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New Framework to Optimise Leagile Supply Chain Design

Thi Hong Dang Nguyen and Thien-My Dao
Department of Mechanical/ Manufacturing Engineering
École de technologie supérieure, l'Université du Québec
1100 rue Notre Dame Ouest, Montréal, QC, Canada
thi-hong-dang.nguyen.1@ens.etsmtl.ca, thien-my.dao@etsmtl.ca

Abstract

The paper presents the new quantitative framework to optimise Leagile Supply Chain (LASC) design. The first step utilises Lean tools to identify the optimal architecture for product families through the so-called Leagile bills-of-material in product design. This step intends to reduce the storage keeping unit of the component set (Lean), while increasing the ability of combining them to create new products (Agile). Meantime, the second stage focuses on outlining the preliminary configuration of LASC with pre-defined decoupling and risk-pooling points. From then, the product architecture is matched with a supplier network before the supply side is refined. Afterwards, step four implements Lean philosophy to leanize the upstream site up to decoupling point. Finally, LASC's cost structure, which comprises from two different product types, is analysed. Based on minimising the total cost at a certain service level, the best configuration of LASC is optimised.The whole framework is illustrated in one specific case study.

Keywords
Leagile Supply Chain (LASC) design; Leagile bills-of-material (LA BOM); decoupling point; optimize

1. Introduction

The pressure of fierce competition in the business market forces enterprises to relentlessly pursue proper ways to survive and thrive. After an era of mass production, Lean Manufacturing (LM) is considered as an effective solution which can create competitive advantages through eliminating waste thereby cutting cost. Yet, it proves very hard for Lean model to satisfy the diversity in customer demand as this model is only suitable for standard products. To scope with this issue, Agile was introduced and evaluated by Iacocca Institute (1991) as *21st-century Manufacturing Enterprise Strategy*. Nonetheless, the model does suffer from significant operating cost.

To take advantages of the two models, Naylor, Naim, and Berry (1999) coined the term "leagility", which integrates both leanness and agility into one hybrid model. This advanced paradigm implements Lean in producing products and switches to Agile in marketing through one decoupling point. As a result, this approach can greatly reduce the production complexity, improve production efficiency and satisfy the various demands of end customers (Zhang, Wang, & Wu, 2012). From then, there are numerous models developed to explore and engineering LASC. Most of previous studies focused on integrating Lean and Agile strategy around the decoupling points. According to Christopher and Towill (2001), it is heated disagreement that Lean methodologies can be powerful contributor for Agile, yet authors Basu and Wright (2010) address the opposite point of view. Moreover, product design (PD) is "*argued to support a leaner and more Agile supply chain (ASC) by postponing the point of differentiation*" (Lee & Sasser, 1995) or in other words, PD affects directly LASC.

Today, LASC is not an option, but a necessity (Myerson, 2014). Yet, to the best of our knowledge, there are two research gaps in this domain: 1. issues related to PD has yet to be taken into account in designing LASC; 2. the design of LASC has not conducted in quantitative method. Inspired from these factors, we propose one novel quantitative framework to design LASC based on Lean methodology while considering product design (PD). Particularly, the next section will review related studies before the novel framework is introduced. The proposed approach is then demonstrated in one numerical study. At last, the final section discusses the management implications, draw the necessary conclusions and make recommendations for future research.

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2. Related Review

The characteristics of LASC - in comparison with traditional SC, Lean SC (LSC), ASC - have been analysed by several studies like Christopher and Towill (2001), Konecka (2010). These authors emphasise that LASC can meet demand unstable and also has the ability to absorb risks throughout the chain. According to Goldsby, Griffis, and Roath (2006), LASC results from three outstanding hybrids: 1. Mixed-model approach in manufacturing (or Pareto rule), in which 20% products having stable demands which contribute to 80% revenue is produced by Lean. Meantime, the remaining 80% fewer anticipatory products should be produced in Agile manner; 2. Outsourcing temporary capacity to meet the peak/seasonal demand; 3. Postponement or delay the final forms of a product until orders are received from customers. The point of postponement is considered as decoupling point, which can be situated different tiers in SC (Zhang et al., 2012). As Basu and Wright (2010), a Lean model can be deployed up to the decoupling point and from then Agile strategy can be implemented downstream.

Regarding LM, it is a topic of long-standing interest. A comprehensive review of Anand and Kodali (2008) enumerates up to 59 Lean tools / technique used so far. In particular, findings from Lee and Sasser (1995) show that Lean applications can be extended in process design, plant design, SCD and PD. Concerning PD, it has been documented for more than a century (Gan & Grunow, 2013). Recently, the relationship between PD and SCD has gained a lot of attention. Findings prove that several LM tools can be applied to enhance PD quality thereby improve SCD efficiency (or both). Some Lean tools in the review of Anand and Kodali (2008) can be used in PD such as Group Technology Use of Common Part Standardisation or Modularity. Meanwhile, the application of Single Sourcing or The Use of Flat Hierarchy can change the structure of SC.

Concerning the relationship between PD and SCD, Dekkers et al. (2006) shows that ACS be obtained by contemporaneously having "design of" the SC holistically and "design for" SC at the PD stage. Meanwhile, PD based on platform commonality (components are interchangeable, autonomous, loosely coupled, individually upgradeable and standardised interfaces) results in an ASC and inventory reduction for finished goods (Huang, Zhang, & Lo, 2007). Relevant to this, Huang, Zhang, and Liang (2005) proposes a generic BOM to manage product complexity by minimising SC total cost through platform commonality. Also, Pero et al. (2010) emphasise the importance of selection of product architecture in PD to match with SCD. To define the best product family achieving market needs, Baud-Lavigne, Agard, and Penz (2012) summarie two approaches: 1. Using generic BOM, in which the BOM are determined to respect assembly constraints; 2. Fixed final products but the BOM are more-or-less flexible. Concerning the design ACS or Lean SC (LSC) in quantitative approach, this direction has very few studies excepted article of Nguyen and Dao (2016). Therefore, this paper inherits its results when building up proposed framework.

3. New Framework of LASC Design

After reviewing the related studies, we propose one new LASC design framework consisting of five main modules: 1. Design LA BOM for product families; 2. Design preliminary LASC; 3. Design supply side; 4. Leanize upstream up to decoupling point; 5. Optimise LASC configuration. Each stage implements properly different LM tools (Fig.1).

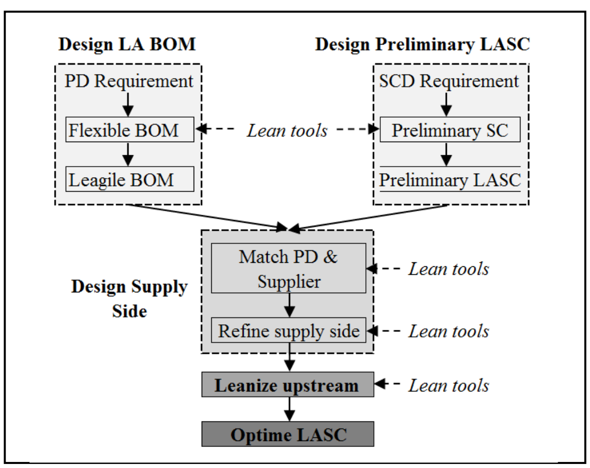

Figure 1. LASC Design Framework

3.1 Design LA BOM

The ability of combination among components in product family greatly influences the diversity of products in SC. Thus, LM tools are applied to boost the capacity of this combination. These tools, *Supplier Involvement in Design*, *Group Technology*, *Standardisation*, *the Use of Common Parts*, can also prevent wastage from increasing agility. Particularly, main suppliers are invited to involve in PD process at very beginning. The involvement of suppliers contributes to the improvement of the creativity and design capabilities of the core company in chains. Regarding PD, they are designed based on *commonality platform* for the whole product family. When designed, the BOMs of all products family are listed in one master BOM. Then, it is refined by considering other possibilities to reduce the storage keeping unit (SKU) through *Group Technology* and *Use of Common Parts* Finally, the functions and physical structures of all components in Master BOM are modified or even redesigned under the concepts of Standardisation and Modularity to generate and increase the possible compatibility among them. The final LA BOM obtained from this stage is then used for SCD (Fig. 2). The illustrated example will be given in case study.

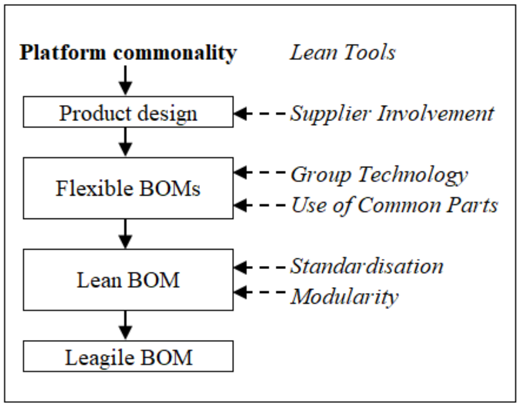

Figure 2. The process of Agile Amplification in designing LA BOM

3.2 Design Preliminary LASC

From necessary information collected, SC designers can outline sketch SC. At this stage, *The Use of Flat Hierarchy* is encouraged to implement to flatten intermediate tiers (suppliers/ distributors) in chain. Presuming that the preliminary LASC model obtained in this step is 4-echelons including suppliers, plant, distribution centre (DC) and customers.

When designing LASC, deciding where decoupling point is an important decision which needs to be pre-defined before designing its structure in detail. At this point, Agile modules (for uncertain demand products) are stocked and only assembled when customers need. This place also functions as a risk pooling point to aggregate and smooth uncertain demands from customers. From then, it stabilises the demands before sending them to plants to produce under LM. In this example, DC is set up as decoupling point (0). Currently, the sketch SC has the nature of a preliminary LASC (Fig. 3)

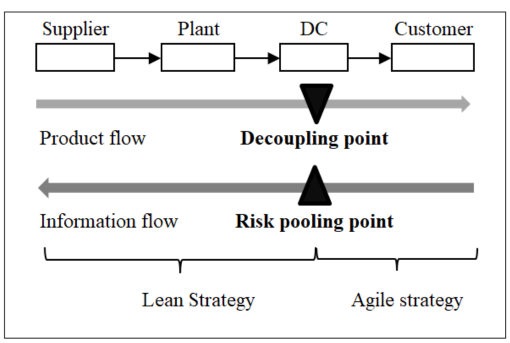

Figure 3. Preliminary LASC

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3.3 Design Supply Side

This step matches PD and SCD through Lean Filter. With new LA BOM, the structure of sketch supply side must be evaluated and redesigned to suit with the product architecture. After that, based on Lean strategy, *Single/Dual Sourcing* is employed, which sets priority for those who did participate in product design process. It is noted that in Lean model, the continuity of the product flow is of key factors to maintain Lean as there are no/very few inventory to back up for the shortfall. Therefore, suppliers nearby the plants are highly appreciated by Geographical Concentration criteria. As a result, the transport system in sourcing networks can be optimised through cross-docking or milk-run delivery. When supply and LA BOM are configured, the process continues to manufacturing areas.

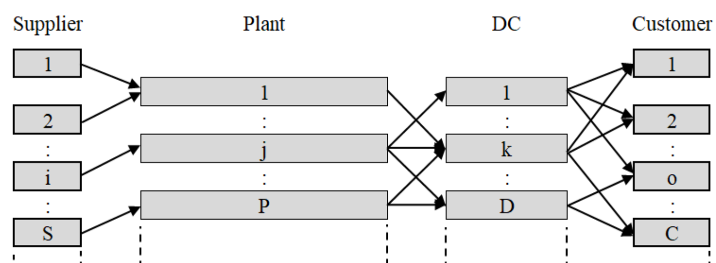
3.4 Leanize upstream from Decouping Point

After defined sourcing network, the configuration of the SC from suppliers up to the decoupling point is refined to simplify the SC's structure which will support for Lean strategy in production and transportation in the future.

3.5 Optimise LASC

The objective of this phase is to identify the optimal configuration of LASC at the lowest cost where 1. Meet all demands of Lean products; 2. Satisfy a pre-defined service level α of Agile products. Both Lean products and Agile modules are made up from Geographical components/modules in LA BOM and produced under LM. Thus, total cost (TC) of LA SC comprises from two types of products, which includes 5 elements: procurement (from plants to suppliers), production (fix cost and variable cost at plants, DC), installation (of plants and DC), transportation cost (from suppliers to plants, from plants to DC and from DC to customers for Agile products; from plant direct to customers for Lean products), and inventory. It is noted that with the different inventory policies between Lean and Agile, inventory cost only appears in decoupling point for Agile modules. In this case, inventory cost is calculated based on period review policy. The unit costs of LA SC are presented in Table 1.

Table 1. Unit cost of LA SC



Products		Lc, Ac		Lc	Lp	Ac	Am		Am	Ap		
Purchasing	Unit Cost			R_{ijLc}	R_{ijAc}							
	Quantity parameter			q_{ijLc}	q_{ijLc}							
Production	Fixed Cost					F_{jLp}	F_{jAm}			F_{kAp}		
	Variable Cost					V_{jLp}	V_{jAm}			V_{kAp}		
	Quantity parameter					q_{jLp}	q_{jAm}			q_{kAp}		
Transports	Unit Cost Lean product				T_{joLp}							
	Q'ty Lean product parameter				q_{joLp}							
	Unit Cost Agile product							T_{jkAm}			T_{koAp}	
	Q'ty Agile product Variable							x_{jkAm}			x_{kmAp}	
Inventory	Unit Cost								H_{kAm}			
	Quantity Variable								Q_{kAm}			
Installation				I_j					I_k			
Binary Variable		x_i		x_j					x_k			

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: index of Supplier, Plant, DC and Customer, Lean components, Lean products, Agile components, Agile modules and Agile products

Q_{kAm} : average inventory levels of Agile modules at DC k;

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r: reorder time
L: Lead time
AVG: Average daily demand;
STD: Standard deviation of daily demand
z: safety factor associated with service level

$$Q_{kAm} = r_{kAm}AVG_{kAm}/2 + z_{kAm}STD_{kAm}\sqrt{r_{kAm} + L_{kAm}} \tag{1}$$

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

$$Z = \sum_S \sum_P \sum_{LC} R_{ijLc}q_{ijLc}x_i x_j + (\sum_P F_{jLp} + \sum_P F_{jAm})x_j + \sum_D F_{kAp}x_k + H_{kAm}Q_{kAm} + I_j x_j + I_k x_k + \sum_P V_{jAm}q_{jAc}x_j + \sum_D V_{kAp}q_{kAp}x_k + \sum_P \sum_D \sum_{Am} T_{jkAm}\, x_{jkpAc}\, x_{jk} + \sum_P \sum_C \sum_{Lp} T_{joLp}\, q_{joLp}\, x_{jo} + \sum_P V_{jLp}q_{jLp}x_j + \sum_D \sum_C \sum_{Ap} T_{koAp}\, x_{koAp}\, x_{ko} \tag{2}$$

Subject to

- Balance between quantities received and amount supplies at each node:

$$\sum_S \sum_{LC} q_{ijLc} = \sum_C \sum_{LP} q_{joLp}, \forall j \tag{3}$$

$$\sum_S \sum_{AC} q_{ijAc} = \sum_K \sum_{AM} x_{jkAm} = \sum_C \sum_{AP} x_{koAp} \tag{4}$$

- Satisfy demands from customers:

$$\sum_P Q_{klp} = D_{oLp}, \forall j \tag{5}$$

$$\sum_D \sum_{AP} x_{koAp} = \sum_{Ap} \alpha\, D_{oAp} \tag{6}$$

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

$$\sum_K \sum_{AM} x_{jkAm} + \sum_O \sum_{Lp} q_{joLp} \leq C_j \tag{7}$$

$$\sum_O \sum_{AP} x_{koAp} \leq C_k \tag{8}$$

- Non-negative conditions:

$$x_i, x_j, x_k, x_{jkAm}, x_{joAp} \geq 0 \tag{9}$$

The best solutions obtained from these algorithms identify the optimal configuration of LASC. To solve the mathematical model, Priority Genetic Algorithm (p-GA), one modification of GA can be applied. In SC design, pGA proves effective in in generating random feasible chromosome and in decoding process (Mitsuo, Fulya, & Lin, 2006). The procedure of p-GA was detailed step by step in study of Gen, Altiparmak, and Lin (2006).

4. Numerical Example

To illustrate the proposed framework, one numerical example of AA plant in which the model-related information is presented. AA re-designs its SC in order to adapt with the development of one new product family including Lean products and Agile products.

Step 1: Design LA BOM. The design of one 4-product-family LA BOM is demonstrated in Fig. 4a in which, the BOM of product family is designed based on platform commonality and *Supplier Involvement*. Then this BOM is examined in order to increase the agility of components. When refined, (F1,G1), (F2,G2), (F3,G3), (F4,G4) are grouped by *Group Technology* and then modulated by H1. Similarly, D2 of product 2 is replaced by D1 under the concept of *Use of Common Parts*. Also, A1, A2, A3 and A4 are standardised by A5 with more functions added. Finally, 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

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combined in a compatible manner. As a result, the LASC architecture becomes simpler (leaner) but having more opportunities to meet the diverse needs of the customer (more agile). In this case, flexible BOMs contain 187 SKU for 4 products P1-P4, while SKU in LA BOM reduces to 7 with maximum 54 various combinations. For instance, the three more new products P5-P7 generated from this LA BOM as shown in Fig. 4c.

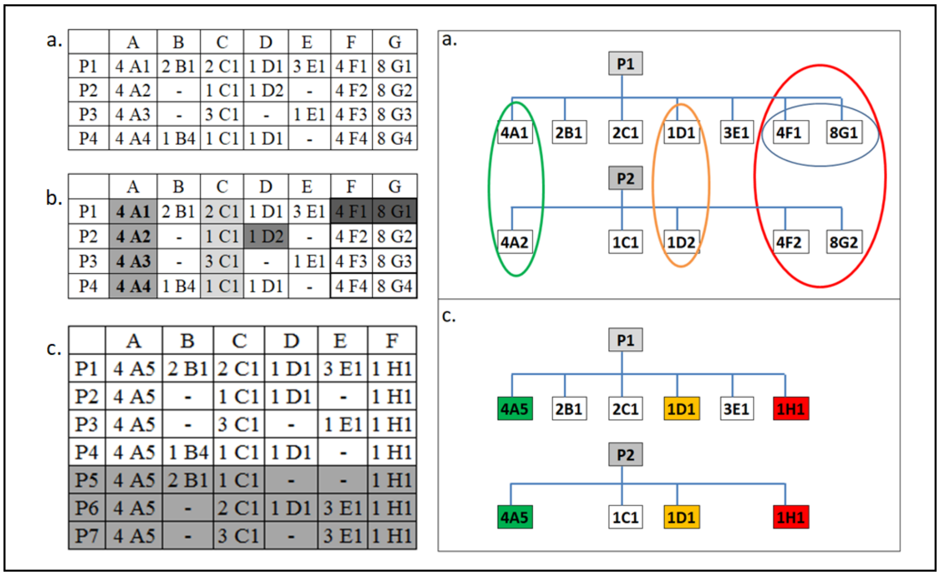

Figure 4. Examples of one LA BOM

Step 2: Design Preliminary LASC. The facilities of AA's SC are established with the decoupling point is DC. Its architecture is redesigned to accommodate with new product development.

Step 3. Design Supply Side. AA uses *Single sourcing* strategy to select their suppliers. For new product, the capacity of current suppliers is re-examined to place order for 7 modules described in Fig. 4c. Also, new suppliers are developed for necessary backup in peak seasons. In addition to cost and technical factors, vendors of proximity are given priority to ensure continuity of product line and maintain Just-in-time system.

Step 4: Leanise upstream from Decouping Point: pre-defined

Step 5: Optimise LASC. After designing the product and selecting the supplier, the issue returns to the classic problem of SC design. The objective is to identify the optimal configuration of AA's LASC, which stays at the lowest cost in Eq. (1). The difference of this case is the coexistence of two flows of products. Particularly, Lean products are manufactured at the factory and delivered directly to the customers, while the Agile components are stocked in DC and assembled to finished goods on orders. The partial data of sketch LA SC is listed in Table 2.

Table 2: Partial information of LA SC

Products	Demand	A5	B1	B4	C1	D1	E1	H1
P1	1000	4000	2000	0	2000	1000	3000	1000
P2	2000	8000	0	0	2000	2000	0	2000
P3	4000	16000	0	0	12000	0	4000	4000
P4	3000	12000	0	3000	3000	3000	0	3000
P5 (4A5-2B1-1C1-1H1)	95	380	190	0	95	0	0	95
P6 (4A5-2C1-1D1-3E1-1H1)	200	800	0	0	400	200	600	200
P7 (4A5-3C1-3E1-1H1)	300	1200	0	0	900	0	900	300
Total	**10595**	**42380**	**2190**	**3000**	**20395**	**6200**	**8500**	**10595**
Raw unit cost		8.5	6.2	7.5	12.1	3.6	2.3	9.4
Transportation cost from Sup. to Plant		0.8	0.3	0.5	0.6	0.7	0.8	0.4

Operation Fix cost				
	D1	D2	D3	D4
P5	120	130	125	120
P6	180	190	170	160
P7	210	220	190	180
Operation Variable cost				
	D1	D2	D3	D4
P5	1.2	1.3	1.25	1.2
P6	1.8	1.9	1.7	1.6
P7	2.1	2.2	1.9	1.8

Using given data in specific case of redesigning AA (Installation Cost = 0) with one plant (j=1) the Eq. (1) yields:

$$Z = 844{,}511.5 + \sum_1 \sum_4 \sum_{Am} T_{jkAm}\, x_{jkpAc}\, x_{jk} + \sum_4 \sum_5 \sum_{Ap} T_{koAp}\, x_{koAp}\, x_{ko} + \sum_1 V_{jAm} q_{jAc} x_j + \sum_5 V_{kAp} q_{kAp} x_k + \sum_5 \left(\sum_3 \left(\frac{r_{kAcAVG_{kAc}}}{2} + z_{kAc} STD_{kAc} \sqrt{r_{kAc} + L_{kAc}}\right)\right) \quad (10)$$

Solutions: Candidate DC2 is excluded. The optimal configuration of LA SC is obtained as depicted in Fig 5 with TC LA SC cost stays at: $853.265,00. It is noted that the costs generated by Aglie products are small because their quantities account for a small proportion of the product family.

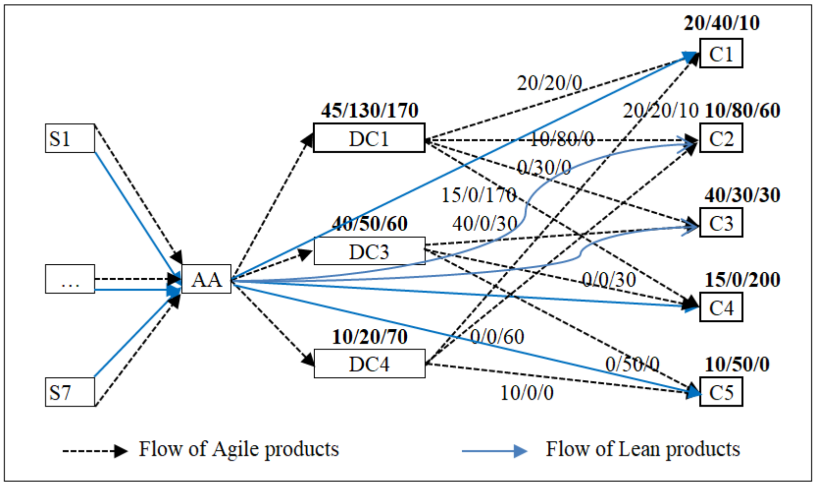

Figure 5. Optimal AA LA SC structure

5. Discussion and Conclusion

This article presents a new framework to optimise the design of LASC. Opposite to the idea from (Christopher and Towill (2001)), findings from this research show that Lean strategy can be a very good foundation for LASC development. The key factor for that success lies at generating the conformation between product family design and LASC design. This framework has fulfilled two research gaps identified before by taking into account the design of the product architecture into a LASC quantitative design. The article also presented the new concept of LA BOM and the procedure to create it. It may be very useful for designers in reality.

However, there are some other obstacles that need careful attention when designing and pursuing LA SC:

- The problem of quality homogeneity of products from different suppliers
- The problem of optimising assembly stations for dynamic schedule
- Optimal inventory levels at decoupling points.
- The necessary of flexible transportation system to support the logistics postponement
- The problem of enhancing the forecasting ability
- The information of customer demand must be updated continuously to timely reflect the quantity of agile inventory at the decoupling point.

There are still plenty of rooms for future studies in this field. For instance, scholars could conduct their research on LA SCD for multi-families product or on designing LASC, while considering reliability and resilience in the risk environment. Researchers also would try to use multi-decoupling points to amplify the agility of LASC.

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Biographies

Thi Hong Dang Nguyen is PhD student of Mechanical/ Manufacturing Engineering Department, École de technologie supérieure (ÉTS), Univesité de Québec, Canada. She earned B.S. in Electrical and Electronic Department, MBA in School of Industrial Management from Ho Chi Minh City University of Technology, Vietnam. She worked in industry for seven years and used to be lecturer at School of Industrial Management from Ho Chi Minh City University of Technology for five years. Her research interests include Lean supply chain design, optimization and hybrid meta-heuristics.

Thien My Dao is an expert in the study of manufacturing systems, reliability, and maintenance. His areas of focus include computer-assisted design, and the implementation and management of manufacturing systems. His development and research activities include research applied to performance analysis and reliability, optimal design/management of manufacturing systems through simulation, the neural systems approach, the evolutionary approach, fuzzy logic, and using the "cellular/just-in-time production" concept. Professor Dao has worked in industry for four years.