged		Replaced by Customization Cost
Customization Cost	A part of Production Cost	$\ll$	Fixed + Variable Customization Cost
Transportation Cost from Plant to DC	For final product	$\gg$	For Agile module

b. Lead Time Constraints

The total supply lead time S of a product includes three main factors: supply time from suppliers; production time of producing finished goods, and delivery time to customers. The value Min(Max S) is considered one of the objective functions in the effort of increasing the efficiency of the production system. In case of LASC, those orders that have ration S/D $\leq$ 1 can be fabricated under MTO (Lean products). On the contrary, DP helps enterprises to be market winners if they can dominate the cost. Therefore, the objective function is not any longer Min(Max S) but positions DP into the best place so that SC stays at lowest TC. As a result, S turns out to be a constraint of Min (SC TC). The condition for DP placement is:

$$S_{from\ DP\ to\ customer} \geq D|_{Min\ SC\ TC} \tag{16}$$

3.4.2. Problem Solving Method

The optimal configuration of LASC can be obtained from solving objective function (6) while respecting constraints (7–16). Generally speaking, to solve the optimization problems in SC domain, many researchers referred to use Meta-Heuristics due to the complexity of the issue. In which, Genetic Algorithm (GA) is one of the most prevalent (Program, 1991). From the original form, various GA versions are developed to improve the search performance, which is summarized by Jauhar and Pant (2016). Among these GA based, Gen et al. (2006) realize that pGA (priority GA) surpasses st-GA (spanned tree GA) in generating random feasible chromosomes when solving SC design problem. Also, pGA proves to be easier than its counterpart in decoding procedure as it sets the priority for transport networks' assignment with the corresponding minimum cost. Thus, while optimizing LASC design, pGA is applied to take its above advantages. Yet, its encoding procedure needs some necessary modifications to conform to the LASC characteristics (as described in the numerical example). The procedure of p-GA can be tracked in study of Gen et al. (2006)

4. Numerical Example

To illustrate the proposed framework, one numerical example of one model-related enterprise is presented. This firm re-designs its SC to adapt with the development of a new product family. According to the customers' specification, the LA BOM of Lean products is designed. From this LA BOM, the set of Agile products are developed in the effort to offer a wider range of products for other markets.

4.1. Step 1: Design LA BOM

The design of 4-product-family LA BOM is demonstrated in Fig. 5.a-c, which is based on *Supplier Involvement* and *Platform Commonality*. Then this BOM is examined to increase the agility of components. When refined, (F1, G1), (F2,G2), (F3,G3) and (F4,G4) are grouped by *Group Technology* and then modulated by H1. Similarly, B4, D2 and D3 are replaced by B1, D1 and D1 under the concept of *Use of Common Parts*. Also, A1, A2, A3 and A4 are standardised by A5. Under the light of *Standardisation* and *Modularity*, the potentials to enhance the combinations

among components are analysed and evaluated. It gives room for candidates to improve both functions and structure so that final components can be combined in a compatible manner. Thus, the LA BOM becomes simpler (leaner) but has more opportunities to meet the diverse needs of the customer (more agile).

At plants, components are fabricated in modules before being shaped in Lean products. The production lead time for each product is calculated based on its structure and production processes (Fig. 6.a). The final LA BOM obtained at plan is presented in Fig.4.d, in which the standardized modules are J, K and E while specialized ones are represented by W. Concerning the combined options to generate Agile products, module J has a unique option while K and E have 4 each. Thus, there are total 1 x 4 x (4-1) new possible Agile products, which can be produced from this LA BOM. Concerning SKU of common components, this number reduces from 27 (in flexible BOM) to 3 (in final LA BOM). Alongside with 4 Lean products, 12 new Agile products are added up, in which P5, P6 and P7 are expected to receive orders from other customers (Fig. 6.b).

4.2. Step 2: Design Preliminary LSC

Once the LA BOM is designed, the designers can deftly outline the preliminary fat SC, following the tight relationship of product architecture and SC configuration as described in Figure 2. Afterwards, the fat chain is refined and transformed into LSA with The Flat Hierarchy to eliminate unnecessary echelons. Assuming that in this numerical example, the intermediate tiers like 2nd, 3rd suppliers, wholesaler and retailer are wiped out, this preliminary LSC facilitates the mentioned products family in Figure 5.d.

4.3. Step 3: Design Supply Side

The LM tools are continuously implemented to eliminate waste in other parts of newly-designed LSC. Particularly, the enterprise uses *Single Sourcing* strategy to limit the numbers of supplier candidates. Along with cost and delivery time, the *Geographical Proximity* is also taken into consideration to maintain the continuity of product line and a just-in-time system. With the light of *Single Sourcing*, the sole supplier who provides one set of components to one specific plant is finally defined in the context of optimizing whole SC to approach the global optimum.

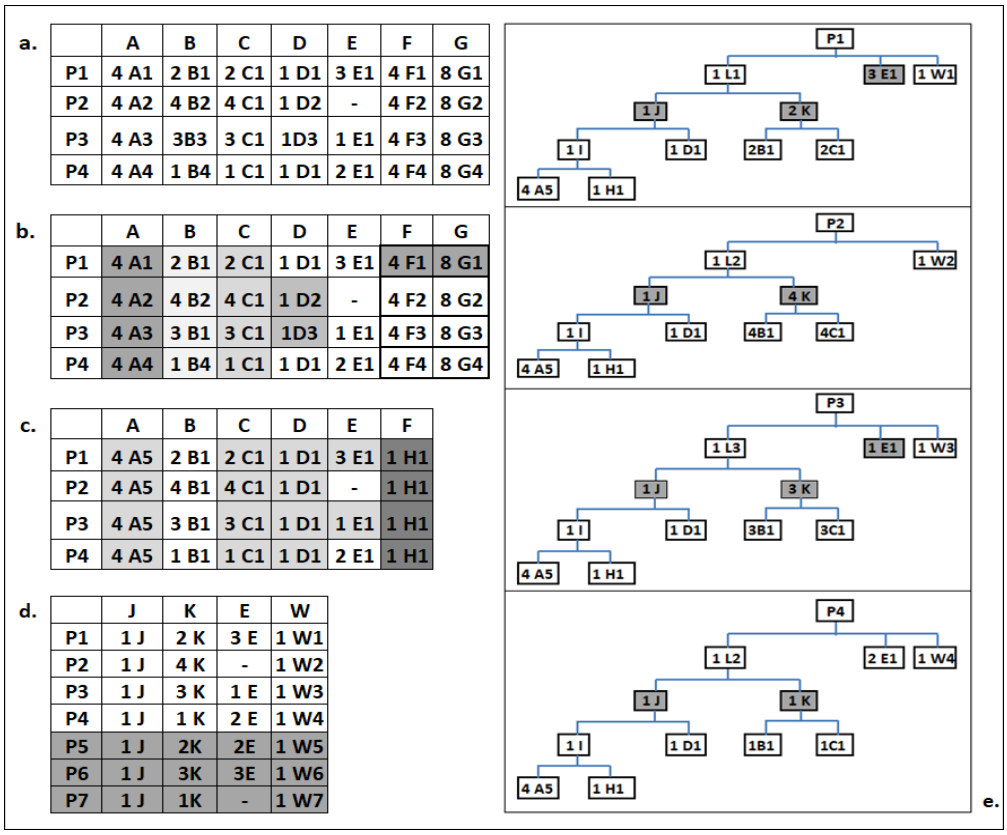


Figure 5a. Flexible BOMs; b. Modify flexible BOMs by LM tools; c. LA BOM for suppliers; d. Final LABOM; e. Lean products' structure

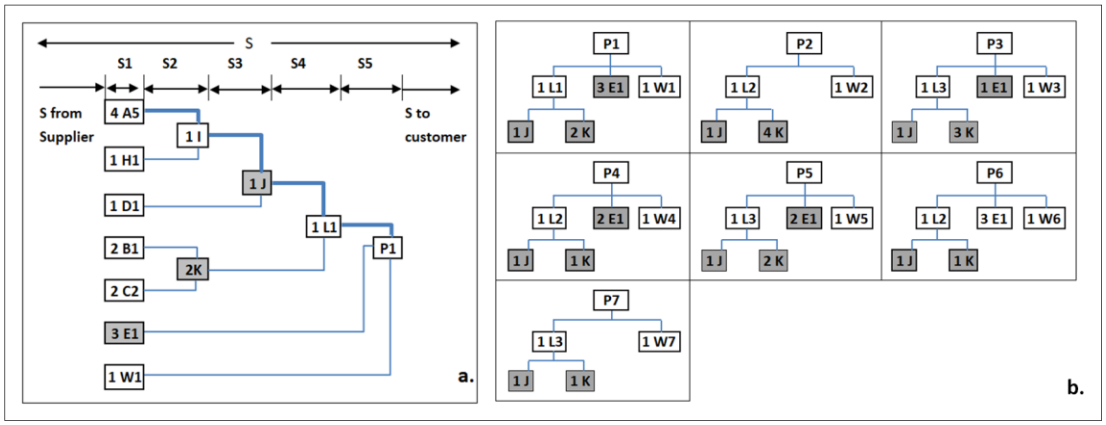


Figure 6a. Supply lead time of P1; b. Structure of product family from final LA BOM

4.4. Step 4: Design LASC

4.4.1. Define the Decoupling Point

a. Cost Objectives

The demand for Lean products and expected Agile products are presented in Table 3 where the required components and modules are enumerated.

Table 3. Demands and required components/modules

Product	Demand (Lean product)	Predict (Agile product)	Order from supplier					Agile module			Specified component
			A	B	C	E	H	J	K	E	W
P1	12,000		48,000	24,000	24,000	12,000	48,000	12,000	24,000	36,000	12,000
P2	8,000		32,000	32,000	32,000	8,000	8,000	8,000	24,000	-	8,000
P3	11,500		46,000	34,500	34,500	11,500	11,500	11,500	34,500	11,500	11,500
P4	15,200		60,800	15,200	15,200	30,400	15,200	15,200	15,200	30,400	15,200
P5		1,500	6,000	3,000	3,000	3,000	1,500	1,500	3,000	3,000	1,500
P6		1,800	7,200	5,400	5,400	5,400	1,800	1,800	5,400	5,400	1,800
P7		2,400	9,600	2,400	2,400	-	2,400	2,400	2,400	-	2,400
Sum	**46,700**	**5,700**	**209,600**	**116,500**	**116,500**	**70,300**	**88,400**	**52,400**	**108,500**	**86,300**	**52,400**

Partly Cost elements of SC are listed in Table 4.

Table 4. Customization cost when DP positioned at DC

	Product	DC1	DC2	DC3	DC4	DC5	DC6	DC7
FC_{DAm}	P5	2,100	2,550	2,740	2,800	2,350	2,950	2,200
	P6	4,430	4,270	4,680	4,390	4,180	4,860	4,500
	P7	1,500	1,800	1,900	1,540	1,670	1,830	1,530
VC_{DAm}	P5	8.3	8.2	8.6	8.8	8.7	8.2	8.4
	P6	9.5	9.2	9.7	8.8	8.5	8.3	9.1
	P7	5.8	6.3	6.9	6.5	6.6	6.9	6.1

Substituting these data in Table 2 into Eq. 7, the objective functions yield:

$$Z = \sum_{16}\sum_{4}\sum_{10}(R_{ijLc}Q_{ijLc} + R_{ijAc}Q_{ijAc})x_{ji} + \sum_{4}\sum_{4}F_{jLp}x_j + \sum_{4}\sum_{6}F_{jAm}x_j\, x_{PAm} + \sum_{4}\sum_{3}F_{jAp}x_j\,(1 - x_{jAm}) + \sum_{4}\sum_{3}F_{kAp}x_k x_{DAp} + \sum_{4}\sum_{4}V_{jLp}Q_{jLp}x_j + \sum_{4}\sum_{6}V_{jAm}Q_{jAm}x_j x_{PAm} + \sum_{4}\sum_{6}V_{jAp}Q_{jAp}x_j(1 - x_{PAm}) + \sum_{4}\sum_{3}\sum_{LP}T_{joLp}Q_{joLp}x_j + \sum_{4}\sum_{7}\sum_{AM}T_{jkAm}y_{jkAm}x_j x_{PAm}x_{jk} + \sum_{4}\sum_{7}\sum_{AP}(T_{jkAp}y_{kAp}x_j(1 - x_{PAm})x_{jk}) + \sum_{4}\sum_{6}(H_{jAm}\,I_{jAm}/2)x_{jAm} + \sum_{7}\sum_{6}(H_{kAm}\,I_{kAm}/2)x_{kAm} + \sum_{7}\sum_{6}FC_k x_k\, x_{KAm} + \sum_{7}\sum_{6}VC_k Q_{kAm}x_{KAm} \quad (17)$$

b. Lead Time Constraints

The critical path Max(S) of one Agile product with different scenarios of D is described in Fig. 7.

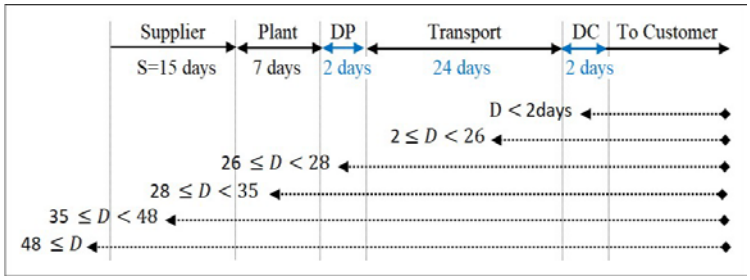


Figure 7. Max(S) and different scenarios of D

From Fig. 7, it can be observed that if the time that customers desire to have the product is less than 2 days – the timeline necessary to assemble finished goods from the available Agile module in DC – the enterprise must store finished goods at DC if it wants to win this order. When this time varies from 2 days to less than 24 days, DC is the unique DP. Similarly, the plant has to stock final products if 26 While this tolerance increases from 28 to less than 35, either Plant or DC can be DP; if fluctuates from 35 to less than 48, the enterprise has more options: The firm can stock components at plant or use DP. When those products should be produced under MTO for Lean products. It is assumed that the enterprise uses market knowledge to define that the D of P5, P6 and P7 are 1, 14 and 30 days in turn. To serve all these orders, the enterprise must have an inventory of final product P5 at DC and set DC as DP for P6. For P7, it has to define the best location of DP, which may be placed either at plant or DC.

4.4.2. Problem Solving

To identify the optimal structure of LASC, pGA is applied to solve the objective function Eq.17. When encoding this case, there are four strikingly different points from the traditional issue of SC design. Firstly, two flows of products, Lean and Agile, coexist in the model, in which Lean products are manufactured at the factories and delivered directly to the customers, while the Agile modules are stocked in DP before being assembled into finished goods once ordered. Secondly, the model includes variables of DP, in which its placements of P5 and P6 are deterministic (no need to encode them on LASC's chromosome). Thirdly, the genes represent the transportation network between plants and suppliers are also deterministic with the application of *Single Sourcing*. Finally, under the impact of this LM tool, each gene of the plant is accompanied with two segments of chromosome denoting two groups of potential suppliers, and just one of them is selected. Fig. 8 exemplifies one chromosome of the LASC.

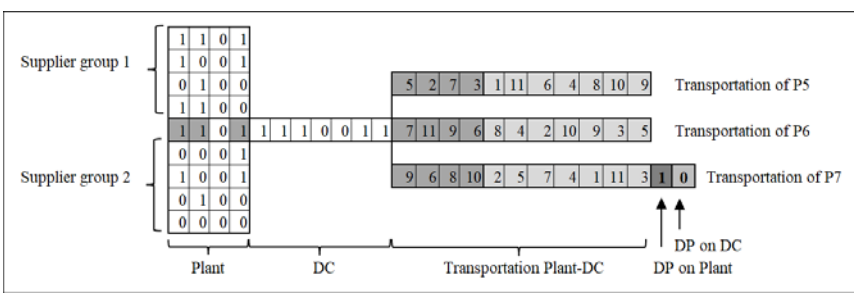


Figure 8. One chromosome of LASC

4.4.3. Solutions

With 50,000 iterations, the pGA determined the best chromosome with offering min LASC total cost (Fig. 9 and Fig. 11). The chromosome embodied the best desired LASC structure including suppliers for each chosen plant, selected plants, DC, the DP of Agile products and the product flows of both Lean and Agile products. Particularly, the lowest cost the optimal LASC stayed at $3,428,385.77; the selected suppliers are depicted in Figure 10 corresponding with the plants. The Plant 2, DC3, and DC6 candidates are excluded. As the DP of Agile product P5, P6 had been predefined, DC echelon is identified the DP of Agile product P7. The material flows in LASC are also identified, in which the Lean products are shifted directly from selected plant to customers. Meanwhile, Agile modules and Agile products are transported through the logistics networks (Figure 10) which are decoded from the chromosomes segments Transportation Plant - DC of product P6 - P7 in Figure 9.

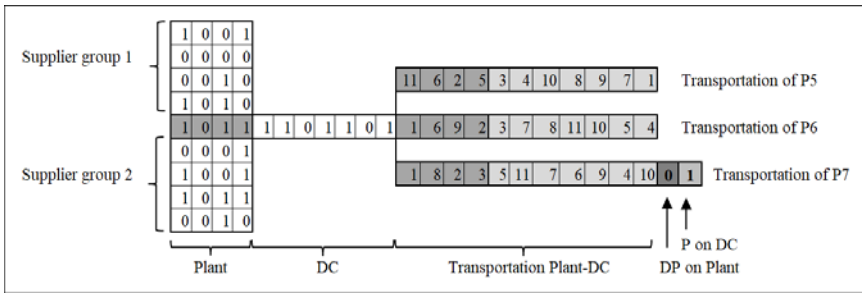


Figure 9. The best chromosome of LASC

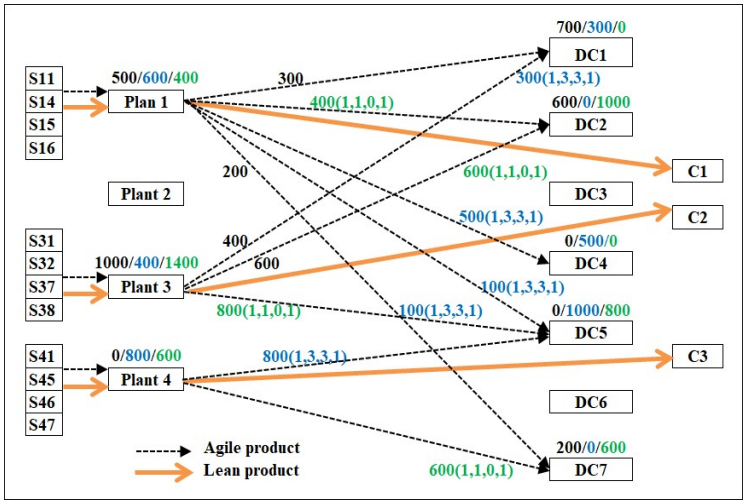


Figure 10. The optimal configuration of LASC

5. Discussion

Without the equivalent case studies for benchmarking, the article qualifies the solutions given by the pGA. Particular, the obtained LASC TC when DP placing DP in plants and in DC are observed at different iterations in pGA procedure. The testing results are listed in Table 5 and Fig. 11. The data show that min LASC TC when DP positioned at DC keep smaller than the one situated at plant regardless the number of iterations. Although the TC of two cases fluctuates, they begin to converge when iterations are greater than 20,000 and maintain stability after the loop reaches 50,000. The obtained solutions are well match with study of Hedenstierna and Amos (2011), in which the placement of DP close to the downstream results in the min SC TC. In the example, even though the Lean products comprise up to 88.3% the cost structure of LASC, locating PD at DC saves up to 6.3% of the cost of Agile products ($24,392). This benefit mainly stems from the low cost of inventory and customization at DC. Yet, the advantage seems lost in the case of complex products because customization costs at the plant are relatively lower than those in DC due to the availability of facilities and equipment. The complexity of product appears not only in multi-hierarchy components but also at a large number of modules in final LA BOM. In this case, the logic of placing DP near downstream should be re-examined carefully. Stocking a large SKU of modules for expected demand, the company has to cost a fortune to invest on premises and equipment on DC. In the numerical example, when customization cost at DC increases by 3.2 times, the designer must think of shifting the DP backward plant tier.

Table 5. Min LASC TC within different scenarios of DP placement and iterations

Interation	1,000	10,000	20,000	50,000	75,000	100,000
PD at Plant	4,108,806	3,556,361	3,501,807	3,454,504	3,453,535	3,452,778
PD at DC	3,736,940	3,524,038	3,449,299	3,430,031	3,429,096	3,428,386
Variation	371,865	32,323	52,508	24,473	24,439	24,392

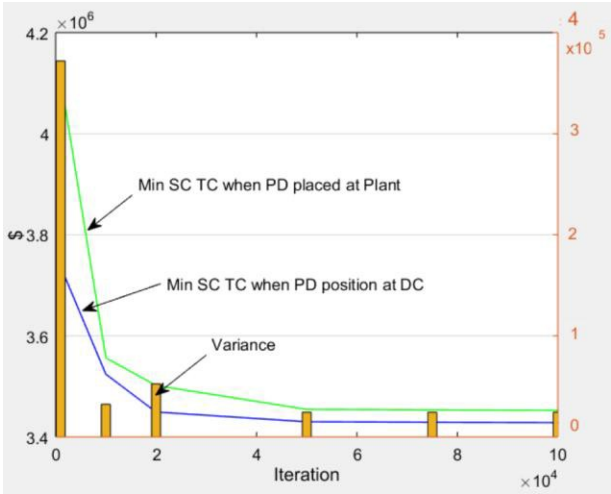


Figure 11. The variations of LASC TC with different placement of PD

6. Conclusion

This article presents a new framework to optimise the design of LASC. The approach proves feasible and promising through the qualification in the specific example, from which the convergent solutions are defined from pGA Meta-Heuristic. Its practical implications are highlighted as the paper analysed all possible cases of lead times from customers in the example thereby proposing the corresponding responses when choosing the best DP in LASC. The proposed framework has fulfilled the aforementioned research gaps as following:

7. *The new framework for designing LASC concurring product design and SC design:* In product design, the framework coined the concept of the so-called LA BOM, which bears the characteristics of both LM (as it generated from a group of Lean tools), and AM (as it escalates the ability of combination among components in product families). The LA BOM formed a good foundation for LASC thanks to the reduction of SKU number in product structure (Leaner) while it can offer wider range of product to customers (more agile). Meanwhile, when the draft fat SC is outlined, Lean tools is applied to transform it into LSC before the LA BOM is matched with its supply side. Finally, the best placement of desirable DP is defined while optimizing the optimal configuration of LASC though mathematical model.

8. *To examine the best placements of desirable DPs under different scenarios of LASC design:* without repeating the elements studied in the literature review, the framework defined two important factors which affect DPs' location: lead time and the complexity of the products. They were considered in mathematical model where the former was used to fine all possibilities of DPs'positions. Meantime, the former impacts directly the Customisation cost of the chain. In two cases, the best DPs placements were identified where their locations contributed to the minimum LASC total cost.

9. *The managerial implications withdrawn from the model:*

a. Different with typical LASC model where LM is implemented up to DP, this approach employed Lean tools in product design, sourcing base and SC design as well. Thus, managing cadre may apply this new model when design LASC to eliminate waste more strictly in the whole chain.

b. The application of LA BOM. The LA BOM can be generated from Lean tools, which not only can simplify the components of the product family but also can amplify the combination capacity among them. This approach is superior to traditional LASC that it generates the agile base in very early step of product design thereby ensuring the customization of finished goods at DP. Practitioners might reference the concept of LA BOM design for their knockdown product family by applying Platform Commonality, Component Commonality, Modularity and Standardsation in product design.

c. The impact of product complexity on DPs placement. The results from this paper showed that in case of a complicated product, when the customization cost at DP surpasses a certain threshold, the advantages of DP being close to customers lose, and the DP tends to be shifted upstream. The findings contributed to the body of knowledge of LASC, which is worth notice by designers and managers as it are contrary to the general belief, from which, loosing speaking, the best place of DP is downstream, near customers.

To conclude, in today's fiercely competitive environment, Practitioners of different industrial sectors may reference this promising framework to simultaneously gain competitive advantages from both Lean and Agile strategies. There are still plenty of unexploited rooms in this field for research future. For instance, scholars could conduct their research on LASC design for a multi-family product or/and use multi-DPs on material flow within each product to amplify the agility of LASC. Researchers might testify the quality of the new model by evaluating the performance of the four models LSC, ASC, original LASC and the LASC designed following this approach. Furthermore, they may use this procedure to design LASC while considering reliability and resilience in the risk environment.

References

Altfeld, N., Hinckeldeyn, J., Kreutzfeldt, J., and Gust, P., *Impacts on supply chain management through component commonality and postponement: A case study.* Proceedings of the International MultiConference of Engineers and Computer Scientists, 2011

Anand, G., and Kodali, R., A conceptual framework for lean supply chain and its implementation, *International Journal of Value Chain Management,* vol. 2, no. 3, pp. 313-357, 2008.

Andreev, O., and Koleva, N., *Opportunities for Applying Customer Order Decoupling Point Approach in Bulgarian SMEs from Furniture Sector.* The European Entrepreneurship: How Entrepreneurs (Should) Act in Global Business Environment, 2013

Basu, R., and Wright, J. N., *Total supply chain management*: Routledge, 2010.

Baud-Lavigne, B., Agard, B., and Penz, B., Mutual impacts of product standardization and supply chain design, *International Journal of Production Economics,* vol. 135, no. 1, pp. 50-60, 2012.

Chan, F. T. S., and Kumar, V., Performance optimization of a leagility inspired supply chain model: a CFGTSA algorithm based approach, *International Journal of Production Research,* vol. 47, no. 3, pp. 777-799, 2009.

Christopher, M., and Towill, D., An integrated model for the design of agile supply chains, *International Journal of Physical Distribution & Logistics Management,* vol. 31, no. 4, pp. 235-246, 2001.

Dekkers, R., Sharifi, H., Ismail, H., and Reid, I., Achieving agility in supply chain through simultaneous "design of" and "design for" supply chain, *Journal of Manufacturing Technology Management,* vol. 17, no. 8, pp. 1078-1098, 2006.

Ebrahimiarjestan, M., and Wang, G., Determining decoupling points in a supply chain networks using NSGA II algorithm, *Journal of Industrial Engineering and Management,* vol. 10, no. 2, pp. 352-372, 2017.

Fujita, K., Amaya, H., and Akai, R., Mathematical model for simultaneous design of module commonalization and supply chain configuration toward global product family, *Journal of Intelligent Manufacturing,* vol. 24, no. 5, pp. 991-1004, 2013.

Gen, M., Altiparmak, F., and Lin, L., A genetic algorithm for two-stage transportation problem using priority-based encoding, *OR spectrum,* vol. 28, no. 3, pp. 337-354, 2006.

Gligor, D. M., and Holcomb, M. C., Understanding the role of logistics capabilities in achieving supply chain agility: a systematic literature review, *Supply Chain Management: An International Journal,* vol. 17, no. 4, pp. 438-453, 2012.

Goldsby, T. J., Griffis, S. E., and Roath, A. S., Modeling lean, agile, and leagile supply chain strategies, *Journal of business logistics,* vol. 27, no. 1, pp. 57-80, 2006.

Hedenstierna, P., and Amos, N. H. C., Dynamic implications of customer order decoupling point positioning, *Journal of Manufacturing Technology Management,* vol. 22, no. 8, pp. 1032-1042, 2011.

Huang, G. Q., Zhang, X., and Liang, L., Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains, *Journal of operations management,* vol. 23, no. 3, pp. 267-290, 2005.

Huang, G. Q., Zhang, X. Y., and Lo, V. H., Integrated configuration of platform products and supply chains for mass customization: a game-theoretic approach, *IEEE Transactions on engineering management,* vol. 54, no. 1, pp. 156-171, 2007.

Jauhar, S. K., and Pant, M., Genetic algorithms in supply chain management: a critical analysis of the literature, *Sādhanā,* vol. 41, no. 9, pp. 993-1017, 2016.

Jeong, I. J., A dynamic model for the optimization of decoupling point and production planning in a supply chain, *International Journal of Production Economics,* vol. 131, no. 2, pp. 561-567, 2011.

Jia, H. M., Yu, K. C., and Zhang, J. C., *A Study on Leagile Supply Chain Model and Performance Evaluation System Based on Lean Agile Theory.* Applied Mechanics and Materials, 2014

Kasperski, A., *Discrete optimization with interval data*: Springer, 2008.

Konecka, S., Lean and agile supply chain management concept in the aspect of risk management, *LogForum*, vol. 6, no. 4, pp. 23-31, 2010.

Lee, H. L., and Sasser, M. M., Product universality and design for supply chain management, *Production Planning & Control*, vol. 6, no. 3, pp. 270-277, 1995.

Madsen, J., and Mavraj, B. (2015). Feasible customer order decoupling points and associated inventory costs. Myerson, P. A., A Lean and Agile Supply Chain: Not an Option, But a Necessity, no., pp., 2014.

Naylor, J. B., Naim, M. M., and Berry, D., Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain, *International Journal of Production Economics*, vol. 62, no. 1, pp. 107-118, 1999.

Nguyen, T. H. D., and Dao, T. M., *Robust Optimization for Lean Supply Chain design under disruptive risk.* Industrial Engineering and Engineering Management (IEEM), 2016 IEEE International Conference on Bali, 2016

Olhager, J., Strategic positioning of the order penetration point, *International Journal of Production Economics*, vol. 85, no. 3, pp. 319-329, 2003.

Pero, M., Abdelkafi, N., Sianesi, A., and Blecker, T., A framework for the alignment of new product development and supply chains, *Supply Chain Management: An International Journal*, vol. 15, no. 2, pp. 115-128, 2010.

Raj, S. A., Jayakrishna, K., and Vimal, K. E. K., Modelling the metrics of leagile supply chain and leagility evaluation, *International Journal of Agile Systems and Management*, vol. 11, no. 2, pp. 179-202, 2018.

Rudberg, M., and Wikner, J., Mass customization in terms of the customer order decoupling point, *Production planning & control*, vol. 15, no. 4, pp. 445-458, 2004.

Saaty, T. L., The analytic hierarchy and analytic network measurement processes: applications to decisions under risk, *European Journal of Pure and Applied Mathematics*, vol. 1, no. 1, pp. 122-196, 2007.

Sarkis, J., Benchmarking for agility, *Benchmarking: An International Journal*, vol. 8, no. 2, pp. 88-107, 2001.

Shamsuzzoha, A., Piya, S., Al-Kindi, M., and Al-Hinai, N., Metrics of product modularity: lessons learned from case companies, *Journal of Modelling in Management*, no. just-accepted, pp. 00-00, 2018.

Simchi-Levi, D., Kaminsky, P., and Simchi-Levi, E., Designing and managing the supply chain, *Concepts, strategies, and case studies*, vol. 2, 2000.

Sun, X., Ji, P., Sun, L., and Wang, Y., Positioning multiple decoupling points in a supply network, *International Journal of Production Economics*, vol. 113, no. 2, pp. 943-956, 2008.

Ulrich, K. T., and Eppinger, S. D., *Product Design and Development*: McGraw-Hill, 1995.

Venkatesh, I., and Bharathi, S. V., Bibliometric Analysis of Lean, Agile, and Leagile Supply Chains in Automobile Industry (1990 - 2017), *International Journal of Information Systems and Supply Chain Management*, vol. 11, no. 3, pp., 2018.

Virmani, N., Saha, R., and Sahai, R., Leagile manufacturing: a review paper, *International Journal of Productivity and Quality Management*, vol. 23, no. 3, pp. 385-421, 2018.

Vollmann, T., Berry, W., Whybark, D. C., and Jacobs, F. R., *Manufacturing planning and control systems for supply chain management: the definitive guide for professionals* (Vol. 5): McGraw-Hill Professional, 2004.

Wang, Y., *Research on Main Characteristics and Application of Manufacturing Legal Supply Chain.* Information Management, Innovation Management and Industrial Engineering (ICIII), 2011., 2011

Zhang, Y., Wang, Y., and Wu, L., Research on demand-driven leagile supply chain operation model: a simulation based on anylogic in system engineering, *Systems Engineering Procedia*, vol. 3, pp. 249-258, 2012.

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