The Optimization of the Lean Supply Chain Management Using Meta-Heuristic Approach

by

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L'optimisation de la gestion de la chaîne d'approvisionnement épurée à l'aide de l'approche métaheuristique

Thi Hong Dang NGUYEN

RÉSUMÉ

Depuis le début des années 1990, la gestion épurée (le Lean Manufacturing—LM) a reçu une considérable attention par des chercheurs et des professionnels manufacturiers grâce au succès reconnu de Toyota. Voyant les fruits du fondateur de LM, les entrepreneurs tentaient d'appliquer LM au sein de l'entreprise et ainsi qu'à la chaîne d'approvisionnement (LSC). Au fil du temps, la gestion de la chaîne d'approvisionnement épuré (LSCM) est considérée comme le modèle idéal permettant aux entreprises d'obtenir des avantages concurrentiels et de se protéger contre les menaces. Inspiré de cela, la présente thèse intitulée «*L'optimisation de la gestion de la chaîne d'approvisionnement épuré à l'aide de l'approche métaheuristique*», qui étudie les possibilités d'améliorer les performances des LSCM en résolvant les problèmes de ce domaine de manière optimale. La thèse est développée sur la base des résultats de quatre articles menés dans LSCM à ce sujet.

La thèse commence par une revue systématique des domaines les plus pertinents pour la LSCM afin de définir la fondation qui orientera ainsi la direction de la recherche. À partir de ces bases, la thèse introduit ensuite un nouveau cadre quantitatif de la conception de la LSC. Ce travail applique le filtre double LM afin d'éliminer les gaspillages sur la fonction et la structure de la SC. Le problème est illustré par un exemple numérique et résolu par la priorité algorithme génétique métaheuristique (l'Annexe I, p.161).

Dans le développement de LSCM, à partir du paradigme épuré, elle a été intégrée au modèle agile via un point de découplage pour former la chaîne d'approvisionnement leagile (LA SC). Cette LA SC hybride est largement considérée comme le modèle avancé et intelligent du management moderne. Suite à cette progression, la thèse crée le concept de la nomenclature leagile (LA BOM) pour placer l'agilité dans le nouveau LSC ci-dessus. Dans cette nomenclature LA, les outils LM sont utilisés pour simplifier la structure d'une famille de produits et pour amplifier la combinaison de composants. La conception de la famille de produits à travers LA BOM et son LA SC est menée et optimisée simultanément. La conception conjointe prend en compte l'emplacement des points de découplage pour définir la meilleure configuration de la chaîne et son affectation de produit. Le cadre est illustré par une étude de cas dans l'industrie du meuble et résolu par algorithme génétique métaheuristique. Le cadre est validé en le comparant à LINGO.

À l'ère de la globalisation, les facilités de la LSC peuvent être développées dans différentes régions afin d'atteindre des résultats économiques. Pour réduire les coûts, les usines ont souvent tendance à prioriser le réseau des fournisseurs locaux, regroupé au sein d'un groupement de livraison de lait (milk-run delivery ou milk-run) dans une région peu étendue.

Gardant ces faits à l'esprit, cette thèse utilise l'étude de cas susmentionnée LA SC pour construire un réseau de leagile resilient green (LARG). Il vise à gagner simultanément une multitude d'avantages comme la réduction des coûts, la réactivité et la valorisation de leur image environnementale tout en améliorant la résilience aux risques perturbateurs. Pour atteindre cet objectif, la thèse se concentre à la fois sur les étapes de conception et de gestion. Dans la conception du produit, elle ajoute le facteur vert en intégrant la mention LA BOM. Ensuite, pour améliorer la résilience du système aux menaces, l'inventaire et deux pratiques rigoureuses, « l'approvisionnement à double sources » et la « fiabilité du fournisseur » sont utilisées dans la sélection des fournisseurs. La pratique épurée verte est également appliquée à travers la mise en œuvre de la livraison de lait dans le réseau d'approvisionnement. Ces travaux sont formulés dans un modèle mathématique à deux objectifs dans le but de minimiser le coût d'achat ainsi que la valeur « perte sur objectif » (miss-the-target) des fournisseurs. Au stade de la gestion, deux mesures rigoureuses, à savoir la « réserve de capacité » et la « capacité excédentaire du fournisseur », sont utilisées. De plus, la thèse partage une pratique rigoureuse de la « règle 70/30 » qui s'applique actuellement dans l'étude de cas ci-dessus.

La problématique rencontrée dans l'étape de conception est optimisée par la programmation d'objectifs pondérés. Cependant confronté à la nature complexe de la livraison de lait, le problème NP-complet est difficile à optimiser par la méthode exacte. Il inspire la thèse pour implémenter une approche méta-heuristique. Plus précisément, la thèse tente de développer une nouvelle méta-heuristique hybride (HMH), à savoir HAT, qui est hybridée à partir des deux méta-heuristiques optimisation des colonies de fourmis (Ant Colony Optimation—ACO)-recherche tabou (Tabu Search—TS). La HAT est testée dans une étude de cas sur la livraison de lait à travers un LSC automobile de petite taille qui a été résolue par ACO.

La thèse qualifie également la HAT dans des livraisons de lait à grande échelle par des données aléatoires en le comparant avec ACO, TS et LINGO. Dans le premier cas, la HAT se révèle supérieure aux résultats originaux bien qu'elle n'ait pas encore atteint son résultat optimal. Dans ce dernier, les solutions de la HAT sont assez prometteuses lorsqu'elle dépasse à la fois celles d'ACO et de TS pour la qualité de recherche et surpasse LINGO au moment du temps de traitement. À partir de ces résultats prometteurs, la thèse propose une nouvelle méthode pour optimiser le problème de livraison de lait, qui utilise l'approche exacte pour les petites structures et la HAT pour des livraisons de lait de grande taille. Enfin, cette HMH HAT est appliquée pour optimiser le modèle LARG proposé. Les solutions démontrent comment l'entreprise réelle peut développer simultanément le lean, l'agile, le vert et la résilience dans la réalité.

Mots-clés: chaîne d'approvisionnement épuré, chaîne d'approvisionnement leagile, chaîne d'approvisionnement leagile vert résilient, gestion de la chaîne d'approvisionnement, conception de la chaîne d'approvisionnement, nomenclature leagile, conception de la famille de produits, hybride métaheuristique optimisation des colonies de fourmis-recherche tabou, optimisation, livraison de lait.

The Optimization of the Lean Supply Chain Management Using Meta-Heuristic Approach

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ABSTRACT

Since the early 1990s, Lean Manufacturing (LM) has received worldwide attention from both scholars and practitioners due to the tremendous success of Toyota. Witnessing the fruitage of LM's founder, enterprises have been attempting to implement LM within the factory and then the supply chain (SC) under the form of lean supply chain (LSC). Over time, lean supply chain management (LSCM) is now being considered as the ideal model for companies to gain competitive advantages and also hedge against threats. Inspired by this, the thesis here entitled "*The optimization of the lean supply chain management using meta-heuristic approach,*" studies the opportunities of improving the performance of LSCM through solving its problems in an optimal manner. The thesis is developed based on the findings from four articles conducted in this field.

The thesis begins with a systematic review of the most relevant areas from LSCM in order to build up the necessary background, thereby orienting the research direction. Ensuing these bases, a novel quantitative framework of optimizing the design of pure LSC is introduced. This work applies LM as a dual filter to eliminate waste on both SC function and SC structure. The problem is illustrated through a numerical example and solved by priority Genetic Algorithm meta-heuristic (APPENDIX I, p.161).

In the development of LSCM, the lean model was integrated with an agile paradigm through a decoupling point to form the leagile supply chain (LA SC). This hybrid SC was widely evaluated as the most advanced and intelligent model in modern management. Following this progression, the thesis coins the concept of leagile bill of material (LA BOM) to add agility into the above new-designed LSC. In this LA BOM, LM tools are employed to simplify the structure of a product family and to amplify the combination of components. The joint design of the product family through LA BOM and its LA SC is conducted and optimized simultaneously. The joint design also takes into account the placement of decoupling points to define the best configuration of the chain and its product allocation. The framework is illustrated by a case study in the furniture industry and solved by Genetic Algorithm MH. The framework is validated by comparing it with the exact solver LINGO.

In an era of globalization, SC facilities may scatter in different regions to meet business goals. To save costs, the plants tend to select local suppliers who are aggregated into the milk-run delivery (or milk-run) within a relatively narrow region. Bearing in mind the facts, this thesis uses the aforementioned LA SC in case study to build up a leagile resilient green (LARG) SC. It aims at contemporaneously gaining a raft of benefits of cost reductions, responsiveness, and environmental reputation, while improving resilience to disruptive risks.

To attain this goal, this work focuses on both design and management stages. In product design, the thesis adds the green factor in the mentioned LA BOM. Next, to enhance the system's resilience to threats, besides inventory, two resilient practices—'dual sourcing' and 'supplier's reliability'—are employed in the supplier selection. The lean-green practice is also applied through the implementation of 'milk-run delivery' in the sourcing network. These works are formulated into a bi-objectives mathematical model with the objective of minimizing the total purchasing cost as well as the 'Miss-the-Target' value of suppliers. In the management stage, two robust measures namely 'capacity reserve' and 'surplus capacity of supplier', are employed. Moreover, the thesis shares one practical robust practice, the so-called 70/30 rule, which is currently applied in the above case study.

Here, the problem in the design step is optimized by weighted goal programming. However, it confronts the complex nature of the milk-run, the NP-complete problem, which is hard to optimize by the exact method. This has inspired the thesis to implement a meta-heuristic approach. Specifically, the thesis tries to develop a novel hybrid meta-heuristic (HMH), namely HAT, which is hybridized from the two meta-heuristics of Ant Colony Optimization (ACO) and Tabu Search (TS). HAT is tested in one milk-run case study of a small-sized automobile LSC, which was solved by ACO. The thesis also qualifies the HAT in large-scale milk-runs through random data by comparing it with ACO, TS and LINGO. In the former, HAT proves superior to the original results although it has yet to reach the global optimum. In the latter, the HAT's solution is quite promising when it surpasses both those of ACO and TS on quality search and outperforms LINGO at processing time. From such promising results, the thesis proposes a new method to optimize the milk-run delivery problem, which uses exact method for small cases and HAT for large milk-runs. Finally, this HMH HAT is applied to optimize the proposed LARG SCD. The solutions demonstrate how a real company can simultaneously develop LARG model in reality.

Keywords: Lean supply chain, leagile supply chain, leagile resilient green supply chain, supply chain management, supply chain design, leagile bill of material, product family design, hybrid meta-heuristic Ant Colony Optimization-Tabu Search, optimization, milk-run.

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AM	Agile Manufacturing
ASC	Agile Supply Chain
BIP	Binary Integer Programming
BOM	Bill-of-Material
CE	Carbon Emission
DC	Distribution Centre
DP	Decoupling Point
ECF	Embodied Carbon Footprints
FSC	Forest Stewardship Council
GA	Genetic Algorithm
GSC	Green Supply Chain
GSCM	Green Supply Chain Management
HAT	Hybrid Ant Colony Optimization–Tabu Search
HMH	Hybrid Meta-Heuristic
JIT	Just-in-Time
KPI	Key Performance Indicator
LA	Leagile
LARG	Lean Agile Resilient Green
LM	Lean Manufacturing
LSC	Lean Supply Chain
LSCD	Lean Supply Chain Design
LSCM	Lean Supply Chain Management
MH	Meta-Heuristic
MIP	Mixed Integer Linear Programming
MIP	Mixed Integer Programming
MTO	Make to Order
MTS	Make to Stock

MtT	Miss-to-Target
OB	Objective Function
PFD	Product Family Design
pGA	propriety Genetic Algorithm
PSO	Particle Swam Optimization
R&D	Research and development
RQ	Research Question
RSC	Resilient Supply Chain
RSCM	Resilient Supply Chain Management
SA	Simulated Annealing
SKU	Stock Keeping Unit
SC	Supply Chain
SCD	Supply Chain Design
SCE	Supply Chain Execution
SCM	Supply Chain Management
SCO	Supply Chain Optimization
SCOP	Supply Chain Outline Process
SCP	Supply Chain Performance
SSC	Sustainable Supply Chain
SSCM	Sustainable Supply Chain Management
TC	Total Cost
TIM WOOD	**T**ransportation, **I**nventory, **M**ovements, **W**aiting, **O**ver-processing **O**verproduction, and **D**efect
TO	Thesis Objective
TSP	Travelling Salesman Problem
TPS	Toyota Production System
TS	Tabu Search
WGP	Weight Goal Programming

INTRODUCTION

This section consists of six main sections. The first part provides the general context of lean supply chain management (LSCM). The second session presents opportunities in this domain before the next one addresses the problem statement. Afterwards, the fourth portion defines the thesis objectives (TO) followed by the fifth section which draws the thesis outline. The final section dedicates the thesis' contributions.

General Context

Supply chain (SC) is an attractive topic as today's business competition is among SCs rather than individual companies (U. Paschal, E. Jon, & L. Jostein, 2012a). According to Stadtler & Kilger (2011), the term 'SC' was first coined in 1982 by Oliver and Webber as a "*network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.*" Robinson (2015) recalled that SC has been publicly recognized since the mid-1990s when Chinese manufacturing quickly grew to serve the US market. Mentzer *et al.* (2001) defined supply chain management (SCM) as "*the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the SC for the purposes of improving the long-term performance of the individual companies and the SC as a whole*".

Certain SCM models exist in which the lean supply chain (LSC) attracts a lot of interest from researchers as well as practitioners. One SC is considered as an LSC when "*Lean manufacturing (LM) is implemented across the entire SC."* (Paschal *et al.*, 2012a) LM was known as the Toyota Production System (TPS), developed by Taiichi Ōno, over 25 years on the shop floor of Toyota since 1948. LM was broadly introduced by Womack, Jones, & Roos (1991) in the famous book, *The Machine That Changed The World.* The book compares the automotive assembly plants in Japan, the USA and Europe, thereby emphasizing the benefits that Toyota gains when implementing LM: eliminating waste and reducing costs with only "*half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time.*" From manufacturing, LM's implementation extended to SC. As Shah & Ward (2003) noted, LSC creates a streamlined, highly efficient system, which produces finished goods keeping pace with customer demand, with little to no waste. Recently, the rampant increase in cheap Chinese products has made business competition fiercer. Consequently, enterprises must constantly cut costs while maintaining or increasing products' quality. This affirms the important role of LSC in today's business.

Opportunities for Lean Supply Chain

LM eventually became the standard for systematic productivity and quality improvement (Pearce & Pons, 2012). The huge success of Toyota has inspired numerous researchers' entry into this field. The studies of LM adoption in SC began in 1997, at the onset of the Asian financial crisis in hopes that LM might efficiently deal with the difficult situation. After the Great Recession in 2008, the attention towards LSC resurged (Cudney & Elrod, 2011) as Singh (2009) believed that "*Lean can be a survival strategy during recessionary times.*" Thus, after the crisis, LSC was appreciated as an "*ideal SC*" (Srinivasan, 2012).

Since China joined the World Trade Organization (WTO), enterprises witnessed a new era of stiff competition from the knockoff Chinese goods. The waves of cheap Chinese products killed numerous domestic manufacturers in various industries worldwide. For instance, Gerd, general director of European Aluminium, admitted that "*Chinese dumping a 'slow death' for European industry.*" (James, 2015) The same calamitous situation happened in America. In his book "*Death by China: Confronting the Dragon*", Navarro (2011) had statistics that millions of jobs in the U.S. had been lost. He illustrated that "*textile jobs alone were beaten down by 70%,*" apparel and furniture "*have shrunk to half their size*" (p. 2), and "*other critical industries like chemicals, paper, steel and tyres are under similar siege . . . employment in high-tech industries has plummeted by more than 40%*" (p. 3).

The competitive pressure on manufacturers became more intense when e-commerce became global. From the platform of e-markets, customers can easily compare the prices of different producers. Based on the investigation of Forbes magazine, after Amazon boosted its supply from Chinese suppliers in 2015, the excessive number of small American producers had their products ripped off on Amazon.com. The reason postulated was that their high quality but high price goods were not fairly competitive with shoddy cheap and counterfeit Chinese products (Wade, 2017). This tendency puts righteous manufacturers under unprecedented competition in cutting costs while diversifying products and maintaining quality.

To confront these critical situations, Navarro (2011) suggested the U.S. government to immediately implement counter-attack strategies. Besides, DeLisle & Goldstein (2017) recommended U.S. enterprises to master LM. According to them, LM is "*not just a fundamental example of innovation, but also a core managerial and operational competency*." They believed that China had developed its own paradigm, a "pro-manufacturing" equivalent to lean—from which U.S. companies should learn —to support the rapid economic development.

Today, businesses must not only prepare to face such tough competition but may also suffer the next global economic recession or crisis in 2020 as many symptoms have already begun to appear (Graham, 2018). This may be a favorable opportunity for LSCM.

Opportunities for Leagile Supply Chain

Although the benefits of LSC are undeniable, its shortcomings are also well-noted. Chantarachalee, Carvalho, & Cruz-Machado (2014) stressed that LSC lacks external responsiveness to customer demands, which requires flexibility in product design. Similarly, Banomyong & Supatn (2004) doubted that LSC "*itself does not guarantee a response to the flexibility of demand.*"

In the early 1990s, the U.S. launched its reaction to the rapid growth of Japanese industry. Agile Manufacturing (AM) was built up as the counterpart of LM. Opposite to the mentioned weakness of LM, AM has the "*capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets.*" (Angappa, 1998) As mentioned by Richards (1996), the modern view considers agile supply chain (ASC) as a substitute to leanness. Yet, AM's weakness of significant cost was soon revealed. Thus, Mason-Jones, Naylor, & Towill (2000) prospected that "*once leanness has been achieved, the SC must fight for agility"* as "*pure leanness and agility can seldom be found in real-world problems*" (Kisperska-Moron & De Haan, 2011).

To take advantage of the two models, while reducing the disadvantages from each, Naylor, Naim, & Berry (1999) introduced the Leagile (LA) paradigm which combined lean and agile through decoupling points (DP). The new model created a management revolution in making it competitive and more profitable (Madhani, 2017). Boschi, Borin, & Batocchio (2011) specified that concurrent engineering in LA SCM generates the joint development of products and services to respond to market demand. The exemplar of the LA model is also Toyota, the cradle of LM. For instance, Cherise (2017) compared car brands and found that just in that year, Toyota offered a wide variety of hybrid vehicles in higher quality than Ford with eight line-up hybrid cars, while Ford introduced just four. In particular, even the lowest-ranked hybrid of Toyota, the Prius c, still better than other competitors. Thus, it might be a big challenge for businesses to compete with Toyota, the LA flagship.

Opportunities for Leagile Resilient Green Supply Chain

Notably, LSC was evaluated as a high-risk sensitive system and perhaps even dangerous (Guy & Jennifer, 2013). Purvis, Spall, Naim, & Spiegler (2016) asserted the common belief that the pursuit of cost reduction through LM implementation in a 'boom' period resulted in economic pains in 2007 and made SC lack resilience and too fragile. Although LA SC can cover some shortages of lean and agile models, it still has two fatal weaknesses of lean while keeping very few, or zero inventory upstream of the DP. First, it bears the risk of disruption from uncertainties; and second, it is difficult to recover once disrupted. As a result, the leaner it is the more vulnerable it is to risks (Christopher & Peck, 2004a).

Taha, Abdallah, Sadek, El-Kharbotly, & Afia (2014) realized the increasing research awareness of risk and uncertainty in SC in the past 20 years resulting from the trend of LM applications. Besides, the rising frequency of billion-dollar disaster events from 1980 to 2016 has caused massive SC disruptions worldwide (Smith, 2018). As the rearrangement and recovery costs in disrupted lean systems were very expensive (Garcia-Herreros, Wassick, & Grossmann, 2014) Also, Kim *et al.* (2004) advised enterprises and SCs to develop the responding capacity to risk and uncertainty through robustness and resilience.

Recently, environmental issues have become one of the current topics of discussion. Enterprises have experienced an increase in environmental awareness (Kawitkar, 2013) from consumers, communities and governments. The study expressed the change of customers' purchasing behaviour through a survey in the 90s, in which up to 83% of respondents preferred to buy environmentally safer products. Besides, some international organizations such as the United Nations Framework Convention on Climate Change (UNFCCC) hold annual Conference of the Parties (COP) to seek commitments from nations to protect the environment. For instance, COP 22 in 2016 provided measures to reduce greenhouse emissions and utilize low-carbon energy sources. In Canada, the government has set a target of reducing Canada's total greenhouse gas emissions by 17% by 2020 relative to 2005 emission levels (https://www.ec.gc.ca). Driven under such intense pressure, companies now attempt to adjust their activities to an environmentally responsible manner like the introduction of green products (Kawitkar, 2013).

Presently, businesses must compete not only on pricing, but also on the ability of customization while bearing an environmentally conscious image and self-protecting from threats. Reaching the first two goals is the main work of LA strategies, while attaining the third task is functioned through the green strategy on SC. Generally, green supply chain (GSC*) "strives for minimal environmental impact"* by *"managing the product after its useful* *life while helping the environment."* (Jain & Sharma, 2014) It is an increasingly discussed topic nowadays (Amirbagheri, Núñez-Carballosa, Guitart-Tarrés, & Merigó, 2019). GSC practices reap the rewards from both environmental and cost performances (Cousins, Lawson, Petersen, & Fugate, 2019) and can be integrated with lean under the supporting, and synergistic categories (Ciccullo, Pero, Caridi, Gosling, & Purvis, 2018).

Nowadays, there is an increasing tendency of the integrating four paradigms: lean, agile, resilience and green (LARG), into a hybrid SC to take advantage of them (Akbarzadeh, Safaei, Madhoushi, & Aghajani, 2019). The LARG model was first introduced in 2009 by Carvalho & Machado (2009), and several years later Akbarzadeh *et al.* (2019) pointed out that LARG SCM was an appropriate approach for confronting the challenges of today's turbulent and uncertain environments. They also stated that this field still contains many uncovered gaps. Combined from the four advanced management models, LARG SC is expected to have the capacity of coping with the problems of the dairy industry: "*more efficiency in order to produce lower-cost products, quick response to customers' diversified demands, reduce disruption and risks in supply, produce and distribute perishable products, and also produce organic products with environment-friendly packaging and so on*" (Pieter van Donk, Akkerman, and Van der Vaart (2008).

Opportunities for Optimization by Meta-Heuristic Approach

According to Melo, Nickel, & Saldanha-da-Gama (2008a), the solution method for SCM problems consists of two main categories: 1.) *exact solution,* and 2.) *heuristics*. The former has been studied and used long before the latter became popular. A heuristic is *"any approach to problem solving or self-discovery that employs a practical method, not guaranteed to be optimal, perfect, logical, or rational, but instead sufficient for reaching an immediate goal."* (https://en.wikipedia.org/wiki/Heuristic) Developed from heuristics, *meta-heuristic (MH)* is a "*higher-level procedure or heuristic designed to find, generate, or select a heuristic (partial search algorithm) that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited* *computation capacity."* (Balamurugan, Natarajan, & Premalatha, 2015) The advantage of MHs over heuristics is that they ''*perform a much more thorough search of the solution space, allowing inferior and sometimes infeasible moves, as well as re-combinations of solutions to create new ones."* (Jiang, Huang, & Wang, 2010) Tiwari, Raghavendra, Agrawal, & Goyal (2010) saw the growing tendency of using MH for complex SCM problems. In those cases, where a global optimum cannot be found by exact methods, MH can offer the two benefits of: 1.) providing acceptably good solutions, and 2.) consuming relatively little processing time (Griffis, Bell, & Closs, 2012).

These advantages of MH are proved in solving the famous problem of SCM, the *Travelling Salesman Problem* (TSP). In TSP, a salesman travels make a round tour throughout a number of defined cities in doing his business. He has to choose the best route to optimize the travelling distance, cost and time. The problem was classified as an NP-complete problem (''*the deterministic polynomial time problem, where each input to the problem should be associated with a set of solutions of polynomial length, whose validity can be tested quickly in polynomial time",* (Wikipedia.com). In 2001, one TSP of 15,112 cities was solved by an exact solution, namely the cutting-plane method, on 110 Alpha processors of 500 MHz. The total computation time was around 22.6 years for each processor (David, Robert, Vašek, William, & Keld, 2004). Then, Rego, Gamboa, Glover, & Osterman (2011) found that the heuristic approach could quickly define and yield good solutions (just 2–3% away from the optimal solution) even for an extremely large TSP with a million nodes.

As MH can deal with some large, complex and nonlinear-natured problems, it became a preferred method to manage complex real-world cases (Griffis *et al.*, 2012). Some MHs surpass even certain optimization softwares like CPLEX, as shown in the study of Miao, Yang, Fu, & Xu (2012), or LINGO, from Fathian, Jouzdani, Heydari, & Makui (2018), in solving SCM problems. So far, up to 80 different MHs have been introduced in which more than thirty MHs have been applied to solve problems in SCM (APPENDIX II, p.175).

From MH, a number of HMH were developed recently, which combine a single MH with various algorithmic components of other optimization techniques (Blum, Puchinger, Raidl, & Roli, 2011). These authors enumerated five basic ways to create HMH, which combine one MH with: 1.) another MH, 2.) a constraint programming, 3.) tree search techniques, 4.) a problem relaxation, and 5.) dynamic programming. Based on the research of this thesis, there are more than 20 types of HMH used in SCM so far. The superiority of these HMHs to original MHs or other algorithms is proved in almost all studies. For instance, the HMH of Simulated Annealing (SA) and Mutation Operator is more efficient than SA in optimizing the capacitated location-routing problem (Golozari, Jafari, & Amiri, 2013); or HMH of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) outperforms GA in determining consignment inventory strategy for a vendor and multiple buyers (Molamohamadi, Sharifyazdi, Arshizadeh, Jafari, & Ismail, 2013b).

Today, the problems in SC are more complex in the globalization context. The corresponding solving techniques are also developed with a greater number of new MHs and numerous novel HMHs formulated through various procedures. The success of MH and HMH in solving such realistic problems of SCM opens up many new opportunities in this domain.

Problem Statement

These mentioned opportunities are partly in line with the SCM review from the study of Asgari, Nikbakhsh, Hill, & Farahani (2016). They conducted one bibliometric analysis on SCM from 1982 to 2016 on over 40,000 articles and books and took a snapshot of SCM development with the main current research level of SCM being highlighted below.

- *Risk management*, sustainability, global SC and *safety issues* (to deal with business uncertainty) have the strongest growth in this period. On the contrary, scheduling in SCM is the only domain that received a strong decline.
- *Supply chain design (SCD), supply chain performance (SCP)*, SC implementation, SC coordination, negotiation, dynamics, and humanitarian logistics gained only a slight growth.

- *Quantitative tools and techniques* are commonly used in SCM. Among them, *optimization*, simulation and fuzzy theory tools and techniques are used most often. *Multi-objective optimization* techniques are beginning to be implemented.
- The most common SCM tools and techniques used in SCM are *Lean, Agility, JIT,* Coordination and Synchronization, *Robustness, Make to order (MTO)*, Stability, *Postponement***,** Reliability, Vendor-Managed Inventory.
- Food, energy, and automotive industries accounted for the largest proportion of studied industries followed by agricultural, retail, and chemicals.

These authors gave some suggestions for future research, which should investigate more on the problems of:

- Security, *sourcing*, sustainability, competition, and human behaviour.
- *Risk and disruption management*, disaster and humanitarian efforts.
- Healthcare, *small and medium-sized enterprises***.**
- Developing educational programs on SCM-related issues especially though relevant success stories and *case studies.*

The mentioned opportunities and suggestions given in the study of Asgari *et al.* (2016) have prompted the development of this thesis titled "*The optimization of the lean supply chain management using meta-heuristic approach.*" It attempts to bridge the research gaps in LSCM presented in Chapter 1 by satisfactorily answering research questions (RQ) below.

The first RQ is addressed to shed light on the current research level of LSCM. The necessary supporting background which orients the thesis direction is identified in the efforts of profoundly responding to this RQ. It covers a systematic review of the most related areas of this field with milestone findings, research gaps and research trends. It is:

- [RQ1] What is the state-of-the-art LCSM and its possible tendencies?

After attempting to settle the RQ1 as presented in the literature review, the thesis begins to design LSC. SCD is considered one of the most important tasks of SCM because it facilitates an essential platform for the SC's activities thereon. The SC's structure, shaped in the design stage, influences the SCP directly. Thus, if the LSC is designed at a very early stage of LSCM rather than in the execution stage, it could provide these advantages long term due to optimal decisions taken in SCD stage. Developed from the research gap of LSC (p.75), the question is posed as:

- [RQ2] How to design LSC in quantitative approach?

The next step takes place following the advice of Mason-Jones *et al.* (2000) that when lean is established, an enterprise should develop agility. By transforming the LSC into LA SC, an enterprise expands its product range thereby better responding to the larger market. The third RQ is driven from this context as well as from research gaps in the field of LA SC (p.76), which indicates the lack of product family design (PFD) in LA SCD:

- [RQ3] How to design the LA SC while concurring PFD?

After responding to RQ3, the thesis identifies ways to integrate green factors in the system and employs contingency measures to protect the LA system from disruptive risk. At this step, the enterprise focuses on creating more competitive advantages towards larger markets with an environmentally friendly image while protecting the business from new threats. Thus, the thesis draws the roadmap to build up the LARG SC. The initial effort must take place on the scope of the supply side where the suppliers are selected in the satellite network in a small region and consolidated in one milk-run. In this case, green elements are implemented in product design and also in logistics while resilient practices are added in SCD and supply chain execution (SCE).

To solve these problems in an optimal manner, this thesis confronts the complex nature of the milk-run in the LARG supply side, which bears the same characteristics of the foregoing NP-complete TSP problem. Thus, it refers to prepare a practical solution method using a MH approach, which theoretically is an effective MH or a new practical HMH. Therefore, the fourth RQ can be addressed as:

- [RQ4] What is a suitable solution method that may be used to optimize the milk-run problem for the LARG network?

When the technical problem in RQ4 is fixed, the optimization of the LARG SCD can be resolved. Through answering the following RQ, this work helps partly cover up the research gaps in the LARG SC domain (p.77).

[RQ5] How to design and manage the LARG SC?

Thesis objectives

Realizing the importance of LSCM in current and upcoming businesses, this thesis attempts to find opportunities to optimize LSCM by covering the research gaps presented in Chapter 1 to some extent. From there, it seeks to provide practical and applicable solutions to the industry and suggest certain managing implications. To achieve these, specific objectives have been developed corresponding to the five RQs given above.

To resolve the first RQ, this thesis conducts a systematic literature review on LSCM, which includes some previous important reviews. The review here takes into account the LSCM model in the form of pure and hybrid lean to better understand its development flow. To cope with possible technical obstacles resulting from the complex nature of SCM, this thesis specifically studies the MH approach through a review from a 2012 to 2019 publication (while referencing another paper which summarized the period before 2012). The following TO is set as:

- TO1: Define the research level LSCM and its solution methods and thereby identify its research gaps and research direction.

The objectives TO1 attempt to respond to RQ1 and support the answers to RQ2-5. After defining research gaps and supporting background, the following objective is:

- TO2: Fill the gaps in LSCM given in Chapter 1 by responding to the RQ2.

This step attempts to develop a framework for a pure lean supply chain design (LSCD). From there, the thesis expands the scope to LA SCD with the objective:

- TO3: Partly cover the gaps of LA LSCM as noted in Chapter 1 by answering RQ3.

This work inherits the newly designed LSCD model to develop the procedure of LA SCD by concurring PFD and SCD. In contrast to the previous LA SC studies, this work amplifies the agility of the supply base through the application of LM tools in both PFD and SCD, thereby facilitating the lean platform for product architecture based on current LSC.

The next objective is to implement green and resilience practices into the novel LA model to form to LARG SC. When solving the milk-run problem of the new LARG system, the unanswered question of a desirable solution method still remains. So the objective related to the technical aspects is:

- TO4: To develop the applicative solving method for milk-run in LARG SC.

This objective is established to respond to the technical need existing in the proposed LARG SC. Based on the research gaps in the LARG SC (Chapter 1), the thesis presents the mixed integer programming (MIP) to solve the small-sized milk-run. Also, it proposes a new HMH, which expectedly outperforms the current pure MHs in optimizing the large scale milk-run. The promising significance of the new HMH is that once qualified, it could replace original algorithms in the hybrid to resolve SCM problems assumedly with better quality. Here, the HMH of Ant Colony Optimization (ACO) and Tabu Search (TS), namely HAT, is developed to optimize the milk-run delivery.

With the support of the newly proposed solution method, the problems of the LARG network are tackled, which partly closes the gaps presented in Chapter 1 by clearly answering RQ5. Specifically, the TO in this step is:

- TO5: Develop a framework to optimize the design and management of the LARG SC.

Thesis Outline

The rest of this thesis includes 7 sessions with five main chapters, the conclusion and appendices. The corresponding scope of each part is outlined as shown in Table 0.1.

Table **Erreur ! Utilisez l'onglet Accueil pour appliquer Title au texte que vous souhaitez faire apparaître ici.**.1 The thesis outline

Thesis contents	Scope			
	LSCM	LA SCM	Solution method	LARG SCM
Chapter 1: Literature review	✓	✓	✓	✓
Chapter 2: Research methodology	✓	✓	✓	✓
Chapter 3: New framework to optimize LA SCD		✓		
Chapter 4: New HMH to optimize milk-run delivery			✓	
Chapter 5: New framework to optimize the LARG SCM				✓
Conclusion	✓	✓	✓	✓
Appendices	✓	✓	✓	✓

Research Contributions

This thesis is built up based on four articles published in journals as well as under review:

- Article 1: Nguyen, Thi Hong Dang and Dao, Thien-My. 2017. "*New strategy to optimise lean supply chain design by meta-heuristic.*" American Journal of Engineering and Applied Sciences, vol. 10, n. 1. p. 156-164. It presents a novel framework to design pure LSC using a quantitative approach by applying dual lean filters to eliminate waste on both the SC function and SC structure. It serves as a stepping stone to develop the hybrid LSC in the following steps.
- Article 2: Nguyen, Thi Hong Dang and Dao, Thien My. "*New framework to optimise Leagile supply chain design*." Industrial Engineering and Operations Management, published May, vol. 1, n.1, 2019. This work is partly described in Chapter 3. It extends certain results from the first article when introducing the new procedure to optimize LA SC through concurring PFD and SCD. The work coined the new concept of leagile bill of material (LA BOM) to implement lean to amplify the agility of a product family.

The proposed LA BOM is allocated to the LA SC. The framework is illustrated in one case study in furniture industry and then optimized by GA and validated by LINGO.

- Article 3: Thi Hong Dang Nguyen, Thien My Dao. 2015, "*Supply Chain Milk-run Delivery Optimization.*" The Journal of Management and Engineering Integration, vol. 8. n.1, p 29-38. This article is partly addressed in Chapter 4. It functions as an intermediate buffer in order to find a technical solution for the milk-run problem in the LARG model in the next paper. This work presents the ways to optimize small-sized milk-runs by MIP. It also develops a new HMH HAT from ACO and TS to optimize the milk-run in large scales. The novel techniques are qualified through the case study of a small-sized milk-run in an automobile SC, which was solved by ACO. Realizing that ACO did not offer the global optimum, this paper uses mixed-integer programming (MIP) to resolve the problem of defining the best solutions. The HAT is superior to ACO in the original case; it also surpasses ACO and TS in terms of quality search and LINGO in processing tiem through a random large scale milk-run. Based on that reference, the article proposes a general procedure to optimize the milk-run by using exact method (small sized) and HAT (large scale). This work also discusses the applicability of the HAT on one branch of the logistics Canadian company in Montréal.
- Article 4: "*New framework to develop LARG supply chain management: a case study*", under the review of the journal International Journal of Logistics Management. The article is extracted in Chapter 5. It inherits the aforementioned framework to develop the LARG SC by integrating green and resilient practices into the aforementioned LA SC model. For the former, it adds green factors like green design and environmentally friendly packaging in design. It also uses the lean-green logistic through milk-run. With the latter, besides inventory, it takes into account the dual sourcing, and the reliability of suppliers through their Miss-to-Target (MtT) values. The design stage is formulated through the bi-objective model of minimizing both purchasing cost and MtT values of supplier candidates. They are solved by weighted goal programming (WGP), with the co-operation of the new HAT. In the execution step, this work implements capacity reserve and surplus capacity of suppliers. The thesis also reveals one robust practice which is currently used in the case study, called the '70/30 rule'.

CHAPTER 1

LITERATURE REVIEW

This chapter summarizes the most relevant supporting background of LSCM (see Figure 1.1). From there, its research gaps are pointed out and discussed to orient the thesis direction.

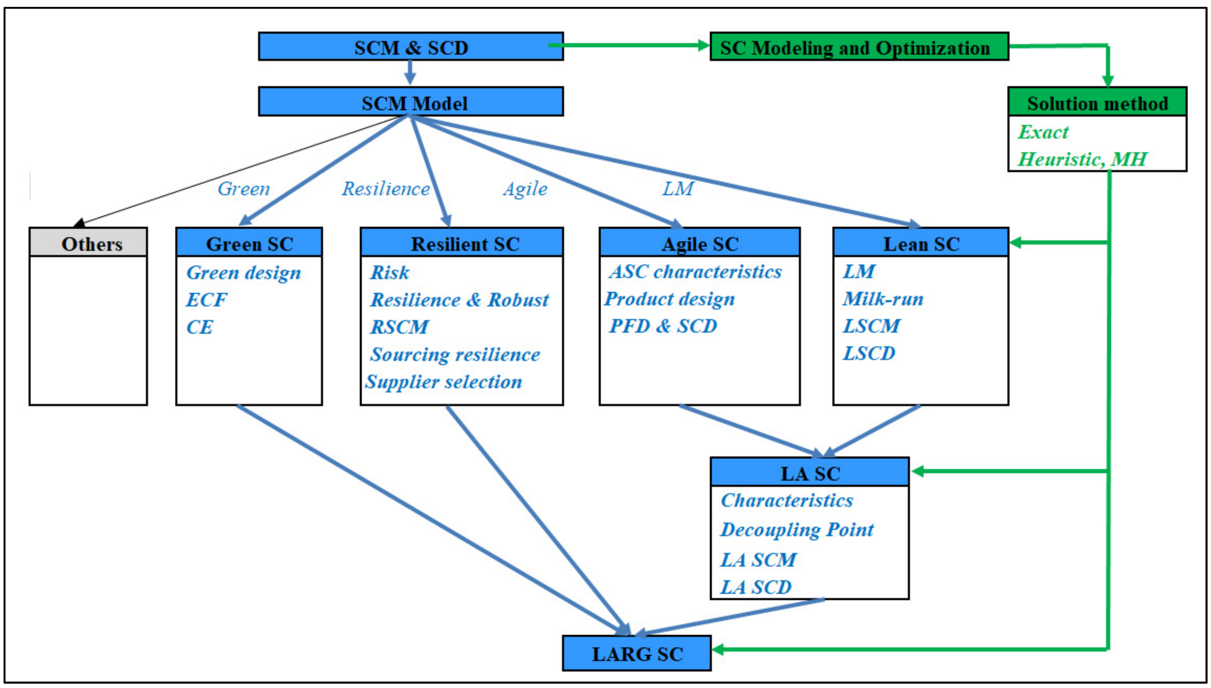

Figure 1.1 The indicators of thesis' supporting background

1.1 Supply Chain Management

SCM is a very popular topic in the field of management (Asgari *et al.*, 2016). Taylor (2003) categorized main activities of SC in the SCM matrix (see Figure 1.2). It aligns three main functions of SC: 1.) supply, 2.) production, and 3.) demand; with three phases: 1.) design (consists of product design and SCD), 2. planning, and 3.) operations. To manage SC properly, Kim *et al.* (2004) proposed to use SC modelling.

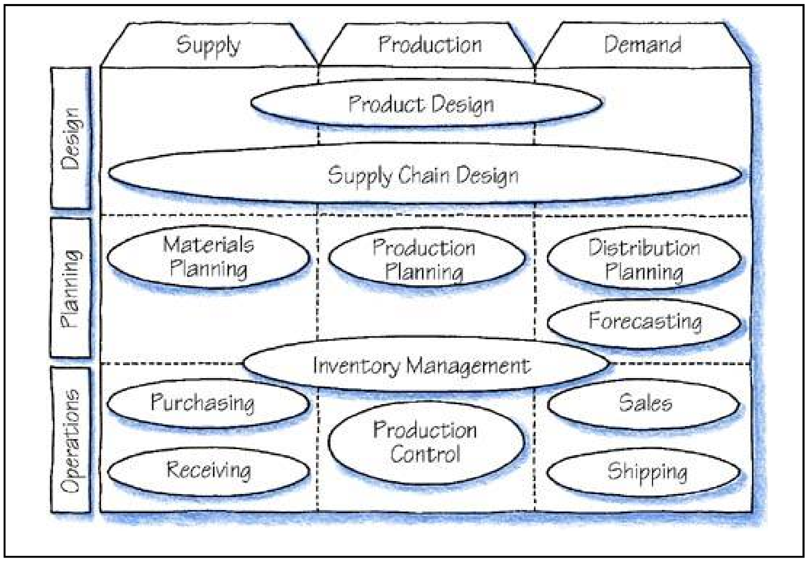

Figure 1.2 SCM matrix
Taken from Taylor (2003)

1.1.1 Supply Chain Modelling

SC modelling is "*a technique typically employed to improve the efficiency of logistical and business processes.*" (Watkins, MacKerrow, & Merritt, 2010) Queirós, Faria, & Almeida (2017) presented two methodologies adopted in modelling and analysis used in scientific research in general, the qualitative and quantitative. According to these authors, the former is "*not concerned with numerical representativeness, but with the deepening of understanding a given problem,"* while the latter "*seeks to obtain accurate and reliable measurements that allow a statistical analysis*." The main difference between qualitative and quantitative methods is that the former consists of words whereas the latter comprises numbers (Atieno, 2009). This author also stated that quantitative research ensures validity through rigorous clarification, definition or the use of pilot experiments. Both have proper pros and cons, yet quantitative research is evaluated as more reliable due to the internal structure of the study and the assessment data produced by standardized testing (Duffy, 1985). Another advantage of quantitative research is it can involve a larger sample (Rahman, 2017).

The study done by Queirós *et al.* (2017) summed up seven qualitative and five quantitative methods, thereby highlighting their key strengths and limitations. Among them, the case study is widely used (Baskarada, 2014), and it can be employed by both qualitative and quantitative research (Gerring, 2004). The case study can offer an "*opportunity for the researcher to gain a deep holistic view of the research problem, and may facilitate describing, understanding and explaining a research problem or situation."* (Baxter & Jack, 2008) As a result, this thesis refers to the quantitative method and case study.

According to Hammami, Frein, & Hadj-Alouane (2008), the principal purpose of SC modelling is to minimize or maximize the objective function of decision making while satisfying conflicting objectives. Thus, they asserted that optimization approaches mainly based on mathematical models are often suggested in SCD.

1.1.2 Optimization Problems in Supply Chain Management

Supply chain optimization (SCO) is one of the prime components for effective SCM (Veluscek, 2016). SCO is evaluated as "*a powerful, practical tool that can improve performance now and position SC for the future.*" (USAID, 2014) As mentioned by Trisna, Marimin, Arkeman, & Sunarti (2016), SCO problems fall into: 1.) SC strategy, 2.) SC type, and 3.) SC designing and planning. Particularly:

- SC strategy: supplier selection, SCD, facility location, selection, risk and disruption mitigation.
- SC type: open loop SC, closed loop SC, and flexible SC (customers can directly purchase products from plants or distribution centers).
- SCD and planning: network design, production, distribution, inventory, capacity planning, and also scheduling.

Sanders (2014) concretized the SCO by applying mathematical and statistical tools to define optimal solutions to SC problems.

1.1.3 Mathematical Formulation Modeling

In the comprehensive review of Trisna *et al.* (2016), SCO's mathematical formulation modelling is classified based on environmental conditions. Specifically:
Certain environments: SC is modelled through a deterministic programming approach like linear programming (LP), integer programming (IP), MIP, non-linear programming (NLP), mixed-integer linear programming (MILP), and mixed-integer non-linear programming (MINLP). Among them, MIP uses integer and real variables. The MIP's weakness lies at "*impossibility of taking into account nonlinear effects; the necessity of considering all the time periods at once; the risk of high-dimensionality of the problem.*" Yet, MIP is widely used due to its striking advantages: "*non-linearity, potential non-convexity, and the large number of variables.*" (Urbanucci, 2018) IP and MIP are used in this thesis.

- Uncertain environments: fuzzy, stochastic programming and robust optimization

Based on the objectives, SCO problems consist of single and multi-objectives. Specifically, multi-objective optimization problems have received an increasing amount of attention in academic literature and publications in recent decades (Trisna *et al.*, 2016). These authors highlighted that it "*has objective function more than one which fulfilled simultaneously and sometimes, there are conflicts among the objectives.*" This thesis adopts deterministic models, both single and multiple objectives.

1.1.4 Optimization Technique

1.1.4.1 Classical method

Solving single objective problems is a subject that has been studied for a long time. To deal with multi-objective problems, Trisna *et al.* (2016) classified the solution method into two categories: the classical method and MH. Some typical methods in the first group are the weighted sum, ε-constraint, weighted metrics, or weighted goal programming (WGP). They transform a multi-objective model to a single objective one by "*optimizing the most important objective and carrying out other objectives as constraints.*" (Trisna *et al.*, 2016)

For instance, in the WGP model, all multi-objective functions are transferred to one objective with the new goal of minimizing the weighted deviation around the goals. To do that, different units from each goal are excluded through percentage normalization. Then, the weight of each deviation objective is assigned based on its importance (Mari, Lee, & Memon, 2014). Today, some exact solvers like LINGO, GAMS, CPLEX or Excel Solver help to effectively solve several optimization problems. In this thesis, WGP is applied to solve the multi-objective model while LINGO is used to qualify the results solved by MH.

1.1.4.2 Meta-Heuristic Method

A heuristic approach is developed in order to overcome obstacles that the exact method confronts, such as large, complex or NP-hard and NP complete problems. Srinivasan (2019) realized that "*most real-world optimization problems belong to the class of NP-hard problems*." The new generation of heuristics, namely MHs, have been introduced in recent years. According to Sabareswari, Sathya, & Sharmila (2017), any MH bears two main elements: 1.) intensification, and 2.) diversification. Particularly:

- Intensification: the capacity of generating diverse solutions to explore throughout the search space (global scale).
- Diversification: the ability to orient the search on local regions to define a current good solution there.

Sabareswari *et al.* (2017) stressed that the combination of the two often helps the algorithm reach the global optimality. Moreover, Srinivasan (2019) evaluated MH as an excellent approach for SCM thanks to its striking advantages, such as it being "*simple, easy to implement, robust and have been proven highly effective to solve hard problems*." By now, there are many different MHs have been introduced (see APPENDIX II, p.175). The application of MH in SCM is briefly reviewed as shown below.

a.) Meta-Heuristics for Supply Chain Management (before 2012)

Up to 2012, Griffis *et al.* (2012) identified the four most used MHs in SCM were GA, TS, ACO and Simulated Annealing (SA). Out of these, GA, TS, ACO, and one GA-based MH, are employed in this thesis. GA is a global search MH that uses techniques inspired by evolutionary biology such as inheritance, mutation, selection and crossovers (Holland, 1992). *TS* is still actively researched and continuing to evolve and improve. The overall TS approach is to avoid entrainment in cycles by forbidding or penalizing moves that make the solution, in the next iteration, return to points in the solution space previously visited (Glover, 1995). *ACO* takes inspiration from the behaviour of ant colonies while exploring their environment (Dorigo, 1992). The advantages, weaknesses and matching problems in SCM of GA, ACO and TS are recapped in Table 1.1 and Table 1.2 respectively.

Along with GA, ACO and TS in the form of HMH HAT, this thesis used one GA-based MH, namely priority-based Genetic Algorithm (pb-GA or pGA). The pGA was developed by Altiparmak, Gen, Lin, & Paksoy (2006) and proves effective in generating random feasible chromosomes and in encoding-decoding. In their paper, these authors provide a step-by-step procedure of pGA and illustrated it in one SCD case study.

Table 1.1 Advantages and disadvantages of GA, TS and ACO
Taken from Griffis *et al.* (2012)

	Advantages	**Disadvantage**
GA	• Not requiring a linear formulation to generate solutions and extensive knowledge of the constraints/rules of the actual problem. • Quickly converges.	• No guarantee of optimality. • Can be difficult for the development of a fitness function to evaluate the new offspring.
TS	• Can find near-optimal results for complex problems with excellent speed and accuracy • Able to self-adjust parameters and change the search toward the optimal solution.	• Complex and lack of flexibility in coding and application.
ACO	• Well fits with problems that can be made analogous to a routing or TSP.	• Difficult to tune several parameters in specific problems. • Difficult in coding and take processing time.

Table 1.2 SCM problems match with GA, TS and ACO
Taken from Griffis *et al.* (2012)

TS	**GA**	**ACO**
• Vehicle routing • Combined purchasing & routing problems	• Facility /warehouse • Carrier bid optimization	• Vehicle routing
• Facility location modelling	• Layout/Service levels optimization	
• Crew scheduling		• Fleet sizing
• Returns management		• Multi-echelon SCD

b.) Meta-Heuristics for Supply Chain Management (2012-2019)

The general characteristics of 135 articles selected in this period are presented as follows:

- GA, SA, ACO and TS (in the basis and modified forms) are still prevalent MHs (with 49, 22, 10 and 8 papers respectively). Besides, PSO and Variable Neighborhood Search (VNS) are regularly used (11 and 6 papers in turn).
- There are up to 32 different MHs employed in SCM. Some new MHs that were developed in recent years are also implemented. For instance, Ghorashi, Hamedi, & Sadeghian (2019) used multi-objective Grey Wolf Optimization which was introduced by Mirjalili, Mirjalili, & Lewis (2014) to solve the optimization of blood SC; also Bányai, Illés, & Bányai (2018) employed Black Hole Algorithm from the study of Kumar, Sharma, & Agarwal (2015) to find the optimal smart scheduling.
- Some well-known MHs like GA, SA, TS, ACO and PSO are usually used as the benchmarking tools to verify the search quality of novel algorithms. For example, Pasandideh, Niaki, & Ahmadi (2018) compared the results obtained from Teaching-Learning-Based Optimization (TLBO) with GA to prove the advantage of this algorithm in optimizing the joint replenishment problem.
- Several popular MHs are modified to improve their quality. For example, Mousavi, Bahreininejad, Musa, & Yusof (2017) modified PSO to solve the inventory control problems. The modified PSO made its solutions superior to the ones from GA.
- Some MHs are modified to adapt to multi-objective problems, like multi-objective PSO (Mohtashami, Tavana, Santos-Arteaga, & Fallahian-Najafabadi, 2015), multi-

objective SA (Jalali, Seifbarghy, Sadeghi, & Ahmadi, 2016) or multi-objective Intelligent Water Drop Algorithm (Moncayo–Martínez & Mastrocinque, 2016).

- For future trends, Srinivasan (2019) predicted the rapid growth of the combination of exact and heuristics approaches. He believed that the decision support system based on MH may be a potential technique to solve SCM problems.

c.) Hybrid Meta-Heuristics for Supply Chain Management

Since implemented in SCM, there are a great number of HMHs that have been introduced for solving various problems. Table 1.3 summarized HMHs used in previous studies. Some striking points of this implementation are presented as follows:

- GA-based HMH is the most favorable form used. It hybridizes with various algorithms like Firefly Algorithm (Saghaeeian & Ramezanian, 2018), PSO (Diabat, 2014), or SA (Mehdizadeh, Afrabandpei, Mohaselafshar, & Afshar-Nadjafi, 2013).
- The original MH in HMH and GA are usually employed to validate the new proposed HMH. Specifically, Inoue & Gen (2012), used five different modified GA.
- HMHs developed in recent years seem to increase in complexity as they are formed from more than two MHs or algorithms. For instance, HICA, which combined GA, PSO and Improved Co-evolutionary Algorithm (Sadeghi, Mousavi, & Niaki, 2016) was developed to solve the integrated inventory system under consignment stock policy. Similarly, Yi & Sarker (2013) introduced three HMH from PSO, Harmony Search (HS), Differential Evolution (DE) and Hooke and Jeeve's method (HJ) namely PSO-HS-HJ, PSO-DE-HJ and DE-HS-HJ.
- The order of algorithms in hybrids create various HMHs. In Cheraghalipour, Paydar, & Hajiaghaei-Keshteli (2019), the hybrid PSO-GA and GA-PSO are different.
- Proposed HMHs are often superior to original MHs on quality search or CPU time (or both). For example, HMH of parallel GA-SA (Li, Guo, Wang, & Fu, 2013) outstrips GA in optimal solution, CPU time, and computing stability.
- In some cases, new HMHs dominate exact solvers like HMH SA-GA had a shorter CPU time than LINGO in the study done by Asgari *et al.* (2016).

The application of some HMH in SCM from 2012 is briefly summarized in the Table 1.3.

Table 1.3 The application of HMH in SCM

Problems	**Modeling**	**HMH**	**Validation**	**Results**
Health care routing (Erdem & Koç, 2019)	S-C OB: S-Min Cost	GA-VNS	CPLEX	GA-VNS : same results, less CPU time.
Designing rice SC (Cheraghalipour *et al.*, 2019)	D-C OB:S-Min Cost	PSO-GA GA-PSO GPA	PSO, GA, NBL-PSO	GPA and NBL-PSO have less deviation than others.
Truck scheduling in cross-docking (Gruler, Panadero, de Armas, Pérez, & Juan, 2018)	D-C OB: S-Max Completion time	PSA-SA	GA, EMA	PSA-SA outperforms GA, EMA.
Location and transportation planning (Fathian *et al.*, 2018)	S-U OB: S-Min Cost	IEMA (EMA-SA)	LINGO EMA	Both IEMA and EMA outperform LINGO.
Multi-product competitive SCD (Saghaeeian & Ramezanian, 2018)	S-C Bi-level: Max profit	GA-FFA	GAMS (small size) GA (large)	GA-FFA: better in both GAMS and GA
SC scheduling problem (Zarei & Rasti-Barzoki, 2018)	S-C. OB: M-Min (Cost, inventory & tardiness)	NSGA-II-Pareto	MOPSO, NSGA-II	New HMH has an average but robust performance.
Blood SC planning (Zahiri, Torabi, Mohammadi, & Aghabegloo, 2018)	D-U. OB: M-Min risk; Max products life	MSDV	MOICA, NSGA-II	MSDV outperforms the rest.
Flow shop scheduling with batch delivery (Wang, Luo, Liu, & Yue, 2017)	S-C OB: S-Min Cost	GA-TLB-VNS	GA, GA-VNS	GA-TLB-VNS performs the best.
Multi-depot green VR (Jabir, Panicker, & Sridharan, 2017)	S-C OB:S-Min Cost	ACO- VNS	ACO	ACO-VNS better ACO in search quality.
LRI (Gholamian & Heydari, 2017)	S-U OB: S-Min Cost	SA-GA	LINGO	SA-GA consumes shorter CPU time.
Multi-echelon SC network modelling and optimization (Rooeinfar, Azimi, & Pourvaziri, 2016)	D-C OB: S-Min Cost	HSIM-META HSIM-GA HSIM-SA	GA, SA	HSIM-META has suitable accuracy and speed for real world applications.
Supplier selection (Kanagaraj, Ponnambalam, & Jawahar, 2016)	S-C OB: M-Min cost	CS-GA	CS	CS-GA better than CS.
Dynamic SCD under traffic congestion and uncertainty (Jouzdani & Fathian, 2016)	D-U OB: S-Min Cost	EMA-VNS EMA-SA EMA-TS	LINGO (small size) EMA (large size)	• EMA-TS better than EMA on value, higher CPU time; • EMA-VNS & EMA-SA better EMA-TS
Optimizing an inventory model (Sadeghi *et al.*, 2016)	S-U OB: S-Min Cost	HICA (GA-PSO-ICA)	SA, ICA	HICA performed better and faster.
SCO with shipping option (Jamshidi, Ghomi, & Karimi, 2015)	S-C OB: S-Min Cost	GATA	AIS	GATA more effective and efficient.

Table 1.3 (Continued)

Problems	Modeling	HMH	Validation	Results
SC coordination (Alaei & Khoshalhan, 2015)	D-C. OB: M-Min (Cost; defective & late delivered items); Max value purchasing	HS-CA HS-pop	HS, PSO, SS	HS-pop and HS-CA: • Better HS quality • Better SS and PSO quality & CPU time
Sustainable SC network strategic design (Govindan, Jafarian, & Nourbakhsh, 2015b)	S-U OB: M-Min Cost Min of impact on environment	MOHEV (AMOEMA - AMOVNS)	NSGAII, MOPSO	MOHEV yielded better solutions than NSGAII and MOPSO.
VMI (Diabat, 2014)	D-C OB: S-Max inventory turnover	GA-PSO	GA, PSO	• GA-PSO: best solutions; PSO: least CPU time. • GA lowest value of spacing metric.
Optimization of blood SC with shortened shelf live (Duan & Liao, 2014)	D-C. OB: S-Min system-wide outdate rate	TA-TS		TA-TS can locate near-optimal solution in much less CPU time
VR scheduling with cross docking and split deliveries (Moghadam, Ghomi, & Karimi, 2014)	S-C OB:S-Min Cost	ACO-SA	SA	ACO-SA outperforms SA.
Sustainable closed-loop SC network (Devika, Jafarian, & Nourbakhsh, 2014)	S-C OB: M-Min Cost; Min impact on environment	TIV NIV	GA-SA 2-phase SA-TS, Nested GA-SA	NIV almost dominate the results of other approaches.
Multi-period inventory routing (Rabbani, Baghersad, & Jafari, 2013)	D-C OB:S-Min (Max completion time)	GA-PSO	GAMS	GA-PSO better.
SCD (Shankar, Basavarajappa, Kadadevaramath, & Chen, 2013)	D-C OB: M-Min cost; Max Fill rate	MOHPSO-NDS		MOHPSO-NDS performs efficiently.
Crossdocking (Marjani, Husseini, & Karimi, 2012)	D-C OB: M-Min (Cost, tardiness)	SA-LS	VNS, TS	VNS outperforms two others.
Consignment Inventory strategy (Molamohamadi *et al.*, 2013b)	D-C OB:S-Max net profit	PSO-SA	GA	PSA-SA outperforms GA.
LIR (Y. Li *et al.*, 2013)	S-U OB: S-Min Cost	Parallel GA-SA	GA	HMH better GA (quality & CPU time)
VMI (Sadeghi, Mousavi, Niaki, & Sadeghi, 2013)	S-C OB: S-Min Cost	PSO-GA	PSO, GA, GA-BO	PSO-GA is better algorithm
VR scheduling (Vahdani, Tavakkoli-Moghaddam, Zandieh, & Razmi, 2012)	S-C OB:S-Min Cost	PSO-SA-VNS	TS	PSO-SA-VNS outperform TS.
Mitigate disruption risks (Azad & Davoudpour, 2013)	S-U OB: S-Min Cost	TS-SA	CPLEX	TS-SA outperforms CPLEX.

Table 1.3 (Continued)

Problems	Modeling	HMH	Validation	Results
Integrated inventory system under consignment stock policy (Yi & Sarker, 2013)	S-C OB: S-Min Cost	PSO-DE-HJ DE-HS-HJ PSO-HS-HJ		PSO-HS-HJ better both sucess rate and time.
Green SCO (Jamshidi, Ghomi, & Karimi, 2012)	S-C. OB: M-Min (cost, dangerous gas)	MA-TA	GATA	MA-TA: close to optimum at lower iteration than GATA.
Huge logistics network (Shimizu & Rusman, 2012)	S-U OB: S-Min Cost	TS-Graph Algorithm	CLEX	Preliminary result same with CPLEX.
Multistage logistics system design with inventory considering (Inoue & Gen, 2012)	D-U OB: S-Min Cost	h-rkGA	st-GA, pGA, rk-GA, h-GA1, h-GA2	h-rkGA: best result with low variability and little CPU time.
Optimal design of water distribution systems (Sedki & Ouazar, 2012)	S-C OB: S-Min Cost	PSO-DE	PSO	HMH better PSO (quality & CPU time).
Distribution network under risk (Sedki & Ouazar, 2012)	S-U OB: S-Min Cost	TS-SA	SA	TS-SA outperforms SA.
Where VR: vehicle routing; LIR: location inventory routing; VMI: vendor managed inventory;	C: Certain; D: Dynamic; S: Statis; U: Uncertain; OB: S/M: Single/Multi objective function;			

- MO: Multi-Objective;
- AIS: Artificial Immune System;
- AMOEMA: Adapted Multi-objective Electromagnetism-like Algorithm;
- AMOVNS: Adapted Multi-objective Variable Neighborhood Search;
- CA: Cultural Algorithm;
- CS: Cuckoo Search;
- DE: Differential Evolution;
- EMA: Electromagnetism-like Algorithm;
- FFA: Firefly Algorithm;
- GPA: modified GA used PSO's movement formula;
- GATA: GA-Taguchi Algorithm;
- HJ: Hooke and Jeeve's method;
- GA-BO: GA with Boundary Operator;
- LS: Local Search;
- HS: Harmony Search;
- HSIM-META: Hybrid Simulation-GA-SA;
- HSIM-GA: Hybrid Simulation-GA;
- HSIM-SA: Hybrid Simulation-SA;
- HS-pop: Population-based HS;
- h-rkGA: Random Key-based GA;
- hGA1: h-GA by only local search;
- hGA2: h-GA by only parameter tuning;
- IEMA: Improved EMA (result of augmenting EMA with SA);
- ICA: Improved Co-evolutionary Algorithm;
- LS: Local Search;
- MA: Memetic Algorithm;
- MSDV: Multi Objective self-adaptive Differential Evolution Variable Neighborhood Search;
- NBL-PSO: Nested Bi-level PSO;
- NDS: Non-dominated Sorting Algorithm;
- NIV: Nested ICA and VNS;
- NSGA-II: Non-dominated Sorting GA;
- rkGA: Random Key-based GA;
- st-GA: Spanning tree GA;
- SS: Scatter Search;
- TIV: Two-phase ICA-VNS;
- TA: Threshold Accepting;
- TLB: Teaching-learning-based Optimization;
- VNS: Variable Neighborhood Search;

1.2 Supply Chain Design

Harrison (2004) divided SCM into SCD and SCE, in which SCD belongs to the strategic level determining SC infrastructure in a timeline of months or years, while SCE identifies tactical decisions with the timeline of days or weeks. As mentioned by Sunil & Peter (2013), SCD *"comprises the decisions regarding the number and location of production facilities, the amount of capacity at each facility, the assignment of each market region to one or more locations, and supplier selection for subassemblies, components and materials.*" SCD is considered as the prime strategy to obtain *c*ompetitiveness in present business environments (Guerrero, Olivares-Benitez, Miranda, Perez-Loaiza, & Ablanedo-Rosas, 2018). Harrison (2004) found that 5%–60% of the cost and 25%–75% of service times can be reduced with an optimum SC structure through SCD. Research on SCD expanded in many different aspects. Farahani, Rezapour, Drezner, & Fallah (2014) classified SCD into five rubrics (see Figure 1.3). Furthermore, managerial and scholar cadres have been trying to integrate the concepts of lean, green, agile, sustainable and global, into both SCD and management to take advantage of each type (Mollenkopf, Stolze, Tate, & Ueltschy, 2010).

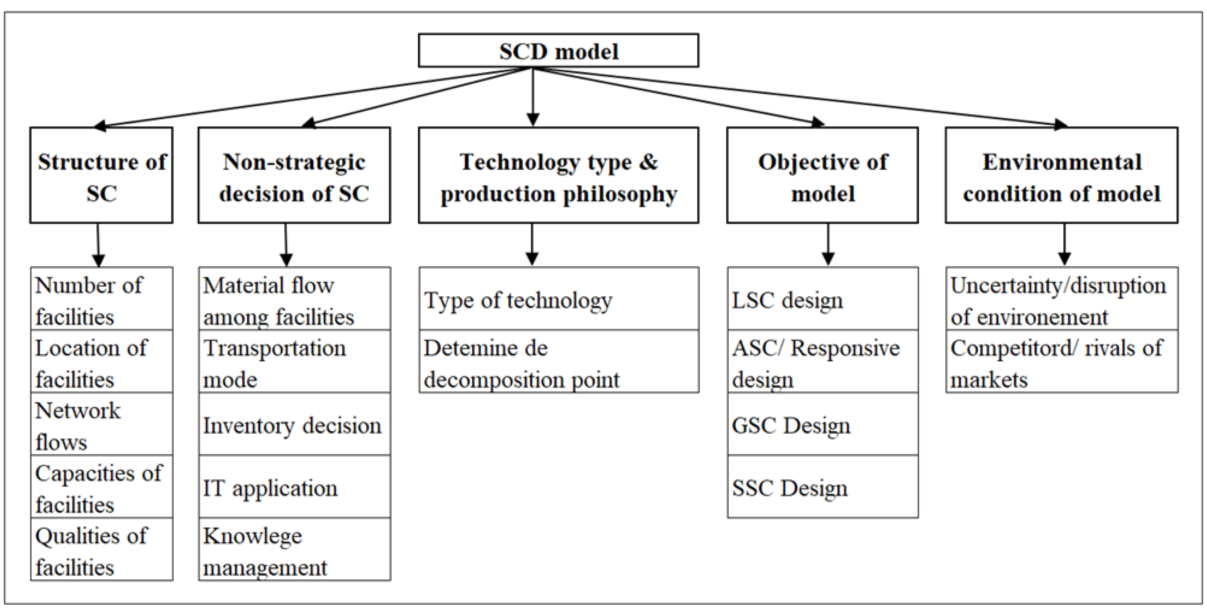

Figure 1.3 SCD classification
Taken from Farahani *et al.* (2014)

1.2.1 Supply Chain Design Process

To efficiently design SC, Carvalho, Silveira, & Ramos (2010) highlighted the importance of understanding market requirements as well as identifying the current situation of the SC. Recently, Corominas, Mateo, Ribas, & Rubio (2015) introduced the 5-stage Supply Chain Outline Process (SCOP), which detailed the SCD roadmap (see Figure 1.4). This hierarchical top-down approach is used as supporting tool for design of SCD (Lusa *et al.*, 2016). In SCOP, the first stage focuses on identifying the environment and objectives of the new SC before the next stage defines the SC macrostructure. Then, stage 3 identifies the SC mesostructure. Stage 4 specifies the SC microstructure, in which all SC specifications (objectives, parameters, constraints, and variables) are formulated into mathematical models. From then, the last step solves this mathematical model to define the best SC structure to satisfy the expected SCP. This thesis applies SCOP in the design LSC.

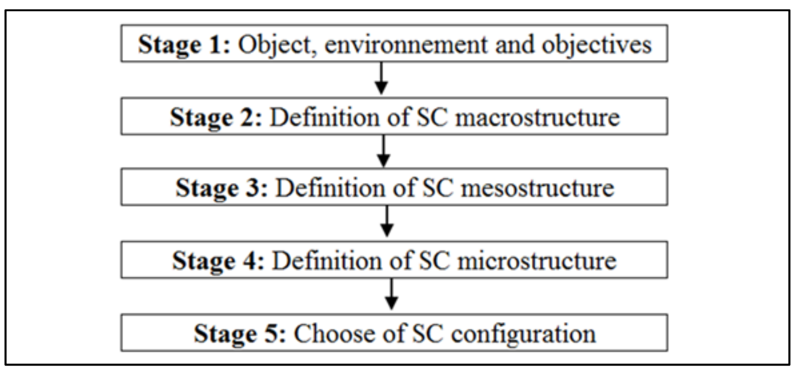

Figure 1.4 The SCOP framework for SCD
Taken from Corominas *et al.* (2015)

1.2.2 Supply Chain Design Modelling and Optimization

1.2.2.1 Supply Chain Design Modelling

Chopra (2004) presented certain SCD models such as demand allocation, plant location and demand allocation, or simultaneous plant and warehouse location models. The latest mentioned one is also the multiple-level facility location-transshipment model (see Figure

1.5). This model is used to illustrate the procedure of SCD modelling. Notably, each SCD problem is modelled based on various predefined assumptions.

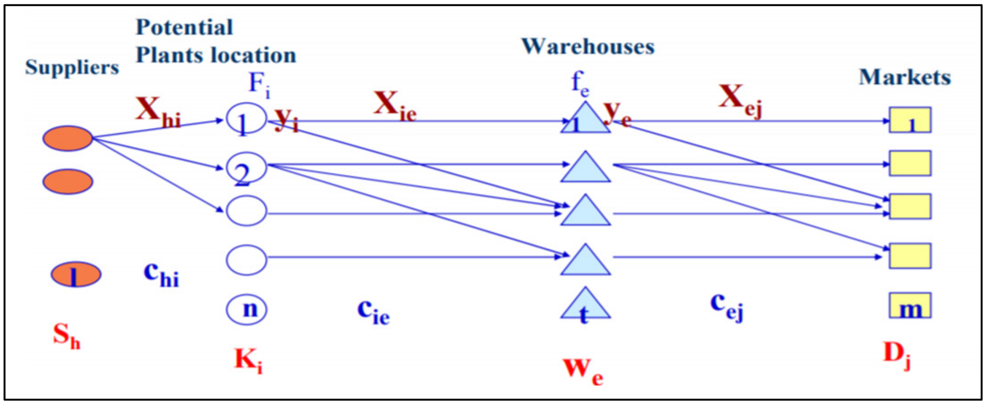

Figure 1.5 Simultaneous location plans and warehouse in SCD
Taken from Chopra (2004)

a.) Assumptions

The predefined assumptions in SCD may be around availability, demand, costs or lead times (https://www.businessmodelling.com/). They vary widely according to the specific SCD case. For instance, when building up the model for simultaneous design products with module commonalization and its SC, Fujita, Amaya, & Akai (2013) stated 19 various assumptions related to product, product family, manufacturing, network and market. Meanwhile, Luis & David (2011) assumed the new SC would have an unlimited capacity of resources and applied a single sourcing policy in an attempt to minimize both SC total cost (TC) and lead-time. In the model of Chopra (2004), the assumptions of market (demand), facilities (costs, capacity, facilities, availability) are pre-defined.

b.) Parameters

Concerning parameters, they are necessary information and worth capturing for designers in the first step of SCOP model. The requirements' information selected is different depending on particular design objectives. These critical elements need to be evaluated before being used in following design steps. According to Lambiase, Mastrocinque, Miranda, & Lambiase (2013), the complexity of the SC relies on the chosen parameters such as the number of echelons, number of products and number of periods. Taking the period in SCD into consideration, Baud-Lavigne, Agard, & Penz (2016) prefer to use a single period because it "*will have impacts on the design of the products, the components, the operations of manufacturing, the make or buy decisions, the repartition of labor and so on. It is not really possible to change all those decisions much often. When a decision is taken, it may take months to execute. For this reason the problem is considered as single period.*" In the model of Chopra (2004), the SC includes three echelons facilitating one product in a single period.

In this thesis, the SCD framework is built up based on the assumption that steps 1 to 3 of the SCOP model have been accomplished. After determining the assumptions for LSCD problem, the thesis goes to step 4 by formulating the mathematical model.

c.) Decisions

Farahani *et al.* (2014) arranged decisions made in SCD (variables) into three levels: 1.) strategic, 2.) tactical, and 3.) operational decisions (see Table 1.4). They can be binary (location of SC's facilities), integer (number of SC's facilities) or real (pricing), and can coexist in the same SCD model.

Table 1.4 Decisions made in SCD
Taken from Farahani *et al.* (2014)

Strategic decisions	Tactical decisions	Operational decisions
• Number of SC's facilities • Location of SC's facilities • Capacity of SC's facilities • Quality of SC's facilities • Type of technology • Number of contracted providers • Reserved capacity of contracted providers • Decomposition point	• Amount of flow • Transportation among the SC's facilities • Transportation mode among the SC's facilities • Inventory volume and type in SC's facilities • Amount and type of purchase from contracted providers • IT knowledge management	• Fulfilment of customer demands • Pricing • Provided service level

The decisions made in this SCD problem of Chopra (2004) are the location and number of SC's facilities, transportation among the SC's facilities and amount of flow.

d.) Objectives

Lambiase *et al.* (2013) emphasized the importance of getting the best SCD and SCM for global performances. Beamon (1998) summarized the SC key performance indicators (KPI) both qualitative and quantitative (objectives in SCD mathematical models) as in Table 1.5.

Table 1.5 SCP criteria
Taken from Beamon (1998)

Qualitative performance	Quantitative performance	Notes
• Customer satisfaction • Flexibility • Information and material integration • Effective risk management • Supplier performance	Min (Cost, Inventory investment)	Measure based on cost
	Max (Sales, Profit, Return on investment)	
	Min (Customer response time, Product lateness, Lead time, Function duplication)	Measure based on customer responsiveness
	Max (Fill Rate)	

Among the above KPIs, Beamon (1998) asserted that *cost minimization* is one of the most used. Therefore, Lambiase *et al.* (2013) tried to summarize the component of costs and also revenues as the frequent economic criteria (see Table 1.6).

Table 1.6 Component of costs and revenues
Taken from Lambiase *et al.* (2013)

Economic criteria	Components
Costs	Fixed, Variable, Investment, Production, Raw material, Labour, Energy, Transportation, Inventory, Pipeline inventory
Revenues	Demand variability, Price variability, Transfer pricing, Taxes, Exchange rates

Chopra (2004) formulated the objective of his model as to minimize the SC TC (called TC).

$$\text{Min} \sum_i f_i\, y_i + \sum_e f_e\, y_e + \sum_h \sum_i c_{hi}\, X_{hi} + \sum_i \sum_e c_{ie}\, X_{ie} + \sum_e \sum_j c_{ej}\, X_{ej} \tag{1.1}$$

Where

S is the set suppliers, indexed by h, h= {1... l}.

F is the set plants, indexed by i, i = {1... n}.

f is the set warehouse, indexed by e, e = {1... t}.

M is the set markets, indexed by j, j = {1... m}.

K: capacity of plant

W: capacity of warehouse

D: demand from market

c: unit transportation cost

X: variable denoted the quality of items shipped between 2 adjacent echelons

y: binary variable, denoted the status of facilities (y = 1 when facility opened and y = 0 otherwise).

e.) Constraints

Depending on the nature of the problem, constraints may vary, such as the limitation of facilities or technology selection (Lambiase *et al.*, 2013). The common constraints in SCD are *customers' demands satisfaction* and the *restriction number of potential facilities*. Besides, Zhou, Xu, & Deng (2011) listed four other categories including:

- Network structure constraints: the links between the two adjacent tiers exists if, and only if, the sourcing node is established.
- Balance constraints of products: the amount of products shipped from one node is smaller or equal to the amount it received and its inventory.
- Capacity constraints: the amount of items produced or shipped from any node is smaller or equal to its capacity.
- Integrity and non-negative constraints: ensuring the nature of variables is respected.

In the SCD model of Chopra (2004), these constraints are given:

- Customers' demands satisfaction

$$\sum_e X_{ej} = D_j, \forall j \tag{1.2}$$

- Balance constraints of products

$$\sum_h X_{hi} - \sum_e X_{ie} \geq 0, \forall i \tag{1.3}$$

$$\sum_i X_{ie} - \sum_j X_{ej} \geq 0, \forall e \tag{1.4}$$

- Capacity constraints of products of suppliers

$$\sum_i X_{hi} \leq S_h, \forall h \tag{1.5}$$

$$\sum_e X_{ie} \leq K_i y_i, \forall i \tag{1.6}$$

$$\sum_j X_{ej} \leq W_e y_e, \forall e \tag{1.7}$$

- Integrity and non-negative constraints: $y_i, y_e \in \{0.1\}$ (1.8)

1.2.2.2 Meta-Heuristc Solution Method for Supply Chain Design

SCD decisions hugely influence SCP (Sunil & Peter, 2013). However the optimization of SCD faces two main barriers: 1.) "*The design space contains a vast number of alternatives, which makes it hard for designers to evaluate and select the best alternative,*" and 2.) "*requires sharing and understanding design information by various parties.*" (Leukel & Sugumaran, 2013) Some studies showed that the most SCD mathematical model is NP-Hard (Olivares-Benitez, Ríos-Mercado, & González-Velarde, 2013). This makes the SCD solution too large and formidable to solve by exact methods while this is MH's strength. Among the 105 papers related to the implementation of MH and HMH on SCD found in this work, from 2012 until now, GA-based algorithms are still the most prevalent followed by the MH-based algorithm of SA, PSO, TS and ACO (see Table 1.7). Mula (2014) summarized the characteristics of the MH solution in SCD as shown in Table 1.8.

Table 1.7 The most used MH-based in SCD

HM-based	GA	PSO	SA	TS	ACO
Quantity	40	14	13	8	7

Table 1.8 Characteristics of MH solution in SCD
Taken from Mula (2014)

Criteria	Characteristics
Programming model	• Hybrid approaches combining integer-mixed linear/Multi-objective integer mixed linear with MH
Objectives	• Minimize cost or combine with other customers-based criteria
	• Operations-base criteria
Validated model	• Numerical examples rather than real
New aspects	• Develop MH rather than problem modelling
Limitation	• Simple nature of model problem • Poor computational efficiency • Uncertainties in parameters

Table 1.9 below gives an example of SCD optimization using pGA MH.

Table 1.9 The example of SCD optimization using pGA

Problems	Modeling	Solution
Optimization plastic SCD in Turkey (Altiparmak *et al.*, 2006)	• Mixed-integer non-linear programming model. • Certain, static, multi objectives. **Assumptions** • Number of customers, suppliers and their demand and capacities are known. • Number of potential plants and DCs and their maximum capacities are known. • Customers are supplied product from a single DC. **Objective Functions** • Min SC TC (fixed costs of operating and opening plants and DCs, variable costs of transportation). • Max customer service • Min equity of the capacity utilization ratio **Variables** • Quantity of items shipped from adjacent echelons • Status opened/closed of plant and DC • DC serves customer **Constraints** • Constraints on: supplier capacity, plant production capacity, raw material supply restriction, capacity for DC. • Unique assignment of a DC to a customer • Limits the number of plant and DCs can be opened • Satisfaction of customer and DCs demands • Restriction on the decision variables non-negativity	• **Solution method:** pGA • **Validated:** Multi objective SA (MOSA) • **Results:** pGA has higher serach quality than MOSA; pGA comsumed two times higher than MOSA.

After going through the SC modelling and SCO, the work reviews the relevant SC models.

1.3 Supply Chain Models

1.3.1 Lean Supply Chain

1.3.1.1 Lean Manufacturing

LM originated from the TPS, being formed from two principles: Just-in-Time (JIT) and Jidoka (Womack *et al.*, 1991). Based on the TPS Basic Handbook (www.artoflean.com), JIT aims at "*producing and delivering the right parts, in the right amount, at the right time using the minimum necessary resources.*" Jidoka "*refers simply to the ability of humans or machines to detect an abnormal condition in materials, machines, or methods, and to prevent the abnormality from being passed on to the next process.*" The objective of LM is defined by Ōno (1988) as "*the absolute elimination of waste,*" and "*cost reduction is the goal*." Waste, or *muda* (無) in Japanese, is any "*activity that consumes resources but brings no value to the end customer.*" Ōno (1978) categorized waste into 7 types: **T**ransportation, **I**nventory, **M**ovements, **W**aiting, **O**ver-processing, **O**verproduction, and **D**efect. They are also well-known via the easily remembered acronym TIM WOOD.

Recently, an 8th waste-type was added, *'non-utilized talent',* referring to the failure of ensuring that all of the potential employee talent is being utilized (Gay, 2016). After this, the 9th and 10th types were also added, which included '*ineffective performance measures'* and '*poor supplier quality,'* introduced from FreePoint Technologies Inc (2018). This list has yet to come to an end as the waste website (www.allaboutlean.com/muda) complemented 24 other wastes (see APPENDIX III, p.179). This website admitted that there are somewhat overlaps between some of these wastes and TIM WOOD. As the consensus on the new waste types is elusive, TIM WOOD is still most commonly used. Anand & Kodali (2008) extended the definition of TIM WOOD beyond the scope of manufacturing to SC (see Table 1.10).

Table 1.10 Seven waste in manufacturer and SC
Taken from Anand & Kodali (2008)

No	Forms of waste	Manufacturer	SC equivalent
1	Transportation	The transportation of materials	Waste in shipping supplies/parts/equipment into/out of storage between supply nodes prior to consumption.
2	Inventory	Stocks are more than the absolute minimum	Excess inventory within SC as a result of poor inventory visibility within the system.
3	Movements	Unnecessary movements by employees	Any wasted motion to pick/pack/consolidate/move material in warehouse.
4	Waiting	Waiting for the next process step	Lead time: Procurement lead time, or time cargo is frustrated at intermediate nodes.
5	Over-processing	Due to poor tools/ product design.	Do more work than necessary: redundant process/double handling/excess supply nodes.
6	Overproduction	Producing ahead of demand	Producing more than what is demanded by the next stage of customers in the SC. Having too many product varieties and models, which may not have the adequate demand.
7	Defect	The production of defective products	Reports of discrepancy: lost/damaged/incorrect items shipped.

Supporting waste elimination is the lean toolkit, including 59 tools and techniques summarized in the review done by Anand & Kodali (2008). Among them, some LM can be extensively applied in process design, plant design, product design and SCD (Li, Zhang, & Xue, 2004). Table 1.11 lists the application of some LM which will be used in this thesis.

Table 1.11 LM used in product design and SCD

LM Tools (Anand & Kodali, 2008)	**Application Examples**
Early supplier envolement: suppliers are involved from the beginning of a new product development project	It accelerate the research and development timeline, and allow for risk sharing (Chiang & Wu, 2016).
Group technology: group of similar parts based on similarities in design features or manufacturing processes into part families	It creates product and machine groups, simplifying material flows and reconfigurating shop-floor (Suzić, Stevanov, Ćosić, Anišić, & Sremčev, 2012)
Standardization: use standard parts, materials, processes and procedures.	Standardization can: reduce variation, lower transaction costs and prices; create flexibility and predictable outcomes; increased product safety and quality (Lorenz, Raven, & Blind, 2017)
Modularity: a process of decomposition or demarcation of the product architecture into subassemblies	Modular product design "*enables mass customization allows environmentally friendly end-of-life strategies, reduces development costs and allows efficient work in loosely coupled organizations*." (Bonvoisin, Halstenberg, Buchert, & Stark, 2016)

Table 1.11 (Continued)

LM Tools (Anand & Kodali, 2008)	**Application Examples**
Common parts: use common parts in different products	Thakur, Nair, & Wen (2001) optimized product line design to maximize total profit to the firm through the use of common parts, features and manufacturing facilities.
Use of flat hierarchy: minimize amount of organization levels for decision-making and approval and number of stages in SC	The use of flat hierarchy affects the organizational structure (Duarte & Cruz Machado, 2017).
Geographical concentration: refers to the development of supplier and distributor parks in closer proximity to the manufacturer	Geographical concentration may increases both SC efficiency and risk (Wiengarten, Humphreys, Gimenez, & McIvor, 2016). It might affect the resiliency of a SC to disruption which were resulted from the high density of suppliers or manufacturers (Rienkhemaniyom & Pazhani, 2015)
Single sourcing: relies on a single supplier for a particular component	It usually used to reduce the supplier list or in sourcing base reduction (Mandal, 2015).

Regarding *single sourcing*, its advantages and disadvantages in comparison with multiple sourcing are summarized in Table 1.12.

Table 1.12 The comparison of single and multiple sourcing
Taken from Costantino & Pellegrino (2010)

Single sourcing	**Multiple sourcing**
Advantages • Share benefits and long-term relationship based on high trust levels • Large commitment that willing to invest in new facilities or new technology • Lower purchase price, reduce production costs • Better knowledge of supplier's capacity help to achieve economies of scale	• Alternative sources of materials • Reduce probability of bottlenecks • Capacity to meet peak demand • Increase competition among suppliers leads to better quality, price, delivery, product innovation and buyer's negotiation power • More flexibility to react to unexpected events that could endanger supplier's capacity
Disadvantages • Great dependency between buyer and supplier • Increase vulnerability of supply • Increase risk of supply interruption	• Reduce efforts by supplier to match buyer's requirements • Higher costs for the purchasing organization

1.3.1.2 Milk-run delivery

1.3.1.3 Milk-Run Definition and Application

Milk-run delivery (or milk-run, see Figure 1.6) is defined as "*a route on which a truck either delivers a product from a single supplier to multiple retailers or goes from multiple suppliers* *to a single buyer location*" (Sunil & Peter, 2013). The term 'milk-run' stemmed from the traditional system of door-to-door selling of milk in the West. Milk-run is considered as one of the most efficient and regular transportation models (Kitamura & Okamoto, 2012); and an essential factor for an integrated lean logistics strategy (Donald, David, & Cooper, 2002).

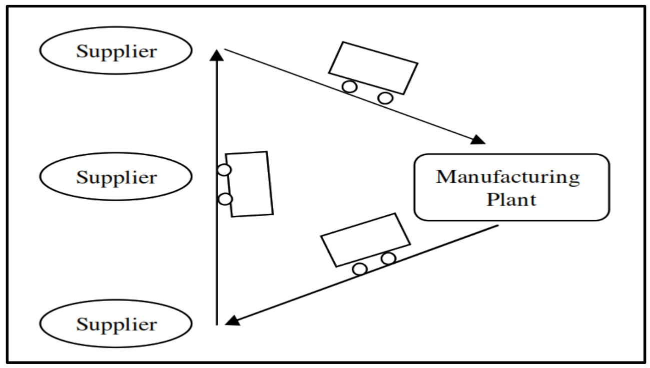

Figure 1.6 Milk-run operations
Taken from Sadjadi, Jafari, & Amini (2009)

Once applied, milk-run distributes items in small quantities with high frequency instead of large batches. To balance the milk-run pace, companies maintain a production output at the level that fits with the number of products needed by each milk-run. As a result, it eliminates waste relating to inventory in LSC, speeds up the circulation of materials through facilities (Du, Wang, & Lu, 2007), compresses cycle time, minimizes distance, decreases TC, increases vehicle utilization and improves profitability (Patel, 2017). Also, milk-run ameliorates the accuracy of JIT delivery through synchronization and improves the vehicle loading rate from around 30% to 65%, which was found in the study done by Brar & Saini (2011). From an environmental perspective, milk-runs are very encouraging due to CO_2 reduction from the transportation and packaging materials utilized (Patel, Patel, & Vadher, 2017). With such advantages, milk-runs are widely applied in inbound and outbound logistics (Kilic & Durmusoglu, 2013), assembly lines, and workstations (Pesce, Frazão, Civinskas, & Pires, 2000). In reality, Toyota and Seven-Eleven are the worldwide successful cases of the milk-run application (Brar & Saini, 2011).

1.3.1.4 Milk-run Modeling and Optimization

Notably, the milk-run route optimization is quite specific to the nature of the traditional TSP, which has been studied for a long time through many different methods (Laporte, 1992). TSP is a famous NP-complete optimization problem where the objective is to determine the shortest possible route or time, or the lowest travelling cost of a salesperson while taking a round tour of m predefined cities. When the number of towns is sufficiently large, the exact methods become inapplicable. For example, it took 136 CPU years to optimize the TSP of 85,900 cities by Concorde TSP Solver (Applegate, Bixby, Chvátal, & Cook, 2006). Thus, researchers have recently opted to solve it by using optimal software or heuristics as shown in the study done by Raman & Gill (2017).

Milk-run-related problems are more complex than TSPs because they involve other fields of SCM like production, scheduling or logistics. Nowadays, several MHs and HMHs have been employed to solve milk-run like problems like GA (Halawa, Sah, Srihari, & Chung, 2018), ACO (Miao & Xu, 2011) or HMH Harmony Search-SA (Hosseini, Shirazi, & Karimi, 2014). In a small-sized milk-run, these algorithms provide near-optimal solutions while the exact method can offer global optimum results. Otherwise, in a large size, the exact method becomes infeasible while MH or HMH can offer approximate results with acceptable processing times. The papers related to milk-run problems are presented in Table 1.13.

Table 1.13 Milk-run problems published recently

Problem	Modeling	Methodology	Results
Milk-run truck scheduling (Halawa *et al.*, 2018)	Dynamic, certain **OB:** Single (Min the lateness time of truck arrival at vendor) **Variable:** truck visit vendor in defined days, and truck late arrival for visit	GA	**Result** from a case study of a US third-party logistics firm shown that milk-run approach can achieve cost savings and reduce the transportation planning efforts.
Multi-plant milk-run pickup problem with uncertain demand (Wu, Wang, He, Xuan, & He, 2018)	Dynamic, uncertain Mix-integer programing **OB:** Single (Min inventory and distribution cost) **Variable:** truck selection from node, assigned to depot, and picks up at part supplier	Hybrid Adaptive GA and Local Search (AGA-LS)	**Validated**: GA **Result:** AGA-LS outperformes the standard GA in the reduction of overall cost.

Table 1.13 (Continued)

Problem	Modeling	Methodology	Results
Utilizing excess capacity in last mile using 4th party milk-run (Kian & de Souza, 2017)	**OB:** Multi (Max number of orders fulfilled by the milk; Min transportation cost; Max utilized unused milk-run capacity). **Variables:** an order is fulfilled by milk-run, origin node order is fulfilled from by milk-run	Excel Solver	**Validated:** real case **Results** • Be possible to utilize excess capacity in milk-runs. • Introduced the concept of 4th party milk-run which leverages on last mile excess capacity from a company to conduct deliveries.
Milk-run with time windows and simultaneous pickups and deliveries (Patel *et al.*, 2017)	Dynamic, certain OB: Sing (Min cost of penalty, transportation, fixed cost of initial cost of vehicle, taxes, insurance charges, vehicle permit charges) **Variables:** from (Patel *et al.*, 2017)	GA	Reduction of the overall cost, time and distance when using milk-run instead of direct shipment..
Dynamic routing for milk-run tours with time windows in stochastic time-dependent networks (Güner, Murat, & Chinnam, 2017)	Stochastic dynamic programming **OB**: single, min the robustness cost **Variables:** random variable of arrival time at a site by following the partial tour	Simulation	**Validated:** the static routing policy in real case study **Results** of dynamic policy : • Save trip duration • Reduce standard deviation • Increase on-time delivery performance
Multi-depot collaborative transportation problem of milk-run pattern (Lou, Li, Luo, & Dai, 2016)	Dynamic, certain OB: Single (Max synergies transport) **Variables:** vehicle starting from a yard then drive from one to another	Node-arc discharge and geometric method	• Introduces the concept of node-arc discharge • The new approach proves effective and reasonable through numerical example
Common frequency routing problem with vehicle type choice in the milk-run (Lin, Xu, & Bian, 2015)	Dynamic, certain **OB:** Single (Min cost of transportation, inventory cost and dispatched vehicles). **Variable:** frequency of route; pickup quantity of supplier	Two-Phase heuristic algorithm: Greedy and TS	**Validated:** TS and SA **Results** • Proposed method has shorter time and more stable. • Vehicle type choice may save cost of transportation, inventory, and dispatch
Milk-run routing optimization (Wang, He, & Jiang, 2015)	Static, certain **OB:** Single (Min transport cost) **Variable:** route line; points assigned to route line	Firefly Algorithm	**Validated:** TS **Result:** FA outperforms both CPU time and search quality
Milk-run with inventory uncertainty (Nozari, Aliahmadi, Jafari-eskandari, & Khaleghi, 2015)	Static, uncertain **OB:** Single (Min TC of transportation and inventory) **Variables:** number of shipping palates of part transported with vehicle from supplier	Extended Compact GA	**Results** • Robust solution can be protected from unmet stock yet it imposes extra cost

Table 1.13 (Continued)

Problem	Modeling	Methodology	Results
Cross-docking and milk-run logistics in a consolidation network (Hosseini *et al.*, 2014)	Integer programming Static, certain **OB:** Single (Min shipping TC) **Variables:** number of trucks, and others (tracked in original paper)	HMH HS-SA	**Validated:** GAMS/CPLEX **Results:** HMH HS-SA better than GAMS/CPLEX in search quality and CPU time
Modeling LSC considering of delivery consolidation (Miao & Xu, 2011)	MIP Static, certain **OB:** Single (Min SC TC of transportation, production and inventory) **Variables:** best milk-run route and frequency	ACO	The shortest milk-run contributes to approximate min SC TC

1.3.1.5 Lean Supply Chain Management

a.) Lean Supply Chain Definition and Characteristics

In regards to LSC, its objectives are to eliminate non-value-added activities and to reduce the required non-value-added activities (Anand & Kodali, 2008) . The typical characteristics of a conventional and lean model are categorized in APPENDIX IV, p.181.

In Figure 1.7, Anand & Kodali (2008) built the LSC framework which is supported by the four main pillars: 1.) customer focus, 2.) elimination of waste, 3), respect for all stakeholders and utilizing their full capability, 4.) and continuous improvement. These pillars stand on the leadership, commitment and involvement of all stakeholders and their willingness to change the culture. These hold up the roof of competitive priorities, performance measurement and metrics. Supporting them is the lean toolkit which can be divided into 4 groups: 1.) IT, 2.) JIT, 3.) SCM, and 4.) organization-based elements.

LSCM includes "*a set of organizations directly linked by upstream and downstream flows of products, services, finances and information that collaboratively work to reduce cost and waste by efficiently and effectively pulling what is required meeting the needs of the individual customer.*" (Kimani, 2013) A study done by Jasti & Kodali (2015) reviewed previous studies, thereby constructing the LSCM house framework. The house's foundation comprises top management commitment and the seven columns of: 1.) supplier relationship management, 2.) customer relationship management, 3.) information technology, 4.) elimination of waste, 5.) JIT manufacturing, 6.) continuous improvement, and 7.) logistics management (see Figure 1.7).

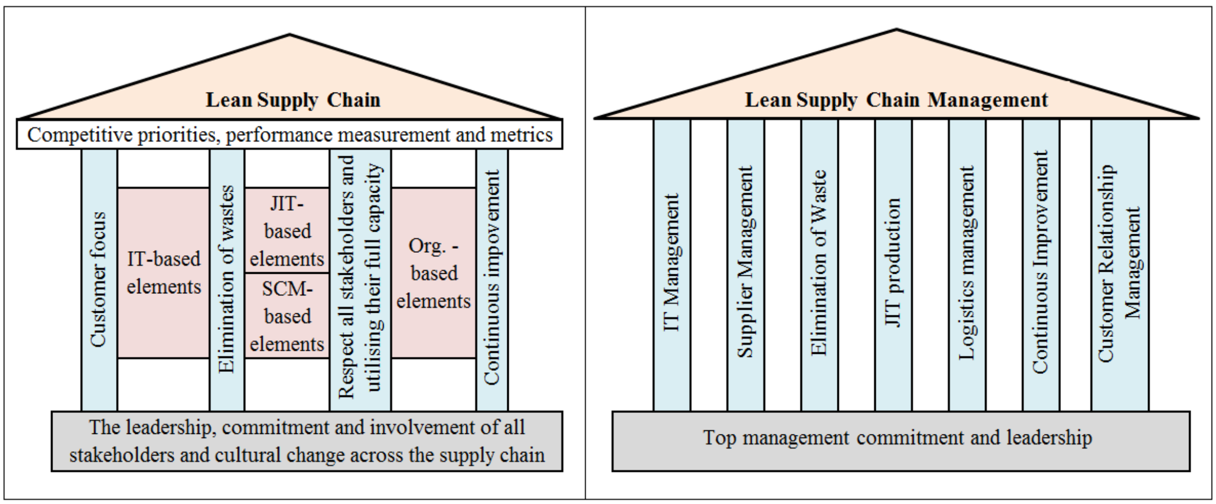

Figure 1.7 LSC and LSCM framework
Taken from Anand & Kodali (2008), and Jasti & Kodali (2015)

b.) Lean Supply Chain Management Review

One of the most recent studies conducted on LSCM from Marodin, Tortorella, Frank, & Godinho Filho (2017) realized that "*the current knowledge about LSCM is still limited.*" In this section, the review of LSCM is presented, which is summarized from three periods:

- From 1990 to 2012 through a review of Paschal *et al.* (2012a).
- Up to 2015 by studies done by Jasti & Kodali (2015).
- From 2015 to the present conducted by this thesis.

From 1990 to 2012: Paschal *et al.* (2012a) collected 40 articles of LSCM in their review. They divided them into two subgroups. The first is basic descriptive characteristics of lean system while the second presented the view of the author on LSC. In manufacturing, these papers focus on waste elimination, while in SC they discuss supply involvement and the benefits of LSC. The review realized that previous studies tried to apply lean in different industrial sectors, among them the automobile one was accounted as the largest proportion. The research gaps drawn from this review include:

- Case studies missed illustrative evidence to prove the benefits of LM in SC.
- Lacking the quantitative approach as most were conducted by qualitative one.
- Almost all studies focused on LM applications on partial SC such as the supply side and focal company while neglecting the entire system.

From here, some corresponding suggestions were given:

- Conducting more quantitative empirical research, like surveys and modelling.
- Introducing more case studies based on illustrative evidence and predictive research using mathematical modelling and simulation.
- Extending more research to other industry sectors.
- Implementing LM on the whole SC.

Up to 2015: Jasti & Kodali (2015) conducted one comprehensive review on LSC with 748 articles on 24 journals. The purpose of this study was to build up one synthetic LSCM framework based on previous findings. The contribution of this study was the framework of LSCM which was constructed based on the 9 main pillars and 87 elements (shown in Figure 1.7). They recognized that this case study was most used to qualify the proposed endeavour.

From 2015 onwards, this thesis found 48 relevant articles, which can be classified into two groups: basic LSC and hybrid LSC models. In the first group, some authors continue working with lean supply by analyzing the trade-off between lean and outsourced SC (Swenseth & Olson, 2016) or by studying the impact of lean logistics and the information system management (Khlie, Serrou, & Abouabdellah, 2016). Some tried to modulate the LSC bullwhip (Gjeldum, Crnjac, & Bilić, 2017), or inventory strategies (Berger, Tortorella, & Frazzon, 2018) and LSC performance (Rossini & Staudacher, 2016). To gain benefits from LM implementation, others employed different LM tools and techniques in various sectors like aviation (B. R. Kumar, Raghu *et al.*, 2015), book publishing (Hartono, Astanti, & Ai, 2015), and drug (Regattieri, Bartolini, Cima, Fanti, & Lauritano, 2018). Lean is also combined with some cutting-edge management techniques. For instance, Jayaram (2016) proposed the lean six sigma approach for global SCM in industry 4.0. Also, Perboli, Musso, & Rosano (2018) implemented lean for block chain. Rarely, Nguyen & Dao (2017) designed an LSC by employing LM at the SCD stage through a quantitative approach.

The second group lies in the increasing number of hybrid LSC models. Beside LA SC, which is still an attractive object, there are various hybrid LSCs developed from lean and other paradigms. The characteristics, methodology and main contributions of lean-based SCs are presented in Table 1.14. Especially, the LA and LARG SC will be presented later.

Table 1.14 The review of lean-based hybrid models

Problems	Methodolody	Contributions
Lean eco-efficient innovation in operations through the maintenance (Peter & Peter, 2018) **Combined model**: Green	Qualitative approach	• Maintenance may support eco-efficiency in innovation-led lean organizations • Community, training, tools and organizational structure have important role in pursuing eco-efficiency targets. Proposed the ways to embed eco-efficiency in an organization. • It is possible to pursue eco-efficiency within existing lean organizational structures by re-defining the role of maintenance
Lean and green assessment of SCP (Thanki & Thakkar, 2018) **Combined model**: Green	Quantitative, solved by fuzzy decision-making trial and evaluation laboratory analytical network	• Lean and green SCM can be a suitable strategy for organizations to improve performance • New approach to develop a lean and green SCP evaluation and interrelation model • Analyzing the complex interrelationships between lean and green SC measures
Lean, green and profitable SC from sustainable development (Wong, Wong, & Boonitt, 2018) **Combined model:** Green	Survey of 203 Thai manufacturers	• Just only when all three dimensions (economic, environmental and social) of sustainable supply chain (SSC) development are successfully orchestrated can firms improve environmental performance while reducing cost and improving financial performance
Model for GSC performance (Anass *et al.*, 2018) **Combined model**: Green	Survey and structural equation modelling	• The adoption of lean practices improves the performance of GSCs while green practices have positive effect on GSC performance • Process innovation does not have a direct positive effect on GSC performance

Table 1.14 (Continued)

Problems	Methodolody	Contributions
The lean and resilient performance (Rocío, Cristina, & Real., 2018) **Combined model**: Resilience	Importance-performance analysis (IPA) Interpretive structural modelling (ISM)	• Systemic framework for lean, resilience practices and SCP metrics. • LSC practices drive RSC practices and it have a higher rate of application than resilient supply chain (RSC) practices in the aerospace sector • '*Use of control information system*' and '*Flexible supply base*' are resilient practices that remains resilience in JIT system.
Lean benchmarking for sustainability assessment (Ramos, Ferreira, Kumar, Garza-Reyes, & Cherrafi, 2018). **Combined model**: Sustainability	Benchmarking	• Cost was the priority factor in decision making, second is quality, followed by flexibility and preserve the environment
Subtraction Integrating product deletion with lean and sustainable SCM (Zhu, Shah, & Sarkis, 2018) **Combined model**: Sustainability	Analytical Hierarchy/Network Process (AHP/ANP) Benefits, Opportunities, Cost and Risks analysis (BOCR)	• The first research conducted on the model that integrated product deletion, SCM and sustainability • This flexible model allows to incorporate fewer or more factors corresponding with the level of complexity acceptable to managers
Integrating lean systems in sustainable SCD (Kanchan, 2018). **Combined model**: Sustainability	Integer programming solved by WGP	• Method to select lean and green practices for achieving their triple bottom-line targets.
Intermodal transport in fast-moving consumer goods industry (Colicchia, Creazza, & Dallari, 2017) **Combined model**: Green	The scenario-based estimation tool	• Proposing a scenario-based estimation tool of the potential demand for intermodal transport • The actual feasibility of the modal shift from road to rail
Modelling green and LSC (Helena, Kannan, Susana, & Virgílio, 2017) **Combined model**: Green	Linear programming model solved by eco-efficiency concept	• There is the trade-offs between 'geographic concentration with suppliers' and 'just-in-sequence': both oppositely affect environmental and economic performance • Not all firms can be absolutely lean or green • Model of integrated lean and green SC context without compromising its eco-efficiency
Robust model of lean & responsive for alternative risk mitigation strategies in SCD (Mohammaddust, Rezapour, Farahani, Mofidfar, & Hill, 2017) **Combined model**: Responsiveness	Empirical data from an automotive and robust optimization	• Considering several risk mitigation strategies • Proposed Path-based formulation which can be extended to handle different risk mitigation strategies.

Table 1.14 (Continued)

Problems	Methodolody	Contributions
Environmental benefits of the case of the aerospace sector (Ruiz-Benitez, López, & Real, 2017) **Combined model:** Green and resilience	Interpretive structural modeling Importance performance analysis	• Lean practices act as important drivers of resilient practices, while green practices appear as autonomous practices. • Lean and green practices improve environmental sustainability in the aerospace sector, which should adopt some practices such as value stream mapping, communication and information sharing with suppliers and enforced security.
Lean and green synergies (Lucila, Campos, & Vazquez-Brust, 2016) **Combined model**: Green	In-depth case study	• Lean and green synergies can emerge spontaneously • Introduce the concept of hybrid sourcing
Impact of lean logistics on greenhouse gas emissions SC (Gustavo, Jay, & Kevin, 2015). **Combined model**: Green	Simulation model	• Lean distribution of durable and consumable goods raised carbon dioxide emissions while lean retailing operations reduce process emissions • Application of product postponement practices increases capabilities
Lean, green and resilient practices influence on SCP (Govindan, Azevedo, Carvalho, & Cruz-Machado, 2015a). **Combined model:** Green and resilience	Interpretive structural modelling	• Conceptual interpretive structural model which links lean, green and resilient practices and SCP. • JIT (lean practice), flexible transportation (resilient practice) and '*environmentally friendly packaging*' (green practice) are considered very significant in interpretive structural model.

As can be seen in the table above, a popular hybrid model of lean is associated with green. The reasons for this are associated with the rise of recent environmental awareness. According to Dües, Tan, & Lim (2013), the similarity of the lean and green models is reflected in the goal of eliminating excess and waste, including TIM WOOD, in lean and environmental wastes in inefficient resource-use or scraps in green. Some authors studied lean-green modelling (Helena *et al.*, 2017), others focused on its performance (Thanki & Thakkar, 2018). Gustavo *et al.* (2015) and Colicchia *et al.* (2017) attempted to benefit from lean-green logistics. Furthermore, some papers extended this research direction by developing an LSC while considering sustainability and resilience. In particular, the conceptual model of LARG SC, proposed by the authors Carvalho & Cruz-Machado (2011), has attracted a lot of interest from researchers.

In short, articles conducted on LSCM strived to find measures to take advantage of the application of LM in SC. However, the scattered warnings about this LSC model still deserve attention. Kamalahmadi & Parast (2016) asserted that lean enhancements cause SCs to be more vulnerable to disruptions. Particularly, Bandaly, Satir, Kahyaoglu, & Shanker (2012) stressed that it is safer to employ multi-sourcing. One typical instance is the unexpected lightning strike in the Philips plan, a supplier of Nokia (employing multi-sourcing policy) and Ericsson (embraced with single-sourcing agreement) in Albuquerque, New Mexico 2004. The accident caused Ericsson a loss of $400 million and a production delay for a couple of months. Meanwhile, Nokia could immediately switch to other providers (Mohammaddust *et al.*, 2017). To cope with possible threats caused by JIT, these authors proposed to keep inventory buffers. Yet, in fact that the buffer availability cannot always mitigate disasters or unexpected events (Ruiz-Benitez *et al.*, 2017).

1.3.1.6 Lean Supply Chain Design

Most of the research on LSCD has been carried out recently with very few studies. Researchers have worked on conceptual frameworks of LSCD (Kazmane, 2018), or have developed web-based LSC (Yuan & Wang, 2013). The general point of these papers is the relentless attempts to reduce TIM WOOD (Chantarachalee *et al.*, 2014) by applying some LM in SCD (Singh, 2009). Recently, Nguyen and Dao conducted their study on optimizing the LSCD in the basic LSC (2016; 2017) and hybrid LA SC (2019; 2018) forms and solved by MH. The summary of the main SCD papers is presented in Table 1.15 as below.

Table 1.15 Review of LSCD literature

Problem	**Modeling**	**Contributions**
Model for design and development LSC strategy (Kazmane, 2018)	Conceptual framework	Decision support tool to design or develop SC strategies based on LSC
Optimize the design of LSC under disruptive risk (Nguyen & Dao, 2016)	Certain, static **OB:** Min SC TC **Variables:** nodes & arcs, quality shifted among tiers Constraint: facilities capacity, variables nature **Solution method:** pGA	Framework to design LSC with take into account the contingence plans to confront to under disruptive risk

Table 1.15 (Continued)

Problem	Modeling	Contributions
Designing LSCD through a case study (Chantarachalee *et al.*, 2014)	Real case study related to construction materials SC First, a value stream map, a deployment flowchart and a simulation model are presented to describe the case study. Second, a lean tool, the TIM WOOD, is used to analyze and redesign the SC configuration	Eliminate, combine, reduce, and simplify the technique (ECRS) New more lean scenario SC reduced lead time
Design of LSC for real estate operations (Yuan & Wang, 2013)	Developed information service platform, integrating logistics platform and fund flow platform Used Internet technologies	Improve the overall efficiency and core competitiveness of the real estate SC
SCD of an electronic industry using lean principles (Singh, 2009)	**Assumptions**: (tracked from original papers) **OB at strategic level:** Min SCTC **(**procurement, manufacturing, stockpiling and distribution costs) ensuring the min volume flexibility OB at operational level models: **Supply model:** Min TC (controlling raw materials, ordering, inventory holding, backorder penalty cost) **The production model:** min TC (manufacturing and stockpiling), subject to the constraints on customer service availability and the delivery flexibility. **Distribution model:** Min TC **(**controlling finished products inventory at DC involves inventory holding cost, ordering cost and backorder penalty cost) **Variables and constraints** (tracked original papers) **Solution method:** LINGO	LM implementation reduces per product costs considerably

1.3.2 Agile supply Chain

1.3.2.1 Agile supply Chain Characteristics

Agile supply chain (ASC), developed from AM, is "*an essentially practical approach to organising logistics capabilities around end-customer demand. It is about moving from SC that is structured around a focal company and its operating guidelines towards SC that are focused on end customers.*" (Harrison & Van Hoek, 2010) According to Mehdi, Behrooz, et Abbas (2017), the greatest advantage of ACS is that it has the capacity to respond swiftly to market changes and customer needs. Four distinguishing characteristics of ASC are: 1.) market sensitivity; 2.) a virtual SC; 3.) a network; 4.) process integration. Based on this author, *market sensitivity* is the capacity of SC in reading and responding to real demand, while *virtual SC* is the use of information technology to share data among members in the chain. Based on the information, virtual SC collaborations among partners link them as a *network*. *Process integration* is "*collaborative working between buyers and suppliers, joint product development, common systems and shared information.*" Sharifi, Ismail, & Reid (2006) showed that the agility of ACS is obtained from product design.

1.3.2.2 Product Design

Product design is "*an iterative and complex process, which includes defining, conceptualizing, and eventually commercializing a product into a new or existing market.*" (Chiu & Okudan, 2011) To concerning product design process, Gokhan, Needy, & Norman (2010) divided it into four phases as summarized below:

- Conceptual design phase: generate hypothetical design and product function alternatives.
- Physical design phase: determine general features and design specifications of the new products along with some prototyping.
- Detailed design phase: design component of product in detail and satisfactory functionality testing.
- Final design phase: test, finalize and document component and final product.

Pero, Abdelkafi, Sianesi, & Blecker (2010) determined that product design based on *platform commonality* (components are interchangeable, autonomous, loosely coupled, individually upgradeable and standardized interfaces) results in an ASC and inventory reduction for finished goods. Relevant to this, Huang, Zhang, & Liang (2005) used a generic bill-of-material (BOM) to manage product complexity by minimizing TC through platform commonality. BOM is a "*list of the raw materials, subassemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to manufacture an end product.*" (Wikipedia.com) According to Chiu & Okudan (2011b), the increasing of the *modularity* of product architecture improves the agility of the SC.

1.3.2.3 Product Design and Supply Chain Design

Fisher (1997) divided products into: 1.) functional (stable demand, low profit margin, and many competitors), and 2.) innovative products (newly introduced and differentiable products with versatile demand). Two product kinds are compatible with two types of SCs, namely LSC and ASC. Chiu & Okudan (2013) stressed that efficient matching of product types and SC models offer a high likelihood of success (see Table 1.16).

Table 1.16 Product type and SCM
Adapted from Vonderembse, Uppal, Huang, & Dismukes (2006)

	LSC	**ASC**	**LA SC**
Product Type	Standard product	Innovation product	Hybrid
Product design strategies	Maximize performance and minimize cost	Design product to meet individual customer needs	Apply modular design in order to postpone product differentiation for as long as possible

If both the product and the SC are newly developed, the design is considered a '*breakthrough*'; if new products are developed based on existing SC, it is called '*design for logistics*'; and this process is '*reengineering*' if a new SC is configured to match with current product attributes (Chiu & Okudan, 2013).

Baud-Lavigne, Agard, & Penz (2012) found that decisions in product design immensely influence SCD. Particularly, findings from Appelqvist, Lehtonen, & Kokkonen (2004) and Dowlatshahi (1992) remarked that approximately 70% of product cost and 80% of product quality are identified in the product design stage. There are two approaches to design them, the sequential and the simultaneous design. In the former, the SCD takes into account the decisions frozen from product design, which was accomplished in precedent step. This approach is widely used in industry and depicted in Figure 1.2, the SCM matrix of Taylor (2003). The latter has gained more attention in the two recent decades. The two approaches are compared in the study of Gokhan *et al.* (2010) as shown in Figure 1.8.

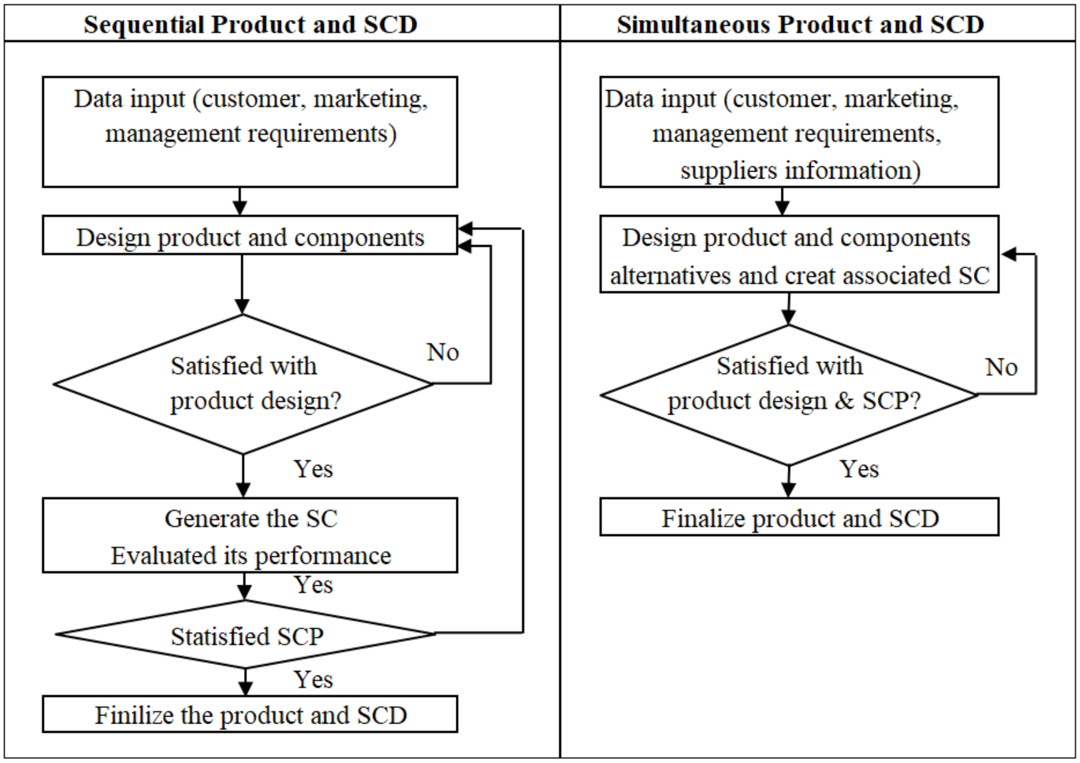

Figure 1.8 Process of sequential and simultaneous product and SCD
Taken from Gokhan *et al.* (2010)

Baud-Lavigne *et al.* (2016) compared the efficiency of these two approaches. They stated that "*a gain of 1–25% can be expected when the product family and the SC are optimized together*." The benefits of this integration have been noticed to "*provide better communication between design teams and operations groups,"* as well as *revealing that "potential SC risks can be highlighted before the launch of a new product."* (Chiu & Okudan, 2011b) Thus, they advised that "*product and SCD decisions should be integrated into the product design phase*".

1.3.2.4 Product Family Design and Supply Chain Design

Baud-Lavigne *et al.* (2016) realized the wide acceptance that mass customization, based on commonality in PFD, increases its variety at minimum cost. A product family is defined as "*individual products that share common technology and address related market applications.*" (Meyer, 1997) In the study of Baud-Lavigne *et al.* (2016), the BOM of a product family (master BOM or BOM) includes members of finished products which are made up from their semi-products (sub-assemblies or module) and common components. The semi-products may be composed of certain intermediate levels of sub- assemblies.

According to these authors, the challenge of PFD is identifying correctly the BOM of each final product member. Baud-Lavigne *et al.* (2012) proposed two ways to find the best product family for achieving market needs: 1.) using a generic BOM, in which the BOM is determined to respect assembly constraints, and 2.) fixed final products where the BOM are more-or-less flexible. Baud-Lavigne *et al.* (2016) considered three substitution possibilities among sub-assemblies in the flexible master BOM by using: 1.) standardization (reviewed), 2.) externalization (sub-assembly is bought directly from subcontractor), and 3.) alternative operating sequence/product decomposition, where *"other component assembly sequences can result in better commonality without necessarily changing costs.*" These substitution possibilities are demonstrated in Figure 1.9 as follows.

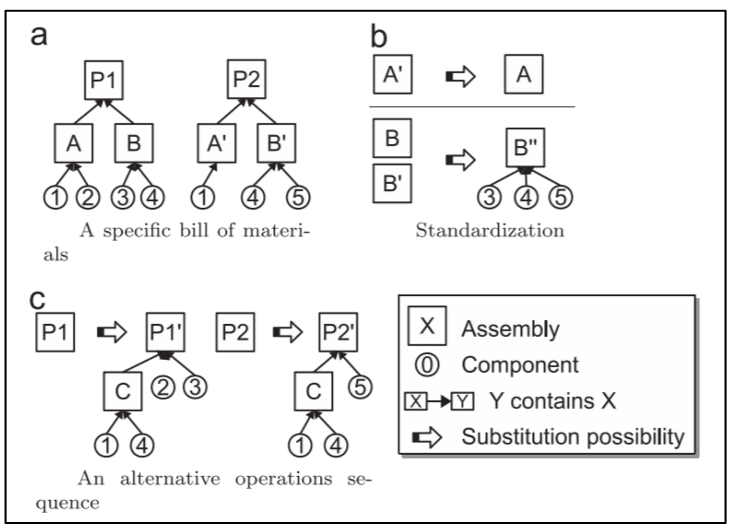

Figure 1.9 Substitution possibilities in a flexible BOM
Taken from Baud-Lavigne *et al.* (2016)

In this thesis, besides standardization, some other LM tools are considered in generating possible substitutions in the BOM.

The research conducted on concurring product design and SCD can be tracked on the series of Chiu and Okudan. Yet, Fujita *et al.* (2013) remarked that Chiu's studies often worked on individual products instead of whole product families. Baud-Lavigne *et al.* (2016) noticed that very few papers were conducted on simultaneous optimization of the product family and the SCD, a 'great challenge'. According to their study, the joint PFD and SCD is when "*a company creates a product family with a number of configuration possibilities. Within a product family, we need to know which possibilities (modules) are equivalent in terms of function and which are upgrades. This information may be difficult to obtain and sometimes not available*." Thus, this problem relates to the complex nature of both PFD and SCD, as well as the interaction between them. These authors depicted this joint problem, which is clarified in the paper of Toi, Sawai, Nomaguchi, & Fujita (2018), as in Figure 1.10.

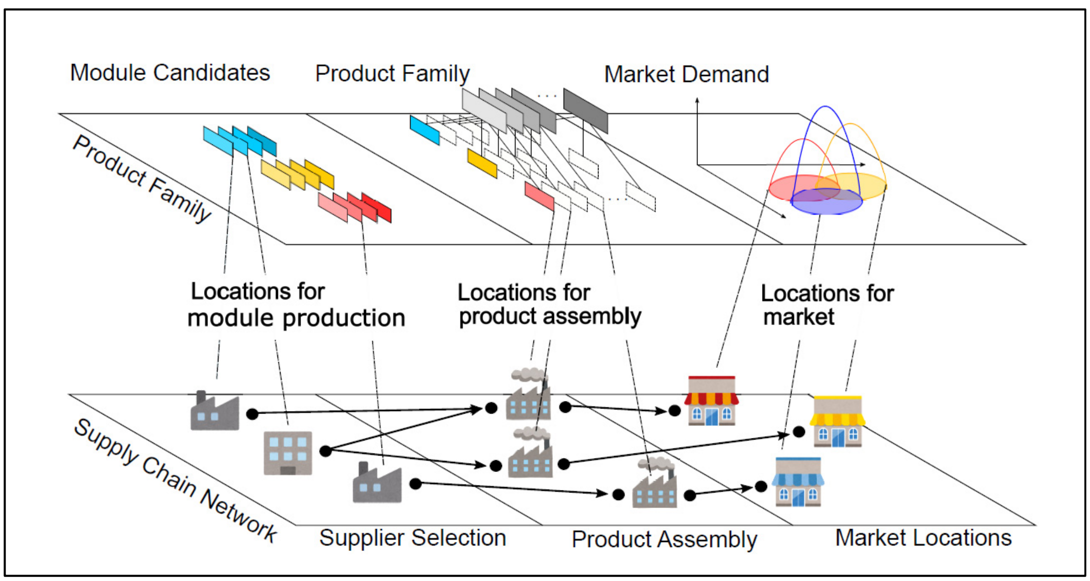

Figure 1.10 Integrated problem of product family and SCD

Taken from Toi *et al.* (2018)

The joint problem of product family and SC is explained as follows:

> The outline of the problem, which consist of two layers. The upper layer represents the contents of a product family. That is, a product is composed of modules with a fixed number of module slots, as shown in the middle part.

> Each variant is configured by selecting modules for the respective slots from their candidates, which is shown in the left part. They are targeted to various markets, which is shown in the right part. The lower layer represents the components of the SC. That is, sites of module production, product production, which can be assembly operations and product sales and geographically different and distant. How to connect them as a network is the strategy-level problem of SC configuration. It is not necessary to utilize all possible routes, and it is important to utilize cost-effective ones. These configurations must be strategically determined within various possibilities and restrictions. In the figure, module design and selection of module production sites, and product design and selection of product production sites are linked among these two layers respectively. That is, it is necessary to simultaneously solve the PFD problem and the SC configuration problem taking into consideration realization of product contents, the merits from commonalization of modules, flexibility in diversion of distribution network, etc. Fujita *et al.* (2013).

In the mathematical model of the mentioned simultaneous design, variable decisions are both the composition of the BOM and SC configuration. Researchers attempted various approaches to tackle the complex nature of this problem:

- Final products are determined but the BOMs remain more or less flexible as reviewed from Baud-Lavigne *et al.* (2016)
- Considering substitution through product transformation or virtual process (Baud-Lavigne *et al.,* 2016).
- Precisely each alternative is formulated as one decision variable, which considerably raised the number of variables (Chen, 2010).
- Designing several alternate BOMs, thereby identifying the optimal. This approach must work with full product configuration options (ElMaraghy & Mahmoudi, 2009).
- Using a genetic BOM for designing the best product family satisfying the markets' demand, as in the study of Yadav, Dashora, Shankar, Chan, & Tiwari (2008), Hadj-

Hamou, Aldanondo, & Lamothe (2003), Lamothe, Hadj-Hamou, & Aldanondo (2006).

In the problem of a joint product family and SCD, the MILP and MIP is the most used (see Table 1.17). The common objective function is still minimizing the TC with the best choice of the final BOM of a product family. Notably, almost all models are NP-Hard problems which are solved by MHs like TS (Khalaf, Agard, & Penz, 2011), GA (Toi *et al.*, 2018) or optimization softwares like CPLEX (Baud-Lavigne *et al.*, 2016) or LINGO (ElMaraghy & Mahmoudi, 2009). These studies often employed the numerical instances or industrial case studies as an experiment evaluation. The studies conducted on simultaneously designing product family and SC is summarized in the following Table.

Table 1.17 Previous studies of joint PFD and SCD

Problems	Methodology	Solutions and Contributions
Strategic-level robust optimal design method of product family and SC (Toi *et al.*, 2018)	MILP **OB**: Max profit (sales – (Fix cost of [equipment cost for modules/ products + product sales] + variable cost of [module production/transport + product production/transport])) **Solution method:** GA, a branch-and-bound technique, a simplex method. Case study of a coffee maker PFD.	• Mathematical framework by considering the optimal profitability and robustness against destructive incidences, also considering a quantity discount.
Optimization the simultaneous product family and SCD (Baud-Lavigne *et al.*, 2016)	MILP **Variables**: Composition of the BOM and SC **OB:** Min cost (procurement, production, and transportation costs) **Solution method:** CPLEX, Branch-and-bound for small instances; 2 new proposed heuristics based on LP rounding for large-sized instances Numerical instances	• Heuristics give better results than CPLEX. • The proposed method adequate for real problems. • Proposed approach allows simple inclusion of the substitution in most SCD models, without adding much resolution complexity.
Simultaneous design of module commonalization and SCD toward global product family Fujita *et al.* (2013)	MIP **Variables:** choice of modules, manufacturing sites for module production, assembly and final distribution **OB**: Max profit (sales – (Fix cost + variable cost) **Solution method:** GA and simplex Numerical instances	• Presented in details all conditions and assumptions for the problem for particular module. • Building up the mathematical model to optimize the global product family which takes into account the product family, platform and SCD issues.

Table 1.17 (continued)

Problems	Methodology	Solutions and Contributions
Simultaneous design of product family and SC considering lead time and modularity design (Khalaf *et al.*, 2011)	MILP **Variables**: Composition of the BOM and supply side of SC **OB:** Min cost assembly and supplying (of suppliers and producers) **Solution method:** TS Numerical instances	• TS results are stable, and very efficient • Defining the efficient BOM in which the final products correspond exactly to demand.
The impact of item substitutions on production–distribution networks for SC (Chen, 2010)	MIP **Variables:** supplier selection, plant location selection, and product allocation to product distribution, and BOM reconfiguration based on substitution possibilities **OB:** max (profit) Factorial experiments	• Considering substitution as product transformation. Each alternative is used as a decision variable (which results in the large number of decision variables).
Concurrent design of product modules structure and global SCD (ElMaraghy & Mahmoudi, 2009)	Integer linear programming **OB:** Min total cost (Procurement, Production, overtime, transportation, inventory (at plants, DC, in-transit) **Solution method:** LINGO Example of automobile wiper system	• New framework of concurrently PFD and SCD in which all alternative BOMs were analyzed to define the best. The model considered the currency exchange rates with fixed product demand transportation lead-time.
Selecting a product family and designing its SC by Interactive PSO (Yadav *et al.*, 2008)	Adopting Generic BOM **Multi-objective**: Min SC (Fix Cost [building of shipping channels + opening of resource lines + opening of facilities] + variable costs [manufacturing, storing, shipping]); Max profit **Solution method:** Interactive PSO approach, coded by C++ Wiring harness supply side	• Framework of model and solution methodology to achieve a trade-off. between SC cost and total sales profit • Enables to accomplish crucial pre-optimization decision making.
Optimal model for selecting a product family and designing its SC (Lamothe *et al.*, 2006)	MILP **Variables**: Composition of the BOM and SC **OB:** Min (operating cost of SC while choosing products variants) **Solution method:** Coded in C++, solved by SUN UltraSPARC Automotive case	• Proving that the optimal design of product family its SC through MILP model. • Possible to solve the problem in acceptable time. • Confirming the effect of Genetic BOM in solving such a problems of large diversity.
Simultaneous design of product family and SC for large diversity product Hadj-Hamou *et al.* (2003)	MILP **Variables**: BOM & SC composition **OB:** Total fixed of exist articles and facilities + variable cost of (shipping manufacturing, inventory and) **Solution method:** CPLEX Automotive wiring harness case	• Introduced the concept of 'Genetic BOM' which "*gathers the set of all possible packs in a single generic hierarchical tree*". • Can solve the PFD problem for large diversity.

1.3.3 Resilient Supply Chain

Aqlan & Lam (2015) realized that the tendency of using LM causes SC to be more susceptible to risks and vulnerability than before. Before the triple disaster in Japan in March 2011, enterprises seemed to underestimate or disregard the impact of SC disruption due to its rare occurrence Lim, Daskin, Bassamboo, & Chopra (2010). The catastrophe's aftermath and its domino effects suspended 80% production of Japanese automobile plants. Among the victims, Nissan emerged as a typical example of the RSC through the capacity to swiftly bounce back after the hit. At the end of 2011, Nissan not only recovered but also raised its production by 9.3%, whereas other firms across the industry dropped similar percentages (Schmidt & Simchi-Levi, 2013). Afterwards the catastrophe, businesses' perception of SC resilience changed sharply. In the World Economic Forum (2013), there were up to 80% of participants who said that resilience had become their top priority. Moreover, Brandon-Jones, Squire, Autry, & Petersen (2014) realized that RSC became one of the key issues of SCM. As Wicher & Lenort (2013), resilience is considered the counterpart of LM, mitigating the problems resulting from LM's implementation in risky or uncertain circumstances.

1.3.3.1 Risk and Uncertainty

According to Campbell (2005), risk "*equals expected damage*". Yet, after reviewing **risk** in chronological order, Jasti & Kodali (2015) found that risk is the concept frequently used with no consensus definition. In SC, risk is "*any risks for the information, material and product flow from the original supplier to the delivery of the final product for the end user,*" (Bandaly *et al.*, 2012) and is managed through contingency plans (Fahad, 2019). Although the risk is somewhat predictable, not all of them would be prevented or managed (Lahmar, Galasso, Chabchoub, & Lamothe, 2016).

With regard to *uncertainty*, Klibi et Martel (2012) identified it as "*the inability to determine the true state of the future business environment which may be partially known or completely unknown.*" Uncertainties can hurt SC to some extent from operational vulnerability to disrupting the whole chain (Snyder, 2006). Fahad (2019) differentiated between risk and uncertainty, in which risks' occurrence can be assigned a probability so that risk can be managed and measured. Otherwise, these traits are not clear for uncertainty. Aqlan & Lam (2015) calculated the risk of one event from its probability of occurrence and its impacts.

Huang, Chou, & Chang (2009) divided the impact of risk into devotional and *disruptive risks***.** The consequence of the former is limited, whereas the latter would disrupt the system's ordinary operations and cause its performance unpredictable. Another category of risk is given by Ravindran, Ufuk Bilsel, Wadhwa, & Yang (2010). For them, risks exist in two kinds: 1.) less frequent but having severe impacts, which were measured by value-at-risk (VaR), and 2.) more frequent at the supply level, with less damage to buyers or MtT. VaR is a globally accepted risk measure, while MtT is applied flexibly according to the criteria of the firms. According to Li, Wu, Holsapple, & Goldsby (2017), enterprises invest in risk prevention to improve resilience in their SC. Moreover, Ivanov, Dolgui, & Sokolov (2015) proposed two methods: 1.) proactive SC protection to prepare contingency plans at SCD stage, and 2.) reactive SC recovery policies to alleviate and recover SC at SCE level. Effectively investing in these measures allows resilience to become an SC's property through design Melnyk, Closs, Griffis, Zobel, & Macdonald (2014).

1.3.3.2 Resilience and Robust

There are many theoretical definitions of resilience specific to particular fields (Ouabouch & Amri, 2013). In SC, resilience was first coined by Rice & Caniato (2003) as the "*ability to react to unexpected disruptions and restore normal supply network operations.*" Brandon-Jones *et al.* (2014) defined RSC as "*the ability of a system to return to its original state, within an acceptable period of time, after being disturbed.*" Azadeh, Atrchin, Salehi, & Shojaei (2014) noted the main characteristic of resilience as the redundancy for managing scope-related risks. Mandal (2012) advized that SCD decisions must be considered to ensure simultaneous resilience and optimal operations of the system. As authors Melnyk *et al.* (2014) have noted, the terms 'robust' and 'resilience' are often used interchangeably. Wieland & Marcus (2012) defined robustness as "*the ability of a SC to resist change without* *adapting its initial stable configuration*"; a robust chain is able to withstand shocks, endures rather than responds, and retains the same stable situation characteristics. Christopher & Peck (2004b) claimed that the RSC includes the capabilities of resistance (robustness) and recoverability. It means an RSC is robust, while the reverse is not always correct. Inventory is a prime driver of robustness (Ivanov & Dolgui, 2018), which encompasses proactive redundancy (Aven, 2017). Therefore, the resilience is enhanced while robust and reactive decisions are integrated by combining mitigation and contingency policies (Rezapour, Farahani, & Pourakbar, 2017).

1.3.3.3 Lean and Resilience Trade-off

Presently, the relationship between lean and resilience remains controversial. The first side tries to highlight the conflict between the two models. Viewed through the lens of LM, redundancy from resilience is an expensive strategy (Birkie, 2016). Specifically, Garcia-Herreros *et al.* (2014) depicted this trade-off through three dimensions of inventory: cost, flexibility and the level of vulnerability (Figure 1.11); from which managers have to look for the balance.

Yet, Shah & Ward (2007) had an opposing perspective. They stressed that lean can be a good background for other strategies because it "*seeks the standardization of all types of processes, knowledge sharing and internal variability reduction."* Birkie (2016) emphasized the necessity of applying resilience in lean systems and the benefit gained from lean outperforms the cost of resilience; lean can function well in uncertain environments, being more fruitful in high-uncertainty contexts. This can explain the fact that in reality, many lean enterprises still maintain high inventory levels to cope with their SC's uncertainty (Sezen, Karakadilar, & Buyukozkan, 2012). According to Govindan *et al.* (2015a), JIT has limited power to enhance all SCP and it should be performed along with the resilient practices.

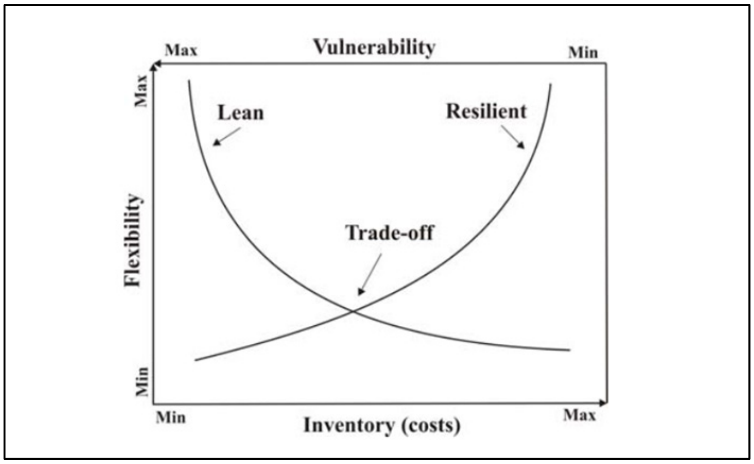

Figure 1.11 The trade-off between lean and resilience
Taken from Garcia-Herreros *et al.* (2014)

1.3.3.4 Resilience Supply Chain Management

Enterprises could benefit from long-term cost savings without a significant loss of efficiency from RSC (Shukla, Agarwal, & Venkatasubramanian, 2011). Ivanov & Dolgui (2018) determined that resilience is mainly driven by uncertainty prediction, SC restoration and reconfiguration processes. They addressed that SCD must considers both disruption propagation and recovery consideration to improve the robustness and recoverability, two sub-factors that contribute to resilience. From there, they presented the framework to build up RSC, both through proactive (to protect SC through contingency plans at the SCD stage) and reactive approaches (to recover SC by recovery policies from threats at SCE). The three main elements of the framework are: 1.) structure variety, 2.) process flexibility, and 3.) parametric redundancy (see Table 1.18).

Table 1.18 Framework on RSC design and planning
Taken from Ivanov & Dolgui (2018)

Structure Variety	Process Flexibility	Parametric Reducdancy
• Diversification • Decentralization • Location • Segmentation • Fortification	• Backup sourcing • Dual sourcing • Postponement and capacity pooling • Product substitution • Coordination	• Risk mitigation inventory • Advanced purchasing • Capacity reservation • Lead time reserves

a.) Structure Variety

Ivanov & Dolgui (2018) asserted that diversification and recoverability were the important drivers of RSC. In particular, Chopra & Sodhi (2014) found that centralization and decentralization influenced SC resilience and disruption risk management, thereby they suggested reducing concentration of resources and SC segmentation. They also found that the location of SCD positively correlated to disruption risk propagation. Basole & Bellamy (2014) tried to enhance resilience through defining healthy nodes in the system based on risk diffusion levels, and the number of functioning nodes. Li, Zeng, & Savachkin (2013) confirmed that the facility fortification can lessen the negative effects of disruptive risks.

b.) Process Flexibility

According to Ivanov & Dolgui (2018), building up flexibility though process redundancy helps enterprises to increase the resilience to adapt to dynamic environments. They gave the example of Toyota, about how this company invested in its supply-side through sourcing flexibility. Meanwhile, Rabbani, Yousefnejad, & Rafiei (2014) concentrated on backup suppliers with *capacity reserve* as well as a backup transshipment node in which the redundancy is given priority to serve demands of higher pricing (in case the prime supplier is disrupted). Others enhanced the resilience by using postponement in product to raise SC flexibility as in the review of Ivanov & Dolgui (2018). Moreover, *product substitution* and *flexible product families* under disruptions are considered as important measures to mitigate disruptive risks in SC (Kumar, Basu, & Avittathur, 2018; Yadav, Mishra, Kumar, & Tiwari, 2011). Other researchers worked on contract-based SC coordination with subcontractors or market disruptions like Gupta, He, & Sethi (2015), who studied contingent sourcing strategies under competition and possible disruptions.

c.) Parametric Reducdancy

Minigating inventory is one major driver of RSC (Kleindorfer & Saad, 2005). As mentioned by Schmitt, Kumar, Stecke, Glover, & Ehlen (2017), increasing inventories in raw materials and finished goods is a preventive way to better cope with disruptions from stochastic demands. The advanced purchase strategy recommended by Yin & Wang (2018) is referred to in high probability disruptions whereas the contingency purchase is referred to in case of low disruption probabilities. Concerning *capacity reservations* and *lead time reserves,* Ivanov & Dolgui (2018) stated that they could promote resilience, although they may hurt the efficiency of the system. Other proposals to build up RSC can be tracked in the study done by Tukamuhabwa, Stevenson, Busby, & Zorzini (2015), in which they summarized up to 18 proactive and 10 reactive strategies (see Table 1.19).

Table 1.19 Management resiliency-related proposals
Summaried from Tukamuhabwa *et al.* (2015)

Proactive Strategies	**Reactive Strategies**
• Appropriate supplier selection • Building logistics capabilities • Building security • Building social capital and relational • Co-operation • Creating appropriate contractual agreements • Creating public-private partnerships • Creating risk management culture • Increasing innovativeness • Increasing visibility • Inventory management • Knowledge management • Portfolio diversification • Supplier development • SC collaboration • SC network structure/design • Sustainability compliance • Use of information technology	• Building logistics capabilities • Building social capital and relational competences • Contingency planning • Creating redundancy • Demand management • Ensuring supply chain agility • Increasing flexibility • Increasing velocity • Supply chain collaboration • Use of information technology

In their comprehensive review, Ivanov & Dolgui (2018) constructed the cost structure for RSC corresponding to three levels of structure, process and control (see Table 1.20). This work was an important reference for this thesis while building on the LARG system later on.

Table 1.20 Costs of RSC design
Extracted from Ivanov & Dolgui (2018)

Analysis level	Resilient cost	Resilient costs on SC
Structure	Complexity	Decentraliation, Diversification, Localization, Segmentation
Process	Flexibility	Backup/Dual sourcing, Postponement Capacity pooling, Product substitutions, Coorditionation
Control	Redundancy	Risk mitigation inventory, Lead time reserves, Capacity redundancy

1.3.3.5 Resilience of Supply Side

Das (2018) summarized eight threats for which SC must build resilient countermeasures: 1.) single sourcing, 2.) global sourcing, 3.) supply delays, 4.) natural calamity accidents, 5.) tight interdependence, 6.) labour disputes, 7.) war and terrorism, and 8.) custom employee strikes. Notably, the first three of them relate directly to a resource base. Xu *et al.* (2015) stated that risk upstream might accumulate with time and propagate to the core enterprise in SC. Similarly, Schmitt *et al.* (2017) warned that the severe consequences of upstream disruptions can be escalated and outlasted throughout the system even though they might not be realized as swiftly as downstream. This highlights the importance of protecting this side as Turner (2011) found that up to 68% of SC risks originated from the disruption of key suppliers. Proposals to build up resilient sourcing network are listed in Table 1.21.

Table 1.21 Proposals to build up resilient sourcing network

Proposal	Notes
Multiple sourcings	• May increase purchase cost, but decreases the risk of production disruptions (Wicher & Lenort, 2013) • Multi-suppliers help the beef SC become more survivable (Jiang, Zhao, & Sun, 2009) • Single sourcing raises the ripple effect in SC (Ivanov, 2018)
Geographical concentration	• Lower cost of transportation and shorter delivery times, more flexible and have shorter delays and lower losses (Wicher & Lenort, 2013) • Suppliers in proximity location are referred.
Choose flexible supply partners, flexible supply base	• Help achieve improvement in all economical and operational performance thereby improving resilience (Melnyk *et al.*, 2014)
Supply base management	• Strategies for better managing suppliers (Melnyk *et al.*, 2014) • Guarantee in the supply contract, quality and reliability based supplier selection, supply location flexibility, spot buying, optimal selection and protection of suppliers by allocating emergency inventory (Das, 2018)

Table 1.21 (Continued)

Proposal	Notes
Emergency stock	• To cope with unreliable suppliers (Rezapour *et al.*, 2017)
Integrate supplier selection and risk mitigation strategy	• Select the reliable suppliers (Sawik, 2017)
Backup suppliers	• Lessens the storage in downstream (Ivanov, 2018)

1.3.3.6 Supplier selection

Purchasing plays a significant role in enterprises to ensure its viability in the long-term. This function impacts directly on a business' competitiveness (Tchokogué, Nollet, & Robineau, 2017) and performance (Foerstl, Franke, & Zimmermann, 2016). As Kumar Kar & K. Pani (2014), supplier selection refers to "*evaluate and select suppliers based on their ability to fulfill the organizations' requirements*." Borges de Araújo, Hazin Alencar, & Coelho Viana (2015) believed that selecting the right supplier helps the plant to meet their customers' demands. The supplier selection criteria are summarized in Table 1.22 as below.

Table 1.22 The supplier selection criteria in various management models

Models	Criteria
Traditional	Quality, delivery, performance history, warranties and claim policies, production facility and capacity, price, technical capability, financial position, procedural compliance, communication system, reputation and position in industry, desire for business, management and organization, operating controls, repair service, attitude, impression, packaging ability, labor relations record, geographical location, amount of past business, training aids, reciprocal arrangements (Weber, Current, & Benton, 1991).
Lean	Delivery, safety, and risk (El Mokadem, 2017).
Agile	Technology, services, research development, manufacturing capability, and flexibility (El Mokadem, 2017).
Resilient	Supplier's reliability, segregation of suppliers, backup supplier, surplus capacity of supplier, additional restorative capacity of supplier (Hosseini *et al.*, 2019).
Green	GHG, energy, life-cycle assessment (LCA) based, water (Banasik, Bloemhof-Ruwaard, Kanellopoulos, Claassen, & van der Vorst, 2018).
Sustainable	**Economic criteria:** initial price, financial stability, and credit strength **Social criteria:** discrimination in employment (age, religion, gender, and other similar factors), child labor, flexible working arrangements, satisfactory working environment, health and safety of the staff and customers, customer privacy, and cultural properties. **Environmental criteria:** environmental management systems for preventing and controlling pollution (such as emissions, effluents, and waste), resource consumption (energy, water, minerals), recycling, and animal rights (Molamohamadi, Ismail, Leman, & Zulkifli, 2013a).

1.3.4 Green Supply Chain

GSC is an emerging topic in coping with environmental problems. Fahimnia, Sarkis, & Davarzani (2015) worked on a pool of more than one thousand publications when reviewing this domain. They found that there are up to 22 different definitions of GSC which have yet to reach a consensus. Meanwhile, green supply chain management (GSCM) is identified as "*integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product its useful life.*" (Matani, Tripathi, Doifode, & Gowardhan, 2015) Srivastava (2007) divided GCSM into two categories, green design and green operations. The former aims at "*designing products with certain environmental considerations,"* while the latter is relevant to "*produce manufacture/remanufacture, usage, handling, logistics and waste management once the design has been finalized."* The author addresses the scopes of GSCM from reactive programmes to proactive practices through various *Rs* (Reduce, Re-use, Rework, Refurbish, Reclaim, Recycle, Remanufacture, Reverse logistics). As Jaggernath & Khan (2015), green initiatives should be "*considered in the initial phase of product design and raw material acquisition"* until disposal steps. Govindan *et al.* (2015a) used one green practice, the *environmentally friendly packaging* in JIT and resilient system, which strongly hugely impact on SCP.

In GSCM, a body of research focuses on minimizing embodied carbon footprints (ECF), a sustainable development indicator (Lindgreen, Swaen, Maon, Walker, & Brammer, 2009). This article recalled the definition of ECF as "*the measure of the total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."* These authors listed out some measurement methods of ECF so far. Additionally, many researchers were interested in sustainable transportation.

As mentioned by Dües *et al.* (2013), the similarity between the lean and green models is reflected in their goals of eliminating excess, TIM WOOD in lean, and environmental wastes in inefficient resource-use and scraps in green. The prime differences among lean, agile, resilience and green are enumerated in APPENDIX V, p.183.

1.3.5 Other Supply Chain Models

Another SC model, sustainable supply chain (SSC), is a topic that has shown an increase in interest. Martins & Pato (2019) found 198 papers related to SSC published from 1995 to 2018. Sustainable supply chain management (SSCM) results from the incorporation of the sustainability outlook in SCM, in which sustainability "*addresses the balance of economic, environmental, and social objectives*" (Moreno-Camacho, Montoya-Torres, Jaegler, & Gondran, 2019). The three mentioned elements are known as the 'triple bottom line' concept (Elkington, 2013). Barbosa-Póvoa, da Silva, & Carvalho (2018) found out the tendency and opportunity of SSCM conducted at a strategic level, especially in SCD. Other authors, like Chaabane, Ramudhin, & Paquet (2011) introduced the SCD where sustainability is taken into consideration. Presently, SSC is often studied in the hybrid form with other models, especially with lean, as shown in Table 1.14.

Some other SC models have also attracted a lot of interest from researchers in recent times such as responsible, flexible and smart SC. According to Vaaland & Owusu (2012), "*a responsible SC is a link of business actors who jointly adopt, implement and coordinate values, strategies and tactics in order to connect all levels of corporate social responsibility to the business processes in the chain*." Meanwhile, being flexible is emphasized as the ability "*to effectively respond to the changes in supply, demand and products.*" (Fayezi, Zutshi, & O'Loughlin, 2014) Specifically, a smart SC's operation is mainly based on an information technology (IT) platform; it is considered "*as a modern SC system emerging in response to the recent IT-initiated movements, such as the smart city, e-supply chain, IoT* (Internet of Things)*, or smart factory*" (Reaidy, Gunasekaran, & Spalanzani, 2015).

Yet, these models are out of this thesis' scope. Moreover, it is now often referred to as hybrid SCs, like LA and LARG SC, which are expected to respond better to the increasingly complex demands from the business market.

1.4 Leagile Supply Chain

1.4.1 Leagile Supply Chain Characteristics

The LA paradigm implements lean in fabricating products and switches to agile in distributing through **DP(s)** as depicted in Figure 1.12. DPs are "*areas that break down the production line to LM systems and AM systems.*" (Ebrahimiarjestan & Wang, 2017) This approach greatly improves production efficiency and satisfies the various demands of the end customer (Zhang, Wang, & Wu, 2012). As a result, numerous researchers have gotten involved in exploring and engineering LA SC. The characteristics of LA SC in comparison with LSC and ASC are presented in APPENDIX VI, p.185.

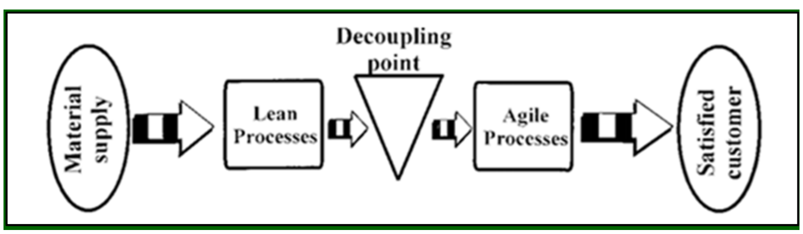

Figure 1.12 LA SC model
Taken from Mason-Jones *et al.* (2000)

According to Christopher & Towill (2001), LA SC can meet unstable demands and has the ability to absorb risks throughout the system. As Goldsby, Griffis, & Roath (2006) found, LA SC results from three outstanding traits: 1.) mixed-model approach in manufacturing (or Pareto rule), in which 20% of the products have stable demands which contribute to 80% of the revenue, is produced by LM. Meanwhile, the remaining 80% of anticipatory products should be fabricated in an agile manner; 2.) outsourcing temporary capacity to meet the needs of the peak and seasonal demands; 3.) postponement or delaying the final form of a product until customer orders are received. Based on the product structure in the Pareto rule, *this thesis names finished goods fabricated under LM as lean products and the ones produced by AM manners as agile products.*

1.4.2 Leagile Supply Chain Management Review

A reference on LA SCM is the summary of Eyüp, Metehan, & Huseyin (2015). They selected 17, 28 and 18 papers related to Lean, Agile and LA respectively thereby highlighting some main points in LA SCM as shown below:

- Researchers often use a comparative approach between three paradigms.
- Picking a case study or special subject in an approach style.
- Many researchers mentioned the leagility concept in SCM with different perspectives.
- Lack of a standard to create a structure of any SC paradigm.

Other remarks are given from the thesis' work:

- In the following years after being introduced, research conducted on LA SC was mainly theoretical exploration. Studies in this period often analyzed LA SC properties and compared it with lean and agile models like in studies of Mason-Jones *et al.* (2000) or Fan, Xu, & Gong (2007).
- From the conceptual models, some authors tried to apply LA SC into specific industry sectors such as housing (Li *et al.*, 2004), steel (Kumar, Maull, Smart, & Tiwari, 2006), or aeronautics (Moussaid, Aggour, & El Hassan, 2017).
- Like in LSC research, the automobile industry received special attention from LA implementation.
- In another direction, researchers worked on LA SC's KPI. Specifically, Virmani, Saha, & Sahai (2018) summarized the 12 main KPIs of the LA system. Some of these KPIs reflect the distinctive characteristics of the LA SC, such as *product variety* or *reconfiguration capabilities*. Particularly, *takt time* is deeply underlined.

The novelty and contribution of recent study of LA SCM is summarized in 23.

Table 1.23 Recent papers on LA SC

Problems	Methodology	Findings and contributions
Quantifying the degree of LA SC and assessing its impact on firm performance (Fadaki, Rahman, & Chan, 2019)	The partial least squares method Survey of 299 firms in Australia.	• Most companies adopt the LA SC rather than the lean or pure agile design. • Better performance is achievable when deviation from a balanced SC in which both aspects of leanness and agility are equally embedded is minimized
Inventory attributes in LA SC (Mukesh, Dixit, & Ashish, 2019)	Cause and effect diagram	• Lean and agile inventory attributes were found to significant effect on inventory attributes
Modelling the metrics of LA SC and leagility evaluation (Raj, Jayakrishna, & Vimal, 2018)	Using multi-grade fuzzy approach and AHP	• A conceptual model for LA SC metrics • LA SC has been selected as the best SC strategy comparison with lean and agile
Evaluating KPI of LA SC using fuzzy TISM (Virmani *et al.*, 2018)	Experts Fuzzy TISM MICMAC analysis	• The framework to evaluate KPI of LA SC which digraph to show relationship between various KPI's
LA index for SC Sustenance (Banerjee & Ganjeizadeh, 2017)	Conjoint analysis and optimized by SA.	• The index acts as a guide for sustenance model of SC. •
Analysis of enablers for the implementation of LA SCM (Haq & Boddu, 2017)	QFD integrated with Analytical Hierarchy Process Case study from the Indian food	• This approach is suitable to enhance the leagility of the SC • Exploiting the most influential enablers to achieve the desired leagility.
Adoption TOC achieve LA SC (Banerjee & Mukhopadhyay, 2016)	7-stepped approach to achieve LA SC DEA, design thinking process and nominal group technique Real case study	• Improving various parameters of leanness and agility over a period of one year. • Reducing rework, improving cash flow, reducing operating cost, reducing order backlog and better customer interaction
Leagility evaluation framework using fuzzy logic (Matawale, Datta, & Mahapatra, 2016)	Proposes a fuzzy overall performance index to assess leagility of the organizational SC	• Standardization of leagility evaluation methodology and adoption of new strategic technique for an organizational SCM • The fuzzy based leagility evaluation model can be effectively implemented
Achieving LA SC through a project management orientation (Gaudenzi & Christopher, 2016)	Case study	• Three steps are essential for approaching an implementation of leagility • The applicability of the DP and the essential role of a project management orientation in achieving LA SC
Assessment LA SC strategies (Rahiminezhad Galankashi & Helmi, 2016)	AHP and cycle view of SC	• New framework to evaluate the operational activities of LA SC

Table 1.23 (Continued)

Problems	Methodology	Findings and contributions
Development of a LA transformation methodology for product development (Lemieux, Lamouri, Pellerin, & Tamayo, 2015)	Intervention qualitative and transformative research Real project (2.5 years) in partnership with an international firm of luxury products	• LA transformation model for product development
LA SC model and performance evaluation (Jia, Yu, & Zhang, 2014)	DEA and performance evaluation index system of LA SC Case study	• Reference model to evaluate LA SCP
Evaluating leagility in SC (Vinodh & Aravindraj, 2013)	A fuzzy logic approach Case study	• Conceptual model to evaluate leagility • Product service level and mass customization are most important enablers
Evaluating performance metrics of LA SC (Ramana, Rao, & Kumar, 2013)	Fuzzy AHP Fuzzy logarithmic least square method	• Four-factor model with 16 items of the performance measurement of a LA SC • 'Responsiveness' is emerged as the most important enabler. 'Product development flexibility', 'customer satisfaction' and 'sourcing flexibility' may be considered as equally important enablers.
LA SC for apparel manufacturing (Miah *et al.*, 2013)	Case study AHP	• LA SC is best suited for the case • Responsiveness is the key factors for LA SC • Modular products and market information sharing is a vital point in order to improve lead time • SC must be informative by real time data.
RFID enabled LA SC (Visich, Qiannong, Faiza, & Huilin, 2012)	Competitive priorities RFID	• RFID technology can be used to create LASC
Evaluating reliability and validity of lean, agile and LA SC Indian constructs (Soni & Kodali, 2012)	Survey on database of 753 companies	• The proposed framework of lean, agile and LA SC in Indian manufacturing industry
Where • AHP: Analytical Hierarchy Process; • DEA: Data Enveloping Analysis; • QFD: Quality function deployment; • RFID: Radio frequency identification; • TOC: Theory of Constraint;		

1.4.3 Leagile Supply Chain Design

1.4.3.1 Decoupling Point

This point can be situated at different tiers in SC (Virmani *et al.*, 2018) as shown Figure 1.13.

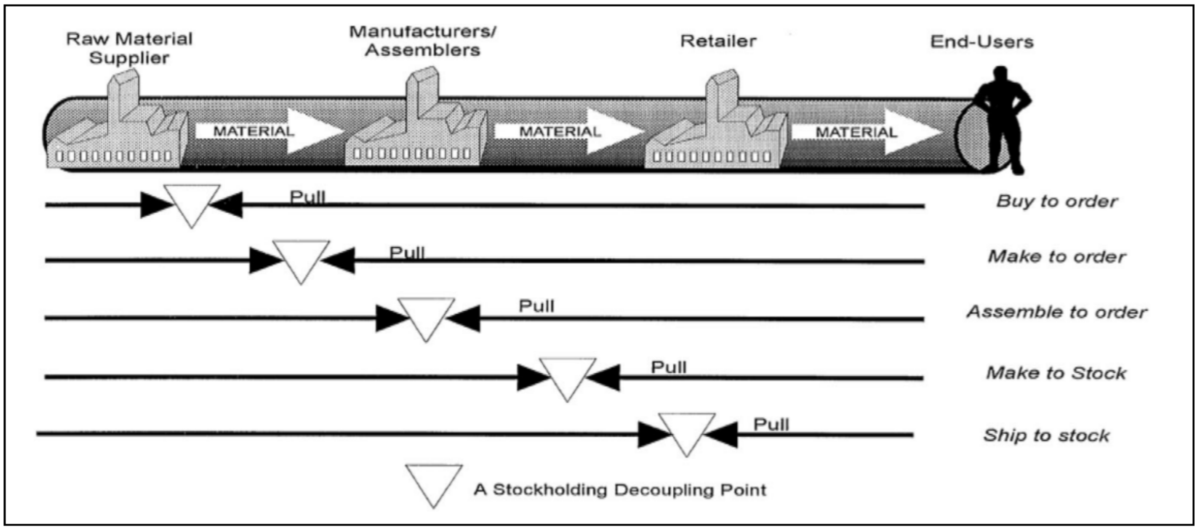

Figure 1.13 Possible placements of DPs in LA SC
Taken from Virmani *et al.* (2018)

Many researchers have suggested that DPs should be located near the end customer to minimize the delivery time to the customer (Chan & Kumar, 2009). Hedenstierna & Amos (2011) even affirmed that positioning DPs far upstream "*may be ill-advised ... as it passes demand variability directly to the physical SC, leading to excessive inventory and capacity requirements.*" Nonetheless, Olhager (2003) indicates that the best place for a DP is unstable, it is not permanently fixed but can be shifted upstream or downstream when factors like markets, product and production change. According to this author, placing a DP far upstream can reduce the stock while locating it downstream smoothens production. Table 1.24 summarizes the previous studies in both points of view.

Table 1.24 Effects of differnent DP

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

Multiplying the DP has been been taken into account. For instance, Wikner, Bäckstrand, Tiedemann, & Johansson (2015) located multi-DPs to increase the agility of the LA SC. However, related research is very limited.

1.4.3.2 Leagile Supply Chain Design

The definition and placement of DPs is an important task in LA SCD. The position of this point can be identified from two main approaches: 1.) a knowledge-based conceptual model—which was used by Naylor *et al.* (1999), and 2.) a quantitative approach as some can be seen in Table 1.23. Aktan & Akyuz (2017) summarized factors affecting the location of this point, which are related to market, product and process (see Table 1.25).

Table 1.25 Factors affect product design location
Taken from Aktan & Akyuz (2017)

Criteria	Factors effect decoupling position
Market related	Delivery reliability, *delivery time*, predictability of demand, order size, order frequency, product range, seasonal demand, product customization requirements, supplier commitment, pricing policy.
Product related	Holding cost, backorder cost, risk of obsolescence, modular product design, product structure, customization opportunities, product cost, product quality.
Process related	*Production lead time,* process flexibility, human resources flexibility, amount of planning points, equipment flexibility, position of the bottleneck.

As can be seen in the table above, the relationship between this point and product design is bold. Yet, based on our own studies, product design accounted for a very small proportion of LA SC literature. Nguyen & Dao (2019) introduced the framework to design LA SC considering PFD by using the so-called LA BOM. Other methods to define the best position of this point from previous studies are presented in Table 1.26.

In short, the LA SCD, especially in a quantitative approach, is still nascent based on the best of our knowledge. During the time, the LA SC is improved to adapt to new requirements from reality. In this direction, Banerjee & Mukhopadhyay (2015) suggested using information techniques, while others hybridized LA models with other strategies like resilience and green to form the LARG SC.

Table 1.26 Studies on definition DP in LA SC

Problem	**Methodology**	**Findings and contributions**
Optimizing the design LA SC (Nguyen & Dao, 2019)	pGA Numerical example	• New framework to optimize the design of LA SC. concurring product design and using LA BOM.
Positioning the DP along a SC (Aktan & Akyuz, 2017)	Demand with ANP (DANP) Fuzzy TOPSIS 0–1 goal programming Case study of a furniture components manufacturing firm	• New framework to demonstrate how the product-SC strategy matching can be performed; how to locate the DP.
Determining DPs in a using NSGA II (Ebrahimiarjestan & Wang, 2017)	NSGA II Algorithm OB: triple-objective of 1.) Min cost (production and product); 2. Min (delivery time to customers); 3.) Max (customer consistency) Numerical examples	• NSGA II has good performance when determining DP in a supply network.
A new approach for estimating LA DP using data envelopment analysis (Shahin, Gunasekaran, Khalili, & Shirouyehzad, 2016)	DEA approach Input- and output-oriented Banker, Charnes and Cooper methods 3 case studies	• Fuzzy DP and LA distance can provide the basis for distinguishing the two strategies. • Introduce concepts: decoupling distance and decoupling area.
New approach toward locating optimal DP (Rabbani *et al.*, 2014)	Hybrid fuzzy DEA/AHP method Case study of the food industries.	• The proposed method proved feasible in real case study when define DP.
Where • AHP: Analytical Hierarchy Process; • DEA: Data Enveloping Analysis; • NSGAII: Non dominated sorting genetic algorithm;		

1.5 Lean Agile Resilient Green Supply Chain

Since 2011, the Machado and Carvalho groups began to present a series of studies conducted on the complex LARG SC. First of all, Carvalho & Cruz-Machado (2011) investigated the possibility to merge the four models lean, agile, resilience and green into the hybrid LARG paradigm. Afterwards, they introduced the conceptual model of LARG SCM ((Cabral, Grilo, Puga-Leal, & Cruz-Machado, 2011b), its modelling (Cabral *et al.*, 2011b), the supporting IT model (Cabral *et al.*, 2011b), and the way to evaluate it (Espadinha-Cruz, Grilo, Puga-Leal, & Cruz-Machado, 2011). These works affirmed the important role of LARG as a strategic advancement towards the worldwide marketplace. Other authors are involved in this field by continuing to work on conceptual models on different aspects like decision-making (Cabral, Grilo, & Cruz-Machado, 2012) or analyzing the relationships between LARG SC and SCP (Esmaeel, Sukati, & Jamal, 2015). They also tried to apply LARG models in particular sectors like automobiles (Azevedo, Carvalho, & Cruz-Machado, 2016), or cement (Jamali, Karimi Asl, Hashemkhani Zolfani, & Šaparauskas, 2017). In particular, the risk management and optimization of this hybrid model has begun to raise concern recently (Amiri, Hosseini Dehshiri, & Yousefi Hanoomarvar, 2018; Rachid, Roland, Sebastien, & Ivana, 2017). Most of the above studies are exploratory studies by qualitative methods using many different management tools and illustrated through case studies. Table 1.27 summarizes the previous studies done in this field.

Table 1.27 Studies on LARG SCM

Problems	Methodology	Contributions
Optimal combination of LARG SC strategies (Amiri *et al.*, 2018)	• SWOT • SWARA • Game theory	• Most important criteria are business waste, quality and cost
Competitive strategies of LARG SCM cement industries in Iran (Jamali *et al.*, 2017)	• SWOT • SWARA • SPACE matrix	• Competitive strategies for LARG SCM cement industries
Application of LARG paradigm framework on China–Pakistan economic corridor (Azfar, Shahzad, & Mumtaz, 2017)	• Scenario planning in logistics case study	• Reduction in transportation distance and lead time in integrating and aligning LARG paradigm lead to optimum and synergetic results.

Table 1.27 (Continued)

Problems	Methodology	Contributions
Risk management approach for LARG SCM (Rachid *et al.*, 2017)	• Risk management approach • Academic case study	• LARG risk map
Making LARG SCM smart (Ghotbabadi, Gandaee, & Gandaee, 2016)	• SWOT • BI • RFID	• IT systems such as BI and RFID resolve the LARG SC problems and make it smart.
Theoretical integrating LARG models (do Rosário Cabrita, Duarte, Carvalho, & Cruz-Machado, 2016)	• Systematic approach to integrate the LARG principles in a BMC	• Theoretical foundations of LARG integration.
Benchmarking tool for improving automotive LARG SC (Azevedo *et al.*, 2016)	• Delphi technique • Case study	• Index incorporates LARG SCM.
Advanced manufacturing technology on LARG SC and SCP (Esmaeel *et al.*, 2015)	• Advanced Manufacturing Technology	• LARG SC contributed to achieving model excellence in SCP.
Influence of LARG practises on manufacturing (Azevedo, Carvalho, & Cruz-Machado, 2012)	• Literature review	• JIT and supplier relationships influence most SCP. • SCP is the most affected by inventory levels.
Decision-making model LARG SCM (Cabral *et al.*, 2012)	• AHP • Case study	• The LARG analytic network process model is an excellent tool for decision-making.
A model for evaluating LARG practises interoperability (Espadinha-Cruz *et al.*, 2011)	• Decision-theory AHP • Case study	• Method to analyze interoperability across SC.
Modelling LARG SCM (Cabral, Grilo, Leal, & Machado, 2011a)	• Cases diagrams • Class diagram • Information and communication technology	• An information model for a SCM platform to support LARG SCM.
An information model LARG SC (Cabral *et al.*, 2011b)	• Case diagram • Unified modelling language class diagram	• Information model to support the LARG SCM development • Conceptual model to identify relationships among practices.
Integrating LARG in SCM (Cabral *et al.*, 2011a)	• Deductive research approach. • Causal diagram	• Conceptual model of LARG SCM.
LARG divergencies and synergies (Carvalho, Duarte, & Cruz Machado, 2011)	• Empirical research • Causal diagrams	• Divergencies and synergies among paradigms in LARG SC.
Where • AHP: Analytical Hierarchy Process; • BI: Business Intelligence; • BMC: Business Model Canvas; • IT: Information Technique; • RFID: Radio frequency identification; • SPACE: Strategic Position and Action Evaluation; • SWARA: Step-wise Weight Assessment Ratio Analysis; • SWOT: Weighting strengths, Weaknesses, Opportunities and Threats;		

1.6 Research gaps

1.6.1 Gaps in Lean Supply Chain Management

After reviewing previous studies on LSCM and considering the antecedent research gaps left by other articles, the thesis highlights some remaining gaps and places them in the research streamline in Figure 1.1. Its snapshot is depicted as in Figure 1.14.

- Lacking research conducted on quantitative approaches.
- Yet to apply LM on entire SC.
- Missing the profound studies on implementing LM on SC at the design stage, thereby have yet to exploit the significant impact of SCD on SCP in SCE later on.
- Lacking contingency measures to protect LSC from risk and uncertainty.

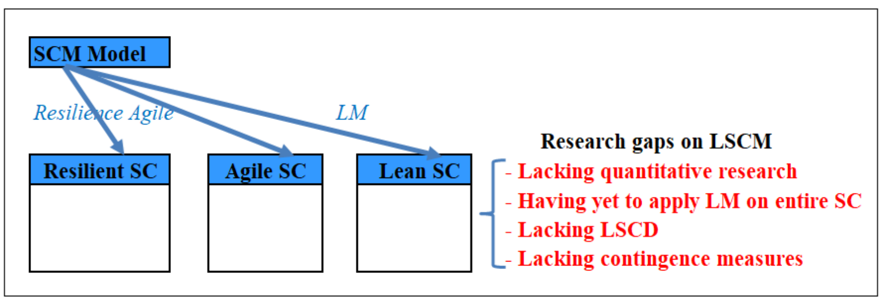

Figure 1.14 Research gaps in LSC domain

1.6.2 Gap in Leagile Supply Chain

Some research gaps can be withdrawn from the LA SCM (see Figure 1.15).

- Lacking study of LA SCD in quantitative approaches.
- Lacking the research on LA SCD joint with PFD.
- Lacking the study on multi-DPs.
- There are almost no risk studies on LA SC.

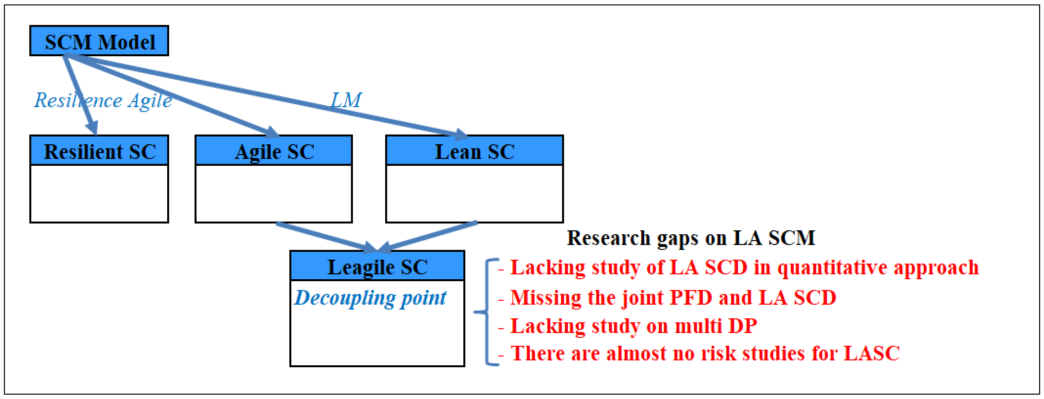

Figure 1.15 Research gaps in LA SC domain

1.6.3 Gap in Lean Agile Resilient Green Supply Chain

The main gaps in this field are listed in Figure 1.16 as below:

- Lacking of a LARG SCD model in a quantitative approach.
- Having yet to have the approach that develops LARG SC from LA SC.
- It raises the question related to the suitable MH approach for LARG SCO problems, especially in case the complex model LARG is designed in quantity approach.

These gaps in comparison with the mentioned research gaps are depicted in Figure 1.16, which drew out the whole picture of the main concentration of the thesis.

1.6.4 Discussion

As can be seen in Figure 1.16 the general gaps among the three models relate to SCD. SCD is an essential stage of SCM yet as mentioned by Leukel & Sugumaran (2013), major obstacles associated with the complex SC's nature and solving techniques have prevented researchers from conducting their studies in this field. Concerning LSC, during that time, more and more papers have been published on its design. Among them, from the review of this thesis, the work on complex hybrid Lean models accounts for a relatively small proportion of the LSCM literature. It should be noted that Toyota consumed 25 years to build up TPS (LM) in their shop floor. In today's fierce business competition, there are no companies that are willing to spend such a long time to implement LM in its SC. It highlights the importance of employing LM in the beginning of SCM, at the design stage.

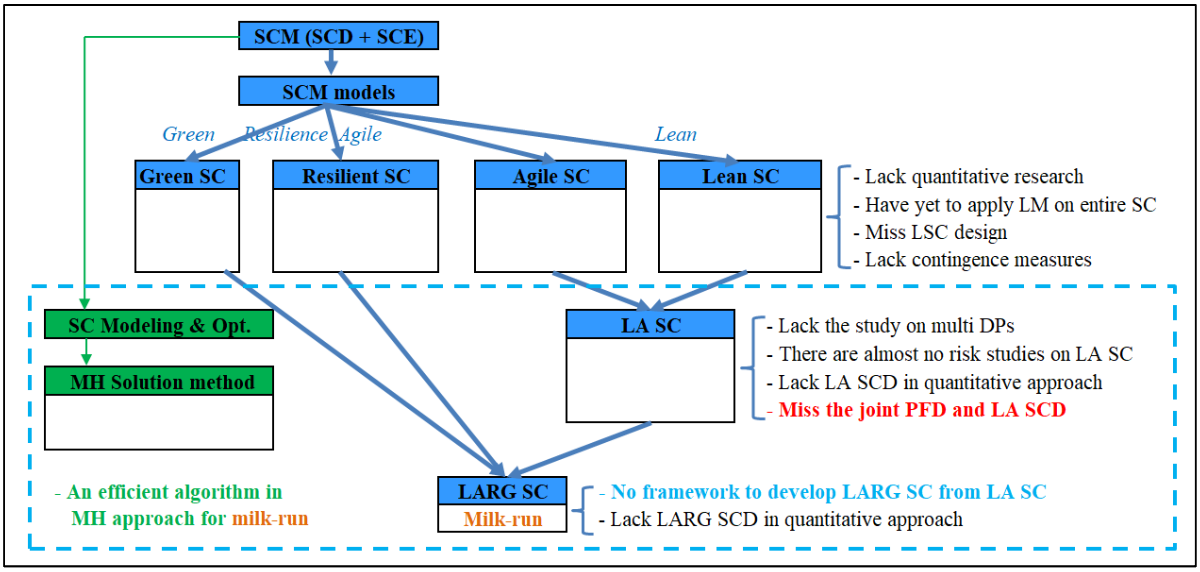

Figure 1.16 Defined research gaps in need to be fulfilled in the thesis

After conducting a review, the thesis is strongly inspired to pursue the lean subject with the affirmation of Shah & Ward (2003) that lean can be a good background for other strategies. Also, these defined gaps motivate the thesis to follow the main stream of LSCM development. It begins from the basic form for LSC, going through to LA, and then working on current popular hybrid LARG models. This direction also stems from the fact that companies cannot easily build up an advanced LARG model without preparatory steps. This roadmap with such bold milestones of LSC and LA SC may be a reference for enterprises who are in different positions on their road of pursuing lean.

Among the gaps in pure LSC, this work evaluates the gap in "*missing the LSCD*" with the most significant one as SCD playing a key role for SCE and SCP. Lacking its consideration, the LSC may miss opportunities to take advantage of SCD optimal decisions. Combined with other gaps, this thesis attempts to design LSC in a quantitative approach to first establish the foundation for hybrid models hereafter and partly cover the gaps in LSC.

The review on LA SC showed that researchers are still conducting exploratory research to understand more about this model. Once something new in LA SC is discovered, it is often compared to LSC and ASC. Similar to LSC, LA SC lacks the design in the quantitative approach and also absents risk management. Although researchers have made many efforts to increase the agility of the system, the opportunities to amplify the agility through multi-DPs is scarcely discussed. Another gap in this domain is related to the missing product design and the PFD in LA SC. This joint design is also nascent even though the product design greatly affects the agility of the system.

It is worth noting that the failure rate to launch a new product to the market is very high even though it varies among industrial sectors. Joan & Julie (2011) cited that "*about 75% of consumer packaged goods and retail products fail to earn even $7.5 million during their first year,*" and "*less than 3% of new consumer packaged goods exceed first-year sales of $50 million—[which is] considered the benchmark of a highly successful launch.*" However, some authors in Table 1.17 like in Toi *et al.* (2018) or Khalaf *et al.* (2011) conducted the the joint design with the assumption that the demand for new products is known. Notably, according to Lonny (2017) "*it's safe to settle (this failure rate) on about 80%.*" This raises questions about the practicality of the assumptions and the applicability of the findings. To avoid the huge uncertainty from a new product launch, the thesis applies the method of Chiu & Okudan (2011a), which defined the joint design of product and its SC based on the unit cost of the new product instead of the market demand.

These encouraged the thesis to develop the framework of simultaneously design product family and its LA SC in Chapter 3 to partly cover up some research gaps in this field. Especially, the gap of lacking risk management is coped in the hybrid LARG SC of the following work. Following the suggestions from previous studies, this thesis picks up a real case study from the furniture industry, to demonstrate the proposed framework.

Another hybrid LSC is the LARG SC, which combines the most recent advanced SCM models. The literature review in this area shows that researchers tried to find a method to harmoniously combine the four models into one complex model. Similar to LA SC, most studies conducted here are exploratory research which misses the framework to design the LARG SC. Also, there is yet to be a paper that delves into the possibility of the development of LARG from LA SC while joining with PFD. Therefore, this thesis attempts to present a new framework to optimize the design and then the management of the LARG model in this direction based on the novel-proposed LA SC.

The sourcing side of the LARG SC, in this case, is consolidated in their milk-run delivery. It generates the work confronts the NP-complex problem of the milk-run optimization. Thus, before solving the problem of LARG, an effective technique of MH approach is prepared in advance. Trailing the development of the MH approach and its application in SCO, this thesis proposes a new HMH of ACO and TS, namely HAT, in the expectation that it has the capacity of overcoming these MHs in solving the milk-run. The new HMH is then qualified in one milk-run of the small-scale case study of Miao & Xu (2011) which was solved by ACO. HAT is then validated through random data in a large size milk-run by comparing its solution with the ones of ACO, TS and LINGO. Realizing the shortcomings of MH and HMH in solving the milk-run in small scale problems, this thesis extends this work to complete a plausible framework to optimize milk-run problems. The main content of this work is presented in Chapter 4 which attempts to optimize the milk-run by new HMH.

After the solution method HAT is validated, it is used to optimize the mentioned milk-run in LARG SCD model. It partly contributes to the final optimal solution of the given problem from the case study. The whole effort is detailed in Chapter 5, optimization of the LARG SCM.

Chapter 1 has reviewed supporting background for LSCM. The following chapter 2 will present methodology of the thesis.

CHAPTER 2

RESEARCH METHODOLOGY

2.1 Proposed Methodology

These five predefined objectives corresponding to the five RQs formed a solid base in developing this thesis. The 5-step research methodology is outlined in Figure 2.1 and used to achieve the objectives mentioned in previous chapter. Each step here is deployed systematically through the inheritance of the LSC literature review and new findings from previous steps.

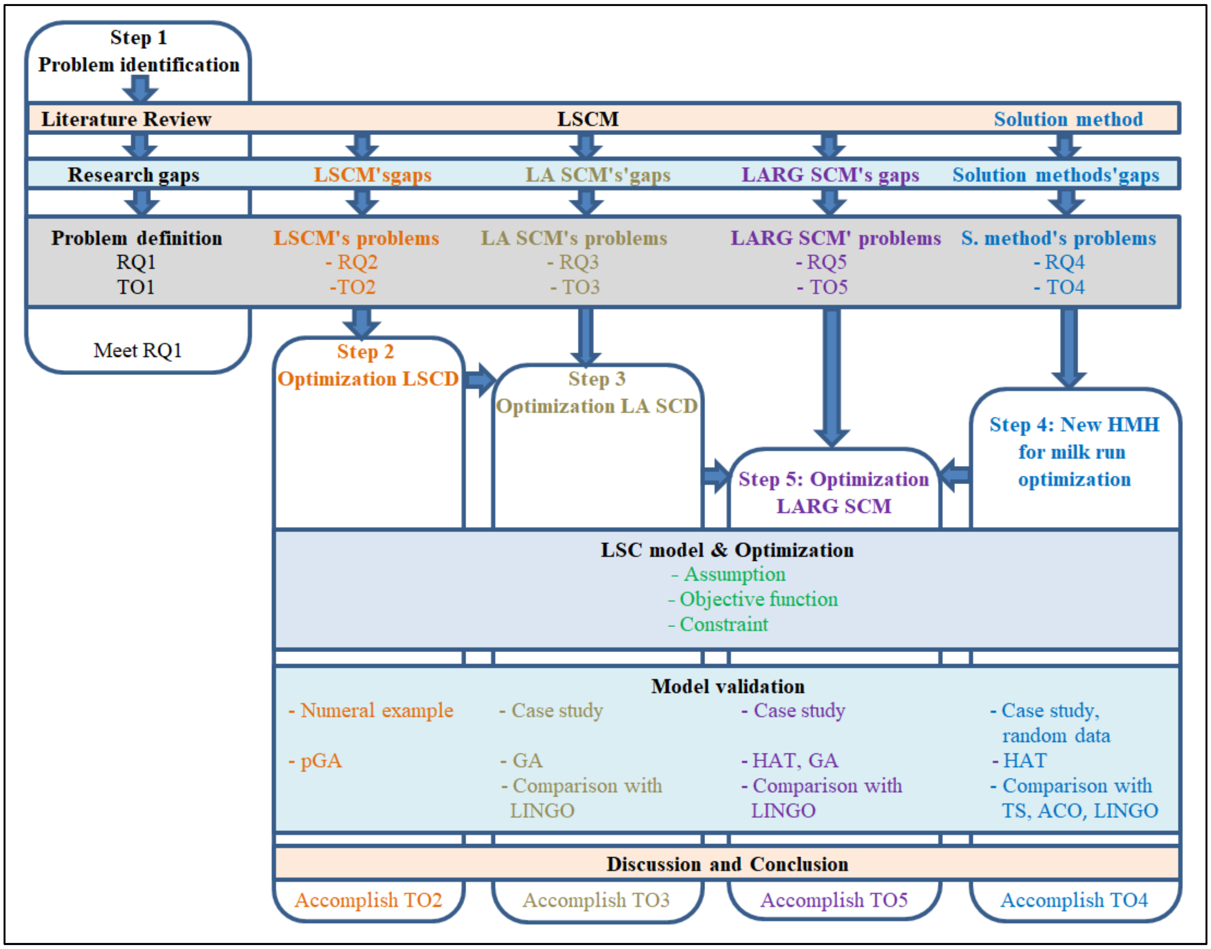

Figure 2.1 Methodological approach

The 5-step methodological approach in Figure 2.1 is detailed as follows. **Step 1,** namely *Problem identification,* defines the possible opportunities of the domains to roughly assess the prospects of this work. After receiving very encouraging signals, it begins to conduct a systematic literature review on the LSC model and the supportive solution methods. Once research gaps are defined, this stage sets specific research goals as well as raises research questions for further works. Following the research flows, **step 2** plans to study the *Optimization LSCD* which presents the new framework to design the LSC system. Afterwards, in **step 3**, the procedure of *LA SCD Optimization* is introduced. The last stages deal with the *LARG SC Optimization* in which one HMH is prepared (**step 4**) to serve the proposed models (**step 5**). Each mentioned step contributes to the achievement of the corresponding research objectives. The following sections present the methodology proposed for future work.

2.2 Optimization of Lean Supply Chain Design

This work paves the first steps for building the hybrid LSCM by proposing the framework to design the LSC. It attempts to fulfil the defined objective TO2 through answering RQ2.

2.2.1 Purpose and Context

Purpose: Introduce a new strategy to optimize LSCD by MH on a quantitative approach.

Context: For entrepreneurs who want to start their business in small or medium-sized ventures with one pilot product, lean may be a preferred approach that helps lay the groundwork to gain benefits from LM. Although lean may be an inspiring strategy, most previous studies in this field are focused on the transformation of current SCs into LSCs by qualitative methods at certain shop floors in the SCE. Thus, the proposed approach here concentrates on the optimization of LSC in the design stage, expecting to take advantages in the long term from optimal decisions made from LSCD steps.

2.2.2 LSCD Modeling and Optimization

a.) Assumptions

Designers had collected sufficient information for SCD. The SC facilities one product in single period. The capacity of suppliers is unlimited. Single sourcing policy is applied.

b.) Objective Function

In the design procedure, using a dual lean filter is proposed to eliminate waste from both the SC structure and function. Particularly, the work first utilizes the SCOP model in the literature review to outline the sketch SC considering all options for candidates. Subsequently, it is simplified by dual lean filters which wipes out waste from the SC structure and operational activities along and across the chain. These works are formulated into a mathematical model when the objective is Min LSC TC. From the SCOP model, the SC TC is comprised of elements as below.

$$SC\ TC = Cost\ (Purchasing + Production + Transportation + Inventory) \quad (2.1)$$

When transformed into LSC, the inventory cost is crossed off and other cost components are also simplified. The new LSC TC yields:

$$LSC\ TC = Cost_{Lean}\ (Purchasing + Production + Transportation) \quad (2.2)$$

The approach also examines the simplification of the chromosome, which encodes the SC structure by pGA during the transformation from the sketch SC to LSC.

c.) Input

The LSCD framework is demonstrated by a numerical example and solved by pGA, programmed by MATLAB. Its transformation is depicted in Figure 2.2.

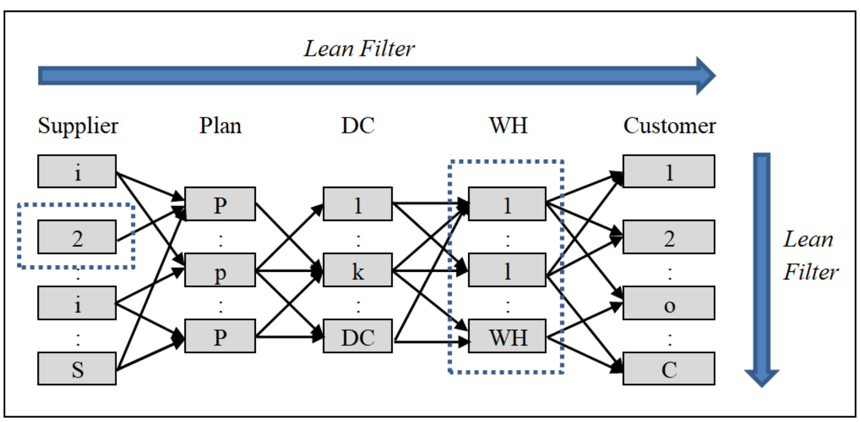

Figure 2.2 LSC transformation

d.) Output

pGA returns the best choice of facility selection (plants and distribution centre—DC) and shipment quantity of items among adjacent echelons, which contribute to the min LSC TC.

e.) Constraint

The model is the multiple-level facility location-transshipment as described in example of Chopra (2004) in literature review. Thus, all the constraints from Eq.1.2 to 1.8 in Chapter 1 must be respected.

2.3 Optimization of Leagile Supply Chain Design

2.3.1 Purpose and Context

Purpose: The proposed methodology aims at optimizing the design of LA SC, which is concurrent with the PFD.

Context: Recently, businesses confront fiercer competition from the saturated market, the ease of accessing real-time information, and the desire to own products of personal preference. These conditions force businesses to compete against each other across many factors such as low prices, responsiveness or capacity for customization. As reviewed before, solely applying lean or agile strategies has yet to be proven sufficient in order to adapt to such requirements. Thus, once Lean is achieved, entrepreneurs should pursue LA SC. This work proposed one joint design product family and SC in which the agility of the system is amplified from both DP and from product design through the flexible LA BOM. In this circumstance, the success of launching new lean products triggers the design of new agile product family in order to introduce to other markets.

2.3.2 LA SCD model and Optimization

Generally, this work belongs to the *design of logistics*, which designs new product families for the current LSC assuming is the one designed in precedent work. This work is built up based on these assumptions as shown below.

a.) Assumptions

Assumptions for product family

i. A unique product family XYZ is concerned.
ii. The product architecture is modular, which includes 3 levels: component, sub-assembly (semi-product) and product.
iii. Each function of the product is performed by a component.
iv. The product family will include one lean product, (which is fabricated by MTO and sent directly to customers). The rest of the whole family is AM products, which are produced under MTS and their sub-assemblies stocked at DP.
v. The agile products are designed once the new lean sample has launched successfully.
vi. The BOM of the lean product is designed under certain LM principles. From then, the number of agile products in this family are developed based on the common platform.
vii. The functions of each agile product are already pre-defined while its structure contains open options (flexible BOM).
viii. The new products must respect the given cost and lead-time range.

Assumptions for SC

ix. The existing LSC, which was designed and simplified through dual lean filters, single sourcing and the use of flat hierarchy, is modified to adapt the new product.
x. The SC considered here include the suppliers, the assemble center (plants), final assemblies (or DP, which can be located at DC or plants) and DC.

xi. Single sourcing policy is applied.
xii. Each plan has its own sourcing network.
xiii. The capacity of suppliers is unlimited.
xiv. Each factory has the capacity of producing all kinds of sub-assemblies and finals products.
xv. The direct shipment is used for two adjacent nodes with variable transportation cost.
xvi. DP can assemble all kinds of products.

b.) Objective function

The product family is represented by the so-called LA BOM, in which components bear the characteristics of both lean (as they are simplified by lean tools) and agile (with greater possibilities of combinations). This flexible LA BOM is allocated to the current LSC through the assignment of product elements to SC facilities. The procedure of optimizing the joint design also takes into account the placement of the DP based on production lead-time and the delivery time committed to customers. Following the method of Chiu et Okudan (2011), the problem is formulated into a binary integer programing (BIP) with the objective function of Min LA SC TC (called TC). The TC is made up from three cost elements of processing, transportation, and inventory costs (of sub-assembly at DP under the concept of postponement). The DP also incurs another expense, the customization cost, which belongs to processing. The LA SC TC at the strategic level yields:

$$\text{LA SC TC} = \text{Cost (Processing + Transportation + Inventory)} \tag{2.3}$$

The model is solved by GA, programmed by MATLAB and validated by the optimization software LINGO.

c.) Input

A real case study in furniture is used to demonstrate the approach, in which a 5-item product family is designed and fabricated through the current LSC designed in the previous stage. The functions of each product are pre-defined. Also, the sketch BOM of the family are prepared. The procedure of joint design product family and LA SC is presented in Figure 2.3.

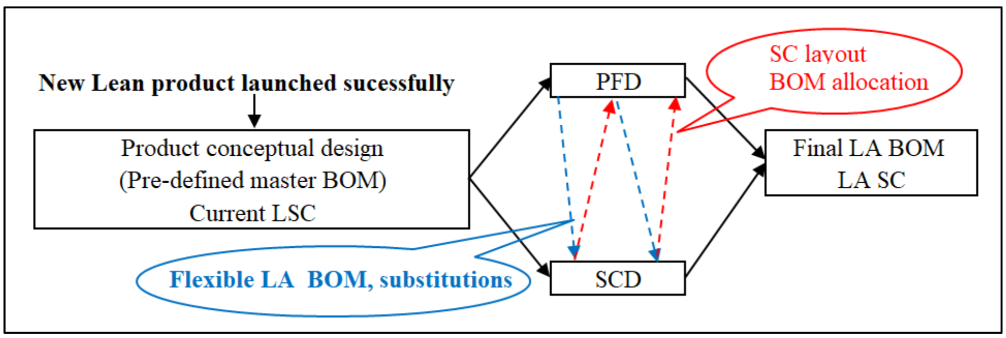

Figure 2.3 The procedure of joint design product family and LA SC

d.) Output

The outcome of this work is the best LA BOM (the structure of final agile products in the family), the optimal selection of product allocation to LA SC.

e.) Constraints

i. Any finished product must be assembled exactly as required for its functions
ii. Respect the delivery time as a commitment when introducing agile products.
iii. Single sourcing
iv. There is one DP only on the flow of a product
v. At least one plant is assigned to produce product
vi. The cost of a new agile product does not exceeds a given limit
vii. Binary varablies

f.) Model Validation

LINGO is used to qualify the results given by binary integer programming (BIP) and GA.

2.4 New Hybrid Meta-Heuristic to Optimize Milk-run Delivery

2.4.1 Purpose and Context

This work is developed in the efforts of finding one promising solution method to optimize the LARG model and satisfy TO4 by responding to RQ4.

Purpose: Forming a practical HMH, which enables to optimize the milk-run problem in the LARG SCD model in the thesis. Precisely, the HMH HAT is developed from ACO and TS.

Context: Milk run delivery is quite a popular transportation mode in small region LSCs or in sourcing networks where the LM tool, namely *geographical concentration,* is applied. The goal of using a milk-run is to minimize SC TC and reduce the amount of CE by consolidating the logistics network into milk-runs. Defining the shortest route for a milk-run is the typical form of the well-known NP-complete problem which was solved effectively by the MH approach. Previously, some MHs were utilized for milk-run, even in small-sized LSCs. Nevertheless, in small scales, MH hardly offers global optimization, while in large cases, the exact method becomes infeasible due to the unacceptable processing time. Thus, it was necessary to find a method to successfully solve this problem, which covers the problem of milk-run size. In particular, this thesis proposes MIP or exact solver to cope with small-sized and HMH HAT for large scale milk-runs.

2.4.2 Hybrid Ant Colony-Tabu Search Model and Optimization

a.) Assumptions

i. The members of the SC locate in relatively small region which can be consolidated in one milk-run.
ii. The production pace (from plant and suppliers) is synchronized with the milk-run's.
iii. The type of truck is pre-selected.
iv. Factors distracting the milk-run are excluded (the LSC function in certain environments).
v. All milk-run deliveries are on time as scheduled and no penalty is taken into account.

b.) Objective function

The objective function of a milk-run is to establish the lowest cost of a LSC which comprises the shortest route and optimal delivery frequency. The milk-run problem was once introduced by Miao & Xu (2011) and solved by ACO with a near optimal solution. However, this thesis endeavours to develop an ACO-based HMH that can optimize the milk-run with better solutions. After trying to hybridize with various algorithms, TS was finally selected as a suitable candidate. The proposed HMH HAT used ACO to generate the initial solution in Tabu lists instead of using random selection. The case study by Miao & Xu (2011) was re-used to qualify the new HMH. In this case, the mathematical model of the LSC is inherited from these authors, in which the objective function is to minimize LSC TC as follows:

$$LSC\ TC = Cost\ (Production + Transportation + Inventory) \tag{2.4}$$

The variables here are the milk-run route and its delivery frequency, in which the distance of the milk-run is proportional to the TC.

c.) Input

In small sizes, the HMH is qualified by the data from the case study of Miao & Xu (2011). The LSC in this case is made up of nine nodes including one core plant (R), three suppliers (S) and five customers (C) as shown in Figure 2.4. In a large case LSC (up to 200 nodes), MATLAB generates the random data of the milk-run geographical distribution.

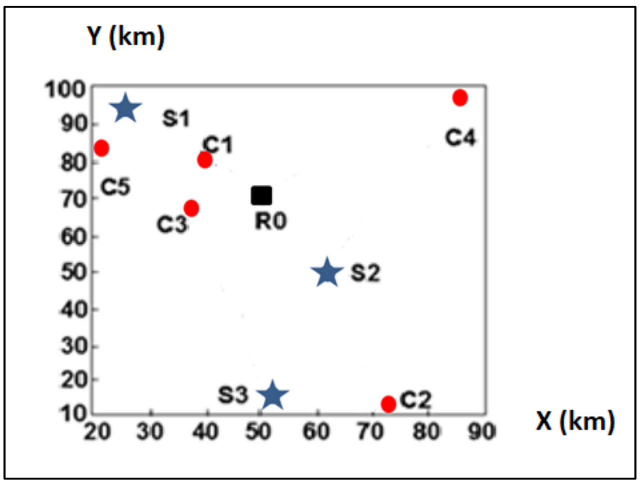

Figure 2.4 Case study's geographical location

d.) Output

The HMH HAT was programmed by MATLAB. The output is the shortest distance of all the possible milk-run routes. Once the best milk-run route is defined, the milk-run delivery frequency is computed to satisfy the shipment requirement in the network. The two outcomes of this approach are: 1.) the new procedure of HAT, and 2.) the novel approach of optimizing the milk-run for both small and large-sized LSCs. In point 1, the new procedure outperforms ACO in identifying Min TC in a small-sized LSC. In the large scale, MHM overweights both ACO and TS in finding the shortest milk-run LSC and outstripes LINGO in terms of CPU time. In point 2, MIP or exact solver are employed to deal with the small case and HAT is preferred to cope with large scale milk-runs.

e.) Constraints

i. Each supplier or customer visits once only
ii. Each supplier or customer is included in one path of one milk-run
iii. Delivery frequency of each supplier or customer in the same path is equal
iv. $n \in$ integer and $n>0$, $dr>0$
v. Delivery capacity constraint (weight restrictions):

f.) Model Validation

The new HMH is validated through an available case study. Their results are then compared with the one obtained from mix integer programming. In large scale milk-runs, HAT is qualified in comparison with two meta-heuristics ACO, TS and software LINGO. Sensitive analysis is also applied to qualify the newly proposed technique. The work also considers the applicability of HAT in one logistics company in Canada.

2.5 Optimization of the Leagile Resilient Green Supply Chain

2.5.1 Purpose and Context

This work aims at building up the LARG SC as pre-defined TO5. It extends the framework of joining PFD and LA SCD by merging some green and resilient practices in this model in both design and execution stage.

Purpose: Propose the framework for LARG SCD and SCE.

Context: The LA SC can offer numerous competitive advantages to the business. Yet, to reach higher competitive advantages toward global markets, entrepreneurs have to develop more value from environmentally friendly images while being able to cope with the lurking dangers. This work prioritizes to employ both green and resilient practice in the supply side from the joint design product family and LA SC to the execution stage later on. The framework of LARG SCM is depicted in Figure 2.5.

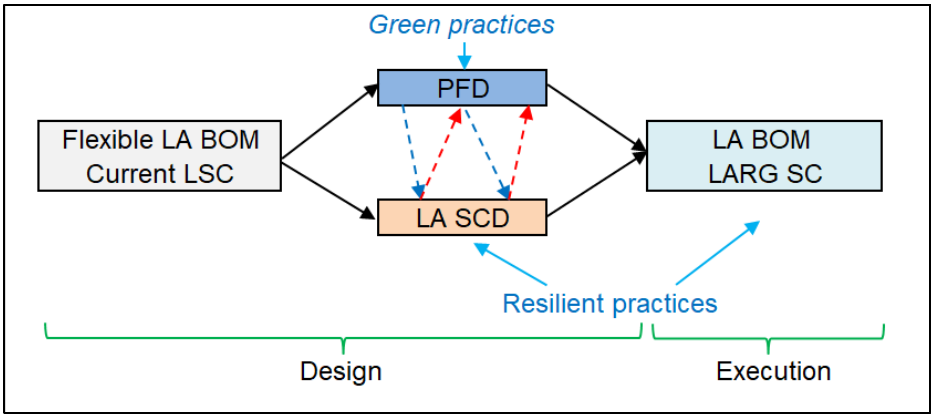

Figure 2.5 The framework of LARG SCM

2.5.2 LARG Model and Optimization

Inheriting the above-noted models, this work begins at the PD process by adding certain suitable green elements into LA BOM. This new BOM is then considered in the supplier selection besides the reliability's supplier (through MtT values). The single sourcing in LA SC is replaced by dual sourcing, while suppliers are connected by lean logistic, the milk-run. An amount of inventory is kept to hedge against risk from suppliers. Those new elements are brought to the model of joining PFD and LA SCD. To boost resilience in the execution stage, along with Capacity reserve and Surplus capacity of supplier, the approaches share the experience of using one robust practice in supplier management of the case study, the so-called 70/30 rule.

a.) Assumptions

The problem stated here is how to design the LARG SC when aforementioned green and resilience practices employed in supply side. Thus, it is bearing the assumptions of LA SCD above along with specific assumption of this problem:

i. LA BOM of product family XYZ is built up as presented in Chapter 3.

ii. The information of the all supplier candidates is collected
iii. There is a group of four supplier candidates for each component, among them two are selected through dual sourcing policy
iv. Suppliers for main components have the FSC certificate
v. All links among ABC sourcing network members can be established.
vi. The trucks used are the same for all milk-run
vii. The milk-run cost is variable, which is proportional with the distance of the milk-run.

b.) Objective Function

The main objective function of this case is min TC of the system which includes the purchasing cost (one element of processing cost in Eq.2.3). As the MtT is considered into supplier selection, it is taken into account along with purchasing cost. Thus, before finding the min TC, the thesis attempts to optimize this choice in sourcing side. The procedure of solving this problem is listed out as below.

- Formulate the problem into bi-objectives model: Z1, Min (purchasing cost) and Z2, Min (MtT) of supplier candidates.
- Select suppliers satisfying the min (Z1,Z2).
- Assigned these supplier into the milk-run
- Define best milk-run which contribute to lowest transportation cost.
- Substitute the values of purchasing cost and transportation cost into Eq.2.3.
- Solve the joint design problem.

c.) Input

This work re-uses the data from the case study of the furniture industry in Chapter 3 but delves deeply into the sourcing network. The optimal solutions for the bi-objective functions are defined from weighted goal programming (WGP) while the NP-complete problem milk-run is solved by HAT HMH. The whole procedure is programed by MATLAB and its solution is qualified with LINGO.

d.) Output

In the design stage, the output is the BOM of LARG system and the allocation of this BOM on the chain. In the execution step, it is the application of 70/30 rule.

e.) Constraint

The constraints of the problem here includes the constraint of milk-run and joint design product family and LA SC as presented. Besides, there are some specific constraints for this problem as follow.

i. Each milk-run truck collects all components of product family from dual suppliers.
ii. Each milk-run truck has to collect all components for each product in the family (for single or dual sourcing).
iii. The milk-run must be done within a working day.

f.) Model validation

The proposed procedure is illustrated in a real case study and compared with the results from the LA SCD model in Chapter 3. The proposed framework is resolved by LINGO. Once validated, the results from each model are discussed, important conclusions are drawn and the managerial implementations are given.

To recapitulate, this chapter summarizes the research methodologies used in this thesis which are systematically presented in the following chapters. In theory, the LSCD framework could be a reference for enterprisers when designing their LSC. Yet, as seen in the literature review, the benefits from LSCD do not last long because the pure lean model is no longer sufficient to reach the necessary competitive advantages in the current business environment; after achieving lean, the enterprises are strongly advised to implement agile to develop LA SC and so on. Therefore, this thesis is developed following the roadmap of the LSC progression from a simple LSC model to hybrids forms which have integrated advanced current strategic management. In the next chapter, the thesis works with a prevailing hybrid LA SC, which is appreciated for its ability to adapt to the ever-changing requirements from customers.

CHAPTER 3

NEW FRAMEWORK TO OPTIMIZE LEAGILE SUPPLY CHAIN DESIGN

This chapter is based on the published paper by Dang Thi Hong Nguyen, Thien-My Dao. 2019. "New framework to optimize leagile supply chain design." *International Journal of Industrial Engineering and Operations Management*, vol. 1, nº 1. The chapter presents the new framework to optimize the joint PFD and its LA SCD.

3.1 Problem presentation

The proposed framework is the design for logistic, which designs a new product family on the current LSC. After the newly designed LSC for a single product was put into operation, the enterprise envisions taking the next step on the lean roadmap by employing agile. This work aims at defining the optimal final BOM and its corresponding LA SC (see Figure 3.1).

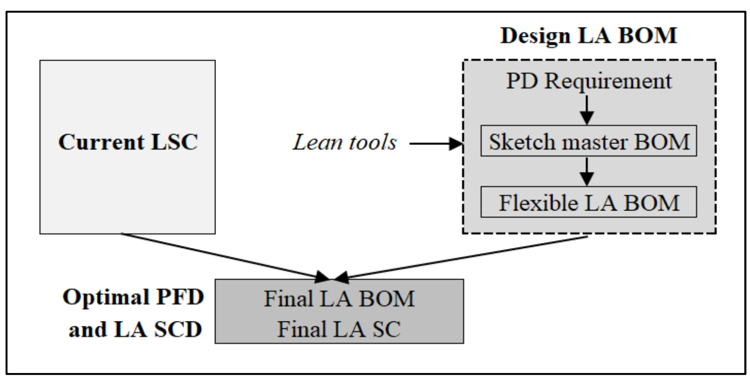

Figure 3.1 LA SCD framework

The BOM of the product family (master BOM or BOM) is named LA BOM as it is developed for lean and agile products by using LM to amplify its agility.

3.2 Process of the Joint Design

3.2.1 Design flexible LA BOM

The preliminary BOM is designed based on the concept of the *commonality platform* and the *use of common parts,* with the *involvement of suppliers*. Then the possible substitutions among component and parts are defined with *group technology* and *modularity.* Afterwards, their functions and physical structures in the BOM are modified or even redesigned under the concept of *standardization* to increase the possible compatibility among them. One example of these substitutions by LM was depicted in Figure 1.9 in Chapter 1. With this approach, the enterprise can offer a broader range of products, thereby create greater customization opportunities. This agility, once increased through the DP, is where customers can personalize their own products from the sets of offered components from LA BOM.

3.2.2 Optimize the Joint Design

The problem of simultaneous design PFD and LA SC is formulated into a mathematical model, which satisfies the min SC LA TC (called TC) within acceptable delivery lead time and cost. Theoretically, DP of one product is placed at the node where the delivery time of the final products from this point is shorter than the time expected from customers. If there are various options of this placement, the best choice is the one which contributes to the min TC. The process of joining PFD and LA SCD is shown in Figure 3.2.

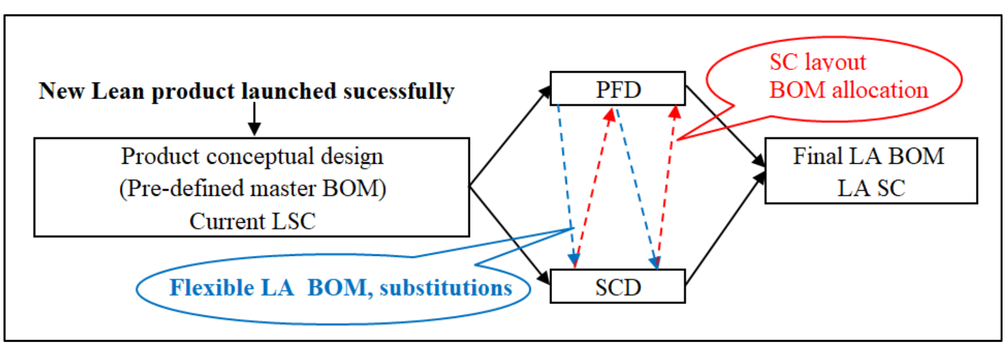

Figure 3.2 The joint PFD and LA SCD

3.2.3 Modelling the Joint Design

3.2.3.1 Assumptions

This work is built up based on these assumptions as shown below.

a.) Product family

i. A unique product family XYZ is concerned.
ii. The product architecture is modular, which includes 3 levels: component, sub-assembly (semi-product) and product.
iii. Each function of the product is performed by a component.
iv. The product family will include one lean product, (which is fabricated by MTO and sent directly to customers). The rest of the whole family AM products, which are produced under MTS and their sub-assemblies stocked at DP.
v. The agile products are designed once the new lean sample has launched successfully.
vi. The BOM of the lean product is designed under certain LM principles. From then, the number of agile products in this family are developed based on the common platform.
vii. The functions of each agile product are already pre-defined while its structure contains open options (flexible BOM).
viii. The new products must respect the given cost and lead-time range.

b.) Supply chain

ix. The existing LSC, which was designed and simplified through dual lean filters, single sourcing and the use of flat hierarchy, is modified to adapt the new product.
x. The SC considered here include the suppliers, the assemble center (plants), final assemblies (or DP, which can be located at DC or plants) and DC.

xi. Single sourcing policy is applied.
xii. Each plan has its own sourcing network.
xiii. The capacity of suppliers is unlimited.
xiv. Each factory has the capacity of producing all kinds of sub-assemblies and finals products.
xv. The direct shipment is used for two adjacent nodes with variable transportation cost.
xvi. DP can assemble all kinds of products.

3.2.3.2 Notation and Index

a.) Product

F is the set finished product family (called product), indexed by i, i = {1... N}.
A is the set of sub-assembly, indexed by j, j= {1... M}.
K is the set of required function of a product, indexed by q, q = {1... O}.
K is also the set of component of because assuming that each component performs one function of a product.

The relationship among F, A and K: $K \subset A \subset F$.

Structurally, F is the matrix size NxM where the column Fi is the possible architect of product i from some j sub-assemblies; A is the matrix size OxM denoting the structure of a sub-assembly j from the set of component k. Column Aj: structure of sub-assembly Aj.
Xij: binary variables represent the BOM of the final product family. Xij=1 when sub-assembly Aj is selected for product Fi, and 0 otherwise.
The structure of A, X and F as well as their relationships are shown in Figure 3.3.

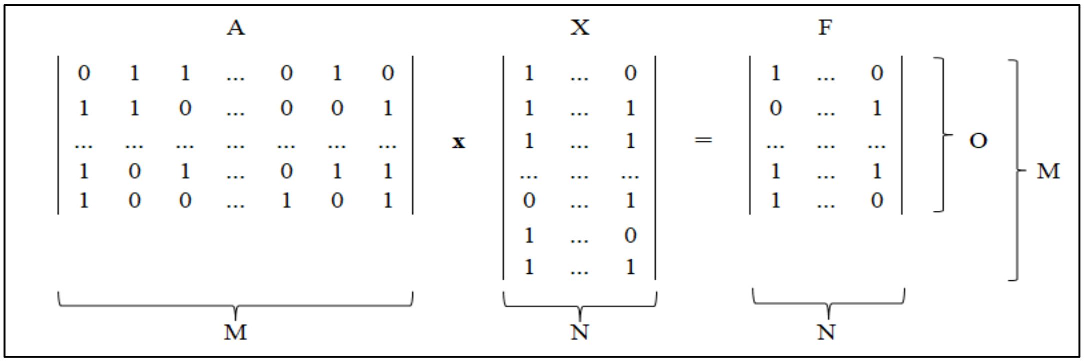

Figure 3.3 Structure of A, X and F as well as their relationship

The Figure 3.4 below describes the structure of two versions of the 3-level product Fi. Two of them have the same pre-defined functions (same components) but are composed from different sub-assemblies Aj. The problem here is to select the best combination of Aj for each final product and allocate them to the current SC.

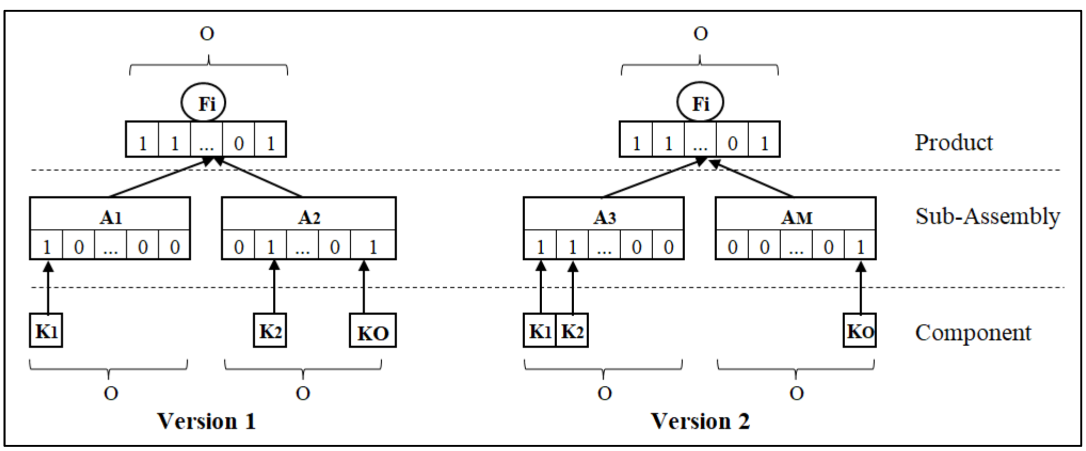

Figure 3.4 Two versions of one 3-level product

b.) Supply Chain

The SC includes 3 tiers of suppliers, plants and DC. The DP can be placed in plants or DC.

S is the set of suppliers, indexed by l (number of supplier candidate) and q, l= {1...L};

P is the set of plan, indexed by u, u= {1...U};

D is the set of DC, indexed by v, v= {1...V};

Y: binary variable related to decisions on both product and SC. Y=1 when a product element is assigned to one facility of the SC. Otherwise Y=0.

Z_{iu}, Z_{iv}: binary variables of DP placement of product i on plant u and DC respectively. These variables = 1 when the DP is placed on these nodes. Otherwise, they = 0.

W: temporary element values (very large number). It is used to store the min TC accumulated from the beginning until the current loop. When the terminated condition, reached W is the globally optimal min TC.

The study here inherits and extends the model of Chiu et Okudan (2011) when concurrently designing product and SC. Their objective function is min TC of processing cost (C1), transportation cost (C2) and inventory cost (C3).

$$TC = \text{Processing cost (C1)} + \text{Transportation cost (C2)} + \text{Inventory cost (C3)} \qquad (3.1)$$

The TC structure incurred from the product family and LA SC is analyzed in Table 3.1. The lead-times (T) of the corresponding activities along the product flows are also listed.

Table 3.1 The cost structure of the model

Cost	XYZ	Supplier (l)	Plant (u)		DC (v)	
			▼ Ziu=1	Ziu=0	▼ Ziv=1	DP=0 Ziv=0
C1	K	**Purchasing** ***C11qlu, Yqlu T11qlu***				
	A		**Production** ***C12iju, Xij, Yiu T12iju***			
	F		**Customization** ***C14iu, Yiu T14iu***		**Customization** ***C15iv, Div T15iv***	**Management** ***C13iv, Div T13iv***
C2	K	**Transportation** ***C21qlu, Yqlu T21qlu***				
	A			**Transportation** ***C22juv, Yjuv T22juv***		
	F		**Transportation** ***C23iuv, Yiuv T23iuv***			
C3	A		**Inventory** ***C31ju, Xij, Yiu***		**Inventory** ***C32jv, Xij, Div***	

The cost components of SC are described as:

$$C1=C11 + C12 + C13 + C14 + C15 \quad (3.2)$$

$$C11 = \sum_q \sum_l \sum_u C11_{qlu} Y_{qlu} \quad (3.3)$$

$$C12= \sum_i \sum_j \sum_u C12_{jiu} X_{ij} Y_{iu} \quad (3.4)$$

$$C13=\sum_i \sum_v C13_{iv} D_{iv} Z_{iu} \quad (3.5)$$

$$C14=\sum_i \sum_u C14_{iu} Y_{iu} Z_{iu} \quad (3.6)$$

$$C15=\sum_i \sum_v C15_{iv} D_{iv} Z_{iv} \quad (3.7)$$

$$C2=C21 + C22 + C23 \quad (3.8)$$

$$C21=\sum_q \sum_l \sum_u C21_{qlu} Y_{qlu} \quad (3.9)$$

$$C22= \sum_i \sum_j \sum_u \sum_v C22_{juv} X_{ji} Y_{juv} Z_{iv} \quad (3.10)$$

$$C23= \sum_i \sum_u \sum_v C23_{iuv} Y_{iuv} Z_{iu} \quad (3.11)$$

$$C3=C31+C32 \quad (3.12)$$

$$C31=\sum_i \sum_j \sum_u C31_{ju} X_{ij} Y_{iu} Z_{iu} \quad (3.13)$$

$$C32= \sum_i \sum_j \sum_v C32_{jv} X_{ij} D_{iv} Z_{iv} \quad (3.14)$$

Substituting 3.1-3.7, 3.9-3.11 and 3.13-3.14 to 3.1, the objective function yields:

$$Z=\text{Min}\ [\sum_q \sum_l \sum_u C11_{qlu} Y_{qlu} + \sum_i \sum_j \sum_u C12_{jiu} X_{ij} Y_{iu} + \sum_i \sum_v C13_{iv} D_{iv} Z_{iu} + \sum_i \sum_u C14_{iu} Y_{iu} Z_{iu} + \sum_i \sum_v C15_{iv} D_{iv} Z_{iv} + \sum_q \sum_l \sum_u C21_{qlu} Y_{qlu} + \sum_i \sum_j \sum_u \sum_v C22_{juv} X_{ji} Y_{juv} Z_{iv} + \sum_i \sum_u \sum_v C23_{iuv} Y_{iuv} Z_{iu} + \sum_i \sum_j \sum_u C31_{ju} X_{ij} Y_{iu} Z_{iu} + \sum_i \sum_j \sum_v C32_{jv} X_{ij} D_{iv} Z_{iv}] \qquad (3.15)$$

Constraints

i. Product: finished product Fi must be assembled exactly as required for its functions

$$AX_i=F_i,\ \forall i \qquad (3.16)$$

ii. Lead-time: respect the delivery time as a commitment when introducing agile products.

T_A: Allowed lead-time for producing sub-assembly

T_o: Commitment delivery lead-time with customer

The longest maximum time for the whole set of sub-assemblies to be available is shorter than its lead-time.

$$\text{Max}\ [(T11_{qlu} + T21_{ju}) Y_{qlu} + T12_{ju} X_{ij} Y_{iu}] \leq T_A,\ \forall i, \qquad (3.17)$$

The maximum time for one product to be ready is shorter than the shipment commitment time.

$$\text{Max}\ [T13_{iv} D_{iv} (1 - Z_{iv}) + T14_{iu} Y_{iu} Z_{iu} + T15_{iv} Z_{iv} D_{iv} Z_{iv} + T22_{juv} Y_{iu} X_{iJ} D_{iv} (1 - Z_{iu}) + T23_{iuv} D_{iv} Z_{iu}] \leq T_o \qquad (3.18)$$

iii. Single sourcing

$$\sum_{qlu} X_{qlu} = 1, \forall q, u \tag{3.19}$$

iv. DP: there is one DP only on the flow of a product

$$z_{ui} = 1 - z_{vi}, \forall i, \forall u, \forall v \tag{3.20}$$

v. At least one plant is assigned to produce product F

$$\sum_{iu} Y_{iu} > 1, \forall i, \forall u \tag{3.21}$$

vi. The cost of a new agile product does not exceeds a given limit C_{Limit}

$$C_i \leq C_{Limit}, \forall i \tag{3.22}$$

vii. Binary varablies

$$X, Y, Z \in \{0,1\} \tag{3.23}$$

The problem defines the selection of sets of sub-assemblies from possible M options to form the final production family. As analyzed by Khalaf *et al.* (2011), it contains the set partitioning problem which is classified into NP-Hard. Along with BOM, the other decisions that need to be made in this problem are supplier selection, product element assignment and DP selection. Khalaf *et al.* (2011) emphasized that even if the decisions of BOM are frozen, the logistics problem still belongs to NP-Hard.

3.2.4 Resolution

The whole selection of choosing BOM, its allocation on SC is coded in binary variables. As a NP-Hard problem, it can be solved by the exact method (for small size) and by MH in large size. The flow chart for the solving method is described in the Figure 3.5 below.

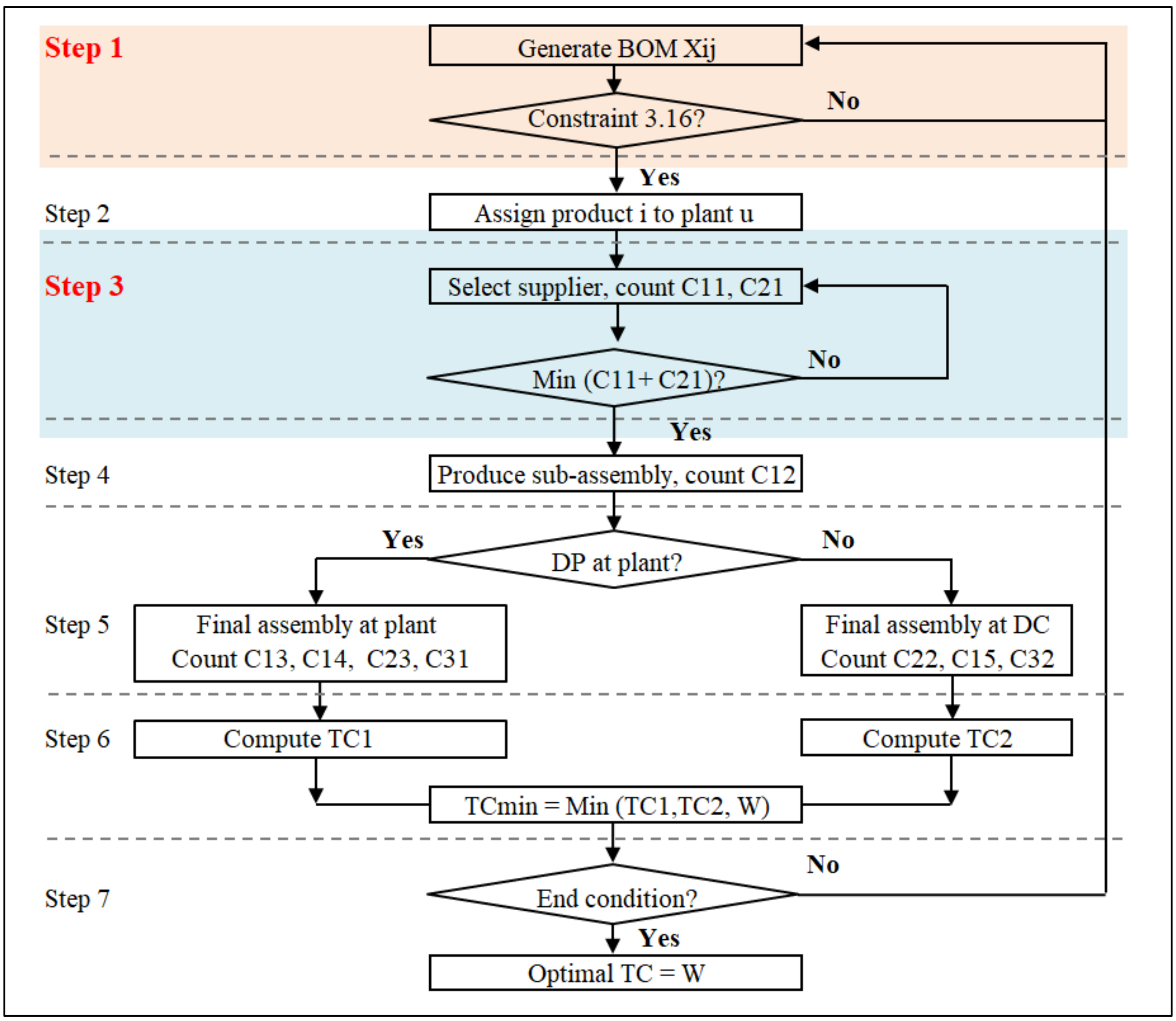

Figure 3.5 The resolution procedure of joint PFD-SCD problem.

The 7-step resolution of the problem is detailed as follows:

- **Step 1:** Randomly generate the BOM of the product family through the variable Xij. Then its feasibility is checked through the constraints 3.16 to ensure the required function of each product. If the random Xij doesn't satisfy these conditions, it is replaced by another new set. The procedure repeats until a valid Xij is found. It is very hard to obtain a feasible Xij from random selection among 2^{N*M} options. This step consumes the majority of processing time.

- **Step 2**: Randomly assign the product family into plants through variable Yiu.
- **Step 3**: randomly select supplier l of plan u for the components q containing in product i. The purchasing cost and transportation cost for components are computed. GA is employed in this step to defined the min of transportation and purchasing cost at supply side.
- **Step 4**: Count the cost for fabricating all possible sub-assemblies
- **Step 5**: Check the delivery time committed to customers and lead-time constraints to define possible PDs for each product and assign them randomly in feasible cases. All costs related to the final assembly are made ready at PD and are counted based on these options (if any).
- **Step 6**: Sum up and compare the TC from different options of PDs. The accumulated TCmin is assigned to W. In other words, W contains the value of Min TC up to the current iteration of the resolution procedure.
- **Step 7**: Check the termination conditions. If it has yet to reach, the procedure comes back to Step 1 and repeats until it comes to an end. Then the global optimal TC is the final W and its corresponding BOM, its serving facilities in SC, including the PD location, are identified.

The whole aforementioned work is demonstrated in the case study from the furniture industry as outlined below.

3.3 Illustrated Example

3.3.1 Supply Chain and the Product Development of the Case

3.3.1.1 General Context

The main processes in furniture manufacturing are presented in the study of Rajesh, Lakshmi, & Ramarao (2016). Many factories in this sector have implemented LM on their shop floors with a lot of success Hunter, Bullard, & Steele (2004). Eksioglu, Eksioglu, Zhang, & Jin (2010) described the effective method from which U.S. upholstery companies can increase the agility of their products. The regional hubs closer to consumers can function as DPs, where imported unfinished white wood components are customized with coating and upholstery features.

Since 2013, the Vietnamese furniture sector has benefitted from U.S. duties on some Chinese wood furniture (Buehlmann & Schuler, 2013). Grasping this valuable opportunity, Vietnam has emerged as a low-cost manufacturer in this industry. Within a short period, furniture has become an important sector of the Vietnamese economy. In 2017, Vietnam was ranked fifth in a worldwide listing of furniture-exporting countries, with a revenue of about $8 billion (Tri, 2017). There are about 7,000 enterprises, mostly small and medium companies, and among them nearly 3,000 of these focus on exports.

3.3.1.2 Supply Chain of the Case

Located in northern Vietnam, ABC is a 100% foreign-owned factory fabricating indoor and outdoor furniture products for export. The head-office of ABC is in Singapore, which does marketing and coordinates the operations of the entire SC. Its SC includes four plants in Vietnam, Indonesia, Malaysia and China who fabricate different products serving four DCs in Singapore, Australia, UK and US and the market of 54 countries worldwide. The ABC’s SC and the scope of this work are depicted in the Figure 3.6.

ABC in Vietnam (called ABC) was established in Vietnam to take advantage of low-cost labour, the proximity of wood sources and tax incentives for foreign businesses. The majority of ABC's capacity is used to fill purchase orders placed by its headquarters. The headquarter functions as a pooling point that absorbs uneven demands and places orders to factories in the smoothest possible manner. Thus, ABC factories can maintain a relatively stable pace of production. With these favourable conditions, ABC implemented some LM on the shop floor. It also standardizes components to reduce the SKU and increasing the products' agility.

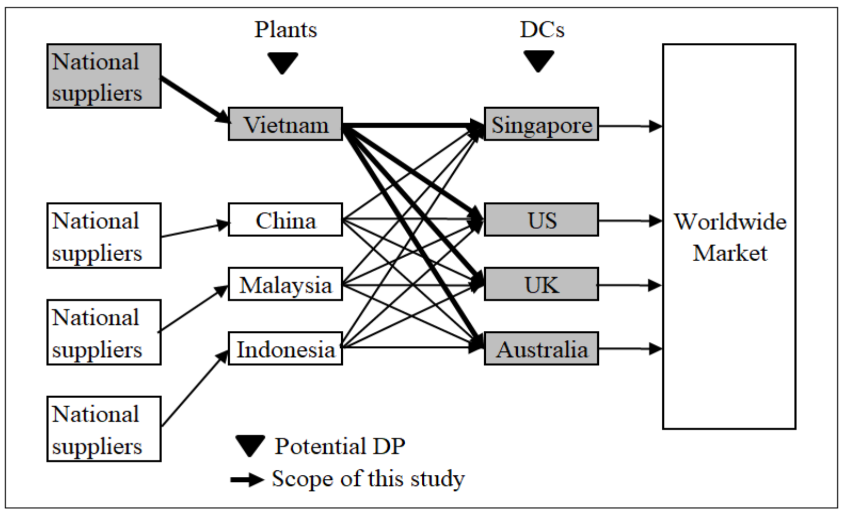

Figure 3.6 The SC of ABC company and the scope of this work

3.3.1.3 Product Development of the Case

ABC is strong at research and development (R&D), including PD and sampling. Annually, around 200 new products are designed and tested there. After being introduced, an average of 85–90% of those products receive orders for production,which is a very impressive rate in comparison with the average industrial fail rate.

When a new product fails to launch, it is evaluated as 'no prospects' on all the markets and therefore no family is developed. On the contrary, once a company receives any orders, it triggers both production and development of a product family for the potential product. Particularly, the product is fabricated by MTO under LM and sent directly to the customers (lean product). Meanwhile, the set of new products in the family (agile products) are designed before its sub-assemblies (agile assemblies) are stocked to DP. The product structure of the company is similar with the description of Goldsby *et al.* (2006): Lean products are usually produced in large quantities (minimum order quantity is one 20 feet container). Meanwhile, agile products are redistributed to regional wholesalers, retailers and consumers with relatively smaller quantities. Agile products help increase the market coverage and, thereby, may attract new potential customers (see Figure 3.7).

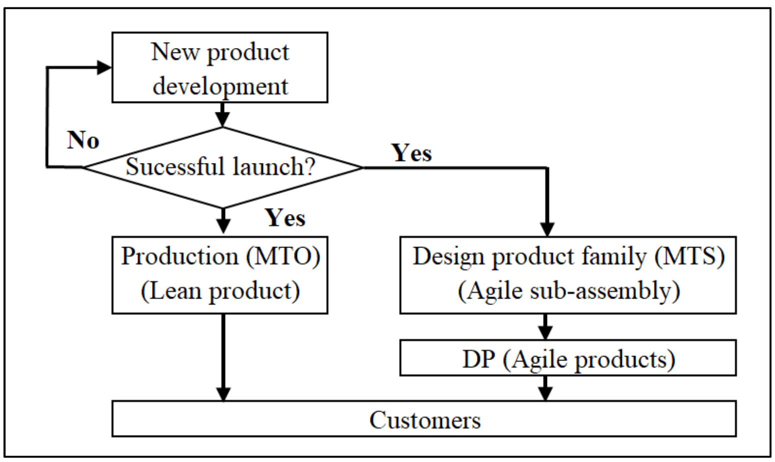

Figure 3.7 The product development at ABC

3.3.1.4 Modelling

The mathematical model of the case is based on given assumptions in section 3.2.3.1 The work begins when one lean product, a XYZ chair, is successfully introduced and received as an order from customers. The chair includes four basic elements: front legs, seat frame, seat, and back stand. To develop its family, designers list all possible functions (or components, O = 12) of agile products as in Table 3.2.

Along with these 12 components considered as sub-assemblies (A1-A12), there are 9 other sub-assemblies (A13-A21) which can be formed based on the concepts of LM. The structure of this set is encoded as in matrix A below, in which each function that exists in components and sub-assemblies are encoded by 1, and 0 otherwise.

Table 3.2 Possible components of XYZ family

No.	Name	Note
1	Front leg	Core function
2	Leg leveler	
3	Front rail	
4	Side rail	
5	Arm	
6	Seat frame	Core function
7	Seat	Core function
8	Cushion	
9	Back stand	Core function
10	Back support	
11	Cover	
12	Decoration	

Table 3.3 The structure of all sub-assemblies (including components)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1,2**	**5,6**	**5,6,7**	**5,6,7,8**	**6,7**	**6,7,8**	**7,8**	**9,10**	**11,12**
Q1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Q2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Q3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Q6	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0
Q7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	0	0
Q8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0
Q9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Q10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Q11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Q12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Based on the study from the marketing department, there are 5 potential products in the family with predefined functions that are required to be developed. The structure of lean product XYZ and matrix F of the 5 new expected agile products are shown in Table 3.4.

Table 3.4 Structure of product family

No.	F						Note
	F0	F1	F2	F3	F4	F5	
1	1	1	1	1	1	1	Core function
2	0	1	0	1	0	1	
3	0	1	1	0	0	0	
4	0	1	0	1	0	1	
5	0	1	0	1	0	0	
6	1	1	1	1	1	1	Core function
7	1	1	1	1	1	1	Core function
8	0	1	0	0	1	1	
9	1	1	1	1	1	1	Core function
10	0	1	1	0	0	0	
11	0	1	0	1	1	1	
12	0	1	0	0	1	1	

3.3.1.5 Resolution

To keep information about the company confidential, the cost structure is secure.

	F1	F2	F3	F4	F5
A1	1	1	0	1	1
A2	0	0	1	0	0
A3	1	1	1	1	1
A4	0	0	0	0	0
A5	0	1	1	1	0
A6	1	1	1	0	1
A7	1	0	1	1	0
A8	1	1	0	1	1
A9	0	0	1	0	0
A10	1	1	1	1	1
A11	0	0	0	0	1
A12	1	0	1	0	0
A13	1	1	0	1	1
A14	1	0	1	0	0
A15	0	0	0	1	1
A16	1	0	1	1	0
A17	0	1	0	0	1
A18	1	0	1	0	0
A19	0	0	0	0	1
A20	1	0	1	0	0
A21	0	1	0	0	0

a) Random Xij

	F1	F2	F3	F4	F5
A1	0	1	0	1	0
A2	0	0	0	0	0
A3	1	1	0	0	0
A4	1	0	0	0	0
A5	0	0	0	0	0
A6	0	0	0	0	0
A7	0	0	0	0	0
A8	0	0	0	1	0
A9	0	0	1	1	1
A10	0	0	0	0	0
A11	0	0	0	0	0
A12	0	0	0	0	0
A13	1	0	1	0	1
A14	0	0	0	0	0
A15	0	0	1	0	0
A16	0	0	0	0	0
A17	1	1	0	0	0
A18	0	0	0	1	1
A19	0	0	0	0	0
A20	1	1	0	0	0
A21	1	0	0	1	1

b) Xij defined by GA

	F1	F2	F3	F4	F5
A1	0	1	0	1	0
A2	0	0	0	0	0
A3	1	1	0	0	0
A4	1	0	0	0	0
A5	0	0	0	0	0
A6	0	0	0	0	0
A7	0	0	0	0	0
A8	0	0	0	1	0
A9	0	0	1	1	1
A10	0	0	0	0	0
A11	0	0	0	0	0
A12	0	0	0	0	0
A13	1	0	1	0	1
A14	0	0	0	0	0
A15	1	0	1	0	0
A16	0	0	0	0	0
A17	0	1	0	1	1
A18	0	0	0	0	0
A19	0	0	0	0	0
A20	1	1	0	0	0
A21	1	0	0	1	1

c) Xij found from IP

Figure 3.8 Xij created from different methods

The mathematical model of the case study's problem is BIP. As it is a classified NP-Hard problem, GA is selected as a solution method thanks to its advantages as reviewed in Chapter 1. GA is combined with BIP and coded by MATLAB as shown in the 7-step flowchart in Figure 3.5. Notably, some steps here are adjusted to adapt to the specific problems of the case study. Particularly, the above mentioned 7-steps, when using GA for the problem, of ABC SC is detailed as follows:

- **Step 1:** randomly generate the master BOM of the product family through variable Xij. Xij is handled by BIP rather than GA. The reason is that a feasible Xij must strictly respect the constraint 3.16. This constraint can be easily violated through crossover or mutation procedure of GA. A random Xij is depicted in Figure 3.8a. Xij is tested to select a feasible one through constraints 3.16. Yet, it is very hard to randomly generate a BOM that satisfies this constraint. Thus, this step proposes one sub-procedure to help generate the feasible BOM at the first step. Product F2 with 5 functions are used to demonstrate this sub-procedure:
    - Only one BOM of product 2 (Xi, i=2) is generated instead of for the whole family. All alleles of X2 are set to 0. X2 is a column matrix size (1,M), where M=21.
    - Use a column matrix size [O,1], called TEMPFUNC, having the same function of F2. Where O=12. TEMPFUNC =$[100001101100]^T$.
    - Group all possible sub-assemblies Aj in A which can perform the required functions of product Fi. This sub-set is named A' (A' $\subset$ A). A' of F2 includes the 7 elements A1, A6, A7, A9, A10, A17, and A20.
    - Randomly select one A'j for functions q on TEMPFUNC. Set value Xij=1, remove all A'j that contain function j, set TEMPFUNC q=0. For example, select in random A17 to perform function 9 and 10. Then set X2-17 =1; remove A17, A9, A10 out of A'; remove function 9 and 10 in TEMPFUNC.
    - The random selection is continued with a smaller set of A' as well as functions on TEMPFUNC. When all alleles in TEMP = 0, the assignment is accomplished, and feasible X2 is generated.

  - The sub-assembly selected in product Xi is reused for other products throughout the family in order to reduce its SKUs.
  - Once X2 is generated, the process is repeated until whole family is fully created.

- **Step 2:** this step is ignored as there is only one plant for ABC.
- **Step 3**: randomly select suppliers from the potential sourcing pool. At ABC, there are two groups of candidates for each component. The selection is encoded by one chromosome which the length 12 (O=12) for the first group by GA. The fitness of GA is to define the optimal sourcing cost (including purchasing and transportation) at each iteration. Its initial population is generated with 100 individuals; termination condition is 100,000 generations; the crossover and mutation probability are set at 0.7 and mutation at 0.1 respectively. Those parameters adapted from the study of Goldberg & Holland (1988), who advised that the crossover probability should range from 0.6-0.9 while the mutation is kept at a small probability. In this case, when the allele of the locus q bears the value 1, the supplier provides the q^{th} component in the first group is selected. Otherwise, its corresponding component in the second group is chosen. After selecting suppliers, the purchasing and transportation cost are computed. It repeats under the GA procedure to define the lowest sum of two costs from different sets of supplier combinations. The lowest sourcing cost is defined after the terminated condition is reached, and the procedure goes to Step 4.

Locus	1	2	3	4	5	6	7	8	9	10	11	12
Allele	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**

Figure 3.9 The chromosome of GA

- **Step 4**: compute the processing cost of all 21 sub-assemblies at the plant.
- **Step 5**: check the possibility of DP. Based on the delivery time of ABC, the delivery time committed at DC is 7-10 days, while the assembly for all final products of XYZ

(with all available sub-assemblies) is around 1-2 days. The shipment to Singapore DC is handled by one shipping agent, which requires the ocean shipping times of two days with the frequency of three times per week while the ocean shipping times from ABC in Vietnam to other DC in Australia, UK and US is much longer than the committed time. Thus, there is only DC in Singapore can meet its commitment regardless the placement of DP at Singapore or Vietnam. On other words, PD of one product fabricates in ABC can be located either in the plant of ABC or at DC in Singapore.

- **Step 6**: Compute all the cost related to the launching of XYZ at all DC with DP options. The TC from two options is compared with the smallest TC of the network from the beginning up to this period (the value of W). The smallest value is assigned to the min TC so far and its corresponding structure of BOM and SC are saved.
- **Step 7**: The whole procedure is repeated until the termination conditions met. The LA BOM for the final product identified by BIP and GA is depicted in Figure 3.10b. The structure of one final product, for instance F2, is depicted in Figure 3.11 and its allocation of the BOM on LA SC is illustrated in Figure 3.12.

	F1	F2	F3	F4	F5
A1	1	1	0	1	1
A2	1	0	0	0	1
A3	1	1	0	1	1
A4	1	0	1	0	0
A5	1	0	0	1	0
A6	1	1	0	0	1
A7	1	1	0	1	1
A8	1	1	0	1	1
A9	1	1	1	0	1
A10	1	1	0	1	0
A11	1	0	1	0	1
A12	1	0	0	0	1
A13	0	0	1	1	0
A14	0	0	0	0	1
A15	0	0	0	1	1
A16	0	0	0	1	0
A17	0	1	1	0	1
A18	0	0	0	0	0
A19	0	0	0	0	1
A20	0	0	0	0	0
A21	0	0	0	0	0

a) Random BOM

	F1	F2	F3	F4	F5
A1	0	1	0	1	0
A2	0	0	0	0	0
A3	1	1	0	0	0
A4	1	0	1	0	1
A5	1	0	1	0	0
A6	0	0	0	0	0
A7	0	0	0	0	0
A8	1	0	0	1	1
A9	0	0	1	1	1
A10	0	0	0	0	0
A11	0	0	1	0	0
A12	0	0	0	0	0
A13	1	0	1	0	1
A14	0	0	0	0	0
A15	0	0	0	0	0
A16	0	0	0	0	0
A17	1	1	1	1	1
A18	0	0	0	0	0
A19	0	0	0	0	0
A20	1	1	0	0	0
A21	1	0	0	1	1

b) BOM from BIP- GA

	F1	F2	F3	F4	F5
A1	0	1	0	1	0
A2	0	0	0	0	0
A3	1	1	0	0	0
A4	1	0	1	0	1
A5	1	0	1	0	0
A6	0	0	0	0	0
A7	0	0	0	0	0
A8	1	0	0	0	0
A9	0	0	1	1	1
A10	0	0	0	0	0
A11	0	0	1	0	0
A12	0	0	0	0	0
A13	1	0	1	0	1
A14	0	0	0	0	0
A15	0	0	0	0	0
A16	0	0	0	0	0
A17	1	1	1	0	0
A18	0	0	0	1	1
A19	0	0	0	0	0
A20	1	1	0	0	0
A21	1	0	0	1	1

c) BOM from LINGO

Figure 3.10 a) Random BOM; b) BOM from GA; c) BOM form LINGO

The structure of one final product (for example P2) is the presented in Figure 3.11 below, in which the 6 functions of F2 is made up from two components, A1 and A3, as well as the two sub-assembliesA17 and A20.

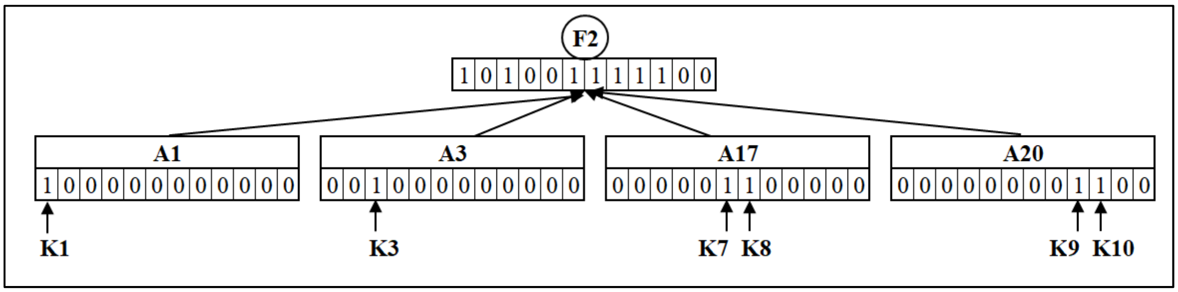

Figure 3.11 Final structure of F2 identified from GA.

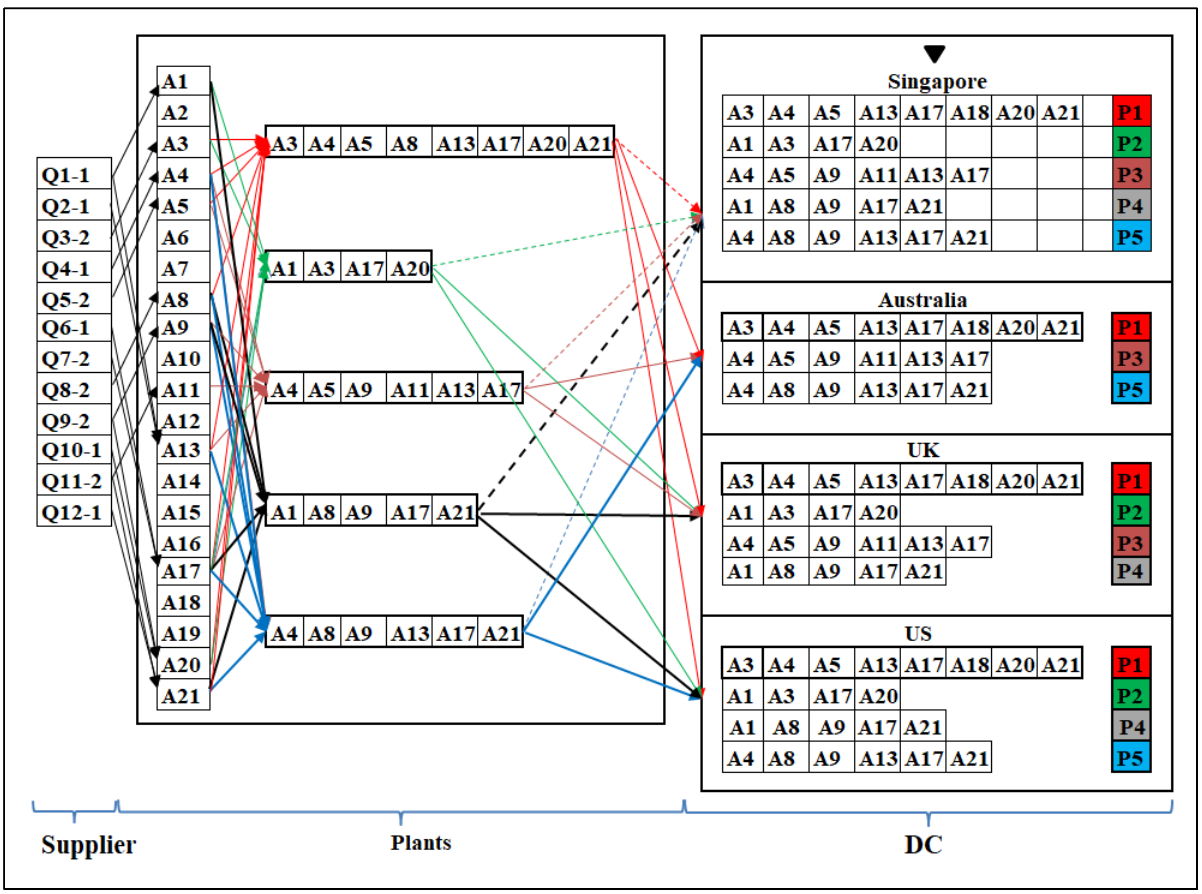

Figure 3.12 The results of the joint PFD and SCD of XYZ

3.3.2 Validation and Discussion

The size of the case study is limited to 1 product family of 5 product members, 12 functions, 23 sub-assemblies, 24 suppliers candidates, 1 plant, 4 DC, and two options of DP. Thus, beside MH, the optimal solution can be found by using exact solver. The model is validated by the optimization software LINGO 18.0. The sub-procedure is employed in order to improve the feasibility of the initial LA BOM. Concerning quality search, GA shows close near global optimum with the average gap of 5.27% from the optimal solution of LINGO. The LA BOM provided by LINGO is shown in Figure 3.10c, where it uses module A18 instead of A17 and 8. However, the allocation of the new LA BOM on demand side remains unchanged. Related to processing time, with the proposed sub-procedure, binary integer combine with GA gives the results after 387.29s while it consumed 13,824,025,29s (more than 2h and half) with random a BOM generated in the 1st step. Impressively, the processing time of LINGO is less than 1s.

The configuration of LA SC obtained from both GA and LINGO matches with findings from Hedenstierna & Amos (2011), which stressed the general tendency of locating the DP downstream to take the advantage of this point when near customers. This conclusion is true in the case study of simple product and low customization cost. The study of the two authors has yet to consider the factors which may affect customization cost, such as the complexity of the product which required heavily investment on machinery or technology.

3.4 Conclusion

This work presents a new framework to optimize the joint design of PFD and LA SC by defining the best choice of both LA BOM and product allocation. It may be an addition to the literature review of SCM, which has very few quantitative studies on LA SCD and has not done any research on optimizing the joint PFD and LA SCD. The work also presents the new concept of the so-called LA BOM which employs LM to simplify the components of the product family and also to amplify the combination capacity among them. This approach proves to be feasible and promising through the validation shown in the specific example.

However, the new model has yet to take into consideration environmental factors as well as contingency measures to hedge against threats. These gaps are covered in the LARG model in the following section.

CHAPTER 4

NEW HYBRID META-HEURISTIC TO OPTIMIZE MILK-RUN DELIVERY

This chapter is partly based on the published paper by Nguyen, Thi Hong Dang and Dao, Thien My, 2015. "Supply chain milk-run delivery optimization." *Journal of Management and Engineering Integration*, vol. 8, nº 1. p. 29-40. The chapter aims at presenting a new HMH to optimize the milk-run. This work is considered as an intermediate step to prepare a solution method for the problem given in the next chapter.

4.1 Problem Definition

4.2 Problematic Milk-run

The milk-run is considered a more effective model than direct shipment in terms of minimizing SC TC (Brar & Saini, 2011), especially in proximity distance. Sunil & Peter (2013) pointed out the two elements that affect delivery cost in milk-runs: 1.) route distance—*dr*, and 2.) delivery frequency—*n*. The shipment planning in milk-runs must be carefully scheduled to ensure the synchronized coordination in the LSC and to make sure the total volumes and weights of all items conveyed are less than a truckload. Thus, optimizing the milk-run problem results in finding the best compromise of *dr* and *n* which contributes to the lowest *TC* while satisfying vehicle capacity restrictions. Yet, finding the best route for a milk-run is not easy when it bears the nature of NP-complete problems as previewed in Chapter 1. In a small scale, the globally optimal result can be defined by the exact method, whereas optimization of the large-size is the subject of the MH approach.

Several techniques are given in this direction in order to find a better quality search. Miao & Xu (2011) built up the model for milk-run and optimized it by ACO. In this model, sharing analogous points of view with Sunil & Peter (2013), Miao & Xu (2011) considered *dr* and *n* as variables while other parameters are designed. This thesis reuses the mathematical model and data in the case study of Miao & Xu (2011) to validate the new proposed HMH.

4.2.1 Modelling the Milk-run

4.2.1.1 Assumption

i. The members of the SC locate in relatively small region which can be consolidated in one milk-run.
ii. The production pace (from plant and suppliers) is synchronized with the milk-run's.
iii. The type of truck is pre-selected.
iv. Factors distracting the milk-run are excluded (the LSC functions in certain environments).
v. All milk-run deliveries are on time as scheduled and no penalty is taken into account.

4.2.1.2 Modelling

As Miao & Xu (2011), SC TC (or TC) is made up of three elements:

$$TC = Cost\ (Production + Delivery + Inventory) \tag{4.1}$$

Where

$$Production\ cost = Start\text{-}up\ cost\ (supplier, plant) + Order\ cost + Production\ cost\ (supplier, plant) \tag{4.2}$$

$$Delivery\ cost = Fixed\ cost\ of\ milk\text{-}run + Variable\ cost\ of\ milk\text{-}run \tag{4.3}$$

Inventory cost = Inventory cost of part (supplier, plant, in-transit) + Inventory cost of the product (plant, customer, in-transit) (4.4)

The objective function at operational level of one-milk-run LSC is formulated by Miao & Xu (2011) as shown:

$$Min\ TC = \sum_{i=1}^{N}\{(UIC_s)^i(SI_s)^i + (UIC_m)^i(SI_m)^i + \frac{(UIC_d)^i P_m dr}{VT} + P_m(UPC_s)^i\}$$
$$+ \sum_{j=1}^{K}\{UIC'_m \text{ x } SI'_m + UIC'_c{}^j(SI'_c)^j + \frac{UIC'_d)^j(D_c)^j dr}{VT} + (D_c)^j\ UPC_m\} + (\sum_{i=1}^{N}\{(USC_s)^i +$$
$$(FOc)^i\} + \sum_{j=1}^{K}\{USC_m + (FOC')^j\} + FDC + UDC * dr)n + \{(UIC_s)^i\ P_m\ (1- \frac{P_m}{2(P_s)^i})$$
$$+\frac{(UIC_m)^i}{2}P_m\} + (\sum_{j=1}^{K}\{UIC'_m((D_c)^j - \frac{((D_c)^j)^2}{2P_m}) + \frac{(UIC'_c)^j(D_c)^j}{2}\})/n \quad (4.5)$$

a.) Constraints

i. Each supplier or customer visits once only
ii. Each supplier or customer is included in one path of one milk-run
iii. Delivery frequency of each supplier or customer in the same path is equal
iv. n ϵ integer and n>0, dr> 0
v. Delivery capacity constraint (weight restrictions):

$$\sum_j \frac{(D_c)^j w\prime}{n} + \sum_i \frac{(P_m)^i}{n} \leq W \quad (4.6)$$

Where

N, K, m: number of suppliers, customers and all members of SC respectively;

$UPC_{s/m}$: unit production cost of suppliers and core business;

$USC_{s/m}$: production start-up cost/batch of suppliers and core business;

P_m, P_s, D_c: productivity/ demand rate from core business; suppliers; customers;

FOC/FOC’: order fixed cost of parts/ finished products;

FDC: delivery start-up cost;

UDC: unit delivery cost;

$UIC_{s/m/d}$: parts unit inventory cost of suppliers, core business and in-transit;

$UIC'_{m/c/d}$: finished product unit inventory cost of core business, customers and in-transit;

$SI_{s/m}$: part safety stock quantity of suppliers and core business;

$SI'_{m/c}$: finished safety stock quantity of core business and customers;

T: core business production cycle;

V: average rate of delivery vehicle;

W: capacity of delivery vehicles;

w, w': weight of part/ finished product (kg);

b.) Solutions

From here, Miao & Xu (2011) used ACO to optimize the problem and illustrated it by presenting data from the case study (see Table 4.2 and 4.3). The solutions obtained from ACO (called original) in comparison with the new proposed approach are presented in Table 4.5 and 4.8. These authors did not compare the results obtained from ACO with the ones from other techniques.

4.2.2 Model Analysis

To develop a new solution method, the thesis delves in depth into the given mathematical model Eq. (4.5) of LSC with the milk-run. It is noted that Eq. (4.5) can be written in the shortened form:

$$TC = A*dr + B*n + C*n*dr + D/n + E \tag{4.7}$$

Where

$$A=\sum_{i=1}^{N}\left(\frac{(UIC_d)^i P_m}{VT}\right) + \sum_{j=1}^{K}\left(\frac{UIC_d'^{)j}(D_c)^j}{VT}\right) \tag{4.8}$$

$$B=\sum_{i=1}^{N}\{(USC_s)^i + (FO_c)^i\} + \sum_{j=1}^{K}\{USC_m + (FOC')^j\} + FDC \tag{4.9}$$

$$C = UDC \tag{4.10}$$

$$D = \sum_{i=1}^{N}\{(UIC_s)^i\, P_m\, (1 - \frac{P_m}{2(P_s)^i}) + \frac{(UIC_m)^i}{2} P_m\} + \sum_{j=1}^{K}\{UIC'_m((D_c)^j - \frac{((D_c)^j)^2}{2P_m}) + \frac{UIC'_c)^j (D_c)^j}{2}\} \tag{4.11}$$

$$E = \sum_{i=1}^{N}\{(UIC_s)^i (SI_s)^i + (UIC_m)^i (SI_m)^i + P_m (UPC_s)^i\} + \sum_{j=1}^{K}\{(UIC'_m)\, SI'_m + (UIC'_c)^j (SI'_c)^j + (D_c)^j\, UPC_m\} \tag{4.12}$$

$$A, B, C, D \text{ and } E > 0 \tag{4.13}$$

Mathematically, *n* and *dr* can be found by:

$$\begin{cases} \frac{\partial(\mathrm{TC})}{\partial \mathrm{n}} = 0 \\ \frac{\partial(\mathrm{TC})}{\partial(dr)} = 0 \end{cases} \tag{4.14}$$

$$\rightarrow \begin{cases} (\mathrm{B} + \mathrm{C} * dr) - \frac{\mathrm{D}}{\mathrm{n}^2} = 0 \\ A + C * n = 0 \end{cases} \tag{4.15}$$

$$\rightarrow \begin{cases} n = -\frac{C}{A} \\ dr = D * \frac{A2}{C3} - \frac{B}{C} \end{cases} \tag{4.16}$$

Particularly,

$$\frac{\partial^2(TC)}{\partial n^2} = \frac{2C}{n^3} \tag{4.17}$$

The compromise of n and dr found from Eq. (4.16) is unaccepted owing to the violation with constraint (iv). However, when $n>0$, $dr>0$, value $\partial^2(TC)/\partial n^2 > 0$ from Eq. 4.17 indicates that TC can obtain the local minimum when Eq. (4.15) $=0$ with one predetermined *shortest dr*. From Eq. (4.15) *optimal n* can be defined as:

$$optimal\ n= \sqrt{\frac{D}{B+C*(shortest\ dr)}} \tag{4.18}$$

Thus, the milk-run optimization becomes solvable once the *shortest dr is* defined. At each number of city m, the *shortest dr* is unique while B, C and D are constant, so value *optimal n* counted by Eq. (4.15) is exclusive. As dr is linear with TC, when dr changes, TC has linear motion along with dr and *optimal TC* attains at the same value of *optimal n.* These arguments are exemplified in the case study. Based on these characteristics, two new approaches (programmed by MATLAB 2013b) are proposed to identify the optimal dr. In a small-scale SC, both MIP and HAT can be used. Yet, when m is sufficiently large, the computer processing time is too long, which makes MIP unsolvable. In this case, HAT proves effective in overcoming the timing trouble. In both methods, when the best dr is defined, the *optimal TC* and n are calculated by programming in MATLAB.

4.3 Proposed Methodology

The size of a SC is defined by the number of members m (or nodes) of SC including the plants, suppliers and customers. In the context of this paper, the SC is considered ‘small’ or ‘large’ depending on the application limit of the two proposed approaches.

4.3.1 MIP Approach for Small-scale LSC

Once a milk-run is deployed, the value of *optimal dr* can be identified by MIP by checking and comparing all possible dr to determine the best one. In a small LSC, dr is the distance of the round route that connects all delivery nodes (departure and arrival at core business). So, the distance matrix (*D*) among all delivery nodes in the milk-run is used as the MIP input. From *D*, the MIP creates a loop of the assignment *i* to find *optimal dr*. Other initial values of MIP parameters are set in Table 4.1.

Table 4.1 Initial values of parameters

Name	**Initial value**	**Note**
mindr	Infinitive	
mini	2,3,…(m-1),m	(m-1) increasing integer numbers
maxi	m,(m-1),…2	(m-1) decreasing integer numbers
maxn		Max loading capacity > 50% truck load

Figure 4.1 illustrates a flowchart of the MIP approach, which proceeds as follows:

i. Setting assignment, i = mini as a minimum increasing integer containing the number of all different nodes.
ii. Transferring value i to one-array route, route is the path of the milk-run.
iii. Checking the validity of the route (no sub-route and all elements ≠ 0)
iv. Creating a full route by assigning the departure and arrival nodes as node 1.
v. Computing *dr* through the geographical coordinate matrix D of LSC
vi. Comparing *dr* with mindr, the smaller value is assigned to mindr.
vii. Continuing to check other possible values of the route by increasing i
viii. When i=maxi, *optimal dr* defined=mindr
ix. From mindr found from (viii), creating a loop of n and compute TC through Eq (4.5)
x. For the finding TC, the smaller TC is assigned to minTC.
xi. Stopping when n reaches maxn. Optimal TC found is minTC. Optimal n identified= bestn, which contributes to optimal TC.

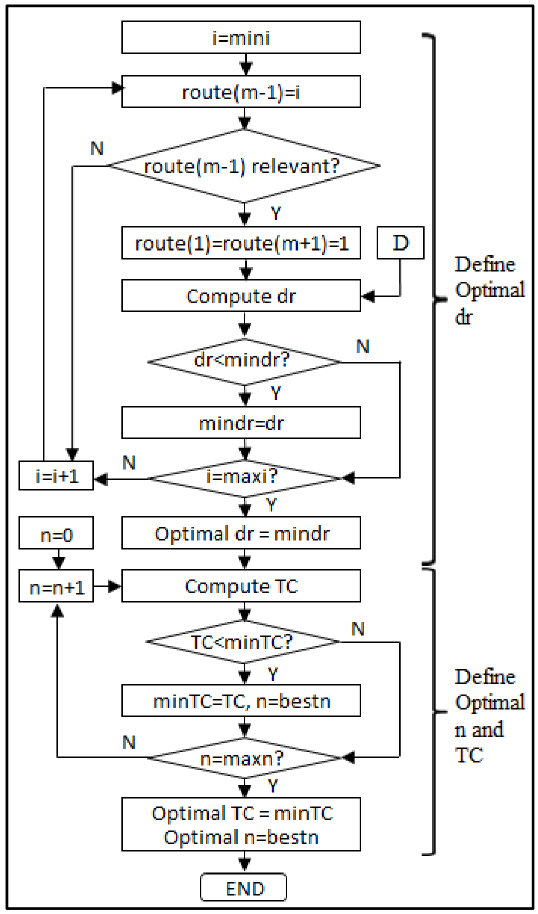

Figure 4.1 MIP flowchart

In the MIP approach, it generates a string (or a chromosome) that contains all the nodes of the LSC (or genes). The order of genes in the chromosome figures the order of nodes that the truck visits in the milk-run. Each gene exists once only (as the vehicle visits one city once in the milk-run) except at the beginning and the end (as the truck returns to the original node after making the round trip). In other words, each chromosome is one route of the milk-run. New chromosomes are generated by changing the order of genes on it. The striking point of the MIP, in this case, is by creating a pool of all feasible chromosomes. With each chromosome, the milk-run distance *dr* is counted. In this case, the MIP compares all *dr* to identify the shortest *dr*. From then on, the *optimal n* is computed through Eq. (4.18) and thereby the *optimal TC* is identified by Eq. (4.5) eventually.

4.3.2 HAT for Large-scale Milk-run

In a large-scale SC, HAT is proposed to figure out the best solution for the milk-run in a complicated logistics network. HAT is developed based on the hybridization of ACO and TS. Defining *optimal dr* in the milk-run has the identical characteristic with seeking the shortest path for the famous TSP. Antosiewicz, Koloch, & Kamiński (2013) compared six MHs in solving TSP: GA, SA, TS, Quantum Annealing, PSO and Harmony Search. The results demonstrated that TS and SA are superior to the rest. Furthermore, TS converges faster with lower variance. Solving TSP by TS, the acceptable initial solution can be obtained quickly by Greedy Search before being refined following a temporary memory or Tabu list (Basu, 2012). Yet, Greedy Search is much less efficient than ACO and other MHs like GA and PSO in solving TSP (Raman & Gill, 2017). Hence, HAT replaces Greedy Search by ACO in TS procedure to improve the initial results which leads to a near-optimal final solution (see Figure 4.2). The procedure of TS in solving TSP was systematically summarized by Basu (2012), so it is not repeated here. When possible *optimal dr* is found by HAT, the following stages are similar to MIP in identifying *optimal n* and *TC* (step ix-xi). To qualify MIP and HAT, a case study and random data are used in the testing stage.

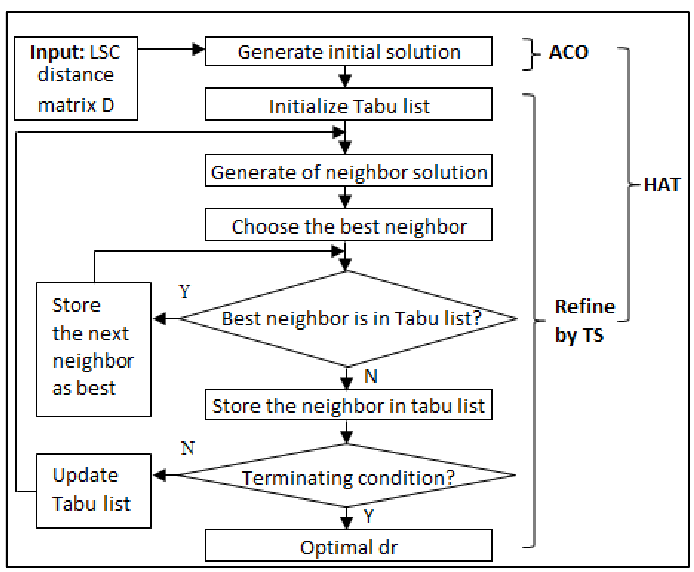

Figure 4.2 HAT flowchart

4.4 Results

4.4.1 Case study and MIP testing

In the original case study, the 9-member automobile LSC (*m=9*), having one plant, 3 (*N*) suppliers, 5 (*K*) customers, was used to demonstrate the milk-run problem. The information of the LSC in the case study is enumerated in Tables 4.2 and 4.3 The distance matrix *D* among all LSC members is computed from Table 4.4. Other values of the chain are: T= 30 days; V=50 km/h; W=20 tons.

Table 4.2 The geographical coordinates in LSC case study

Business code	R0	S1	S2	S3	C1	C2	C3	C4	C5
X coordinate	50	26	62	52	40	73	38	86	21
Y coordinate	70	95	49	15	80	12	66	97	82

Table 4.3 Data of the LSC case study

	UPC_s	$USC_{s/m}$	FOC	UIC_s	UIC_d	SI_s	w(kg)	P_s
S1	10	1000	100	10	12	4000	2	134000
S2	12	1500	100	12	14	5000	1.5	135000
S3	15	2000	100	15	18	8000	1.5	138000
	UPC_m	USC_m	-	UIC_m/UIC'_m	-	SI_m/SI'_m	w'(kg)	P_m
R0	50	5000	-	12/12/15/50	-	4000/16000	5	126000
	-	-	FOC'	UIC'_c	UIC'_d	SI'_d	-	D_c
C1	-	-	200	50	60	2200	-	22000
C2	-	-	200	50	60	2000	-	20000
C3	-	-	200	50	60	1800	-	18000
C4	-	-	200	50	60	2000	-	20000
C5	-	-	200	50	60	1800	-	18000

Substituting these values into Eq. (4.5), *TC* yields:

$$Min\ TC = 10^3 * (11220 + 7.616\ dr + 11.8n + 11798.853/n) + 5\ dr * n \quad (4.19)$$

And Eq. (4.15) becomes:

$$\begin{cases} 10^3 * \left(11.8 - \dfrac{11798.853}{n^2}\right) + 5 * dr = 0 \\ 7616 + 5n \; = 0 \end{cases} \qquad (4.20)$$

Solving Eq. (4.20), n=-1323.20 and *dr* =-2358.65. Obviously, both *n* and *dr* violate constraints (iv). The authors used improved ACO (2-Opt) to find the *acceptably shortest dr* before substituting this value into Eq. (4.18) for *n* and *Min TC* respectively. 2-Opt ACO is one modification of ACO, which was developed in the effort of improving the quality search of the original ACO. Particularly, two selected edges are replaced with their corresponding crossing edges if the objective value of the new route is improved (Harrath, Salman, Alqaddoumi, Hasan, & Radhi, 2019).

Table 4.4 Distance matrix D of LSC

	0.00	34.66	24.19	55.04	14.14	62.39	12.65	45.00	31.38
	34.66	0.00	58.41	84.12	20.52	95.38	31.38	60.03	13.93
	24.19	58.41	0.00	35.44	38.01	38.60	29.41	53.67	52.63
	55.04	84.12	35.44	0.00	66.10	21.21	52.89	88.77	73.82
D=	14.14	20.52	38.01	66.10	0.00	75.58	14.14	49.04	19.10
	62.39	95.38	38.60	21.21	75.58	0.00	64.35	85.99	87.20
	12.65	31.38	29.41	52.89	14.14	64.35	0.00	57.14	23.35
	45.00	60.03	53.67	88.77	49.04	85.99	57.14	0.00	66.71
	31.38	13.93	52.63	73.82	19.10	87.20	23.35	66.71	0.00

With m=9, the LSC is classified as small-scale, so it is solved by exact solutions, MIP. The primary results of MIP in comparison with TS, HAT and originals are presented in Table 4.5.

Table 4.5 Primary results of MIP, HAT, TS and Original

	dr (km)	**Best Route**	**n**	**TC ($)**	**Note**
MIP	283.30	R0-C1-S1-C5-C3-S3-C2-S2-C4-R0	30	14,167,402.90	Min *dr*, Min TC
HAT	286.22	R0-C1-C5-S1-C4-S2-C2-S3-C3-R0	30	14,190,079.62	
TS	286.69	R0-C3-C1-C5-S1-C4-C2-S3-S2-R0	30	14,193,729.64	
Original (ACO)	286.22	R0-C1-C5-S1-C4-S2-C2-S3-C3-R0	19	15,766,546.00	

As can be seen from the table above, the result of *dr* offered from TS is 286.69 km, while the result from HAT and approved ACO stays identical at 286.22 km. In particular, *dr* given from MIP achieves an optimal global value at 283.30 km (Figure 4.3).

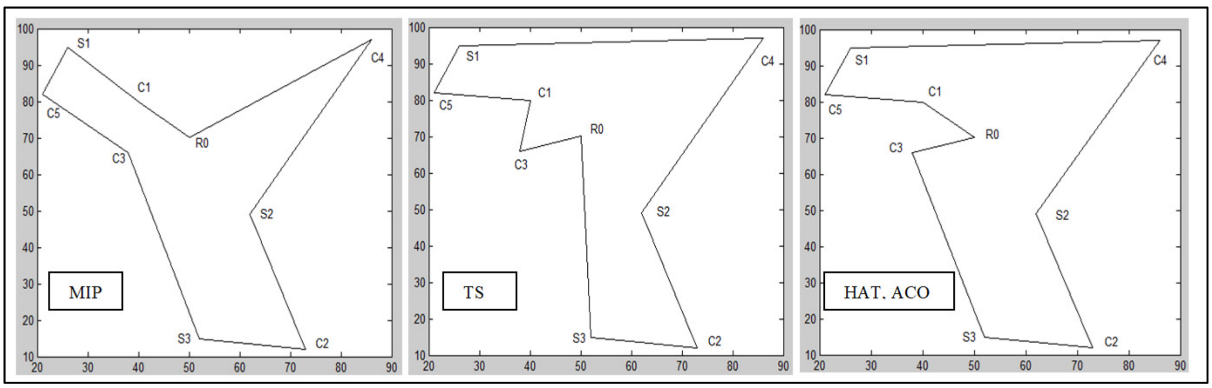

Figure 4.3 Primary results from MIP, TS, HAT and ACO

When the shortest *dr* = 283.30 km and is defined, the optimal frequency n = 30 is computed from (Eq. 4.20) which contribute to the *optimal TC*. To verify whether the milk-run obtained is feasible, the constraints from (i) to (v), especially the limit truck capacity (v), are taken into account. First, it is noted that in milk-run planning, in order to define the direction of the milk-run, the planners or drivers have to consider some factors such as the traffic congestion in some areas at a certain time or time slot scheduled for delivery or receipt, and so on. The milk-run planning is easier if it is set up in either the supply network or distribution channel solely where the vehicle load is accumulated or discharged. On the contrary, if the milk-run links both demand and supply sides, the direction of the milk-run route becomes important because its loadings along the milk-run road vary according to the starting direction. In this case, the total weight of the items in the LSC is 1168 tons, which needs at least 59 times if using direct shipment. In the milk-run, where the condition requires that the truckload must always be larger than 50% of its capacity, the frequency *n* varies from 31 to 71. Table 4.7 describes the changing weight of a truck during the milk-run.

Table 4.6 The changing weight of truckloads during the milk-run with various *n*

n	RO	C1	S1	C5	C3	S3	C2	S2	C4	RO
30	16.33	12.67	19.42	16.42	13.42	20.32	16.98	23.73	20.40	20.40
31	**15.81**	**12.26**	**18.79**	**15.89**	**12.98**	**19.66**	**16.44**	**22.97**	**19.74**	**19.74**
32	15.31	11.88	18.20	15.39	12.58	19.05	15.92	22.25	19.13	19.13
...										
70	7.00	5.43	8.32	7.04	5.75	8.71	7.28	10.17	8.74	8.74
71	**6.90**	**5.35**	**8.20**	**6.94**	**5.67**	**8.58**	**7.18**	**10.03**	**8.62**	**8.62**
72	6.81	5.28	8.09	6.84	5.59	8.47	7.08	9.89	8.50	8.50

The data from Table 4.7 show that this milk-run cannot perform at the optimal frequency of *n* =30 as theoretically counted. Since the sole milk-run causes the delivery truck to be overweight, it is divided into two sub-routes. Consequently, the new delivery distance becomes longer in total while the value of *n* remains unchanged. The possible range of n is computed based on the truckloads along the sub-routes. With the same condition, the range of *n* changes from 25 to 37 as computed in Table 4.8. Thus, the value of n = 30 is accepted.

Table 4.7 Truckload's change in sub-routes with various *n*

n	**First sub-route**							**Second sub-route**				
	R0	C4	S2	C2	S3	C3	R0	R0	C5	S1	C1	R0
24	12.08	7.92	16.35	12.19	20.81	17.06	17.06	8.33	4.58	15.75	11.17	11.17
25	**11.60**	**7.60**	**15.70**	**11.70**	**19.98**	**16.38**	**16.38**	**8.00**	**4.40**	**15.12**	**10.72**	**10.72**
26	11.15	7.31	15.10	11.25	19.21	15.75	15.75	7.69	4.23	14.54	10.31	10.31
...												
36	8.06	5.28	10.90	8.13	13.88	11.38	11.38	5.56	3.06	10.50	7.44	7.44
37	**7.84**	**5.14**	**10.61**	**7.91**	**13.50**	**11.07**	**11.07**	**5.41**	**2.97**	**10.22**	**7.24**	**7.24**
38	7.63	5.00	10.33	7.70	13.14	10.78	10.78	5.26	2.89	9.95	7.05	7.05

The distance of the sub-routes and the final *Min TC* after splitting primary milk-run paths are summarized in Table 4.8. The results from this table show that the cost improvement gained from MIP is 9.52 %, or the LSC can save up to 1,500,909.42$. Similarly, the results offered by HAT and TS are also very positive with 9.23% and 9.01% with the savings of $1,455,898.45 and $1,420,459.09.

Table 4.8 Final results of MIP, TS, HAT and ACO after dividing primary *dr*

	dr (km)	Best sub-route	n	TC ($)	Improving (%)	Note
MIP	295.94	*dr* 1: R0-C4-S2-C2-S3-C3-R0	30	14,265,636.58	9.52%	Min TC
		dr 2: R0-C5-S1-C1-R0	30			
HAT	301.75	*dr* 1: R0-C3-C1-C5-S1-R0	30	14,310,647.55	9.23%	
		dr 2: R0-C4-C2-S3-S2-R0	30			
TS	306.31	*dr* 1: R0-C3-C1-C5-S1-R0	30	14,346,086.91	9.01%	
		dr2: R0-C4-C2-S3-S2-R0	30			
ACO (Original)	301.75	*dr* 1: R0-C1-C5-S1-C4-R0	19	15,766,546.00		
		dr 2: R0-C3-S3-C2-S2-R0	19			

The new milk-run routes defined by MIP, TS, HAT and ACO are figured out in Figure 4.4.

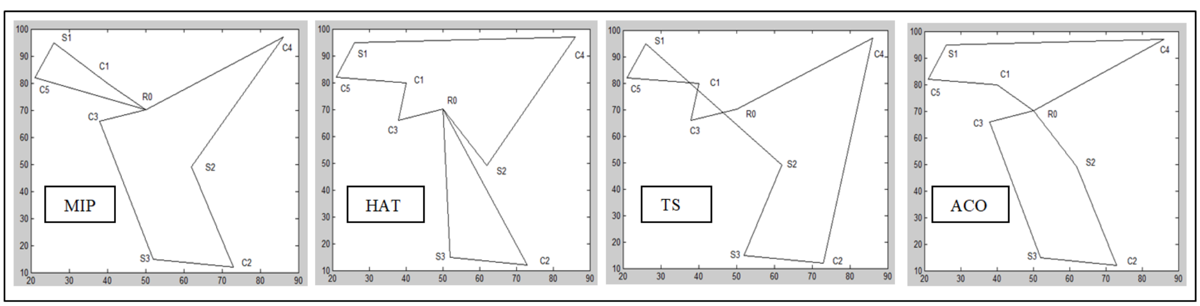

Figure 4.4 Primary and final *dr* found from MIP, TS, HAT and ACO

After being split, the solutions from MIP still remain the global optimal in regards to *final dr* and *TC*, while HAT provides the same *dr* and better TC than the original. The TS offers the worst *dr* but still has an advantage in *TC* when compared to ACO. Besides, o*ptimal n* produced by MIP, HAT and TS are identical at 30. Notably, they are far different from the *n* provided in the original (19). Concerning the CPU time to solve the 9-node-LSC, it takes around 225.23s for MIP, while TS, ACO and HAT can give the result almost immediately.

4.4.2 Results from HAT

The testing of HAT on large scale SC is inspired by the positive solutions obtained in the above case study. HAT performance is evaluated in a big-sized LSC, where MIP is inapplicable. As with each *m*, the shorter *dr* and value of *n* obtained, the smaller the *TC* incurred, and HAT is qualified through its ability to generate better *dr* in comparison with the two parents ACO and TS. To implement the test, distance matrices *D* of a large size LSC (m=20-200) is created randomly (In MATLAB, command *rand(m,m)* returns a random square matrix *D* size m and *D = 0.5(D+D')* makes *D* symmetric, then all values that are diagonal are assigned to 0). These matrices simulate the geographical locations of delivery nodes of the milk-run in the LSC. The values of the elements in matrix *D* are set from 0 to 300 km as acceptable distances for a milk-run. With each *m*, *dr* being repeatedly calculated 100 times. Table 4.9 demonstrates *dr* given by the first 10 tests.

Table 4.9 *dr* attained from TS, ACO, and HAT corresponding with different *m*

	m=20			m=30			m=50			m=100			m=200		
No	TS	ACO	HAT	TS	ACO	HAT	TS	ACO	HAT	TS	ACO	HAT	TS	ACO	HAT
1	1610	1610	1429	1710	1740	1634	2342	2266	2262	3401	3361	3304	5921	5576	5460
2	1498	1498	1494	1757	1612	1612	2448	2324	2285	3201	3020	3006	6513	6595	6426
3	1063	1063	1063	1817	1788	1750	2443	2358	2358	3283	3087	2983	6427	6595	6393
4	1467	1429	1424	1613	1547	1524	2123	2103	2049	3384	3137	3076	5996	5879	6078
5	1500	1342	1290	1771	1658	1646	2384	2209	2176	3253	2998	2936	6281	6328	5760
6	1386	1386	1265	1651	1560	1471	2375	2245	2193	3526	3546	3323	6174	6169	5983
7	1587	1528	1498	1959	1754	1741	2588	2581	2455	3693	3535	3426	5982	5942	6199
8	1530	1262	1321	1894	1792	1769	2338	2204	2196	3429	3269	3254	6399	5894	6375
9	1367	1364	1364	2118	1800	1725	2176	2160	2109	3521	3239	3210	6433	6328	5867
10	1326	1275	1176	1705	1629	1612	2224	2143	2140	3474	3546	3474	6001	5977	6323

Table 4.10 presents the average *dr* found from 100 iterations from TS, ACO and HAT as well as the variations between TS and ACO and its hybrid.

Table 4.10 Average *dr* attained from ACO, TS, HAT and their variations

m	Mean dr			Variation	
	TS	ACO	HAT	TS–HAT	ACO–HAT
20	1438.4	1416.7	1354.6	83.8	62.1
30	1794.5	1758.2	1701.6	92.9	56.6
50	2334.1	2263.9	2231.7	102.4	32.2
100	3277.5	3258.9	3213.7	63.8	45.2
200	6129.7	6102.3	6076.4	53.3	25.9

Figure 4.5 depicted the variation between TS and ACO with HAT shown in Table 4.10. As can be seen from this figure, the variation of both retains the downward trend when the number of nodes increases. It is also noted that in this study, the variation of ACO–HAT is smaller than the one of TS–HAT. In other words, ACO offers better results than TS in finding the shortest milk-run route of TSP.

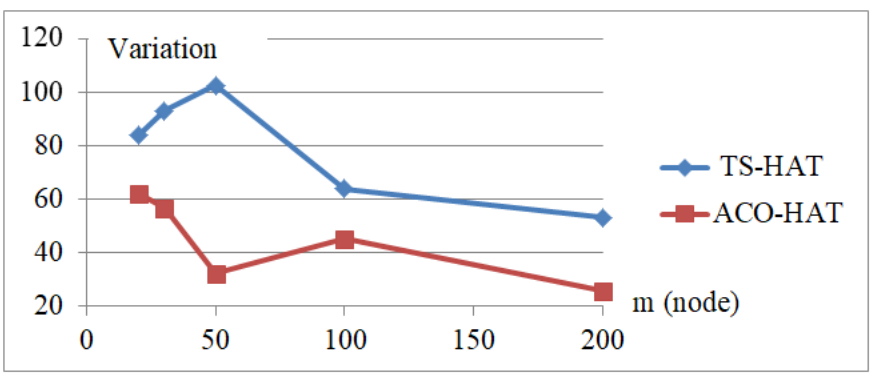

Figure 4.5 ACO–HAT variation

4.4.3 Model Validation

4.4.3.1 Sensitivity Analysis for Small-sized Milk-run

In the small scale milk-run, when *n* is fixed at the optimal value of 30, the *dr* moves from *Min dr* = 295.94 to *Max dr* = 542.7 km. The corresponding SC TC changes from *Min TC* = $14,265,636.58 to *Max TC* = $16,182,058.62. Figure 4.6 shows that *Min TC* is linear within the range of *dr* as in the aforementioned arguments. Besides, with different *dr*, *TC* only gains minimal values with the same *optimal* *n*= 30. This *n* is then combined with the range of *dr* to test the linearity of *Min TC*.

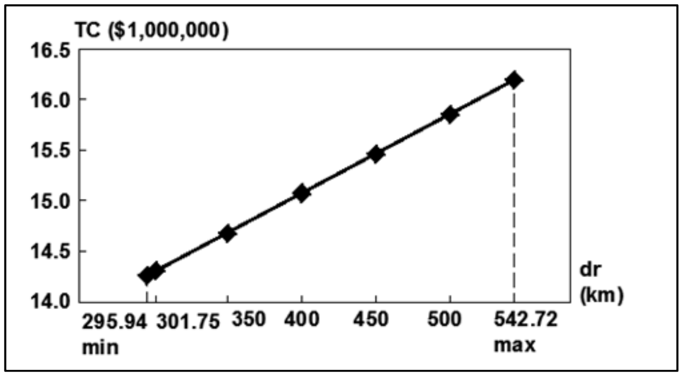

Figure 4.6 *Min TC* within *dr* range and *n*=30

When *dr is kept at min value* 295.94 km, the accepted n varies from 25 to 37 as counted in Table 4.7 and described in Figure 4.7.

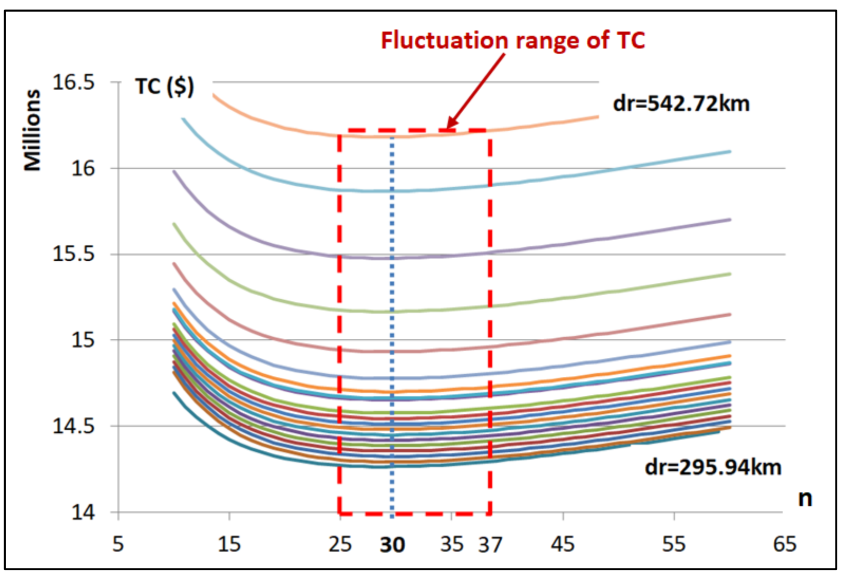

Figure 4.7 The fluctuation range of SC TC with accepted values of *dr* and *n*

4.4.3.2 Convergent Analysis for HAT in Large-Sized Milk-run

Figure 4.8 depicted the values of the average *min dr* offered by HAT with different nodes *m* (test repeated 100 times). The convergence of HAT is inversely proportional to the size of the milk-run. Increasing *m* widens the variation of *min dr*. Especially, when *m* = 200, there exist plenty of outsiders.

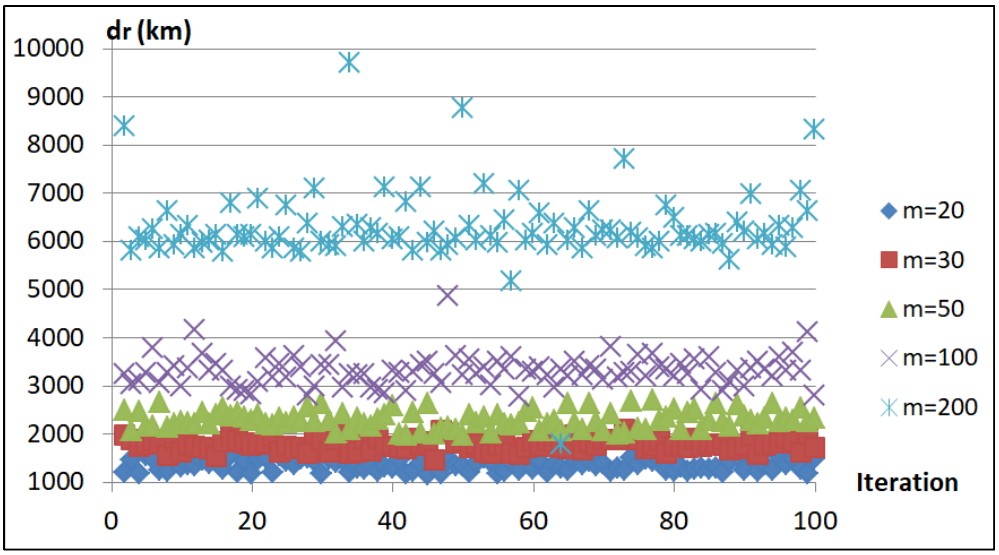

Figure 4.8 The min *dr* obtained from HAT when the test is repeated

4.4.3.3 Compare with LINGO

The quality search of HAT is compared with LINGO 18.0 with the different sizes. Both were run by the same processor Intel®, core ™ i3-45005U CPU@ 1.70GHz, RAM 4.00 GB on Dell, Window 10. Their results are shown in Table 4.11, while the solutions offered by LINGO for milk-runs of sizes 150 and 200 are shown in Figure 4.9. The solutions show that LINGO obtained the optimum results while HAT achieved near global solutions. When the size of the milk-run is increased, this gap seems wider. Concerning processing time, LINGO was superior to HAT when the size was smaller than 120 nodes. Yet, from then on, this time rocketed. With a size of 200, HAT consumed 27.44 minutes while LINGO used up nearly seven hours and half.

Table 4.11 Different milk-runs solved by LINGO and HAT

	Best Routes			Processing Time		
Size	**LINGO**	**HAT**	**Variations**	**LINGO**	**HAT**	**Quotient**
9	283.3	286.68	1.19%	0	1.21	0
20	409.2	429.02	4.84%	1	3.04	32.89%
30	456.3	472.53	3.56%	2	6.85	29.20%
50	630.1	661.47	4.99%	3	22.24	13.49%
100	1597.5	1686.5	5.57%	1.03	165.65	0.62%
120	2013.5	2207.6	9.64%	872.00	292.48	298.14%
150	1984.0	2148.4	8.29%	1,825.00	625.84	291.61%
200	2704.5	3099.5	14.61%	26,905.00	1646.95	1633.63%

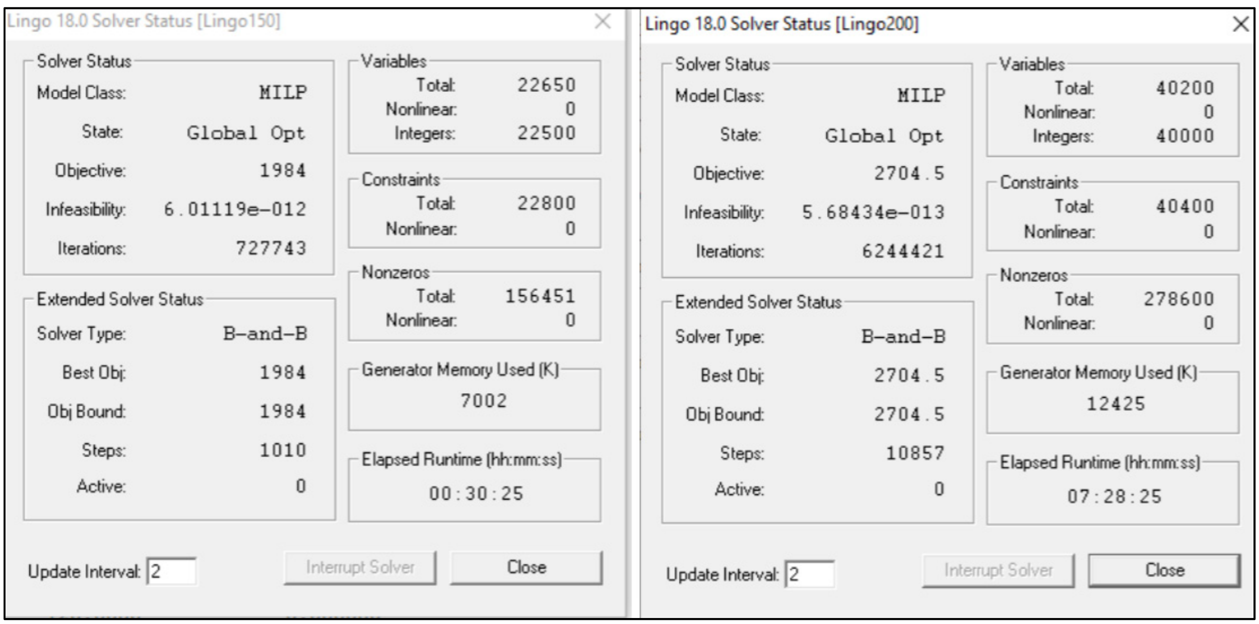

Figure 4.9 The results for milk-runs of sizes 150 and 200 by LINGO

4.5 Discussion and Conclusion

The final *TC* offered by MIP achieves the global optimal value. Compared with the original, the LSC can save *TC* up to $1,500,909.42 and shorten the delivery path by 5.81 km per milk-run. The values of optimal *dr* and delivery frequency *n* obtained from the MIP contribute to the reduction of *TC* globally (9.52%) thanks to the decrease of inventory holding costs of all members in the chain. The result matches the conclusion of Gurinder and Gagan (2011) which emphasizes the importance of cost improvement through high delivery frequency in short distances of milk-runs. However, MIP confronts monumental trouble with large m as TSP is classified as an NP-complete problem where the processing time increases superpolynomially with the number of cities (wikipedia.org). When *m* reaches 15, the processing time of the CPU (with processors that can solve 2 million procedures per second) for MIP exceeds a week, while the TS, ACO and HAT consume just less than one second. In this case, the vast amounts of time spent in finding optimal *dr* makes MIPs meaningless in industrial applications. In this case, the transition from the MIP to the HAT is necessary.

Regarding the factor *dr*, results from HAT with different LSC sizes in Table 4.9 and Figure 4.5 indicate that HAT provides better values for *optimal dr* than both TS and ACO on average. In the test, with 100 iterations, *optimal dr* from the hybrid approach is superior to ACO and TS in most cases. This emphasizes the advantages of HAT because according to the aforementioned study of Antosiewicz *et al.* (2013), TS and SA outperformed the other four different MH in solving TSP.

When *m* increases, variations of TS–HAT and ACO–HAT reveal a declining trend; or with a very large-sized LSC, the differences between them becomes small. However, in a practically sized milk-run, as shown, HAT proves worthy to apply. By providing shorter *dr*, HAT can offer a better solution for a milk-run than TS and ACO with different values of *m*. What is more, another advantage of HAT is emphasized regarding processing time. When *m* reaches 100 and 200, finding *optimal dr* from HAT consumes on average only 163.65s and 1876.42s respectively. The quality of the proposed approaches is validated. However, when the size of the milk-run increases, the results from HAT fluctuate in a wider variations. In other words, the larger the milk-run the harder to find optimal results.

This work assesses the applicability of both HAT and LINGO in reality, for example in Purolator Inc., Côte Vertu branch (https://www.purolator.com). As informed by an employee there, for commodity goods, there are 26 delivery men, each of them having to deliver, on average, around 80-150 parcels in his sectors per day. So, every day, each driver must make approximately these numbers of stops for the milk-run. Presently, he has to find the best route by himself.

If one delivery man cannot deliver all items within that day, the rest are returned to the branch to be delivered the next day. Purolator limits the missed delivery of one item to a maximum of 3 times. There is currently no study evaluating the effectiveness of finding the best route for drivers. This raises the question in relation to the necessity of using certain softwares to support those drivers by pre-defining the optimal routes for them. With these sizes of milk-runs, HAT proves much more practical than LINGO in terms of processing time when defining the best way for each driver before they depart.

To conclude, MIP and LINGO can reach exact *optimal TC* which is proved in the case study. In industry, these approach are valuable in small-size LSC applications. Due to the problem of with processing time in a large network of MIP and LINGO, the HAT is proposed to obtain acceptably good solutions.

CHAPTER 5

NEW FRAMEWORK TO DEVELOP LARG SUPPLY CHAIN MANAGEMENT

This chapter is based on paper Thi Hong Dang Nguyen, Thien-My Dao, (2020), "*New framework to develop LARG SCM: a case study",* under the review of Journal of Logistics Management. The chapter focuses on the building up LARG SC by implementing some green and resilient practices into the new-design LA SC of the case study in Chapter 3.

5.1 Proposed Framework

The proposed model is built up through two stages: design and execution. Particularly, besides the LA BOM, green design is added to the product development. Also, the lean-green logistics and resilient practices are implemented in design stage. In SCE, some robust measures are deployed to protect the models from threats. With these enhancements, the framework of joint PFD and SCD (Figure 3.2 in Chapter 3) is modified as in Figure 5.1.

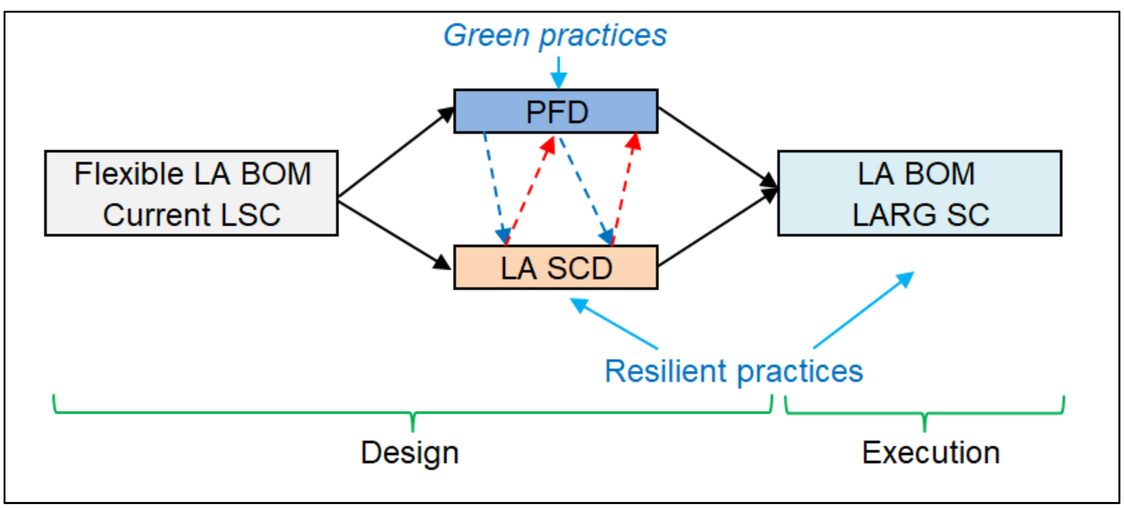

Figure 5.1 The framework of LARG SCM

From the framework above, the specific techniques and measures are selected for each strategy. In this thesis, the ones picked up are those who may be suitable for ABC company's in Chapter 3. This company had built up some basic background in LA with the application of LM in production and agile in designing as well as developing new products. However, the green and resilience practices are still very lacking. The work here focuses more on its sourcing site, where ABC can make its own management decisions. Table 5.1 summarizes the techniques and measures used in the case study.

Table 5.1 Practices used to build up the LASC SC at ABC

Phase	Practice	Lean	Leagile	Resilient	Green
SCD	LA BOM		✓		
	Green design				✓
	Milk-run	✓			
	Geographical concentration	✓		✓	
	Dual sourcing			✓	
	Supplier's reliability			✓	
	Inventory			✓	
SCE	Capacity reserve			✓	
	Surplus capacity of supplier			✓	
	70/30 rule			✓	

5.2 Application LARG model into the case study

5.2.1 LARG Model at Design Stage

5.2.1.1 Green practices

As presented previously, the application of environmental standards in furniture industry in Vietnam is still in nascent stage. Currently, it lacks environmental regulations from the government, as well as lacks industrial statistics for benchmarking. Therefore, furniture companies employ green practices by their own way according to requirements from customers. The same, ABC company has just started to apply some environmental criteria for North America market by changing to environmentally friendly material in product and in packaging.

a.) Green design

Nowadays, the consumer's awareness of the environment is increasingly higher. Specifically, some important markets request Forest Stewardship Council certification (FSC) for furniture products because it works to protect the world's forests for future generations with sustainable forest standards (http://www.fsc.org). Under the pressure of customers, businesses have to make necessary adjustments following green tendencies, which causally impact local material suppliers in furniture SCs.

ABC began to choose wooden suppliers of main components having FSC certificate even though it may suffer up to 10% material cost on average. However, through the negotiation process, most of the customers have agreed to share part of this expense. In return, the company has used the FSC certificate as a competitive advantage and a tool to promote its image of environmentally friendly products.

ABC partly changes to environmentally friendly packaging materials for some customers having demand as shown in Table 5.2. It is recalculating its packaging way to find cheaper replacements because this change makes up an increase about 8-15% packaging cost.

Although the ECF in furniture products are computed and published in the report of FIRA International Ltd. in 2011 (www.fira.co.uk), it have not benchmarked in the manufacturing environment in Vietnam and neither in ABC. Similarly, the CE in logistics has not been concerned. Yet, the situation is likely to change when recently some of Vietnam's cities are ranked among the worst air quality and pollution city in 2019 and 2020. (Airvisual.com).

b.) Lean-green logistics

The milk-run delivery is planned to use to replace direct shipment as it offers the economic and environmental benefits. When milk-run is apply, the transportation cost C21 (in Table 3.1) of direct shipment from suppliers to plants is replaced by the cost of milk run, which is set-up to collect the whole set of components for each product in the family. The cost in this case is the cost of different milk-run to pick-up component for distinct product. As the shortest milk-run contributes to min TC, this work attempts to define the best route for each product.

Table 5.2 The change to environmentally friendly packaging material

	Old packing material	**Envirenmental friendly material**
Front leg	Plastic	Corugating carton
Leg leveler	White form	Corugating carton
Front rail	Plastic	Corugating carton
Side rail	Plastic	Corugating carton
Arm	White form	Corugating carton
Seat frame	White form	Corugating carton
Seat	White form	Corugating carton
Cushion	Plastic	
Bask stand	White form	Corugating carton
Back support	White form	Corugating carton
Cover	Plastic	
Decoration	Plastic	
Hardware	Plastic	
Corner protector	Styroform	Mushroom root-based materials
Outer protector	Corugating carton	

5.2.1.2 Resilient practice

a.) Geographical concentration

As presented in Table 1.11, using geographical concentration help SC increase the efficiency through reducing of transportation, delivery times and losses while rising the flexibility. This technique is used to select suppliers. The candidates who do not meet this requirement can get lower priority in the selected order or even be removed from the list of potential suppliers. Currently, ABC Company has available a supply network in proximity location, the favorable conditions for effectively applying milk-run.

b.) Dual sourcing

The plant will choose two suppliers for each kind of component from the list of candidates.

c.) Supplier's reliability

According the study of Hosseini *et al.* (2019), supplier's reliability is one important factor which contributes directly to the resilience of the system. As a result, it should be taken into account. ABC assesses the reliability of each supplier based on the value of MtT, which reflects the reliability of suppliers in fulfill their delivery with committed quality. At ABC, the MtT value of each supplier is computed based on the percentage of defected products/sample on total amount provided within certain period.

The MtT supplier values are shown in Table 5.3 below, which have been divided into four groups from the best value to the worst.

Table 5.3 MtT values of supplier candidates

Group 1	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**	**S1-11**	**S1-12**
	3.2	0.5	2.7	3.1	1.2	1.3	1.4	1.7	1.6	1.4	1.5	1.1
Group 2	**S2-1**	**S2-2**	**S2-3**	**S2-4**	**S2-5**	**S2-6**	**S2-7**	**S2-8**	**S2-9**	**S2-10**	**S2-11**	**S2-12**
	3.3	1.2	2.9	3.6	3.2	1.7	3.1	2.2	2.1	2.0	1.6	1.2
Group 3	**S3-1**	**S3-2**	**S3-3**	**S3-4**	**S3-5**	**S3-6**	**S3-7**	**S3-8**	**S3-9**	**S3-10**	**S3-11**	**S3-12**
	4.6	2.0	3.9	3.8	4.2	3.2	4.2	2.4	2.4	2.8	5.1	1.4
Group 4	**S4-1**	**S4-2**	**S4-3**	**S4-4**	**S4-5**	**S4-6**	**S4-7**	**S4-8**	**S4-9**	**S4-10**	**S4-11**	**S4-12**
	5.3	5.7	6.4	4.3	6.4	4.7	4.5	4.2	3.5	2.9	5.1	2.1

d.) Inventory

Although operating under the LM, ABC still maintains inventory for components because suppliers have not yet achieved stable reliability in delivery. The inventory levels are keeps at the average MtT values of the suppliers. This generates one more cost element on Table 3.1, namely C33 for the inventory of components.

5.2.1.3 Modelling

The problem stated here is how to design the LARG SC when aforementioned green and resilience practices employed in supply side.

a.) Assumptions

i. LA BOM of product family XYZ is built up as presented in Chapter 3.
ii. The information of the all supplier candidates is collected.
iii. There is a group of four supplier candidates for each component, among them two are selected through dual sourcing policy.
iv. Suppliers for main components have the FSC certificate.
v. All links among ABC sourcing network members can be established.
vi. The trucks used are the same for all milk-run.
vii. The milk-run cost is variable, which is proportional with its distance.

b.) Notation

The same in Chapter 3, excepted that the value of l range from 1-4, which denotes for four candidates variables for each component.

c.) Mathematical model

The main objective function of this case is min TC of the system which includes the purchasing cost and delivery cost in sourcing side. As the MtT is considered into supplier selection, it is taken into account along with purchasing cost. Thus, before finding the min TC, this work attempts to optimize this choice in sourcing side. The procedure of solving this problem is listed out as below.

- Formulate the problem into bi-objectives model: Z1, (purchasing cost) and Z2 (MtT)

$$Z1=\sum_l \sum_q C11_{lq} Y_{lq} \tag{5.1}$$

$$Z2=\sum_{l} \sum_{q} MtT_{lq}Y_{lq} \tag{5.2}$$

- Define the best group of suppliers by simultaneously solving bi-objective Z1 and Z2 and respecting the constraints of the system.
- Assigned this best group into milk-runs.
- Define best milk-run which contribute to lowest transportation cost, as in Eq. 5.3

$$\text{Min} \sum_{l} C21_{i}dr \tag{5.3}$$

- Substitute the values of purchasing cost and transportation costs from this step to TC of the solving procedure.
- Continue to solve the joint design problem at the following steps.

d.) Constraints

Besides the constraints of the joint PFD and the LA SCD in Chapter 3, there are constraints related to the milk-run as presented in Chapter 4. The specific constraints in this case are related to the dual sourcing milk-runs of the 5 products in the family:

i. Each milk-run truck has to collect all components for each product in the family (for single or dual sourcing).
ii. The milk-run must be done within a working day.

5.2.1.4 Resolution

Optimizing the milk-run for 5 products (step 2) is one sub-optimal problem of the joint design PFD and LARG SCD. The procedure for solving the joint PFD and LARG SCD of ABC is described in Figure 5.2. Notably, the step 2 is supplier selection, which comprises one NP-complete problem of milk-run delivery, which was analysed and solved in Chapter 4.

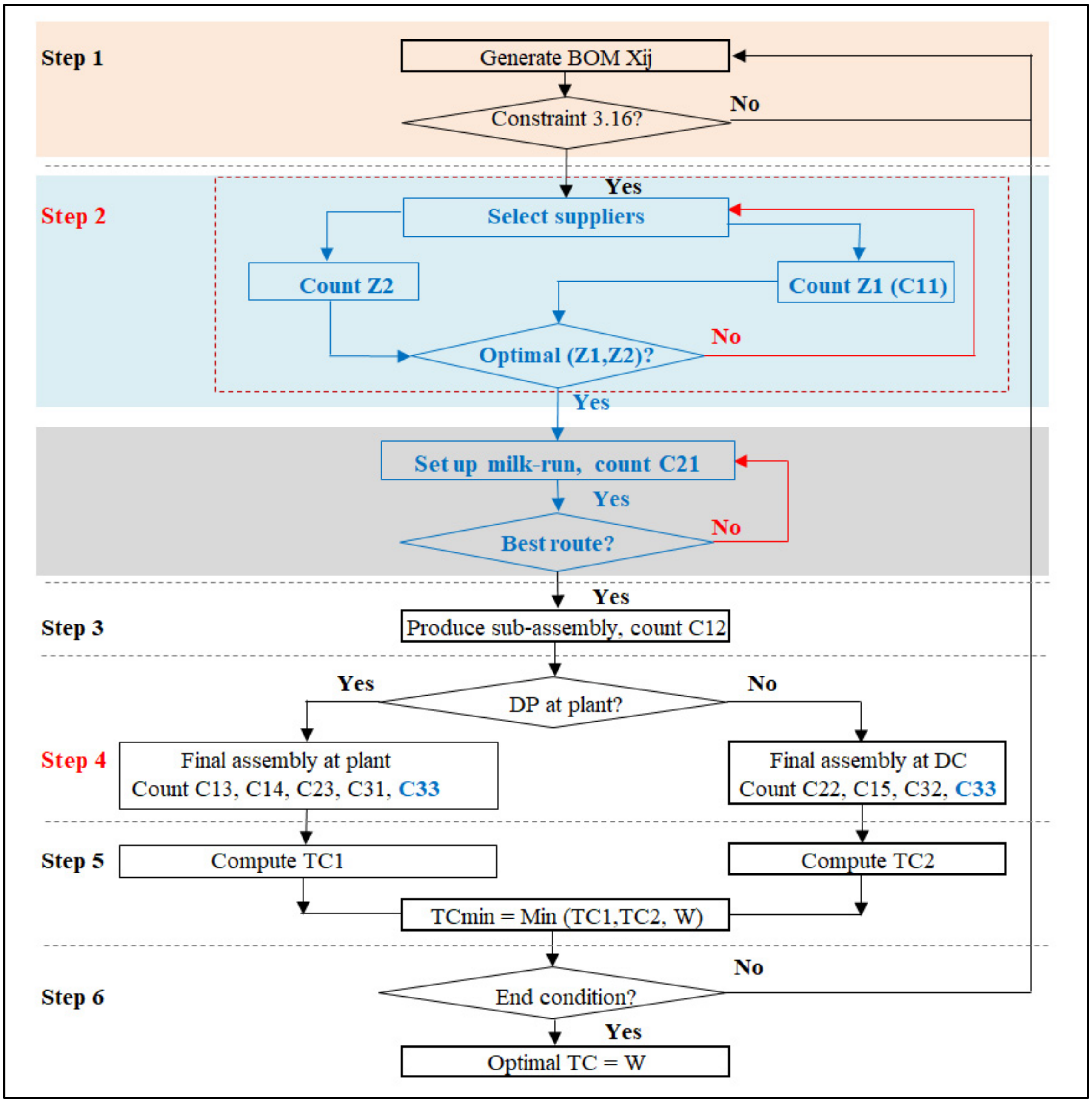

Figure 5.2 The framework to solve the joint PFD and LARG SCD

a.) Solution

With the high frequency of milk-run delivery, ABC can replace defective items by its inventory. These components will be compensated by the subcontractors for free on subsequent deliveries. Therefore, ABC has a higher priority for companies with lower costs. Therefore, the value $\beta 1$ (weight of resilient cost) ranges from 0.7 for WGP. The solutions given by WGP combined with HAT for the supplier selection and BIP are presented below.

- **Supplier selections**: the list of selected suppliers is shown in Table 5.4. It is noted that most of these suppliers belong to the group 1 of low MtT (higher reablilty) and reasonable price as well as group 3 (reasonable price but less reliable). This makes ABC easier to group their suppliers when employing rule 70/30 (presented later).

Table 5.4 Selected suppliers

Group 1	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**		**S1-7**	**S1-8**	**S1-9**	**S1-10**	**S1-11**	**S1-12**
Group 2					**S2-5**	**S2-6**	**S2-7**		**S2-9**		**S2-11**	**S2-12**
Group 3	**S3-1**	**S3-2**	**S3-3**	**S3-4**		**S3-6**		**S3-8**		**S3-10**		

- **Logistics**: The best milk-run of the five products are presented in Figure 5.3 and 5.4.
- **The LARG BOM**: The same as LA BOM
- **LARG SC**: the demand side of the new system is similar to the LA SC, in which all the PDs are positioned at DC.
- **LARG SC TC** of the increases by 5.69% in comparison with LA SC. This rise is made up from: 1.) the cost increase of wooden materials from suppliers who have been granted an FSC certificate; 2.) the rise in packaging cost; 3.) dual sourcing; and 4.) inventory. Yet, the rise in cost is partly offset by the cost reduction from the milk-run and will be partly shared by customers.

b.) Validation

This work is validated by comparing it with the optimal solver LINGO. The differences between them are detailed as follows:

- **Milk-run:** The best routes for the milk-run offered by two solving approaches are presented in Figure 5.4 and 5.5. Notably, in some cases, two of them provided the same global optimum. In the worst case, HAT's results have a gap of 8.9% compared to the optimal routes offered by LINGO.
- **TC:** the result deviates from offers by LINGO of 6.85%.
- **Processing time:** The whole procedure consumed 475.46s while LINGO offered the best solution within 1s.

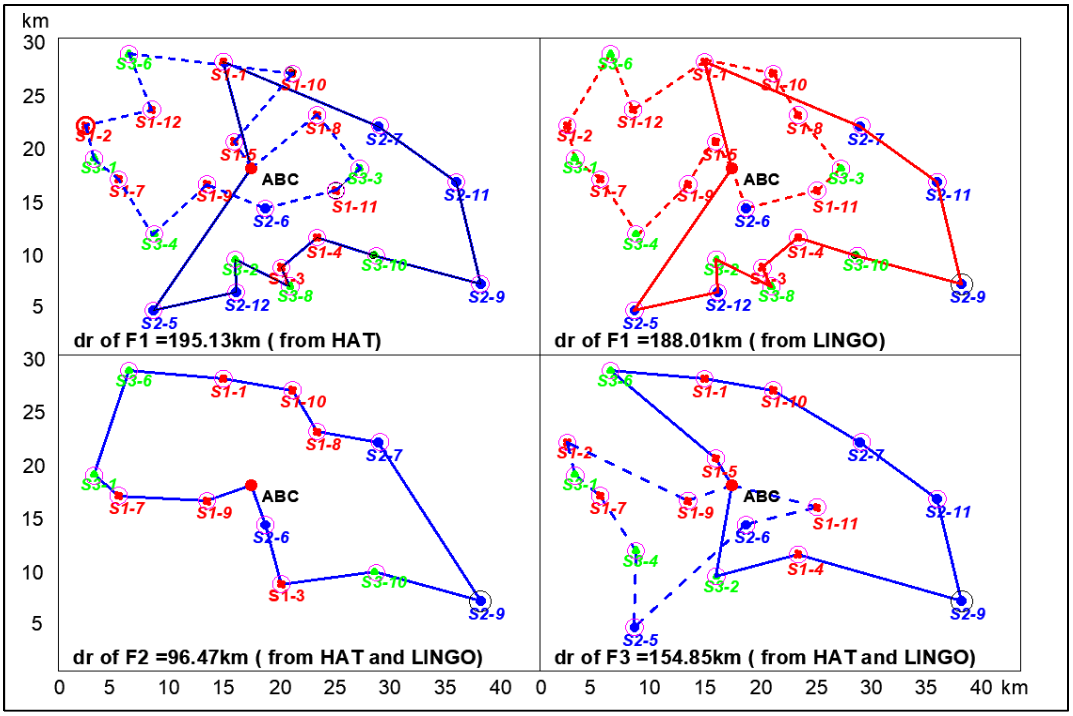

Figure 5.3 The milk-run for product F1, F2 and F3 from HAT and LINGO

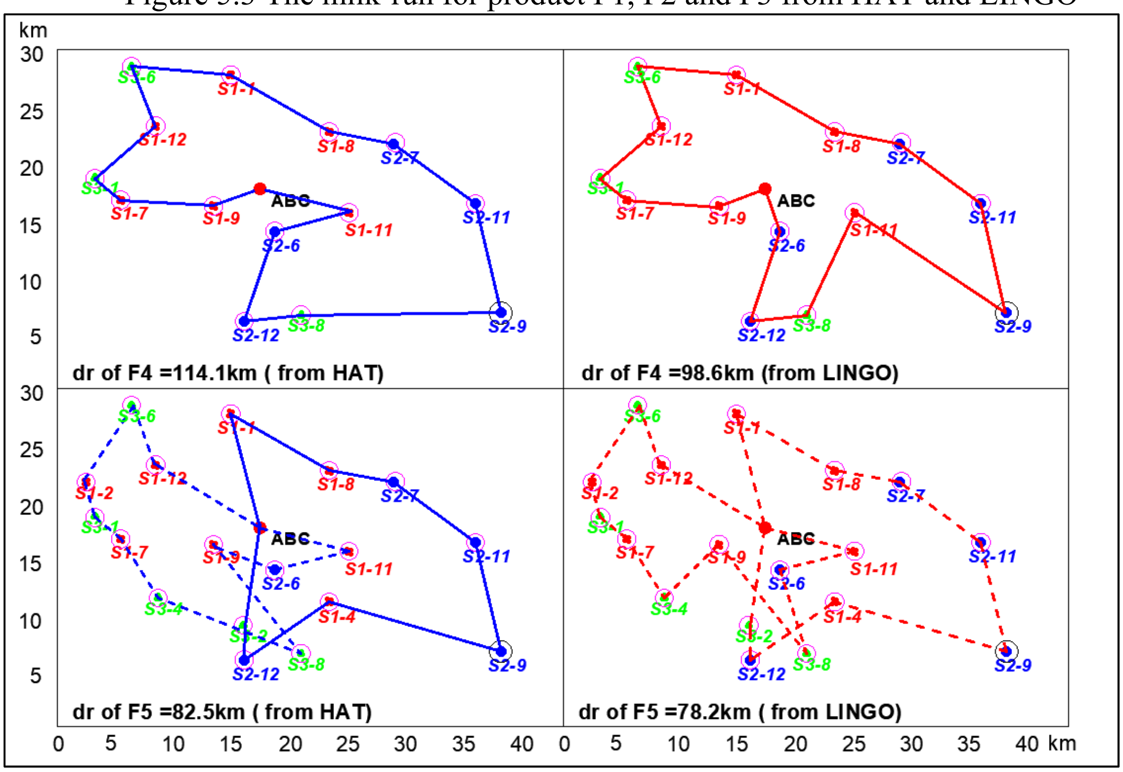

Figure 5.4 The milk-run for product F4 and F5 HAT and LINGO

5.2.2 LARG Supply Base at Excecution Phase

5.2.2.1 Robust measures

a.) Capacity Reserve and Surplus Capacity of Supplier

Some robust measures from Hosseini *et al.* (2019), in Table 1.22 are currently being used at ABC. Particularly, it applies capacity reserve at company by using around 80-90% capacity. Overtime plans are also available, which could increase up to 80% capacity serving unexpected orders. This plan has no difficulties from the workforce who willing to work overtime to increase their relatively low salary.

a) 70/30 rule

In reality, ABC applies an inexpensive 70/30 rule, which utilizes the surplus capacity of supplier to increase its robust. To implement this rule, the plant should expand its supply base by changing from a dual-sourcing to a multi-sourcing policy. With multi-sourcing, each main supplier has three backups. They are divided into four categories. The first group dominates both the cost and MtT. The second and third ones have the advantage in terms of either factor depending on the choice of the plant, while the fourth group is at a relative disadvantage when it comes to both. This rule can be explained as follows (Figure 5.5).

- The first group of suppliers will be assigned about 60–70% of the orders, while the rest will be assigned to other groups. The plant may use up to 60–70% of the capacity of the first group only. Experience shows that these percentages can help the plant in price negotiations, as well as create spare capacity for more orders when demand increases.

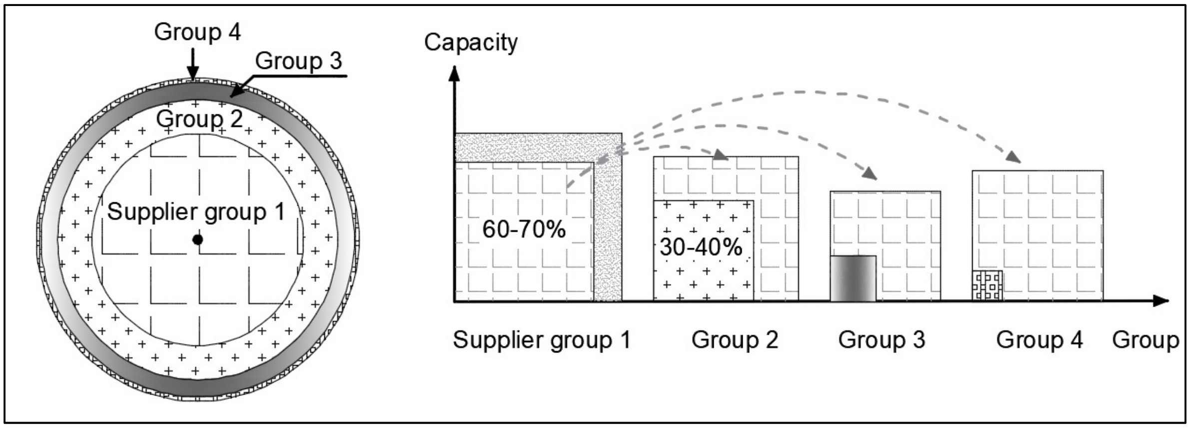

Figure 5.5 Capacity used at various groups of suppliers

- The second group should receive up to about 30–40% of its production capacity. This value is high enough for the plant to enjoy the negotiated advantages. At the same time, the excess capacity is seen as a potential backup for the main suppliers if they are disrupted.

- The third group should be responsible for small orders. This assignment helps these suppliers complete whole process of making components, including sampling, testing, approval, specification development, equipment preparation, and preparing manufacturing processes. Once received orders, this group can shorten the deployment time for back up, thereby reducing the delivery lead time. The use of these suppliers may help the plant to have extra capacity and to reserve lead time in case the second group fails to back up the full capacity of the first group.

- The fourth group should only be used for exceptional small orders, in order to maintain the partnership and to prepare in advance all the technical aspects mentioned above. This group functions as a backup to prevent the worst situations when the spare capacities of the second and third groups are being taken up by other plants.

Employing this rule allows the plant to take advantage of the excess capacity of the suppliers when incidents occur. The plant might also increase the speed of reconfigurations of the supply network when lead time is reserved. As such, applying the 70/30 rule has the similar effect as using both measures surplus capacity of supplier. Notably, the plant must have the capacity for price negotiation and quality control to ensure the uniformity of the raw materials provided from different sources. In addition, the plant must continuously support its suppliers in improving their qualifications through reducing the value of MtT.

5.3 Discussion

Concerning the problem solving method, LINGO outperforms the proposed MH approach in the case study of ABC, which works in the furniture industry, with a simple product and limited numbers of components and suppliers. However, the proposed procedure seems promising because its results are near the globally optimal results produced by the exact solver LINGO. Thus, this method is still interesting if considering the analysis in Chapter 4 that when dealing with large sizes, a MH-approach becomes more practical. Therefore, this method should be tested and re-evaluated in different industries with larger size.

With respect to the joint design, the results show that the company can achieve LARG SC to some extent without a heavy investment. Notably, this cost will be shared by customers to keep the green image as a commitment to consumers.

In relation to the execution phase, when working with small and medium suppliers, especially household companies, ABC has to some the necessary measures to raise their environmental cognition as well as support them to improve their reliability and resilience. It also takes into account the traffic conditions in this region because the traffic congestion is becoming worse. This negatively affects the quality of the milk-run.

Presently, in supplier management, ABC had made a list of potential suppliers in the third group. ABC required them to prepare a sample for testing and approval so they would be familiar with the products. However, these suppliers were not satisfied as they had to make samples for free and had to get in line for a long time to receive any official orders. After prototyping yet failing to sign a contract, some of them skilfully refused to further collaborate. ABC suffered a bad experience when one primary supplier broke down. ABC immediately shipped its order to the second supplier, but it was overwhelmed and could not meet the deadline. As such, ABC split the order and shifted it to the third supplier. However, the supplier was unable to complete the order on time due to the delay in mass production as the approved sample had been handmade. These problems could have been avoided if the 70/30 rule was applied.

5.4 Conclusion

The work has introduced the framework to build up the LAGR SC and its application in a case study in furniture industry. It began at design stage where green and resilient practices were injected in PFD and SCD through supplier selection. The problem is formulated into bi-objectives and solved by WGP and HAT and validated by LINGO. At execution stage, some robust measures are employed to increase the resilience of the system, in which one real method called rule 70/30 in supplier management are shared.

The work also presented benefits gains from the proposed framework as well as revealed challenges and difficult in application.

CONCLUSION

Enterprises are confronting lots of challenges such as shoddy Chinese products, ever-changing customers' tastes, the increase of environmental perceptions, threats from various sources, as well as the risk of an economic crisis in the coming future. This harsh reality forces companies to implement more efficient management strategies to survive and develop. The exemplar of this approach is Toyota, the lean's founder as well as the world's leading automobile manufacturer. Toyota has reputably implemented lean's philosophy, diversifying products, pursuing sustainable and environmental programs, and deploying risk management. Toyota is currently the largest automotive manufacturer and the world's market leader in sales. It is also the world's first company producing more than 10 million vehicles annually (Wikipedia).

Such challenges, along with the spectacular success of Toyota, inspired this thesis to explore and utilize LSC to develop the ability to adapt to the continual changes in a business environment. Looking through the developing direction of LSC, this thesis drew out the systematic roadmap to build up and manage a LSC from a pure lean model to hybrid paradigms (Chapters 3 and 5). In a relentless effort to improve LSC performance, it coined some new concepts to support the proposed framework. This work also introduced one new HMH HAT which integrates ACO and TS as an effective solution method to tackle the milk-run problem posed in the LARG network (Chapter 4).

Contributions

Generally speaking, the thesis has accomplished its objectives set at the beginning and has partly covered certain given research gaps in LSCM. To begin with, it attempted to identify the current research levels of the related fields. In particular, the thesis presented the systematic reviews on LSC, LA SC, milk-run, LARG SC and the application of the MH approach on SCM. Through this step, the research gaps are identified, research directions are oriented and potential solution methods are prepared (TO1).

After addressing the research methodology, the thesis started to design a pure LSC to take advantage of SCD's decisions. This work partly covered the gaps of LSCM (TO2) and served as an intermediary stepping stone to build up hybrid lean models later on.

Inheriting some results from the new LSCD model mentioned above, the thesis then proposed the LA SCD framework (TO3) by concurring PFD and SCD and demonstrated through one case study in furniture industry.

To develop the LARG SC, the following step added green factors and resilient measures into the supply side of the new proposed model. In particular, green practices were implemented in product design and logistics while resilient proposals were taken into both SCD and SCE stages. This procedure re-used the case study above to illustrate the new proposed framework. Yet, the streamline of those works were contemporarily halted due to the technical problem of optimizing the milk-run problem in the LARG system, which bears HP-complete characteristics.

To overcome this obstacle, it was necessary to make a search to seek for a serviceable supporting technique. This led to the introduction of one new HMH HAT which combined ACO and TS, which proved superior to both ACO and TS in terms of quality search and LINGO in processing time when solving the milk-run problem (met TO4). From there, the thesis proposed the method to optimize the milk-run, which employ exact approach for the small size and HAT for the large scale. With the effective aid of these approaches, the addressed problems in LARG were solved, which helped to achieve the TO5.

Findings

First of all, this thesis found that LM can be classified into two categories based on their uses. One group can be used to eliminate waste in the daily activities of the system. They account for a large proportion of LM tools and techniques. The other, even though comprising just a small amount, can flatten the system's structure like unnecessary nodes or intermediate tiers. From this observation, in APPENDIX 1, p.161, the thesis classified LM into functional lean tools and tier lean tools and both of them generated the so-called dual lean filter. The former is then utilized in SCE to remove waste across the system while the latter is employed in the SCD steps to filter waste along the chain. With that approach, the LSC can be formed from both the SCD and SCE stages. Applying this approach, the wastes hidden in the system's structure as well as in operations would be identified and eliminated.

Also, this thesis coined the so-called LA BOM which proved very fruitful in product design. In LA BOM, components were simplified to minimize its SKU and also to enhance its combining capacity. Another contribution of this work is the new quantitative framework to optimize the LA SCD by concurring PFD through LA BOM, which have not been to study before.

Chapter 4 served as an intermediate step in seeking technical support for the problem raised in the LARG SC modelling. Technically, this chapter introduced the mechanism to formulate the new HMH HAT. This HMH proved superior to the two original MHs from which it was hybridized in optimizing the milk-run. HAT also outperforms LINGO in terms of processing time in large scale milk-run. Other findings of this work laid out a new method to effectively optimize the milk-run problem because when qualifying the HAT, this thesis used a previous case study on LSC where the milk-run optimization was solved by ACO. As the original SC examined was small-sized, and that ACO did not offer the best solutions, this thesis resolved it by using MIP and eventually obtained the global optimal results. For a large scale milk-run, where MIP is infeasible, HAT was tested using random data from milk-run sizing up to 200 nodes. The results showed the domination of HAT over ACO, TS and also LINGO. This work is considered as an unexpected bonus of the thesis. Thanks to this work, this method of milk-run optimization was added to the literature of LSC management. This approach ensures that the milk-run can attain the globally optimized solutions at the small size by MIP or exact solver like LINGO, and fairly good results in a large scale LSC through HMH HAT.

Chapter 5 has introduced a new way to design and manage LARG SC as well as demonstrate practical application within a company in industry. To the best of our knowledge, have yet research contemporarily to touch the joint design of product family and LARG SC, the two complex problems in industrial management. It also reveals the one management tactic, the 70/30 rule, which is currently employed at the company of the case study. Previous researchers emphasized the trade-off between lean and resilience models because resilient practices often negatively influenced the cost-cutting efforts central to LM. However, the results of this study show that with a suitable approach, an enterprise can implement these strategies simultaneously without heavy investment. Finally, while applying the model in a furniture company, this thesis found optimistic and practical opportunities to apply all these findings into the furniture industry.

Managerial Implication

SCD is an essential step in SCM in shaping the structure of future SCs. Enterprises with different objectives and available resources look for their own matching SC models. Pursuing the LM's famous philosophy "continuous improvement", this thesis proposed LSCD and management models from pure to hybrids, and from theoretical models to more realistic ones, for different design goals. It began from a very simple model LSCD for a single product which may be suitable for a start-up phase serving a limited market. From there, the thesis combined product design and SCD for a product family in a LA SC, which may be appropriate for the developing stage of expanding to larger market. Finally, it attempted to add environmental factors and resilient measures to contemporaneously design a set of varied product families and LARG SCs, which are expected to enter the global market.

The procedure of optimizing LSCD can clearly draw out a general roadmap for those who want to start a business producing one single product. Their priority is to maximize profits by cutting costs and eliminating waste. The model could assist them in maximizing their LSCD in a quantitative approach. It also offers a reference for the managing cadre in order to flexibly select proper lean tools that will serve their business objectives. The application of lean filters, especially the structural ones, may help designers recognize the waste in the structure of the system, which is often ignored during the design process.

Meanwhile, the LA SCD model can be referenced for the enterprise to redesign their SC to expand their product range to build up their SC with high agility. The main idea drawn from this new approach is using lean tools not only to simplify the components of the product family but also to amplify the combination capacity among them. Thus, the concept of LA BOM in product design is developed for modular products and would be applied in various industrial sectors. Also, the LA SCD framework may be flexibly useful in different industrial sectors to simultaneously implement both lean and agile strategies to gain competitive advantages from cost reduction and product diversity.

The model of LARG is suitable for entrepreneurs who intend to contemporaneously gain various competitive advantages, including the adoption of environmentally friendly brands. The results from the case study in Chapter 5 show that the LARG system can obtain resilience without massive investment, which matches with the findings from Hock & Mohamed (2011). Moreover, the 70/30 rule in supplier management may be useful and practical for practitioners as it increases the robustness and reconfiguration capacity of the system before and after a disruption.

Technically, it is promotive to replace ACO and TS with HMH HAT to solve other SCM problems. The striking advantages of its processing time (on large size milk-run) and search quality (superior to both ACO and TS) make the applicability of HMH very promising. Its benefits sound more encouraging for logistics companies like Purolator Inc., where its delivery staff has to find the optimal path of around 80-150 stops within a milk-run of 120-200 km everyday by themselves.

Limitation and Future Research

The limitations of the LSCD framework are the lack of validation and the absence of contingency proposals to protect it from threats. Meanwhile the proposed LA SCD has yet to deal with the multi-DPs. Similarly, the thesis lacks of various proposals to develop LARG thereby prove the effectiveness of the novel model. To overcome these primary limitations, future research would discover more the potential of multi-DPs or build up the LARG SC from different directions.

Other recommendations would be related to the time window in these models. The thesis is supported by Baud-Lavigne *et al.* (2016), who tried to convince everyone that decisions taken in the product design and SCD are strategic and their optimization problems are suitable for single period. Yet, the researcher could have extended the timeline to multi-periods and specifically focus more on SCE to better assess the impact of the SCD optimization on SCP in long term.

Finally, future research may test HMHs in real large case studies and apply it in other areas of SCM. They are also encouraged to modify current MHs in order to improve their search quality or develop more powerful novel HMHs for solving complex, real SCM problems.

APPENDIX I

NEW STRATEGY TO OPTIMIZE LEAN SUPPLY CHAIN DESIGN BY META-HEURISTIC

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Abstract

This paper aims at presenting one novel quantitative strategy of optimizing the design of Lean supply chain using Meta-Heuristics. While classifying Lean Manufacturing tools in two categories, namely Functional and Tier Lean tools, we propose a new framework to design the Lean supply chain by implementing the former into a 5-echelon Fat supply chain. As the following step, we investigate the effect of the latter on the mentioned Lean supply chain model. Then, we utilize the tight correlation of Tier Lean tools and priority-based Genetic Algorithm Meta-Heuristics in order to optimize the configuration of the Lean supply chain. Finally, these ideas are illustrated step by step in one numeral example.

1. Introduction

Supply chain management (SCM) is a respected area today, as future competition in the field of business will be based on supply chains (SC) system rather than individual enterprises (Agarwal, Shankar, & Tiwari, 2006). Several models of SC have been studied as part of the incessant efforts taken to improve the competitive advantages of enterprises. Among them, the Lean supply chain (LSC) is assessed as an "ideal SC" Srinivasan (2012) since it can promptly and economically deliver the final products/services to customers in a seamless manner. The objective of the LSC is to eliminate non-value added activities as well as reduce the required non-value added activities (Anand & Kodali, 2008). Deborah (2005) analyses and compares the characteristics of the Fat supply chain (FSC) and LSC, thereby asserting the undeniable benefits and power of the LSC over the FSC.

In the SCM domain, the supply chain design (SCD) directly impacts the performance of the SC since it creates a proper platform for all activities in the chain. Harrison (2001) suggests that approximately 80% of the total product cost may be fixed with SCD decisions. Nonetheless, the design space of the SCD contains a vast number of alternatives (Leukel & Sugumaran, 2013), which makes it hard to define the best solutions. Over time, the developments of information technology and optimization techniques make this difficulty solvable through optimization, simulation, or heuristics (Harrison, 2001). Recently, numerous Meta-Heuristics (MH) which are improved from heuristics, have proven effective in resolving SCD issues.

Inspired by such attractions, we introduce in this study a new quantitative strategy to design LSC by MH. The forthcoming sections in this paper are organized into as followings: literature review; new strategic framework of the Lean supply chain design (LSCD), including the FSC formation, LSC transformation, and its optimization by priority-based Genetic Algorithm (pGA); a numerical example; and conclusion.

2. Literature Review

SCD is a rich domain of SCM. Farahani, Rezapour, Drezner, & Fallah (2015) classifies SCD into five main rubrics: 1) Network structure; 2) Non-strategic decision of the SC; 3) Technology type / production philosophy; 4) Environmental condition of the model; and 5) Objective of mode, which includes LSC and other kinds of SC. U. Paschal, E. o. Jon, & L. Jostein (2012b) states, "*When Lean is implemented across the entire SC, the SC is referred as a LSC.*" Findings from the exhaustive review of Anand & Kodali (2008) show that previous studies concentrated on transforming the current FSC into LSC, rather than building a brand new LSC in its design stage. This study enumerates up to 59 LM tools/techniques available for LSC transformation. They are classified into four categories: 1) IT-based; 2) SCM-based; 3) Organization-based; and 4) JIT or LM elements.

Theoretically, the SCD process has been described through various models, in which the 5-stage SC Outline Process (SCOP) proposed by Corominas *et al.* (2015) profoundly draws out an SCD roadmap. To begin with, the first stage focuses on identifying the environment, and objectives of the new SC. Further, stage 2 defines the SC macrostructure. Then, stage 3 identifies the SC mesostructure. Stage 4 specifies the SC microstructure, in which all SC specifications (objectives, parameters, constraints, and variables) are formulated into mathematical models. Final stage chooses the optimal SC configuration among obtained results. There are two main solution methodologies in this stage: exact solution and heuristics or MH (Melo, Nickel, & Saldanha-da-Gama, 2008b). Tiwari *et al.* (2010) realize the growing tendency of using MH as they can offer acceptably good solutions with relatively little CPU time. Especially, the application of MH in SCM and SCD is well reviewed by Griffis *et al.* (2012). The study finds that GA, a globally optimal MH inspired by evolutionary biology (Holland, 1992), is the most prevalent. During the time, GA is modified and hybridised with various algorithms in order to improve its search quality (Jaramillo, Bhadury, & Batta, 2002). Among of which, pGA, proves useful in designing the SC (Gen, Altiparmak, & Lin, 2006). Also, pGA is superior to Spanning Tree-based GA by using a simpler decoding procedure to generate random feasible chromosomes.

3. New Strategic Framework of LSCD

The new strategic framework of the LSCD includes three main stages and eight sub-steps (see Figure-A I-1 and Figure-A I-2). To elaborate, suitable LM tools selected among 59 items in review of Anand & Kodali (2008) are implemented into the fourth and fifth stage of the SCOP model (Corominas *et al.*, 2015). These tools are classified into two categories that play a distinct role in the LSCD process: Functional Lean tools (which influence the SC TC with daily operating functions) and Tier Lean tools (which affect the SC configuration), as depicted in Figure-A I-3. The entire process is particularly explained below.

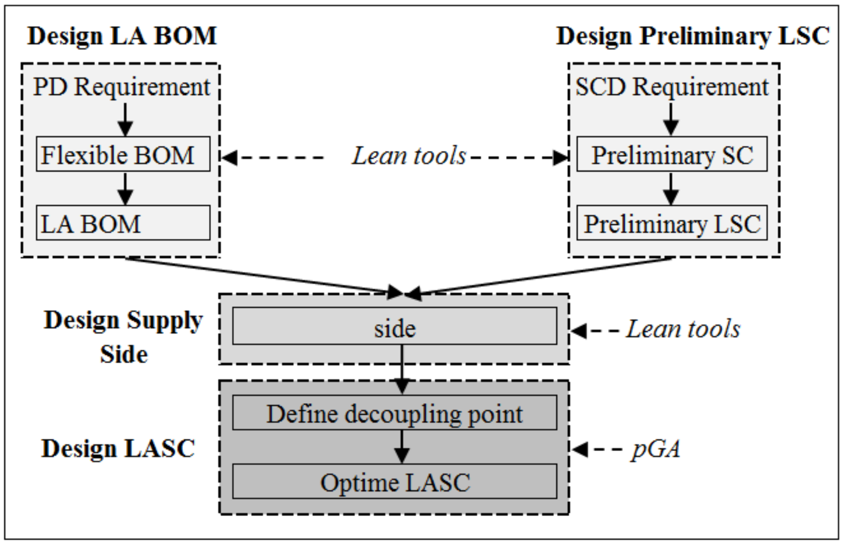

Figure-A I-1 LASC design framework

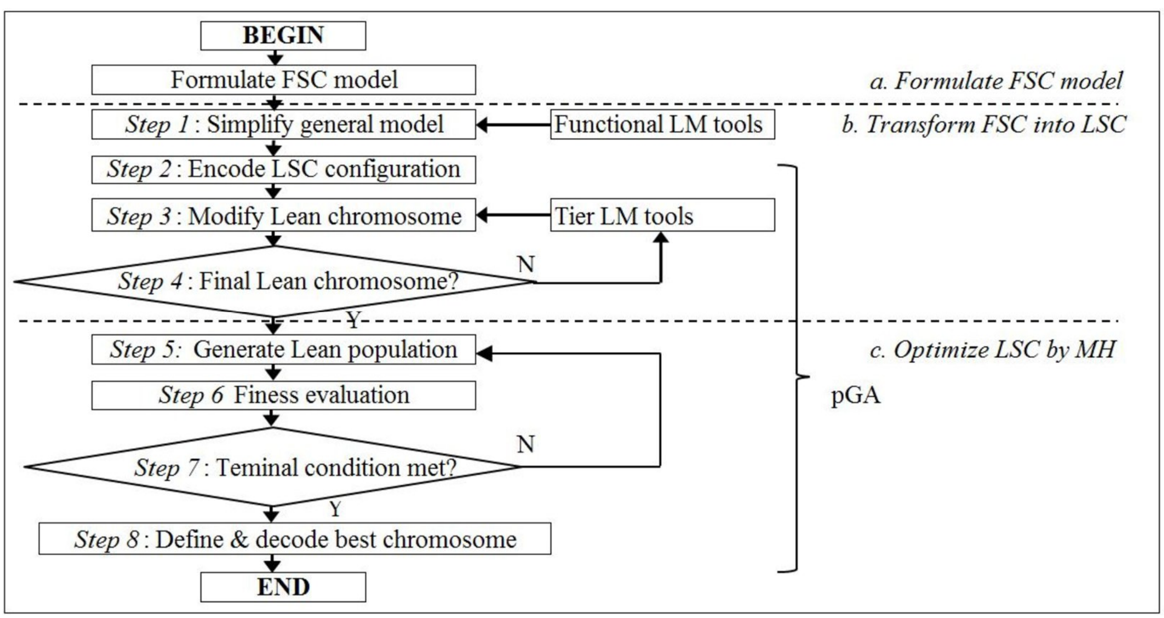

Figure-A I-2 Framework for optimizing the LSCD by the pGA

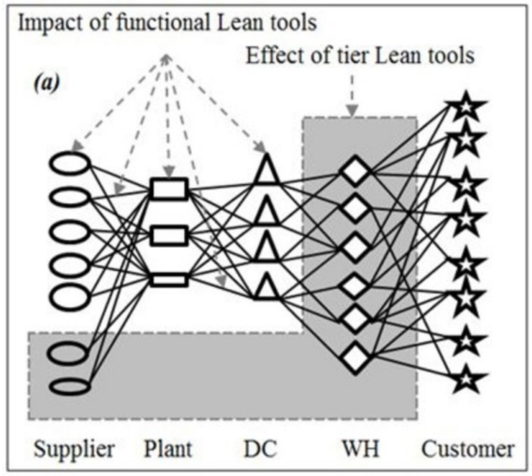

Figure-A I-3 Impact of Lean tools on SC

3.1 Formulate the FSC Model

The objective function of the FSC is to minimize the SC performance - total cost (TC), which is apportioned from SC tiers and functions as modified in study of Shretta *et al.* (2015), (see Figure-A I-4a). The former include the Supplier (S), Plant (P), Distribution Centre (DC), Warehouse (WH), and Customer (C). The latter comprises five basic functions: Procurement, Production, Delivery, Inventory, and Quality Assurance, which are described by the SC TC tree (see Figure-A I-4b). Thus, the general FSC TC can be formulated from the five mentioned elements together with the Facility Installation cost. It is noted that all costs that are derived from suppliers are cumulated with the Material cost. Specifically, FSC TC is formulated in Eq. (A I-1) as follows.

$$FSC\ TC = Total\ Cost\ [Procurement + Production + Inventory + Delivery + Quality + Installation] \qquad \text{(A I-1)}$$

By substituting the SC TC structure in Figure-A I-3a and I-3b into Eq. (A I-1), the FSC TC yields the following:

$$SC\ TC = Total\ Cost\ [(Order_{PDW} + Raw\ Material_{P}) + (Manufacturing_{PDW} + Start\text{-}Up_{P}) + Holding\ (Parts_{P} + Finished\ Goods_{PDW}) + In\text{-}Transit\ (Parts_{S\text{-}P} + Finished\ Goods_{P\text{-}D,D\text{-}W,W\text{-}C}) + WIP_{P}) + Delivery\ (Finished\ Goods_{P\text{-}D,\ D\text{-}W,\ W\text{-}C}) + Quality\ Control_{PDW} + Backoder_{PDW} + Installation_{PDW}] \quad \text{(A I-2)}$$

3.2 LSC Transformation

Step 1: Simplify the general model with Functional Lean tools (see Figure-A I-5). After a period of time, if these tools are strictly implemented, they can reduce various SC costs to some extent (completely, remarkably, or gradually). For example, Order cost, Setup cost, and Holding/work-in-process cost can be almost eliminated by the *IT support system*, *Setup Reduction*, and *JIT-based element* respectively. Similarly, the In-transit and Quality Assurance costs are hugely cut down by the *Proximity Location* and *Built-in Quality System / Point of Sale*. Thus, these costs are almost removed out of the TC model in the long run. As a result, Eq. (A I-2) remains with only four components: Raw Material, Manufacturing, Delivery, and Installation cost. Therefore, the TC of the LSC is simplified from Eq. (A I-2) as follows:

$$LSC\ TC = Total\ Cost\ [Raw\ Material_{P} + Manufacturing_{PDW} + Delivery\ (Finished\ Goods_{P\text{-}D,D\text{-}W,W\text{-}C}) + Installation_{PDW}] \quad \text{(A I-3)}$$

At the operational level, the objective function Eq. (A I-3) can be expressed by integer programing as:

$$Min\ LSC\ TC = [\sum_I \sum_J R_{ij} y_{ij} + (\sum_J F_j x_j + \sum_I \sum_J V_j y_{ij}) + (\sum_K F_k x_k + \sum_J \sum_K V_k y_{jk}) + (\sum_L F_l x_l + \sum_K \sum_L V_k y_{kl}) + (\sum_J \sum_K T_{jk} y_{jk} + \sum_K \sum_L T_{kl} y_{kl} + \sum_L \sum_M T_{lm} y_{lm}) + (\sum_J I_j x_j + \sum_K I_k x_k + \sum_L I_l x_l)] \quad \text{(A I-4)}$$

Where:

R_{ij}: Unit Material cost of plant j with supplier i;

F_j, F_k, F_l: annual fixed Operating cost of plant j, DC k, warehouse l;

V_j, V_k, V_l: Unit variable Operating cost of plant j and unit Throughput cost of DC k, warehouse l;

T_{jk}, T_{kl}, T_{lm}: unit Transportation cost among adjacent tiers;

I_j, I_k, I_l: Installation cost of plant j, DC k, and warehouse l;

C_j, C_k, C_l: capacity of plant j and DC k, and warehouse l;

D_j, D_k, D_l, D_m: demands from plant j, DC k, warehouse l, and customer l;

Variables

x_j, x_k, x_l: binary variable denotes plant j, DC k, warehouse l opened (1) or closed (0);

y_{ij}, y_{jk}, y_{kl}, y_{lm}: quantity of material/product shipped among adjacent tiers;

Subject to

i. Balance between quantities received and amount supplies at each node:

$$\sum_I y_{ij} = \sum_K y_{jk}; \sum_J y_{jk} = \sum_L y_{kl}\ ; \sum_K y_{kl} = \sum_M y_{lm} \qquad \text{(A I-5)}$$

ii. Satisfy demand from plant, DC, warehouse and customers:

$$\sum_I y_{ij} = D_j\ ; \sum_J y_{jk} = D_k\ ; \sum_K y_{kl} = D_m \qquad \text{(A I-6)}$$

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

$$\sum_K y_{jk} \le C_j; \sum_L y_{lk} \le C_k; \sum_M y_{lm} \le C_l; \qquad \text{(A I-7)}$$

iv. Non-negative conditions:

$$y_{ij},\ y_{jk},\ y_{kl} \geq \qquad \text{(A I-8)}$$

Step 2: Encode the LSC configuration. After simplified, the LSC is encoded by the pGA procedure as in study of Mitsuo, Fulya, & Lin (2006) to identify its optimal configuration. The 5-tier SC is encoded through a 7-substring chromosome, in which the first, second, and third substrings contain binary variables (open/close plants, DC, and WH). The last four adjacent substrings denote transport trees between supplier and plant; plant - DC; DC - WH; then finally, WH and customer. These strings contain |I+J|, |J+K|, |K+L|, and |K+M| digits with random values from 1 to |I+J|, |J+K|, |K+L|, and |K+M| respectively (see Figure-A I-6a).

Step 3: Modify the Lean chromosome. When Tier Lean tools are applied, they impact the amount of node/tier in the SC, which changes its denoted chromosome. Particularly, the application of *Single Sourcing* reduces the number of suppliers to one for each component type. Hence, the supplier-plants transport substring is removed because its configuration becomes deterministic (see Figure-A I-6b).

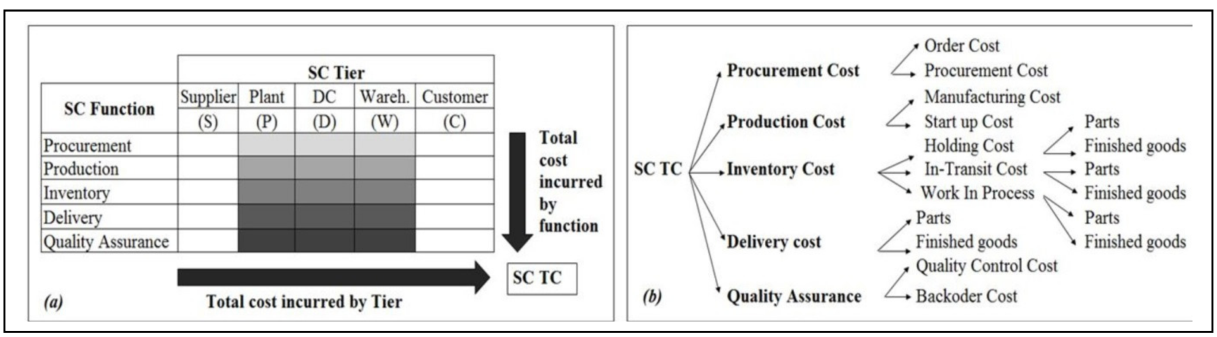

Figure-A I-4a. FSC TC by tier and function; 4b: SC TC tree

Similarly, the *Use of Flat Hierarchy* can minify the intermediary tiers in the supplier-plant or/and plant-customer substrings. Thus, the correlative substrings of these tiers are deleted. Figure-A I-6c represents the chromosome of the LSC when *Single Sourcing* is used and the warehouse stage is flatted. LSC objective in Eq. (A I-4) becomes:

$$Min\ LSC\ TC = [\sum_I \sum_J R_{ij} y_{ij} + (\sum_J F_j x_j + \sum_I \sum_J V_j y_{ij}) + (\sum_K F_k x_k +$$

$$\sum_J \sum_k V_k y_{jk}) + (\sum_J \sum_K T_{jk} y_{jk} + \sum_K \sum_M T_{km} y_{km}) + (\sum_J I_j x_j + \sum_K I_k x_k)] \quad \text{(A I-9)}$$

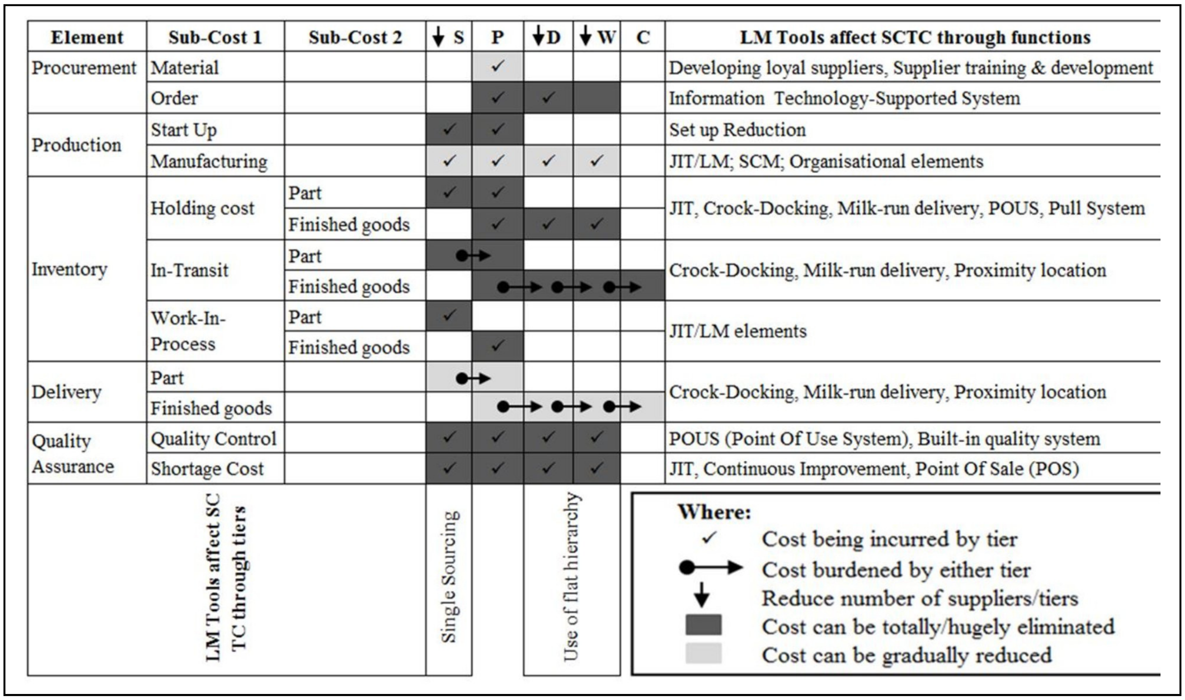

Figure-A I-5 Framework of the LSC transformation

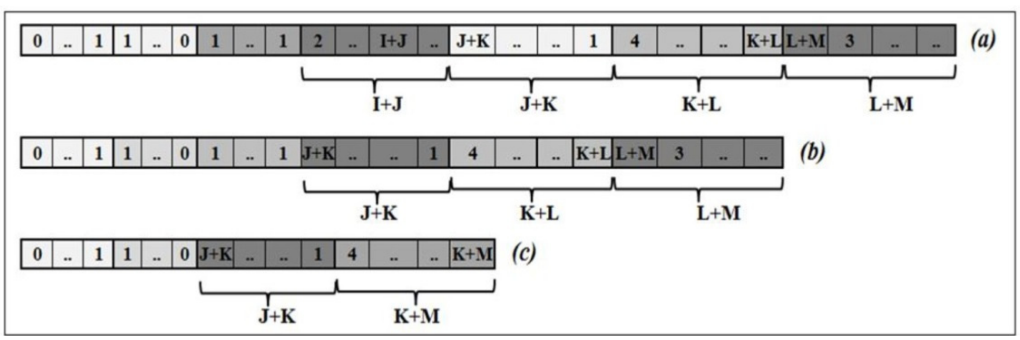

Figure-A I-6 LSC chromosome in: a. General; b. LSC using *Single Sourcing*; c. applying *Single Sourcing* and the *Use of Flat Hierarchy*

Step 4: Final Lean chromosome? The quantity of Tier Lean tools applied depends on the deliberate goals of SC designers. Thereby, the denoted chromosome is correspondingly leaned until the design requirements are met. For instance, other techniques such as *Group Technology*, *Use of Common Part*, and *Modularity* are able to change product structure by decreasing the types of components purchased from subcontractors. So, they reduce number of suppliers and genes on chromosomes simultaneously.

3.3 Optimise LSC by pGA

Step 5: Generate Lean population pool. Heuristically, pGA uses the same procedure as GA to randomly generate and handle the offspring in a population pool.

Step 6: Fitness evaluation. After created, each offspring is decoded to the transportation tree in order to calculate the fitness (LSC TC). In pGA, each gene on a chromosome has two factors: locus and allele. Locus is the position of genes denoting the order of source/destination in the transportation tree. Meanwhile, the gene value of allele bears represents the priority level of nodes assigned to the transportation tree. The decoded procedure determines the highest allele on a chromosome. Its corresponding locus is referred to the node having the priority to be served or delivered. Then, the shipment from this node with its counterpart is established, provided that the transportation cost between them in the cost matrix is the lowest. When any node is completely supplied/ served, its correlative allele is assigned to zero. The assignment repeats until all alleles on the chromosome adopt the null value. At that time, the transportation tree is totally built and the fitness is computed based on this network.

Step 7: Terminated condition met? The terminated condition can be set similar to the GA.

Step 8: Define and decode the best chromosome. Finally, the chromosome contributing to the best fitness is defined and then decoded in order to identify the best configuration of the LSC.

4. Illustrative Example

To illustrate the aforementioned method, one numerical example of the LSC design is described step by step. Assuming that all information in Step 1, 2, and 3 of the SCOP model is defined, the designers outline one potential FSC structure including 7 suppliers, 4 plants, 5 DCs, and 8 WHs to serve 8 customers, in which supplier 1 and 2 provide the same components as supplier 6 and 7. While examining three assumptions and collected data in Table-A I-1 and I-2, the managers want to lean both the supply side and the demand side, with only 5 suppliers, 3 plants, 4 DCs, 6 WHs selected.

Assumptions:

i. Suppliers' capacities satisfy demands of all plants.
ii. Customers' demands are deterministic and must be satisfied completely.
iii. All the transportation links between adjacent tiers are available.

Step 1: Simplify the general model. Designers intend to implement Functional Lean tools in Figure-A I-3 into their draft of the FSC. When transformed, the LSC TC contains four factors like Eq. (A I-3).

Step 2: Encode the LSC configuration. With I = 5, J = 3, K = 4, L = 6, and M = 8, the chromosome of the LSC structure is randomly denoted with 7 substrings, 56 digits (see Figure-A I-6).

Step 3: Modify the Lean chromosome. When *Single Sourcing* is applied, supplier 6 and 7 are dropped (their material cost higher than competitors'), so their supplies are transferred to supplier 1 and 2 (the forth substring is removed). Since the supply side is leaned, *The Use of Flat Hierarchy* is then used to clear the warehouse tier (substrings WH and D-W are wiped out). Thus, DCs serve customers directly and the last substring W-C turns out as D-C. The LSC chromosome is then modified as Figure-A I-7.

Step 4: Final Lean chromosome? In this case, other Tier Lean tools have not been applied. Therefore, the chromosome representing the LSC structure defined in Step 3 is final.

Step 5: Generate Lean population. The mutation and crossover rates are set at 0.1 and 0.8 respectively.

Step 6: Fitness evaluation. Lean chromosomes are decoded to compute the fitness from Eq. A I-10).

$$Min\ LSC\ TC = [\ \sum_5 \sum_3 R_{ij} y_{ij} + (\ \sum_3 F_j x_j + \sum_5 \sum_3 V_j y_{ij}) + (\sum_4 F_k x_k + \sum_4 \sum_3 V_k y_{jk} + (\ \sum_3 \sum_4 T_{jk} y_{jk} + \sum_4 \sum_8 T_{km} y_{km}) + (\sum_3 I_j x_j + \sum_4 I_k x_k)] \quad \text{(A I-10)}$$

Table-A I-1 SC data

No	Plant					DC					Warehouse					Cus
	Dj	Cj	Fj	Vj	Ij	Dk	Ck	Fk	Vk	Ik	Dl	Cl	Fl	Vl	Il	Dm
1	400	500	50,000	25	700,000	700	550	13,200	8,250	245,000	300	350	5,100	2,400	52,500	400
2	800	900	108,000	30	1,400,000	300	800	19,200	12,000	105,000	450	500	7,650	3,600	78,750	250
3	600	750	75,000	28	1,050,000	350	500	12,000	7,500	122,500	500	600	8,500	4,000	87,500	300
4	800	1000	116,000	35	1,480,000	450	300	7,200	4,500	157,500	150	200	2,550	1,200	26,250	150
5						700	450	10,800	6,750	315,000	250	300	4,250	2,000	43,750	50
6											150	250	2,550	1,200	26,250	200
7											300	350	5,100	2,400	58,500	350
8											150	200	2,850	1,200	29,250	100

Table-A I-2 SC cost matrix

	S1	S2	S3	S4	S5	D1	D2	D3	D4	D5	C1	C2	C3	C4	C5	C6	C7	C8	
											18.5	19.6	16.7	16.8	15.3	20.1	15.4	18.9	D1
P1	123.2	129.8	120.4	134.5	132.1	11.3	12.4	13.3	12.7	19.8	17.4	16.8	15.8	15.4	16.8	19.5	16.4	21.4	D2
P2	146.5	150.3	139.2	146.4	148.1	16.3	13.2	14.3	12.1	18.4	16.7	18.3	19.4	15.8	18.5	17.4	15.8	20.4	D3
P3	135.7	137.5	136.4	143.6	129.5	10.5	12.7	11.1	14.7	16.3	15.6	15.2	20.1	17.7	16.4	17.2	21.3	15.7	D4
P4	155.4	168.2	163.3	170.4	161.3	11.8	14.7	14.8	15.1	15.2	18.2	24.1	23.4	17.9	18.7	20.6	22.7	24.5	D5
					W1	5.4	6.2	7.3	9.4	11.5	4.3	5.4	6.8	6.2	5.2	5.7	4.8	4.7	
					W2	7.8	6.4	5.9	8.7	10.6	5.6	5.9	4.1	5.7	4.8	6.3	5.2	7.2	
					W3	10.3	9.5	10.1	6.3	10.4	6.4	6.2	5.3	4.4	5.1	4.6	6.3	4.8	
					W4	8.8	5.7	6.3	5.8	9.5	4.7	6.3	5.5	6.1	4.8	5.2	4.4	7.3	
					W5	6.5	8.4	9.2	7.7	10.5	6.9	6.8	4.1	5.9	6.6	4.3	5.6	4.1	
					W6	8.2	5.9	8.2	7.3	8.8	5.3	4.6	6.4	5.3	4.8	5.8	6.7	5.5	
					W7	7.9	8.7	9.8	9.3	11.4	4.8	5.7	6.6	4.5	5.9	6.1	5.8	4.7	
					W8	8.7	9.2	10.7	10.6	11.5	4.2	6.2	5.3	4.7	6.5	4.6	6.9	5.4	

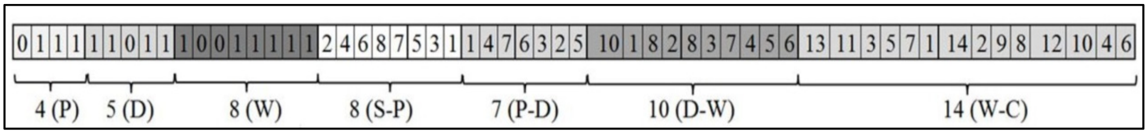

Figure-A I-7 One chromosome of the LSC while using *Functional Lean tools*

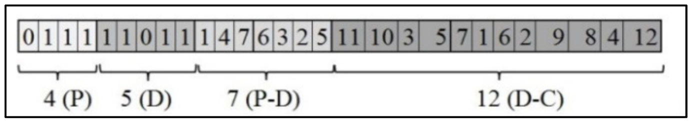

Figure-A I-8 Random LSC chromosome while using
Single Sourcing and *The Use of Flat Hierarchy*

Step 7: Terminated condition met? The iteration is set at 1000.

Step 8: Define and decode the best chromosome. The best chromosome of the LSC affected by Functional Lean tools in Step 2 is in Figure-A I-8a, while the optimal one of final LSC is depicted in Figure-A I-8b. Following this, they are decoded to the best corresponding LSC configurations in Figure-A I-9a and I-9b. The results show that the final structure is much leaner than both FSC and LSC, which are leaned by Functional tools. Concerning fitness, the minimum LSC TC in two situations achieves \$6,198,035 and \$5,332,175 in turn. On the other hand, the implementation of both Functional and Tier Lean tools reduce the LSC TC by up to 16.24% when compared with the cost of the LSC leaned by Functional tools only.

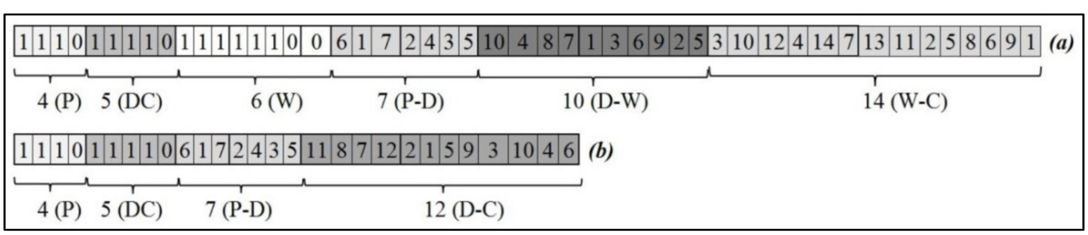

Figure-A I-8a: Best LSC chromosome under the Functional Lean tools effect;
b: Final LSC chromosome

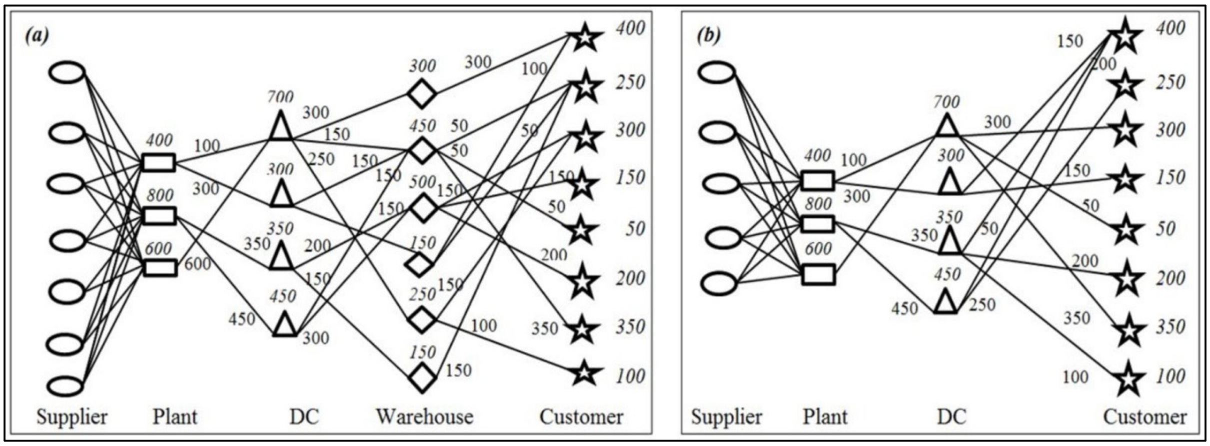

Figure-A I-9 Best LSC under the Functional Lean tools effect;
b. Final LSC configuration

5. Conclusion

The paper presents in detail one new quantitative framework to optimise the design of LSC by MH through three main stages: forming the FSC model; transforming the FSC into LSC; and optimizing the LSCD with pGA. The particular point of this study is that it classifies LM tools into Functional Lean tools and Tier Lean tools. This classification contributes to two important findings: the framework of the LSC transformation through Functional Lean tools and the integration of Tier Lean tools with pGA to optimise the LSC structure. The solutions from the numerical example prove that this novel approach benefits both the LSC configuration and financial aspects. Moreover, this procedure can clearly draw out a general roadmap for designers, which could assist them in designing their LSC in a quantitative approach. It also offers a reference for the managing cadre in order to flexibly select proper Lean tools that will serve their business objectives.

Along with the selected LM tools in the given instances, other LM techniques related to product design like *Modularity*, *Group Technology*, and *Use of Common Parts* also affect the SC structure. Further studies can focus on these areas in order to optimise the conformity of LSC configuration with the product structure.

APPENDIX II THE INTRODUCTION OF NEW META-HEURISTICS

Year	Name of MH	Authors
1962	Genetic Algorithm (GA)	(Holland, 1992)
1977	Tabu Search (TS)	(Glover, 1995)
1983	Simulated Annealing (SA)	(Kirkpatrick, Gelatt, & Vecchi)
1989	Memetic Algorithm	(Moscato)
1992	Ant Colony Optimisation (ACO)	(Dorigo, 1992)
1995	Particle Swarm Optimisation (PSO)	(Kennedy & Eberhart)
1997	Differential Evolution	(Storn & Price)
1998	Quantum Annealing	(Kadowaki & Nishimori, 1998)
2001	Harmony Search	(Geem, Kim, & Loganathan)
2002	Bacterial Foraging Optimization	(Passino, 2002)
	Hysteretic Optimization	(Zarand, Pazmandi, Pál, & Zimányi, 2002)
2003	Electromagnetism-like Algorithm	(Birbil & Fang, 2003)
2005	Bees Algorithm	(Pham *et al.*)
	Glowworm Swarm Optimisation	(Krishnanand & Ghose)
	Particle Collision Algorithm	(Sacco & De Oliveira, 2005)
	Space Gravitational Algorithm	(Hsiao, Chuang, Jiang, & Chien, 2005)
2006	Cat Swarm Optimisation	(Chu, Tsai, & Pan)
	Big Bang-Big Crunch Algorithm	(Erol & Eksin, 2006)
2007	Intelligent Water Cycle Algorithm	Hosseini (2007)
	Central Force Optimization	(Formato, 2007)
	Integrated Radiation Algorithm	(Chuang & Jiang, 2007)
	River Formation Dynamics Algorithm	(Rabanal, Rodríguez, & Rubio, 2007)
	Imperialist Competitive Algorithm	(Atashpaz-Gargari & Lucas)
2008	Big Crunch Optimization	(Kripka & Kripka, 2008)
	Magnetic Optimization Algorithm	(Tayarani-N & Akbarzadeh-T, 2008)
	Biogeography-based Optimization	(Simon, 2008)
2009	Gravitational Search Algorithm	(Rashedi, Nezamabadi-Pour, & Saryazdi)
	Light Ray Optimization Algorithm	(Shen & Li, 2009)
	Cuckoo Search	(Yang & Deb)
	Chemical Reaction Optimization	
	Vibration Damping Optimization Algorithm	(Mehdizadeh & Tavakkoli-Moghaddam, 2009)
	Artificial Physics Algorithm	(Xie, Zeng, & Cui, 2009)
2010	Bat Algorithm	(Yang)
	Charged System Search	(Kaveh & Talatahari, 2010)
2011	League Championship Algorithm (LCA)	(Kashan, 2011)
	Galaxy Based Search Algorithm	(Shah-Hosseini, 2011)

	Gravitational Interactions Optimization	(Flores, López, & Barrera, 2011)
	Spiral Optimization Algorithm	(Tamura & Yasuda, 2011)
	Teaching-learning-based Optimization (TLBO)	
	Water Flow Algorithm	(Hieu, 2011)
2012	Flower Pollination Algorithm	(Yang)
	Water Cycle Algorithm	(Eskandar, Sadollah, Bahreininejad, & Hamdi, 2012)
	Migrating Birds Optimization	(Duman, Uysal, & Alkaya, 2012)
	Krill Herd	(Gandomi & Alavi, 2012)
	Ray optimization	(Kaveh & Khayatazad, 2012)
2013	Cuttlefish Optimisation Algorithm	(Eesa, Brifcani, & Orman)
	Egyptian Vulture Optimization Algorithm	(Sur, Sharma, & Shukla, 2013)
	Improvement of position (IMPRO Algorithm)	(Azar & Seyedmirzaee, 2013)
	Global Neighborhood Algorithm (GNA)	(Alazzam & Lewis, 2013)
	Seven-Spot Ladybird Algorithm	(Wang, Zhu, & Huang, 2013)
	Social Spider Optimization	(Cuevas, Cienfuegos, ZaldíVar, & Pérez-Cisneros, 2013)
	Dłotko–Specogna	(Dłotko & Specogna, 2013)
2014	Colliding Bodies Optimisation	(Kaveh & Mahdavi)
	Symbiotic Organisms	(Cheng & Prayogo, 2014)
	Golden Ball	(Osaba, Diaz, & Onieva, 2014)
2015	Black Hole Algorithm	(Kumar, Datta, & Singh, 2015)
	African Buffalo Optimization (ABO)	(Odili & Kahar, 2015)
	Ion Motion Algorithm	(Javidy, Hatamlou, & Mirjalili, 2015)
2016	Duelist Algorithm	(Biyanto *et al.*)
	Tug Of War Optimization	(Kaveh & Zolghadr, 2016)
	Grey Wolf Optimization	
	Electromagnetic Field Optimization	(Abedinpourshotorban, Shamsuddin, Beheshti, & Jawawi, 2016)
2017	Killer Whale Algorithm	(T. R. Biyanto *et al.*)
	Big Bang Algorithm	(Hosseini, 2017a)
	Vibrating Particles System	(Kaveh & Ghazaan, 2017)
	Hydrological Cycle Algorithm	(Wedyan, Whalley, & Narayanan, 2017)
	Thermal Exchange Optimization	(Kaveh & Dadras, 2017)
	Weighted Superposition Attraction (WSA)	(Adil & Cengiz, 2019)
	Laying Chicken Algorithm	(Hosseini, 2017b)
2018	Farmland Fertility Algorithm	(Shayanfar & Gharehchopogh, 2018)
	Dragonfly Optimizaion Algorithm	(Palappan & Thangavelu, 2018)
	Car Tracking Optimization Algorithm	(Chen, Cai, & Wang, 2018)

	Spring search algorithm	(Dehghani, Montazeri, Dehghani, & Seifi, 2017)
	The Coyote Optimization Algorithm (COA)	(Pierezan & Coelho, 2018)
	Cricket Chirping Algorithm	(Deuri & Sathya, 2018)
	Competitive Learning (CLA)	(Afroughinia & R., 2018)
	Artificial Feeding Birds (AFB)	(Lamy, 2019)
	Tree-Based Optimization	(Ghojogh, Sharifian, & Mohammadzade, 2018)
2019	Rain Water Algorithm	(T. Biyanto *et al.*)
	Atom Search Optimization (ASO)	(Zhao, Wang, & Zhang, 2019) Basic molecular dynamics
	Hydrological Cycle Algorithm	(Wedyan *et al.*)
	Emperor Penguins Colony Optimisation	(Harifi, Khalilian, Mohammadzadeh, & Ebrahimnejad)
	Algorithm of the Innovative Gunner (AIG)	(Pijarski & Kacejko, 2019)
	Flow Regime Algorithm (FRA)	(Tahani & Babayan, 2019)
	Artificial Feeding Birds (AFB)	(Lamy, 2019)
	Deer Hunting Optimization Algorithm	(Brammya *et al.*, 2019)
	Pathfinder Algorithm	(Yapici & Cetinkaya, 2019)

APPENDIX III

LIST OF 24 NEW WASTES

1. Unused (floor) space
2. Manufacturing goods or services that do not meet customer demand or specifications
3. Unused human creativity/Potential (known as knowledge disconnection)
4. Confusion
5. Unsafe working conditions
6. Wasted time in meetings
7. Sub-optimisation
8. Ignoring lessons of history
9. Equipment failure
10. Tool change
11. Ramp up losses
12. Short time stops and small breakdowns
13. Speed losses
14. Planned stops
15. Management losses
16. Line organisation losses
17. Logistic losses (Manufacturing stops due to loading and unloading),
18. Measuring and adjusting losses
19. Line Organization Losses
20. Logistic Losses
21. Measuring and Adjusting Losses
22. Usage losses
23. Energy losses
24. Forms, dies, and tool losses.

APPENDIX IV

CHARACTERISTICS OF SC AND LSC

Taken from Yang & Pan (2004)

Illustrative Characteristics	Conventional SC	LSC
Number & structure	Many; vertical	Fewer; clustered
Procurement personnel	Large	Limited
Outsourcing	Cost-based	Strategic
Nature of interactions	Adversarial; zero-sum	Comparative; positive sum
Relationship focus	Transaction-focused	Mutually beneficial
Selection criteria	Lowest price	Performance
Contract length	Short-term	Long-term
Pricing practices	Competitive bids	Target costing
Price changes	Upward	Downward
Quality	Inspection-intensive	Designed-in
Delivery	Large quantities	Smaller quantities
Inventory buffers	Large	Minimized; eliminated
Communication	Limited; task-related	Extensive; multi-level
Information flow	Directive; one-way	Collaborative; two-way
Role in development	Limited; built-to-print	Substantial
Production flexibility	Low	High
Technology sharing	Very limited; nonexistent	Extensive
Dedicated investments	Minimal-to-some	Substantial
Government	Market-driven	Self-governing
Future expectation	No guarantee	Considerable

APPENDIX V

CHARACTERISTICS LEAN, AGILE, GREEN AND RESILIENT SC

Taken from Carvalho & Cruz-Machado (2011)

	Lean	Agile	Resilience	Green
Manufacturing focus	• High average utilization rate • Use JIT, pull system	• Mass customization	• Emphasis is on flexibility	• Efficiency and waste reduction • Reusable/ remanufactured components
Alliances	• Partnerships & joint ventures at operating level • Share demand infor in SC	• Virtual organization for product design	• Partners join an alliance • Share knowledge • Increasing demand visibility	• Green knowledge to partners
Organizational structure	• Few levels in the hierarchy	• Virtual organizations with partners	• Create SC risk management culture	• Environmental criteria for risk sharing
Supplier selection	• Low cost and high quality	• Speed, flexibility & quality	• Flexible sourcing	• Green purchasing
Inventory strategy	• High turns and minimizes inventory	• Response to customer demand	• Emergency stock in potential critical point	• Parts reusable/ remanufactured • Reduce CO_2 emissions & redundant materials
Lead time focus	• Shorten lead time	• Aggressively reduce lead times	• Reduce lead time • Flexible transport	• Reduce transport lead time
Product design strategy	• Max performance and minimize costs	• Meet individual customer need	• Postponement	• Eco-design and life cycle

APPENDIX VI

CHARACTERISTICS OF LSC, ASC AND LA SC

Taken from Agarwal *et al.* (2006)

Attributes	LSC	ASC	LA SC
Market demand	Predictable	Volatile	Volatile & unpredictable
Product variety	Low	High	Medium
Product life cycle	Long	Short	Short
Customer drivers	Cost	Lead time & availability	Service level
Profit margin	Low	High	Moderate
Dominant Cost	Physical cost	Marketability costs	Both
Stock out penalties	Long-term contractual	Immediate & volatile	No place for stock out
Purchasing policy	Buy goods	Assign capacity	Vendor managed inventory
Information enrichment	Highly desirable	Obligatory	Essential
Forecast mechanism	Algorithmic	Consultative	Both/either
Typical products	Commodities	Faction goods	Customisation
Lead time compression	Essential	Essential	Desirable
Eliminate muda	Essential	Desirable	Arbitrary
Rapid reconfiguration	Desirable	Essential	Essential
Robustness	Arbitrary	Essential	Desirable
Quality	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market qualifier	Market winner
Lead time	Market qualifier	Market qualifier	Market qualifier
Service level	Market qualifier	Market winner	Market winner

LIST OF BIBLIOGRAPHICAL REFERENCES

Abedinpourshotorban, H., Shamsuddin, S. M., Beheshti, Z., & Jawawi, D. N., Electromagnetic field optimization: A physics-inspired metaheuristic optimization algorithm, *Swarm and Evolutionary Computation,* Vol., no., pp. 8-22, 2016.

Adil, B., & Cengiz, B., Optimal design of truss structures using weighted superposition attraction algorithm, *Engineering with Computers,* Vol., no., pp. 1-15, 2019.

Afroughinia, A., & R., K. M., Competitive Learning: A New Meta-Heuristic Optimization Algorithm, *International Journal on Artificial Intelligence Tools,* Vol., no., pp. 1850035, 2018.

Agarwal, A., Shankar, R., & Tiwari, M., Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach, *European Journal of Operational Research,* Vol., no., pp. 211-225, 2006.

Akbarzadeh, Z., Safaei, G. A. H., Madhoushi, M., & Aghajani, H., A Hybrid Fuzzy Multi-criteria Decision Making Model Based on Fuzzy DEMATEL with Fuzzy Analytical Network Process and Interpretative Structural Model for Prioritizing LARG Supply Chain Practices, *IJE TRANSACTIONS C: Aspects,* Vol., no., pp. 413-423, 2019.

Aktan, H. E., & Akyuz, G., Positioning the decoupling point along a supply chain: a case study, *International Journal of Productivity and Quality Management,* Vol., no., pp. 309-339, 2017.

Alaei, S., & Khoshalhan, F., A hybrid cultural-harmony algorithm for multi-objective supply chain coordination, *Scientia Iranica. Transaction E, Industrial Engineering,* Vol., no., pp. 1227, 2015.

Alazzam, A., & Lewis, H. W., A new optimization algorithm for combinatorial problems, *IJARAI) International Journal of Advanced Research in Artificial Intelligence,* Vol., no., 2013.

Altiparmak, F., Gen, M., Lin, L., & Paksoy, T., A genetic algorithm approach for multi-objective optimization of supply chain networks, *Computers & industrial engineering,* Vol., no., pp. 196-215, 2006.

Amirbagheri, K., Núñez-Carballosa, A., Guitart-Tarrés, L., & Merigó, J. M., Research on green supply chain: a bibliometric analysis, *Clean Technologies and Environmental Policy,* Vol., no., pp. 3-22, 2019.

Amiri, M., Hosseini Dehshiri, S., & Yousefi Hanoomarvar, A., Determining the Optimal Combination of LARG Supply Chain Strategies Using SWOT Analysis, Multicriteria Decision-making Techniques and Game Theory, *Industrial Management Journal,* Vol., no., pp. 221-246, 2018.

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

Anass, C., Jose, A. G.-R., Vikas, K., Nishikant, M., Abby, G., & Said, E., Lean, green practices and process innovation: A model for green supply chain performance, *International journal of production economics,* Vol., no., pp. 79–92, 2018.

Angappa, G., Agile Manufacturing: Enablers and an Implementation Framework, *International Journal of Production Research,* Vol., no., pp. 1223-1247, 1998.

Antosiewicz, M., Koloch, G., & Kamiński, B., Choice of best possible metaheuristic algorithm for the travelling salesman problem with limited computational time: quality, uncertainty and speed, *Journal of Theoretical and Applied Computer Science,* Vol., no., pp. 46-55, 2013.

Appelqvist, P., Lehtonen, J.-M., & Kokkonen, J., Modelling in product and supply chain design: literature survey and case study, *Journal of Manufacturing Technology Management,* Vol., no., pp. 675-686, 2004.

Applegate, D. L., Bixby, R. M., Chvátal, V., & Cook, W. J., The Traveling Salesman Problem*,* Vol., no., 2006.

Aqlan, F., & Lam, S. S., Supply chain risk modelling and mitigation, *International Journal of Production Research,* Vol., no., pp. 5640-5656, 2015.

Asgari, N., Nikbakhsh, E., Hill, A., & Farahani, R. Z., Supply chain management 1982–2015: a review, *IMA Journal of Management Mathematics,* Vol., no., pp. 353-379, 2016.

Atashpaz-Gargari, E., & Lucas, C. (2007). *Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition.* Paper presented at the 2007 IEEE congress on evolutionary computation.

Atieno, O. P., An analysis of the strengths and limitation of qualitative and quantitative research paradigms, *Problems of Education in the 21st Century,* Vol., no., pp. 13-38, 2009.

Aven, T., How some types of risk assessments can support resilience analysis and management, *Reliability Engineering & System Safety,* Vol., no., pp. 536-543, 2017.

Azad, N., & Davoudpour, H., Designing a stochastic distribution network model under risk, *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 23-40, 2013.

Azadeh, A., Atrchin, N., Salehi, V., & Shojaei, H., Modelling and improvement of supply chain with imprecise transportation delays and resilience factors, *International Journal of Logistics Research and Applications,* Vol., no., pp. 269-282, 2014.

Azar, A., & Seyedmirzaee, S., Providing new meta-heuristic algorithm for optimization problems inspired by humans' behavior to improve their positions, *International Journal of Artificial Intelligence & Applications,* Vol., no., pp. 1, 2013.

Azevedo, S. G., Carvalho, H., & Cruz-Machado, V., LARG index: a benchmarking tool for improving the leanness, agility, resilience and greenness of the automotive supply chain, *Benchmarking: An International Journal,* Vol., no., pp. 1472-1499, 2016.

Azevedo, S. G., Carvalho, H., & Cruz-Machado, V., Proposal of a conceptual model to analyse the influence of LARG practices on manufacturing supply chain performance, *Journal of Modern Accounting and Auditing,* Vol., no., pp. 174, 2012.

Azfar, K. R. W. A. W., Shahzad, N., & Mumtaz, S., Application of Lean Agile Resilient Green Paradigm Framework on China Pakistan Economic Corridor: A Case Study, *Mehran University Research Journal of Engineering and Technology,* Vol., no., pp. 621-634, 2017.

Balamurugan, R., Natarajan, A., & Premalatha, K., Stellar-mass black hole optimization for biclustering microarray gene expression data, *Applied Artificial Intelligence,* Vol., no., pp. 353-381, 2015.

Banasik, A., Bloemhof-Ruwaard, J. M., Kanellopoulos, A., Claassen, G., & van der Vorst, J. G., Multi-criteria decision making approaches for green supply chains: A review, *Flexible Services and Manufacturing Journal,* Vol., no., pp. 366-396, 2018.

Bandaly, D., Satir, A., Kahyaoglu, Y., & Shanker, L., Supply chain risk management–I: Conceptualization, framework and planning process, *Risk Management,* Vol., no., pp. 249-271, 2012.

Banerjee, A., & Ganjeizadeh, F., Modeling a leagility index for supply chain sustenance, *Procedia Manufacturing,* Vol., no., pp. 996-1003, 2017.

Banerjee, A., & Mukhopadhyay, S. K., A contemporary TOC innovative thinking process in the backdrop of leagile supply chain, *Journal of Enterprise Information Management,* Vol., no., pp. 400-431, 2016.

Banerjee, A., & Mukhopadhyay, S. K., Leagility index in supply chain-part-II: case applications, benchmarking and comparative analysis, *International Journal of Industrial and Systems Engineering,* Vol., no., pp. 242-276, 2015.

Banomyong, R., & Supatn, N., Comparing lean and agile logistics strategies: a case study, *Thammasat Business School, Thailand,* Vol., no., pp. 3-19, 2004.

Bányai, T., Illés, B., & Bányai, Á., Smart scheduling: An integrated first mile and last mile supply approach, *Complexity,* Vol., no., 2018.

Barbosa-Póvoa, A. P., da Silva, C., & Carvalho, A., Opportunities and challenges in sustainable supply chain: An operations research perspective, *European Journal of Operational Research,* Vol., no., pp. 399-431, 2018.

Baskarada, S., Qualitative case study guidelines, *Baškarada, S.(2014). Qualitative case studies guidelines. The Qualitative Report,* Vol., no., pp. 1-25, 2014.

Basole, R. C., & Bellamy, M. A., Supply network structure, visibility, and risk diffusion: A computational approach, *Decision Sciences,* Vol., no., pp. 753-789, 2014.

Baud-Lavigne, B., Agard, B., & Penz, B., Mutual impacts of product standardization and supply chain design, *International journal of production economics,* Vol., no., pp. 50-60, 2012.

Baud-Lavigne, B., Agard, B., & Penz, B., Simultaneous product family and supply chain design: An optimization approach, *International journal of production economics,* Vol., no., pp. 111-118, 2016.

Baxter, P., & Jack, S., Qualitative case study methodology: Study design and implementation for novice researchers, *The qualitative report,* Vol., no., pp. 544-559, 2008.

Beamon, B. M., Supply chain design and analysis:: Models and methods, *International journal of production economics,* Vol., no., pp. 281-294, 1998.

Berger, S. L. T., Tortorella, G. L., & Frazzon, E. M., Simulation-based analysis of inventory strategies in lean supply chains, *IFAC-PapersOnLine,* Vol., no., pp. 1453-1458, 2018.

Birbil, Ş. İ., & Fang, S.-C., An electromagnetism-like mechanism for global optimization, *Journal of global optimization,* Vol., no., pp. 263-282, 2003.

Birkie, S. E., Operational resilience and lean: in search of synergies and trade-offs, *Journal of Manufacturing Technology Management,* Vol., no., pp. 185-207, 2016.

Biyanto, T., Syamsi, M., Fibrianto, H., Afdanny, N., Gunawan, K., Rahman, A., . . . Abdillah, A. (2017). *Optimization of energy efficiency and conservation in green building design using Duelist, Killer-Whale and Rain-Water Algorithms.* Paper presented at the International Conference of Applied Science and Technology for Infrastructure Engineering.

Biyanto, T. R., Fibrianto, H. Y., Nugroho, G., Hatta, A. M., Listijorini, E., Budiati, T., & Huda, H. (2016). *Duelist algorithm: an algorithm inspired by how duelist improve their capabilities in a duel.* Paper presented at the International Conference on Swarm Intelligence.

Biyanto, T. R., Irawan, S., Febrianto, H. Y., Afdanny, N., Rahman, A. H., Gunawan, K. S., . . . Bethiana, T. N., Killer whale algorithm: an algorithm inspired by the life of killer whale, *Procedia computer science,* Vol., no., pp. 151-157, 2017.

Blum, C., Puchinger, J., Raidl, G. R., & Roli, A., Hybrid metaheuristics in combinatorial optimization: A survey, *Applied Soft Computing,* Vol., no., pp. 4135-4151, 2011.

Bonvoisin, J., Halstenberg, F., Buchert, T., & Stark, R., A systematic literature review on modular product design, *Journal of Engineering Design,* Vol., no., pp. 488-514, 2016.

Borges de Araújo, M. C., Hazin Alencar, L., & Coelho Viana, J., Structuring a model for supplier selection, *Management Research Review,* Vol., no., pp. 1213-1232, 2015.

Boschi, A. A., Borin, R., & Batocchio, A. (2011). *Leagile-The New Framework for the Supply Chain Management.* Paper presented at the 61st Annual IIE Conference and Expo Proceedings.

Brammya, G., Praveena, S., Ninu Preetha, N., Ramya, R., Rajakumar, B., & Binu, D., Deer Hunting Optimization Algorithm: A New Nature-Inspired Meta-heuristic Paradigm, *The Computer Journal,* Vol., no., 2019.

Brandon-Jones, E., Squire, B., Autry, C. W., & Petersen, K. J., A contingent resource-based perspective of supply chain resilience and robustness, *Journal of Supply Chain Management,* Vol., no., pp. 55-73, 2014.

Brar, G. S., & Saini, G. (2011). *Milk run logistics: literature review and directions.* Paper presented at the Proceedings of the world congress on engineering.

Buehlmann, U., & Schuler, A., Markets and market forces for secondary wood products, *The Global Forest Sector. New York, Taylor & Francis,* Vol., no., pp. 77-98, 2013.

Cabral, I., Grilo, A., & Cruz-Machado, V., A decision-making model for lean, agile, resilient and green supply chain management, *International Journal of Production Research,* Vol., no., pp. 4830-4845, 2012.

Cabral, I., Grilo, A., Leal, R. P., & Machado, V. C. (2011a). *Modelling lean, agile, resilient, and green supply chain management.* Paper presented at the Proceedings of the ITI 2011, 33rd International Conference on Information Technology Interfaces.

Cabral, I., Grilo, A., Puga-Leal, R., & Cruz-Machado, V. (2011b). *An information model in lean, agile, resilient and green supply chains.* Paper presented at the 2011 IEEE 3rd International Conference on Communication Software and Networks.

Campbell, S., Determining overall risk, *Journal of risk research,* Vol., no., pp. 569-581, 2005.

Carvalho, H., & Cruz-Machado, V. (2011). Integrating lean, agile, resilience and green paradigms in supply chain management (LARG_SCM) *Supply chain management*: IntechOpen.

Carvalho, H., Duarte, S., & Cruz Machado, V., Lean, agile, resilient and green: divergencies and synergies, *International Journal of Lean Six Sigma,* Vol., no., pp. 151-179, 2011.

Carvalho, H., & Machado, V. C. (2009). *Lean, agile, resilient and green supply chain: a review.* Paper presented at the Proceedings of the Third International Conference on Management Science and Engineering Management.

Carvalho, M. F., Silveira, A., & Ramos, J., A Methodology for Supply Chain Design An Application to Auto-part Industry, *IFAC Proceedings Volumes,* Vol., no., pp. 139-143, 2010.

Chaabane, A., Ramudhin, A., & Paquet, M., Designing supply chains with sustainability considerations, *Production Planning & Control,* Vol., no., pp. 727-741, 2011.

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

Chantarachalee, K., Carvalho, H., & Cruz-Machado, V. A. (2014). *Designing lean supply chains: A case study.* Paper presented at the 8th International Conference on Management Science and Engineering Management, ICMSEM 2014, July 25, 2014 - July 27, 2014, Lisbon, Portugal.

Chen, H.-Y., The impact of item substitutions on production–distribution networks for supply chains, *Transportation Research Part E: Logistics and Transportation Review,* Vol., no., pp. 803-819, 2010.

Chen, J., Cai, H., & Wang, W., A new metaheuristic algorithm: car tracking optimization algorithm, *Soft Computing,* Vol., no., pp. 3857-3878, 2018.

Cheng, M.-Y., & Prayogo, D., Symbiotic organisms search: a new metaheuristic optimization algorithm, *Computers & Structures,* Vol., no., pp. 98-112, 2014.

Cheraghalipour, A., Paydar, M. M., & Hajiaghaei-Keshteli, M., Designing and solving a bi-level model for rice supply chain using the evolutionary algorithms, *Computers and Electronics in Agriculture,* Vol., no., pp. 651-668, 2019.

Cherise, T. (2017). Ford vs. Toyota: Battle of the Brands. Retrieved from https://cars.usnews.com/cars-trucks/ford-vs-toyota-battle-of-the-brands

Chiang, I. R., & Wu, S. J., Supplier Involvement and Contract Design during New Product Development, *IEEE Transactions on engineering management,* Vol., no., pp. 248-258, 2016.

Chiu, M. C., & Okudan, G. E., An integrative methodology for product and supply chain design decisions at the product design stage, *Journal of Mechanical Design,* Vol., no., pp. 021008, 2011a.

Chiu, M. C., & Okudan, G. E. (2011b). *An Investigation of product modularity and supply chain performance at the product design stage.* Paper presented at the ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Chiu, M. C., & Okudan, G. E., An investigation on centralized and decentralized supply chain scenarios at the product design stage to increase performance, *IEEE Transactions on engineering management,* Vol., no., pp. 114-128, 2013.

Chopra, S. (2004). [Chapter 5: Network Design in the Supply Chain].

Chopra, S., & Sodhi, M., Reducing the risk of supply chain disruptions, *MIT Sloan management review,* Vol., no., pp. 72-80, 2014.

Christopher, M., & Peck, H., Building the resilient supply chain, *The international journal of logistics management,* Vol., no., pp. 1-14, 2004a.

Christopher, M., & Peck, H., Building the resilient supply chain, Vol., no., 2004b.

Christopher, M., & Towill, D., An integrated model for the design of agile supply chains, *International journal of physical distribution & logistics management,* Vol., no., pp. 235-246, 2001.

Chu, S.-C., Tsai, P.-W., & Pan, J.-S. (2006). *Cat swarm optimization.* Paper presented at the Pacific Rim international conference on artificial intelligence.

Chuang, C.-L., & Jiang, J.-A. (2007). *Integrated radiation optimization: inspired by the gravitational radiation in the curvature of space-time.* Paper presented at the 2007 IEEE congress on evolutionary computation.

Ciccullo, F., Pero, M., Caridi, M., Gosling, J., & Purvis, L., Integrating the environmental and social sustainability pillars into the lean and agile supply chain management paradigms: A literature review and future research directions, *Journal of Cleaner Production,* Vol., no., pp. 2336-2350, 2018.

Colicchia, C., Creazza, A., & Dallari, F., Lean and green supply chain management through intermodal transport insights from the fast moving consumer goods industry, *Production Planning & Control,* Vol., no., pp. 321-334, 2017.

Corominas, A., Mateo, M., Ribas, I., & Rubio, S., Methodological elements of supply chain design, *International Journal of Production Research,* Vol., no., pp. 5017-5030, 2015.

Costantino, N., & Pellegrino, R., Choosing between single and multiple sourcing based on supplier default risk: A real options approach, *Journal of Purchasing and Supply Management,* Vol., no., pp. 27-40, 2010.

Cousins, P. D., Lawson, B., Petersen, K. J., & Fugate, B., Investigating green supply chain management practices and performance, *International Journal of Operations & Production Management,* Vol., no., 2019.

Cudney, E., & Elrod, C., A comparative analysis of integrating lean concepts into supply chain management in manufacturing and service industries, *International Journal of Lean Six Sigma,* Vol., no., pp. 5-22, 2011.

Cuevas, E., Cienfuegos, M., ZaldíVar, D., & Pérez-Cisneros, M., A swarm optimization algorithm inspired in the behavior of the social-spider, *Expert Systems with Applications,* Vol., no., pp. 6374-6384, 2013.

Das, K., Integrating resilience in a supply chain planning model, *International Journal of Quality & Reliability Management,* Vol., no., pp. 570-595, 2018.

David, A., Robert, B., Vašek, C., William, C., & Keld, H. (2004). Retrieved from http://www.math.uwaterloo.ca/tsp/sweden/

Deborah, N., Lean Supply Chain Management Principles and Practices. , *Lecture Notes, Integrating the Lean Enterprise,* Vol., no., 2005.

Dehghani, M., Montazeri, Z., Dehghani, A., & Seifi, A. (2017). *Spring search algorithm: A new meta-heuristic optimization algorithm inspired by Hooke's law.* Paper presented at the 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI).

DeLisle, J., & Goldstein, A. (2017). *China's Global Engagement: Cooperation, Competition, and Influence in the 21st Century*: Brookings Institution Press.

Deuri, J., & Sathya, S. S., Cricket chirping algorithm: an efficient meta-heuristic for numerical function optimisation, *International Journal of Computational Science and Engineering,* Vol., no., pp. 162-172, 2018.

Devika, K., Jafarian, A., & Nourbakhsh, V., Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques, *European Journal of Operational Research,* Vol., no., pp. 594-615, 2014.

Diabat, A., Hybrid algorithm for a vendor managed inventory system in a two-echelon supply chain, *European Journal of Operational Research,* Vol., no., pp. 114-121, 2014.

Dłotko, P., & Specogna, R., Physics inspired algorithms for (co) homology computations of three-dimensional combinatorial manifolds with boundary, *Computer Physics Communications,* Vol., no., pp. 2257-2266, 2013.

do Rosário Cabrita, M., Duarte, S., Carvalho, H., & Cruz-Machado, V., Integration of lean, agile, resilient and green paradigms in a business model perspective: theoretical foundations, *IFAC-PapersOnLine,* Vol., no., pp. 1306-1311, 2016.

Donald, J. B., David, J. C., & Cooper, M. B. (2002). *Supply chain logistics management*. New York: McGraw-Hill/Irwin.

Dorigo, M., Optimization, learning and natural algorithms [Ph. D. thesis], *Politecnico di Milano, Italy,* Vol., no., 1992.

Dowlatshahi, S., Purchasing's role in a concurrent engineering environment, *International Journal of Purchasing and Materials Management,* Vol., no., pp. 21-25, 1992.

Du, T., Wang, F., & Lu, P.-Y., A real-time vehicle-dispatching system for consolidating milk runs, *Transportation Research Part E: Logistics and Transportation Review,* Vol., no., pp. 565-577, 2007.

Duan, Q., & Liao, T. W., Optimization of blood supply chain with shortened shelf lives and ABO compatibility, *International journal of production economics,* Vol., no., pp. 113-129, 2014.

Duarte, S., & Cruz Machado, V., Green and lean implementation: an assessment in the automotive industry, *International Journal of Lean Six Sigma,* Vol., no., pp. 65-88, 2017.

Dües, C. M., Tan, K. H., & Lim, M., Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain, *Journal of Cleaner Production,* Vol., no., pp. 93-100, 2013.

Duffy, M. E., Designing nursing research: the qualitative-quantitative debate, *Journal of advanced nursing,* Vol., no., pp. 225-232, 1985.

Duman, E., Uysal, M., & Alkaya, A. F., Migrating Birds Optimization: A new metaheuristic approach and its performance on quadratic assignment problem, *Information sciences,* Vol., no., pp. 65-77, 2012.

Ebrahimiarjestan, M., & Wang, G., Determining decoupling points in a supply chain networks using NSGA II algorithm, *Journal of Industrial Engineering and Management (JIEM),* Vol., no., pp. 352-372, 2017.

Eesa, A. S., Brifcani, A. M. A., & Orman, Z., Cuttlefish algorithm-a novel bio-inspired optimization algorithm, *International Journal of Scientific & Engineering Research,* Vol., no., pp. 1978-1986, 2013.

Eksioglu, B., Eksioglu, S., Zhang, J., & Jin, M., A simulation model to analyze the impact of outsourcing on furniture supply chain performance, *Forest Products Journal,* Vol., no., pp. 258-265, 2010.

El Mokadem, M., The classification of supplier selection criteria with respect to lean or agile manufacturing strategies, *Journal of Manufacturing Technology Management,* Vol., no., pp. 232-249, 2017.

Elkington, J. (2013). Enter the triple bottom line *The triple bottom line* (pp. 23-38): Routledge.

ElMaraghy, H. A., & Mahmoudi, N., Concurrent design of product modules structure and global supply chain configurations, *International Journal of Computer Integrated Manufacturing,* Vol., no., pp. 483-493, 2009.

Erdem, M., & Koç, Ç., Analysis of electric vehicles in home health care routing problem, *Journal of Cleaner Production,* Vol., no., 2019.

Erol, O. K., & Eksin, I., A new optimization method: big bang–big crunch, *Advances in Engineering Software,* Vol., no., pp. 106-111, 2006.

Eskandar, H., Sadollah, A., Bahreininejad, A., & Hamdi, M., Water cycle algorithm–A novel metaheuristic optimization method for solving constrained engineering optimization problems, *Computers & Structures,* Vol., no., pp. 151-166, 2012.

Esmaeel, R. I., Sukati, I., & Jamal, N. M., The moderating role of advance manufacturing technology (AMT) on the relationship between LARG-supply chain and supply chain performance, *Asian Social Science,* Vol., no., pp. 37, 2015.

Espadinha-Cruz, P., Grilo, A., Puga-Leal, R., & Cruz-Machado, V. (2011). *A model for evaluating lean, agile, resilient and green practices interoperability in supply chains.* Paper presented at the 2011 IEEE International Conference on Industrial Engineering and Engineering Management.

Eyüp, A. D., Metehan, T., & Huseyin, A. E. (2015). *Lean, Agile and Leagile Supply Chain Managements: A Review Study.* Paper presented at the Conference on Value Chain Sustainability

Fadaki, M., Rahman, S., & Chan, C., Quantifying the degree of supply chain leagility and assessing its impact on firm performance, *Asia Pacific Journal of Marketing and Logistics,* Vol., no., pp. 246-264, 2019.

Fahad, U. (2019). Risk vs Uncertainty in Project Management. Retrieved from https://pmstudycircle.com/2012/02/risk-vs-uncertainty/

Fahimnia, B., Sarkis, J., & Davarzani, H., Green supply chain management: A review and bibliometric analysis, *International journal of production economics,* Vol., no., pp. 101-114, 2015.

Fan, Q., Xu, X., & Gong, Z. (2007). *Research on lean, agile and leagile supply chain.* Paper presented at the 2007 international conference on wireless communications, networking and mobile computing.

Farahani, R. Z., Rezapour, S., Drezner, T., & Fallah, S., Competitive supply chain network design: An overview of classifications, models, solution techniques and applications, *Omega,* Vol., no., pp. 92-118, 2014.

Farahani, R. Z., Rezapour, T., Drezner, & Fallah, S., Supply Chain Network design classifications paradigms and analyses, Vol., no., 2015.

Fathian, M., Jouzdani, J., Heydari, M., & Makui, A., Location and transportation planning in supply chains under uncertainty and congestion by using an improved electromagnetism-like algorithm, *Journal of Intelligent Manufacturing,* Vol., no., pp. 1447-1464, 2018.

Fayezi, S., Zutshi, A., & O'Loughlin, A., Developing an analytical framework to assess the uncertainty and flexibility mismatches across the supply chain, *Business Process Management Journal,* Vol., no., pp. 362-391, 2014.

Fisher, M. L., What is the right supply chain for your product?, *Harvard business review,* Vol., no., pp. 105-117, 1997.

Flores, J. J., López, R., & Barrera, J. (2011). *Gravitational interactions optimization.* Paper presented at the Proceedings of the International Conference on Learning and Intelligent Optimization, Rome, Italy.

Foerstl, K., Franke, H., & Zimmermann, F., Mediation effects in the 'purchasing and supply management (PSM) practice–performance link': Findings from a meta-analytical structural equation model, *Journal of Purchasing and Supply Management,* Vol., no., pp. 351-366, 2016.

Formato, R. A. (2007). Central force optimization: a new metaheuristic with applications in applied electromagnetics. Prog Electromagn Res 77: 425–491.

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

Gandomi, A. H., & Alavi, A. H., Krill herd: a new bio-inspired optimization algorithm, *Communications in nonlinear science and numerical simulation,* Vol., no., pp. 4831-4845, 2012.

Garcia-Herreros, P., Wassick, J. M., & Grossmann, I. E., Design of resilient supply chains with risk of facility disruptions, *Industrial & Engineering Chemistry Research,* Vol., no., pp. 17240-17251, 2014.

Gaudenzi, B., & Christopher, M., Achieving supply chain 'Leagility'through a project management orientation, *International Journal of Logistics Research and Applications,* Vol., no., pp. 3-18, 2016.

Gay, C. (2016). 8 Wastes Of Lean Manufacturing. Retrieved from https://www.machinemetrics.com/blog/2016/1/24/8-wastes-of-lean-manufacturing

Geem, Z. W., Kim, J. H., & Loganathan, G. V., A new heuristic optimization algorithm: harmony search, *simulation,* Vol., no., pp. 60-68, 2001.

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

Gerring, J., What is a case study and what is it good for?, *American political science review,* Vol., no., pp. 341-354, 2004.

Ghojogh, B., Sharifian, S., & Mohammadzade, H., Tree-Based Optimization: A Meta-Algorithm for Metaheuristic Optimization, *arXiv preprint arXiv:1809.09284,* Vol., no., 2018.

Gholamian, M., & Heydari, M., An inventory model with METRIC approach in location-routing-inventory problem, *Advances in Production Engineering & Management,* Vol., no., pp. 115, 2017.

Ghorashi, S. B., Hamedi, M., & Sadeghian, R., Modeling and optimization of a reliable blood supply chain network in crisis considering blood compatibility using MOGWO, *Neural Computing and Applications,* Vol., no., pp. 1-28, 2019.

Ghotbabadi, A. R., Gandaee, S., & Gandaee, M. T., Making LARG Supply Chain Management Smart and Identification of its Conditions with Management Tools of SWOT, BI, and RFID Technology, *International Journal of Academic Research in Business and Social Sciences,* Vol., no., pp. 321-333, 2016.

Gjeldum, N., Crnjac, M., & Bilić, B., Simulation of Bullwhip Effect in a Supply Chain for Lean Learning Factory Purposes, *International journal of simulation modelling,* Vol., no., pp. 576-589, 2017.

Glover, F. (1995). *Tabu search fundamentals and uses*: Graduate School of Business, University of Colorado Boulder.

Gokhan, N. M., Needy, K. L., & Norman, B. A., Development of a simultaneous design for supply chain process for the optimization of the product design and supply chain configuration problem, *Engineering Management Journal,* Vol., no., pp. 20-30, 2010.

Goldberg, D. E., & Holland, J. H., Genetic algorithms and machine learning*,* Vol., no., 1988.

Goldsby, T. J., Griffis, S. E., & Roath, A. S., Modeling lean, agile, and leagile supply chain strategies, *Journal of Business Logistics,* Vol., no., pp. 57-80, 2006.

Golozari, F., Jafari, A., & Amiri, M., Application of a hybrid simulated annealing-mutation operator to solve fuzzy capacitated location-routing problem, *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 1791-1807, 2013.

Govindan, K., Azevedo, S. G., Carvalho, H., & Cruz-Machado, V., Lean, green and resilient practices influence on supply chain performance: interpretive structural modeling approach, *International Journal of Environmental Science and Technology,* Vol., no., pp. 15-34, 2015a.

Govindan, K., Jafarian, A., & Nourbakhsh, V., Bi-objective integrating sustainable order allocation and sustainable supply chain network strategic design with stochastic demand using a novel robust hybrid multi-objective metaheuristic, *Computers & Operations Research,* Vol., no., pp. 112-130, 2015b.

Graham, V., The Predicted 2020 Global Recession, *The World Financial Review,* Vol., no., 2018.

Griffis, S. E., Bell, J. E., & Closs, D. J., Metaheuristics in logistics and supply chain management, *Journal of Business Logistics,* Vol., no., pp. 90-106, 2012.

Gruler, A., Panadero, J., de Armas, J., Pérez, J. A. M., & Juan, A. A., Combining variable neighborhood search with simulation for the inventory routing problem with stochastic demands and stock-outs, *Computers & industrial engineering,* Vol., no., pp. 278-288, 2018.

Guerrero, C. A., Olivares-Benitez, E., Miranda, P. A., Perez-Loaiza, R. E., & Ablanedo-Rosas, J. H., Design of a Logistics Nonlinear System for a Complex, Multiechelon, Supply Chain Network with Uncertain Demands, *Complexity,* Vol., no., 2018.

Güner, A. R., Murat, A., & Chinnam, R. B., Dynamic routing for milk-run tours with time windows in stochastic time-dependent networks, *Transportation Research Part E: Logistics and Transportation Review,* Vol., no., pp. 251-267, 2017.

Gupta, V., He, B., & Sethi, S. P., Contingent sourcing under supply disruption and competition, *International Journal of Production Research,* Vol., no., pp. 3006-3027, 2015.

Gustavo, M. U., Jay, S. G., & Kevin, J. D., Lean versus green: The impac to lean logistics on greenhouse gas emissions inconsumer good ssupply chains, *Journal ofPurchasing&SupplyManagement,* Vol., no., pp. 98–109, 2015.

Guy, H., & Jennifer, F. (2013). Is Your Supply Chain Dangerously Lean? Retrieved from http://www.firestorm.com/wp-content/uploads/2016/02/Is-Your-Supply-Chain-Dangerously-Lean-4-22-13.pdf

Hadj-Hamou, K., Aldanondo, M., & Lamothe, J. (2003). *Product with large diversity: an approach towards simultaneous design of product and supply chain.* Paper presented at the DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm.

Halawa, F., Sah, B., Srihari, K., & Chung, S. H. (2018). *A Milk-run Approach of Truck Scheduling Problem: Mathematical Formulation and Genetic Algorithm.* Paper presented at the Proceedings of IISE Annual Conference.

Hammami, R., Frein, Y., & Hadj-Alouane, A. B., Supply Chain Design in the Delocalization Context: Relevant Features and New Modeling Tendencies, *Int. J. Production Economics,* Vol., no., pp. 641-656, 2008.

Haq, A. N., & Boddu, V., Analysis of enablers for the implementation of leagile supply chain management using an integrated fuzzy QFD approach, *Journal of Intelligent Manufacturing,* Vol., no., pp. 1-12, 2017.

Harifi, S., Khalilian, M., Mohammadzadeh, J., & Ebrahimnejad, S., Emperor Penguins Colony: a new metaheuristic algorithm for optimization, *Evolutionary Intelligence,* Vol., no., pp. 211-226, 2019.

Harrath, Y., Salman, A. F., Alqaddoumi, A., Hasan, H., & Radhi, A., A novel hybrid approach for solving the multiple traveling salesmen problem, *Arab Journal of Basic and Applied Sciences,* Vol., no., pp. 103-112, 2019.

Harrison, A., & Van Hoek, R. (2010). *Logistics Management and Strategy*: Prentice Hall.

Harrison, T. P., Global supply chain design, *Information Systems Frontiers,* Vol., no., pp. 413-416, 2001.

Harrison, T. P. (2004). Principles for the strategic design of supply chains *The practice of supply chain management: Where theory and application converge* (pp. 3-12): Springer.

Hartono, Y., Astanti, R. D., & Ai, T. J., Enabler to successful implementation of lean supply chain in a book publisher, *Procedia Manufacturing,* Vol., no., pp. 192-199, 2015.

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

Helena, C., Kannan, G., Susana, G. A., & Virgílio, C.-M., Modelling green and lean supply chains An eco-efficiency perspective, *Resources, Conservation and Recycling,* Vol., no., pp. 75–87, 2017.

Hieu, T. T. (2011). *A water flow algorithm for optimization problems.*

Hock, S. Q., & Mohamed, U. Z., Supply chain management from the perspective of value chain flexibility: an exploratory study, *Journal of Manufacturing Technology Management,* Vol., no., pp. 506-526, 2011.

Holland, J. H. (1992). *Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence*: MIT press.

Hosseini, E., Big bang algorithm: A new meta-heuristic approach for solving optimization problems, *Asian Journal of Applied Sciences,* Vol., no., pp. 134-144, 2017a.

Hosseini, E., Laying chicken algorithm: A new meta-heuristic approach to solve continuous programming problems, *J. Appl. Comput. Math,* Vol., no., pp. 344-351, 2017b.

Hosseini, H. S. (2007). *Problem solving by intelligent water drops.* Paper presented at the 2007 IEEE congress on evolutionary computation.

Hosseini, S., Morshedlou, N., Ivanov, D., Sarder, M., Barker, K., & Al Khaled, A., Resilient supplier selection and optimal order allocation under disruption risks, *International journal of production economics,* Vol., no., pp. 124-137, 2019.

Hosseini, S. D., Shirazi, M. A., & Karimi, B., Cross-docking and milk run logistics in a consolidation network: A hybrid of harmony search and simulated annealing approach, *Journal of Manufacturing Systems,* Vol., no., pp. 567-577, 2014.

Hsiao, Y.-T., Chuang, C.-L., Jiang, J.-A., & Chien, C.-C. (2005). *A novel optimization algorithm: space gravitational optimization.* Paper presented at the 2005 IEEE international conference on systems, man and cybernetics.

Huang, G. Q., Zhang, X. Y., & Liang, L., Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains, *Journal of Operations management,* Vol., no., pp. 267-290, 2005.

Huang, H. Y., Chou, Y. C., & Chang, S., A dynamic system model for proactive control of dynamic events in full-load states of manufacturing chains, *International Journal of Production Research,* Vol., no., pp. 2485-2506, 2009.

Hunter, S. L., Bullard, S., & Steele, P. H., Lean production in the furniture industry: The double D assembly cell, *Forest Products Journal,* Vol., no., pp. 32, 2004.

Inoue, H., & Gen, M., A multistage logistics system design problem with inventory considering demand change by hybrid genetic algorithm, *Electronics and Communications in Japan,* Vol., no., pp. 56-65, 2012.

Ivanov, D., Revealing interfaces of supply chain resilience and sustainability: a simulation study, *International Journal of Production Research,* Vol., no., pp. 3507-3523, 2018.

Ivanov, D., & Dolgui, A., Low-Certainty-Need (LCN) supply chains: a new perspective in managing disruption risks and resilience, *International Journal of Production Research,* Vol., no., pp. 1-18, 2018.

Ivanov, D., Dolgui, A., & Sokolov, B., Supply chain design with disruption considerations: review of research streams on the ripple effect in the supply chain, *IFAC-PapersOnLine,* Vol., no., pp. 1700-1707, 2015.

Jabir, E., Panicker, V. V., & Sridharan, R., Design and development of a hybrid ant colony-variable neighbourhood search algorithm for a multi-depot green vehicle routing problem, *Transportation Research Part D: Transport and Environment,* Vol., no., pp. 422-457, 2017.

Jaggernath, R., & Khan, Z., Green supply chain management, *World Journal of Entrepreneurship, Management and Sustainable Development,* Vol., no., 2015.

Jain, V. K., & Sharma, S., Drivers Affecting the Green Supply Chain Management Adaptation: A Review, *IUP Journal of Operations Management,* Vol., no., 2014.

Jalali, S., Seifbarghy, M., Sadeghi, J., & Ahmadi, S., Optimizing a bi-objective reliable facility location problem with adapted stochastic measures using tuned-parameter multi-objective algorithms, *Knowledge-Based Systems,* Vol., no., pp. 45-57, 2016.

Jamali, G., Karimi Asl, E., Hashemkhani Zolfani, S., & Šaparauskas, J., Analysing larg supply chain management comoptitive strategies in iranian cement industries, *Economics and Management,* Vol., no., 2017.

James, C. (2015). Aluminium boss: Chinese dumping a 'slow death' for European industry. Retrieved from https://www.euractiv.com/section/sustainable-dev/interview/aluminium-boss-chinese-dumping-a-slow-death-for-european-industry/

Jamshidi, R., Ghomi, S. F., & Karimi, B., Flexible supply chain optimization with controllable lead time and shipping option, *Applied Soft Computing,* Vol., no., pp. 26-35, 2015.

Jamshidi, R., Ghomi, S. F., & Karimi, B., Multi-objective green supply chain optimization with a new hybrid memetic algorithm using the Taguchi method, *Scientia Iranica,* Vol., no., pp. 1876-1886, 2012.

Jaramillo, J. H., Bhadury, J., & Batta, R., On the use of genetic algorithms to solve location problems, *Computers & Operations Research,* Vol., no., pp. 761-779, 2002.

Jasti, N. V. K., & Kodali, R., A critical review of lean supply chain management frameworks: proposed framework, *Production Planning & Control,* Vol., no., pp. 1051-1068, 2015.

Javidy, B., Hatamlou, A., & Mirjalili, S., Ions motion algorithm for solving optimization problems, *Applied Soft Computing,* Vol., no., pp. 72-79, 2015.

Jayaram, A. (2016). *Lean six sigma approach for global supply chain management using industry 4.0 and IIoT.* Paper presented at the 2016 2nd International Conference on Contemporary Computing and Informatics (IC3I).

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., no., pp. 561-567, 2011.

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

Jiang, Y., Zhao, L., & Sun, S. (2009). *A resilient strategy for meat-food supply chain network design.* Paper presented at the 2009 IEEE International Conference on Industrial Engineering and Engineering Management.

Jiang, Z., Huang, Y., & Wang, J. (2010). *Routing for the milk-run pickup system in automobile parts supply.* Paper presented at the Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology.

Joan, S., & Julie, H., Why Most Product Launches Fail, *Harvard business review,* Vol., no., 2011.

Jouzdani, J., & Fathian, M., Hybrid electromagnetism-like algorithm for dynamic supply chain network design under traffic congestion and uncertainty, *Mathematical Problems in Engineering,* Vol., no., 2016.

Kadowaki, T., & Nishimori, H., Quantum annealing in the transverse Ising model, *Physical Review E,* Vol., no., pp. 5355, 1998.

Kamalahmadi, M., & Parast, M. M., A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research, *International journal of production economics,* Vol., no., pp. 116-133, 2016.

Kanagaraj, G., Ponnambalam, S., & Jawahar, N., Reliability-based total cost of ownership approach for supplier selection using cuckoo-inspired hybrid algorithm, *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 801-816, 2016.

Kanchan, D., Integrating lean systems in the design of a sustainable supply chain model, *International journal of production economics,* Vol., no., pp. 177-190, 2018.

Kashan, A. H., An efficient algorithm for constrained global optimization and application to mechanical engineering design: League championship algorithm (LCA), *Computer-Aided Design,* Vol., no., pp. 1769-1792, 2011.

Kaveh, A., & Dadras, A., A novel meta-heuristic optimization algorithm: thermal exchange optimization, *Advances in Engineering Software,* Vol., no., pp. 69-84, 2017.

Kaveh, A., & Ghazaan, M. I., A new meta-heuristic algorithm: vibrating particles system, *Scientia Iranica. Transaction A, Civil Engineering,* Vol., no., pp. 551, 2017.

Kaveh, A., & Khayatazad, M., A new meta-heuristic method: ray optimization, *Computers & Structures,* Vol., no., pp. 283-294, 2012.

Kaveh, A., & Mahdavi, V., Colliding bodies optimization: a novel meta-heuristic method, *Computers & Structures,* Vol., no., pp. 18-27, 2014.

Kaveh, A., & Talatahari, S., A novel heuristic optimization method: charged system search, *Acta Mechanica,* Vol., no., pp. 267-289, 2010.

Kaveh, A., & Zolghadr, A., A novel meta-heuristic algorithm: tug of war optimization, *Iran University of Science & Technology,* Vol., no., pp. 469-492, 2016.

Kawitkar, S. S., Impact of eco-friendly products on consumer behavior, *International Indexed & Refereed Research Journal,* Vol., no., pp. 42-44, 2013.

Kazmane, J. (2018). *Proposal and Analysis of a Model for Design and Development of Lean Supply Chain Strategy.* Paper presented at the International Journal of Engineering Research in Africa.

Kennedy, J., & Eberhart, R. (1995). *Particle swarm optimization.* Paper presented at the Proceedings of ICNN'95 - International Conference on Neural Networks.

Khalaf, R. E. H., Agard, B., & Penz, B., Simultaneous design of a product family and its related supply chain using a Tabu Search algorithm, *International Journal of Production Research,* Vol., no., pp. 5637-5656, 2011.

Khlie, K., Serrou, D., & Abouabdellah, A. (2016). *The impact of Lean-logistics and the information system on the information flow management within the healthcare supply chain.* Paper presented at the 2016 11th International Conference on Intelligent Systems: Theories and Applications (SITA).

Kian, L. C., & de Souza, R. (2017). *Utilizing Excess Capacity in Last Mile Using 4 th Party Milk Run.* Paper presented at the 2017 6th IEEE International Conference on Advanced Logistics and Transport (ICALT).

Kilic, H. S., & Durmusoglu, M. B., A mathematical model and a heuristic approach for periodic material delivery in lean production environment, *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 977-992, 2013.

Kim, C., Tannock, J., Byrne, M., Farr, R., Cao, B., & Er, M., Techniques to model the supply chain in an extended enterprise–State-of-the-art review, *VIVACE Deliverable D,* Vol., no., 2004.

Kimani, M. W., Lean Supply Chain Management in Manufacturing Firms in Kenya, *Unpublished MBA project, University of Nairobi,* Vol., no., 2013.

Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P., Optimization by simulated annealing, *science,* Vol., no., pp. 671-680, 1983.

Kisperska-Moron, D., & De Haan, J., Improving supply chain performance to satisfy final customers:"Leagile" experiences of a polish distributor, *International journal of production economics,* Vol., no., pp. 127-134, 2011.

Kleindorfer, P. R., & Saad, G. H., Managing disruption risks in supply chains, *Production and operations management,* Vol., no., pp. 53-68, 2005.

Kripka, M., & Kripka, R. M. L. (2008). *Big crunch optimization method.* Paper presented at the International conference on engineering optimization, Brazil.

Krishnanand, K. N., & Ghose, D. (2005). *Detection of multiple source locations using a glowworm metaphor with applications to collective robotics.* Paper presented at the Proceedings 2005 IEEE Swarm Intelligence Symposium, 2005. SIS 2005.

Kumar, B. R., Raghu, Sharma, M. K., & Agarwal, A., An experimental investigation of lean management in aviation: Avoiding unforced errors for better supply chain, *Journal of Manufacturing Technology Management,* Vol., no., pp. 231-260, 2015.

Kumar Kar, A., & K. Pani, A., Exploring the importance of different supplier selection criteria, *Management Research Review,* Vol., no., pp. 89-105, 2014.

Kumar, M., Basu, P., & Avittathur, B., Pricing and sourcing strategies for competing retailers in supply chains under disruption risk, *European Journal of Operational Research,* Vol., no., pp. 533-543, 2018.

Kumar, S., Datta, D., & Singh, S. K. (2015). Black hole algorithm and its applications *Computational intelligence applications in modeling and control* (pp. 147-170): Springer.

Kumar, V., Maull, R. S., Smart, P. A., & Tiwari, M. (2006). *Artificial Immune System (AIS) based information system to solve scheduling problem in leagile driven steel industries.* Paper presented at the 2006 1st International Conference on Digital Information Management.

Lahmar, A., Galasso, F., Chabchoub, H., & Lamothe, J. (2016). *Conceptual Framework of Supply Chain Vulnerability.* Paper presented at the ILS 2016-6th International Conference on Information Systems, Logistics and Supply Chain.

Lambiase, A., Mastrocinque, E., Miranda, S., & Lambiase, A., Strategic planning and design of supply chains: a literature review, *International Journal of Engineering Business Management,* Vol., no., pp. 5-49, 2013.

Lamothe, J., Hadj-Hamou, K., & Aldanondo, M., An optimization model for selecting a product family and designing its supply chain, *European Journal of Operational Research,* Vol., no., pp. 1030-1047, 2006.

Lamy, J.-B. (2019). Artificial Feeding Birds (AFB): a new metaheuristic inspired by the behavior of pigeons *Advances in nature-inspired computing and applications* (pp. 43-60): Springer.

Laporte, G., The traveling salesman problem: An overview of exact and approximate algorithms, *European Journal of Operational Research,* Vol., no., pp. 231-247, 1992.

Lemieux, A.-A., Lamouri, S., Pellerin, R., & Tamayo, S., Development of a leagile transformation methodology for product development, *Business Process Management Journal,* Vol., no., pp. 791-819, 2015.

Leukel, J., & Sugumaran, V., Formal correctness of supply chain design, *Decision support systems,* Vol., no., pp. 288-299, 2013.

Li, Q., Zeng, B., & Savachkin, A., Reliable facility location design under disruptions, *Computers & Operations Research,* Vol., no., pp. 901-909, 2013.

Li, X., Wu, Q., Holsapple, C. W., & Goldsby, T., An empirical examination of firm financial performance along dimensions of supply chain resilience, *Management Research Review,* Vol., no., pp. 254-269, 2017.

Li, Y., Guo, H., Wang, L., & Fu, J., A hybrid genetic-simulated annealing algorithm for the location-inventory-routing problem considering returns under E-supply chain environment, *The Scientific World Journal,* Vol., no., 2013.

Li, Z.-f., Zhang, R., & Xue, X.-l., Leagile supply chain strategy in housing industry facing the customer satisfaction [J], *Journal of Harbin Institute of Technology,* Vol., no., 2004.

Lim, M., Daskin, M. S., Bassamboo, A., & Chopra, S., A facility reliability problem: Formulation, properties, and algorithm, *Naval Research Logistics (NRL),* Vol., no., pp. 58-70, 2010.

Lin, Y., Xu, T., & Bian, Z., A two-phase heuristic algorithm for the common frequency routing problem with vehicle type choice in the milk run, *Mathematical Problems in Engineering,* Vol., no., 2015.

Lindgreen, A., Swaen, V., Maon, F., Walker, H., & Brammer, S., Sustainable procurement in the United Kingdom public sector, *Supply Chain Management: An International Journal,* Vol., no., 2009.

Lonny, K. (2017). What percentage of new products fail and why? *MarketSmart Newsletters*.

Lorenz, A., Raven, M., & Blind, K., The role of standardization at the interface of product and process development in biotechnology, *The Journal of Technology Transfer,* Vol., no., pp. 1-37, 2017.

Lou, Z., Li, Z., Luo, L., & Dai, X. (2016). *Study on multi-depot collaborative transportation problem of milk-run pattern.* Paper presented at the MATEC Web of Conferences.

Lucila, M. S., Campos, D. A., & Vazquez-Brust, Lean and green synergies in supply chain management, *Supply Chain Management: An International Journal,* Vol., no., pp. 627-641, 2016.

Luis, A. M.-M. n., & David, Z. Z., Multi-objective ant colony optimisation: A meta-heuristic approach to supply chain design, *Int. J. Production Economics,* Vol., no., pp. 407–420, 2011.

Lusa, A., Mateo, M., Benedito, E., Calleja, G., Olivella, J., Martínez, C., . . . Corominas, A. (2016). Concepts, tools, models and algorithms for the Supply Chain design. Retrieved from https://scom.upc.edu/en/projects/proyecto-investigacion-4?set_language=en

Mandal, S., An empirical investigation into supply chain resilience, *IUP Journal of supply chain management,* Vol., no., pp. 46, 2012.

Mandal, S., Single Or Multiple Sourcing: A Mathematical Approach To Decision Making, *International Journal of Business and Management Invention,* Vol., no., pp. 41-51, 2015.

Mari, S. I., Lee, Y. H., & Memon, M. S., Sustainable and resilient supply chain network design under disruption risks, *Sustainability,* Vol., no., pp. 6666-6686, 2014.

Marjani, M. R., Husseini, S. M. M., & Karimi, B., Bi-objective heuristics for multi-item freights distribution planning problem in crossdocking networks, *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 1201-1216, 2012.

Marodin, G. A., Tortorella, G. L., Frank, A. G., & Godinho Filho, M., The moderating effect of Lean supply chain management on the impact of Lean shop floor practices on quality and inventory, *Supply Chain Management: An International Journal,* Vol., no., pp. 473-485, 2017.

Martins, C. L., & Pato, M. V., Supply chain sustainability: A tertiary literature review, *Journal of Cleaner Production,* Vol., no., pp. 995-1016, 2019.

Mason-Jones, R., Naylor, B., & Towill, D. R., Lean, agile or leagile? Matching your supply chain to the marketplace, *International Journal of Production Research,* Vol., no., pp. 4061-4070, 2000.

Matani, A., Tripathi, M., Doifode, S., & Gowardhan, S., Green Supply Chain Management in Food Industries, *International Journal of Engineering and Technical Research,* Vol., no., pp. 261-263, 2015.

Matawale, C. R., Datta, S., & Mahapatra, S. S., A fuzzy embedded leagility assessment module in supply chain, *Benchmarking: An International Journal,* Vol., no., pp. 1937-1982, 2016.

Mehdizadeh, E., Afrabandpei, F., Mohaselafshar, S., & Afshar-Nadjafi, B., Design of a multi-stage transportation network in a supply chain system: Formulation and efficient solution procedure, *Scientia Iranica. Transaction E, Industrial Engineering,* Vol., no., pp. 2188, 2013.

Mehdizadeh, E., & Tavakkoli-Moghaddam, R. (2009). *Vibration damping optimization algorithm for an identical parallel machine scheduling problem.* Paper presented at the Proceeding of the 2nd International Conference of Iranian Operations Research Society, Babolsar, Iran.

Melnyk, S. A., Closs, D. J., Griffis, S. E., Zobel, C. W., & Macdonald, J. R., Understanding supply chain resilience, *Supply Chain Management Review,* Vol., no., pp. 34-41, 2014.

Melo, T., Nickel, S., & Saldanha-da-Gama, F. (2008a). *Network design decisions in supply chain planning*. Paper presented at the Fraunhofer-Institut für Techno- und Wirtschaftsmathematik ITWM.

Melo, T., Nickel, S., & Saldanha-da-Gama, F., Network design decisions in supply chain planning, Vol., no., 2008b.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G., Defining supply chain management, *Journal of Business Logistics,* Vol., no., pp. 1-25, 2001.

Meyer, M. H., Revitalize your product lines through continuous platform renewal, *Research-Technology Management,* Vol., no., pp. 17-28, 1997.

Miah, M. R., Roy, H. N., Saha, S., Parvez, M. S., Alom, M. J., & Dhar, N. R., Is Leagile Supply Chain Suitable for Apparel Manufacturing Organizations? A Multicriteria Decision Making Perspective, *International Journal of Scientific & Engineering Research,* Vol., no., pp. 933-938, 2013.

Miao, Z., & Xu, K., Modeling and simulation of lean supply chain with the consideration of delivery consolidation, *Key Engrg. Materials,* Vol., no., pp. 853–858, 2011.

Miao, Z., Yang, F., Fu, K., & Xu, D., Transshipment service through crossdocks with both soft and hard time windows, *Annals of Operations Research,* Vol., no., pp. 21-47, 2012.

Mirjalili, S., Mirjalili, S. M., & Lewis, A., Grey wolf optimizer, *Advances in Engineering Software,* Vol., no., pp. 46-61, 2014.

Mitsuo, G., Fulya, A., & Lin, L., A genetic algorithm for two-stage transportation problem using priority-based encoding, *OR Spectrum,* Vol., no., pp. 337-354, 2006.

Moghadam, S. S., Ghomi, S. F., & Karimi, B., Vehicle routing scheduling problem with cross docking and split deliveries, *Computers & chemical engineering,* Vol., no., pp. 98-107, 2014.

Mohammaddust, F., Rezapour, S., Farahani, R. Z., Mofidfar, M., & Hill, A., Developing lean and responsive supply chains: A robust model for alternative risk mitigation strategies in supply chain designs, *International journal of production economics,* Vol., no., pp. 632-653, 2017.

Mohtashami, A., Tavana, M., Santos-Arteaga, F. J., & Fallahian-Najafabadi, A., A novel multi-objective meta-heuristic model for solving cross-docking scheduling problems, *Applied Soft Computing,* Vol., no., pp. 30-47, 2015.

Molamohamadi, Z., Ismail, N., Leman, Z., & Zulkifli, N., Supplier selection in a sustainable supply chain, *Journal of Advanced Management Science,* Vol., no., 2013a.

Molamohamadi, Z., Sharifyazdi, M., Arshizadeh, R., Jafari, A., & Ismail, N., Determining consignment inventory strategy for a vendor and multiple buyers using a hybrid metaheuristic algorithm, *Production & Manufacturing Research,* Vol., no., pp. 65-78, 2013b.

Mollenkopf, D., Stolze, H., Tate, W. L., & Ueltschy, M., Green, lean, and global supply chains, *International journal of physical distribution & logistics management,* Vol., no., pp. 14-41, 2010.

Moncayo–Martínez, L. A., & Mastrocinque, E., A multi-objective intelligent water drop algorithm to minimise cost Of goods sold and time to market in logistics networks, *Expert Systems with Applications,* Vol., no., pp. 455-466, 2016.

Moreno-Camacho, C. A., Montoya-Torres, J. R., Jaegler, A., & Gondran, N., Sustainability Metrics for Real Case Applications of the Supply Chain Network Design Problem: A Systematic Literature Review, *Journal of Cleaner Production,* Vol., no., 2019.

Moscato, P., On evolution, search, optimization, genetic algorithms and martial arts: Towards memetic algorithms, *Caltech concurrent computation program, C3P Report,* Vol., no., pp. 1989, 1989.

Mousavi, S. M., Bahreininejad, A., Musa, S. N., & Yusof, F., A modified particle swarm optimization for solving the integrated location and inventory control problems in a two-echelon supply chain network, *Journal of Intelligent Manufacturing,* Vol., no., pp. 191-206, 2017.

Moussaid, A., Aggour, A., & El Hassan, A. A. (2017). *Impact of the leagility concept on the logistics flows optimization: The Moroccan aeronautic industry case.* Paper presented at the 2017 International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA).

Mukesh, K., Dixit, G., & Ashish, A., An Analysis of Inventory Attributes in Leagile Supply Chain: Cause and Effect Analysis *International Journal of Mathematical, Engineering and Management Sciences,* Vol., no., pp. 870–881, 2019.

Mula, B., Josefa, Reporting on Internationalization of Operations, GLOBOP: Design and Management of Global Supply Chains, *Industrial Engineering and Management,* Vol., no., pp. 1-3, 2014.

Navarro, P. (2011). *Death by China: Confronting the Dragon*: Prentice Hall.

Naylor, J. B., Naim, M. M., & Berry, D., Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain, *International journal of production economics,* Vol., no., pp. 107-118, 1999.

Nguyen, T., & Dao, T. (2016). *Robust Optimization for Lean Supply Chain design under disruptive risk.* Paper presented at the 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM).

Nguyen, T. H. D., & Dao, T.-M., New Framework to Optimise Leagile Supply Chain Design, *International Journal of Industrial Engineering and Operations Management (IJIEOM),* Vol., no., 2019.

Nguyen, T. H. D., & Dao, T. M., New Framework To Develop Larg Supply Chain Management: A case Study, *Journal of Logistics Management (Under Review),* Vol., no., 2020.

Nguyen, T. H. D., & Dao, T. M., New strategy to optimize lean supply chain design by meta-heuristic, *American Journal of Engineering and Applied Sciences,* Vol., no., pp. 156-164, 2017.

Nozari, H., Aliahmadi, A., Jafari-eskandari, M., & Khaleghi, G., An Extended Compact Genetic Algorithm for Milk Run Problem with Time Windows and Inventory Uncertainty, *International Journal of Applied,* Vol., no., pp. 35-48, 2015.

Odili, J. B., & Kahar, M. N. M., African buffalo optimization (ABO): a new meta-heuristic algorithm, *Journal of Advanced & Applied Sciences,* Vol., no., pp. 101-106, 2015.

Olhager, J., Strategic positioning of the order penetration point, *International journal of production economics,* Vol., no., pp. 319-329, 2003.

Olivares-Benitez, E., Ríos-Mercado, R. Z., & González-Velarde, J. L., A metaheuristic algorithm to solve the selection of transportation channels in supply chain design, *International journal of production economics,* Vol., no., pp. 161-172, 2013.

Ōno, T. (1988). *Toyota Production System: Beyond Large-Scale Production*: Productivity Press.

Ōno, T., Toyota Seisan Hoshiki, *Diamond Bar, Calif.: Diamond Publishing,* Vol., no., 1978.

Osaba, E., Diaz, F., & Onieva, E., Golden ball: a novel meta-heuristic to solve combinatorial optimization problems based on soccer concepts, *Applied Intelligence,* Vol., no., pp. 145-166, 2014.

Ouabouch, L., & Amri, M., Analysing supply chain risk factors: a probability-impact matrix applied to pharmaceutical industry, *Journal of Logistics Management,* Vol., no., pp. 35-40, 2013.

Palappan, A., & Thangavelu, J., A New Meta Heuristic Dragonfly Optimizaion Algorithm for Optimal Reactive Power Dispatch Problem, *Gazi University Journal of Science,* Vol., no., pp. 1107-1121, 2018.

Pasandideh, S. H. R., Niaki, S. T. A., & Ahmadi, P., Vendor-managed inventory in the joint replenishment problem of a multi-product single-supplier multiple-retailer supply chain: A teacher-learner-based optimization algorithm, *Journal of Modelling in Management,* Vol., no., pp. 156-178, 2018.

Paschal, U., Jon, E., & Jostein, L., Lean In The Supply Chain: A Literature Review, *Management and Production Engineering Review,* Vol., no., pp. 87–96 2012a.

Paschal, U., Jon, E. o., & Jostein, L., Lean In The Supply Chain: A Literature Review, *Management and Production Engineering Review,* Vol., no., pp. 87–96 2012b.

Passino, K. M., Biomimicry of bacterial foraging for distributed optimization and control, *IEEE control systems magazine,* Vol., no., pp. 52-67, 2002.

Patel, D., Patel, M., & Vadher, J., Design and Development of Milk-Run Material Supply System with Time Windows and Simultaneous Pickups and Deliveries, *International Journal for Innovative Research in Science & Technology,* Vol., no., pp. 158-166, 2017.

Patel, D. R., Design and optimization of milkrun material supply system with simultaneous pickups and deliveries in time windows*,* Vol., no., 2017.

Pearce, A., & Pons, D. (2012). *Risk in Implementing Lean Practices: Lean manufacturing as a strategic business transformation*. Paper presented at the 6th National Conference of the New Zealand Society for Risk Management Inc., New Zealand. http://www.risksociety.org.nz

Perboli, G., Musso, S., & Rosano, M., Blockchain in logistics and supply chain: A lean approach for designing real-world use cases, *IEEE Access,* Vol., no., pp. 62018-62028, 2018.

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

Pesce, L. F., Frazão, C. D., Civinskas, J., & Pires, M. V. (2000). *The next step for a lean production: Milk run* (0148-7191).

Peter, B., & Peter, L., Lean eco-efficient innovation in operations through the maintenance organisation, *International journal of production economics,* Vol., no., 2018.

Pham, D., Ghanbarzadeh, A., Koc, E., Otri, S., Rahim, S., & Zaidi, M., The bees algorithm. technical note, manufacturing engineering centre, *Cardiff University, Cardiff, UK,* Vol., no., 2005.

Pierezan, J., & Coelho, L. D. S. (2018). *Coyote optimization algorithm: a new metaheuristic for global optimization problems.* Paper presented at the 2018 IEEE Congress on Evolutionary Computation (CEC).

Pijarski, P., & Kacejko, P., A new metaheuristic optimization method: the algorithm of the innovative gunner (AIG), *Engineering Optimization,* Vol., no., pp. 1-20, 2019.

Purvis, L., Spall, S., Naim, M., & Spiegler, V., Developing a resilient supply chain strategy during 'boom'and 'bust', *Production Planning & Control,* Vol., no., pp. 579-590, 2016.

Queirós, A., Faria, D., & Almeida, F., Strengths and limitations of qualitative and quantitative research methods, *European Journal of Education Studies,* Vol., no., 2017.

Rabanal, P., Rodríguez, I., & Rubio, F. (2007). *Using river formation dynamics to design heuristic algorithms.* Paper presented at the International conference on unconventional computation.

Rabbani, M., Baghersad, M., & Jafari, R., A new hybrid GA-PSO method for solving multi-period inventory routing problem with considering financial decisions, *Journal of Industrial Engineering and Management (JIEM),* Vol., no., pp. 909-929, 2013.

Rabbani, M., Yousefnejad, H., & Rafiei, H., Presenting a new approach toward locating optimal decoupling point in supply chains, *International Journal of Research in Industrial Engineering,* Vol., no., pp. 49, 2014.

Rachid, B., Roland, D., Sebastien, D., & Ivana, R., Risk management approach for lean, agile, resilient and green supply chain, *World Academy of Science, Engineering and Technology, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering,* Vol., no., pp. 742-750, 2017.

Rahiminezhad Galankashi, M., & Helmi, S. A., Assessment of hybrid Lean-Agile (Leagile) supply chain strategies, *Journal of Manufacturing Technology Management,* Vol., no., pp. 470-482, 2016.

Rahman, M. S., The Advantages and Disadvantages of Using Qualitative and Quantitative Approaches and Methods in Language" Testing and Assessment" Research: A Literature Review, *Journal of Education and Learning,* Vol., no., pp. 102-112, 2017.

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

Rajesh, K., Lakshmi, J. S., & Ramarao, T., Best Practices With Lean Principles In Furniture Green Manufacturing, Vol., no., 2016.

Raman, V., & Gill, N. S., Review of different heuristic algorithms for solving Travelling Salesman Problem, *International Journal of Advanced Research in Computer Science,* Vol., no., 2017.

Ramana, D., Rao, K., & Kumar, J., Evaluation of performance metrics of leagile supply chain through fuzzy MCDM, *Decision Science Letters,* Vol., no., pp. 211-222, 2013
.

Ramos, A. R., Ferreira, J. C. E., Kumar, V., Garza-Reyes, J. A., & Cherrafi, A., A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil, *Journal of Cleaner Production,* Vol., no., pp. 218-231, 2018.

Rashedi, E., Nezamabadi-Pour, H., & Saryazdi, S., GSA: a gravitational search algorithm, *Information sciences,* Vol., no., pp. 2232-2248, 2009.

Ravindran, A. R., Ufuk Bilsel, R., Wadhwa, V., & Yang, T., Risk adjusted multicriteria supplier selection models with applications, *International Journal of Production Research,* Vol., no., pp. 405-424, 2010.

Reaidy, P. J., Gunasekaran, A., & Spalanzani, A., Bottom-up approach based on Internet of Things for order fulfillment in a collaborative warehousing environment, *International journal of production economics,* Vol., no., pp. 29-40, 2015.

Regattieri, A., Bartolini, A., Cima, M., Fanti, M. G., & Lauritano, D., An innovative procedure for introducing the lean concept into the internal drug supply chain of a hospital, *The TQM Journal,* Vol., no., pp. 717-731, 2018.

Rego, C., Gamboa, D., Glover, F., & Osterman, C., Traveling salesman problem heuristics: Leading methods, implementations and latest advances, *European Journal of Operational Research,* Vol., no., pp. 427-441, 2011.

Rezapour, S., Farahani, R. Z., & Pourakbar, M., Resilient supply chain network design under competition: a case study, *European Journal of Operational Research,* Vol., no., pp. 1017-1035, 2017.

Rice, J. B., & Caniato, F., Building a secure and resilient supply network, *Supply Chain Management Review,* Vol., no., pp. 22-30, 2003.

Richards, C. W., Agile manufacturing: beyond lean?, *Production and Inventory Management Journal,* Vol., no., pp. 60, 1996.

Rienkhemaniyom, K., & Pazhani, S. (2015). A supply chain network design considering network density *Toward Sustainable Operations of Supply Chain and Logistics Systems* (pp. 3-19): Springer.

Robinson, A. (2015). History of supply chain management. *Infographic, Supply Chain*.

Rocío, R.-B., Cristina, L., & Real., J. C., The lean and resilient management of the supply chain and its impact on performance, *International journal of production economics,* Vol., no., pp. 190–202, 2018.

Rooeinfar, R., Azimi, P., & Pourvaziri, H., Multi-echelon supply chain network modelling and optimization via simulation and metaheuristic algorithms, *Scientia Iranica. Transaction E, Industrial Engineering,* Vol., no., pp. 330, 2016.

Rossini, M., & Staudacher, A. P. (2016). *Lean supply chain planning: A performance evaluation through simulation.* Paper presented at the MATEC Web of Conferences.

Rudberg, M., & Wikner, J., Mass customization in terms of the customer order decoupling point, *Production Planning & Control,* Vol., no., pp. 445-458, 2004.

Ruiz-Benitez, R., López, C., & Real, J. C., Environmental benefits of lean, green and resilient supply chain management: The case of the aerospace sector, *Journal of Cleaner Production,* Vol., no., pp. 850-862, 2017.

Sabareswari, D., Sathya, N., & Sharmila, K., Meta Heuristics Approach for a Class of Supply Chain Optimization Problems, *International Journal Of Innovative Research In Management, Engineering And Technology,* Vol., no., pp. 33-39, 2017.

Sacco, W. F., & De Oliveira, C. R., A new stochastic optimization algorithm based on a particle collision metaheuristic, *Proceedings of 6th WCSMO,* Vol., no., 2005.

Sadeghi, J., Mousavi, S. M., & Niaki, S. T. A., Optimizing an inventory model with fuzzy demand, backordering, and discount using a hybrid imperialist competitive algorithm, *Applied Mathematical Modelling,* Vol., no., pp. 7318-7335, 2016.

Sadeghi, J., Mousavi, S. M., Niaki, S. T. A., & Sadeghi, S., Optimizing a multi-vendor multi-retailer vendor managed inventory problem: Two tuned meta-heuristic algorithms, *Knowledge-Based Systems,* Vol., no., pp. 159-170, 2013.

Sadjadi, S. J., Jafari, M., & Amini, T., A new mathematical modeling and a genetic algorithm search for milk run problem (an auto industry supply chain case study), *The International Journal of Advanced Manufacturing Technology,* Vol., no., pp. 194, 2009.

Saghaeeian, A., & Ramezanian, R., An efficient hybrid genetic algorithm for multi-product competitive supply chain network design with price-dependent demand, *Applied Soft Computing,* Vol., no., pp. 872-893, 2018.

Sanders, N. R. (2014). *Big data driven supply chain management: A framework for implementing analytics and turning information into intelligence*: Pearson Education.

Sawik, T., A portfolio approach to supply chain disruption management, *International Journal of Production Research,* Vol., no., pp. 1970-1991, 2017.

Schmidt, W., & Simchi-Levi, D., Nissan Motor Company Ltd.: Building Operational Resiliency, *MIT Sloan management Review,* Vol., no., 2013.

Schmitt, T. G., Kumar, S., Stecke, K. E., Glover, F. W., & Ehlen, M. A., Mitigating disruptions in a multi-echelon supply chain using adaptive ordering, *Omega,* Vol., no., pp. 185-198, 2017.

Sedki, A., & Ouazar, D., Hybrid particle swarm optimization and differential evolution for optimal design of water distribution systems, *Advanced Engineering Informatics,* Vol., no., pp. 582-591, 2012.

Sezen, B., Karakadilar, I. S., & Buyukozkan, G., Proposition of a model for measuring adherence to lean practices: applied to Turkish automotive part suppliers, *International Journal of Production Research,* Vol., no., pp. 3878-3894, 2012.

Shah-Hosseini, H. (2011). *Otsu's criterion-based multilevel thresholding by a nature-inspired metaheuristic called galaxy-based search algorithm.* Paper presented at the 2011 Third World Congress on Nature and Biologically Inspired Computing.

Shah, R., & Ward, P. T., Defining and developing measures of lean production, *Journal of Operations management,* Vol., no., pp. 785-805, 2007.

Shah, R., & Ward, P. T., Lean manufacturing: context, practice bundles, and performance, *Journal of Operations management,* Vol., no., pp. 129-149, 2003.

Shahin, A., Gunasekaran, A., Khalili, A., & Shirouyehzad, H., A new approach for estimating leagile decoupling point using data envelopment analysis, *Assembly Automation,* Vol., no., pp. 233-245, 2016.

Shahin, A., & Jaberi, R., Designing an integrative model of leagile production and analyzing its influence on the quality of auto parts based on Six Sigma approach with a case study in a manufacturing company, *International Journal of Lean Six Sigma,* Vol., no., pp. 215-240, 2011.

Shankar, B. L., Basavarajappa, S., Kadadevaramath, R. S., & Chen, J. C., A bi-objective optimization of supply chain design and distribution operations using non-dominated sorting algorithm: A case study, *Expert Systems with Applications,* Vol., no., pp. 5730-5739, 2013.

Sharifi, H., Ismail, H., & Reid, I., Achieving agility in supply chain through simultaneous “design of” and “design for” supply chain, *Journal of Manufacturing Technology Management,* Vol., no., pp. 1078-1098, 2006.

Shayanfar, H., & Gharehchopogh, F. S., Farmland fertility: A new metaheuristic algorithm for solving continuous optimization problems, *Applied Soft Computing,* Vol., no., pp. 728-746, 2018.

Shen, J., & Li, Y. (2009). *Light ray optimization and its parameter analysis.* Paper presented at the 2009 International Joint Conference on Computational Sciences and Optimization.

Shimizu, Y., & Rusman, M., A Hybrid Approach for Huge Multi-stage Logistics Network Optimization under Disruption Risk, *Journal of Chemical Engineering of Japan,* Vol., no., pp. 1204180367-1204180367, 2012.

Shretta, R., Johnson, B., Smith, L., Doumbia, S., de Savigny, D., Anupindi, R., & Yadav, P., Costing the supply chain for delivery of ACT and RDTs in the public sector in Benin and Kenya, *Malaria journal,* Vol., no., pp. 57, 2015.

Shukla, A., Agarwal, L. V., & Venkatasubramanian, V., Optimizing efficiency-robustness trade-offs in supply chain design under uncertainty due to disruptions, *International journal of physical distribution & logistics management,* Vol., no., pp. 623-647, 2011.

Simon, D., Biogeography-based optimization, *IEEE transactions on evolutionary computation,* Vol., no., pp. 702-713, 2008.

Singh, O. P., Supply chain design of an electronic industry using lean principles, *International Journal of Services, Economics and Management,* Vol., no., pp. 315-339, 2009.

Smith, A. B. (2018). *2017 U.S. billion-dollar weather and climate disasters: a historic year in context*. Retrieved from https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year.

Soni, G., & Kodali, R., Evaluating reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry, *Production Planning & Control,* Vol., no., pp. 864-884, 2012.

Srinivasan, M. M. (2012). *Building Lean Supply chains with the Theory of Constraints*: Mc Graw Hill.

Srinivasan, S. P. (2019). Meta-Heuristic Approaches for Supply Chain Management (pp. 153-162): IGI Global.

Srivastava, S. K., Green supply-chain management: a state-of-the-art literature review, *International journal of management reviews,* Vol., no., pp. 53-80, 2007.

Stadtler, H., & Kilger, C. (2011). *Supply chain management and advanced planning: Concepts, models, software, and case studies*: Berlin: Springer-Verlag.

Storn, R., & Price, K., Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces, *Journal of global optimization,* Vol., no., pp. 341-359, 1997.

Sunil, C., & Peter, M. (2013). *Supply Chain Management, Strategy, Planning and Operation* (5th ed.): Prentice Hall.

Sur, C., Sharma, S., & Shukla, A. (2013). *Egyptian vulture optimization algorithm–a new nature inspired meta-heuristics for knapsack problem.* Paper presented at the The 9th International Conference on Computing and InformationTechnology (IC2IT2013).

Suzić, N., Stevanov, B., Ćosić, I., Anišić, Z., & Sremčev, N., Customizing products through application of group technology: A case study of furniture manufacturing, *Strojniški vestnik-Journal of Mechanical Engineering,* Vol., no., pp. 724-731, 2012.

Swenseth, S. R., & Olson, D. L., Trade-offs in lean vs. outsourced supply chains, *International Journal of Production Research,* Vol., no., pp. 4065-4080, 2016.

Taha, R., Abdallah, K., Sadek, Y., El-Kharbotly, A., & Afia, N., Design of supply chain networks with supply disruptions using genetic algorithm, Vol., no., 2014.

Tahani, M., & Babayan, N., Flow Regime Algorithm (FRA): a physics-based meta-heuristics algorithm, *Knowledge and Information Systems,* Vol., no., pp. 1001-1038, 2019.

Tamura, K., & Yasuda, K., Primary study of spiral dynamics inspired optimization, *IEEJ Transactions on Electrical and Electronic Engineering,* Vol., no., pp. S98-S100, 2011.

Tayarani-N, M.-H., & Akbarzadeh-T, M. (2008). *Magnetic optimization algorithms a new synthesis.* Paper presented at the 2008 IEEE Congress on Evolutionary Computation (IEEE World Congress on Computational Intelligence).

Taylor, D. A. (2003). *Supply chains: A manager's guide*: Pearson Education India.

Tchokogué, A., Nollet, J., & Robineau, J., Supply's strategic contribution: An empirical reality, *Journal of Purchasing and Supply Management,* Vol., no., pp. 105-122, 2017.

Thakur, L. S., Nair, S. K., & Wen, K.-W., Product Line Design for Profit Maximization Using Common Parts, Features and Manufacturing Facilities, *Opsearch,* Vol., no., pp. 596-611, 2001.

Thanki, S., & Thakkar, J., A quantitative framework for lean and green assessment of supply chain performance, *International Journal of Productivity and Performance Management,* Vol., no., pp. 366-400, 2018.

Tiwari, M. K., Raghavendra, N., Agrawal, S., & Goyal, S., A Hybrid Taguchi–Immune approach to optimize an integrated supply chain design problem with multiple shipping, *European Journal of Operational Research,* Vol., no., pp. 95-106, 2010.

Toi, M., Sawai, K., Nomaguchi, Y., & Fujita, K. (2018). *Strategic-Level Robust Optimal Design Method of Product Family and Supply Chain Network.* Paper presented at the ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Trisna, T., Marimin, M., Arkeman, Y., & Sunarti, T., Multi-objective optimization for supply chain management problem: A literature review, *Decision Science Letters,* Vol., no., pp. 283-316, 2016.

Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M., Supply chain resilience: definition, review and theoretical foundations for further study, *International Journal of Production Research,* Vol., no., pp. 5592-5623, 2015.

Turner, M., Be prepared to bounce back: Building a resilient supply chain, *Booz and Company,* Vol., no., 2011.

Urbanucci, L., Limits and potentials of Mixed Integer Linear Programming methods for optimization of polygeneration energy systems, *Energy Procedia,* Vol., no., pp. 1199-1205, 2018.

Vaaland, T., & Owusu, R., What is a Responsible Supply Chain?, *International Journal of Business and Management,* Vol., no., 2012.

Vahdani, B., Tavakkoli-Moghaddam, R., Zandieh, M., & Razmi, J., Vehicle routing scheduling using an enhanced hybrid optimization approach, *Journal of Intelligent Manufacturing,* Vol., no., pp. 759-774, 2012.

Vinodh, S., & Aravindraj, S., Evaluation of leagility in supply chains using fuzzy logic approach, *International Journal of Production Research,* Vol., no., pp. 1186-1195, 2013.

Virmani, N., Saha, R., & Sahai, R., Evaluating key performance indicators of leagile manufacturing using fuzzy TISM approach, *International Journal of System Assurance Engineering and Management,* Vol., no., pp. 427-439, 2018.

Visich, J. K., Qiannong, G., Faiza, Z., & Huilin, Y., RFID enabled Leagile Supply Chain, *IJAIT,* Vol., no., pp. 41-49, 2012.

Vonderembse, M. A., Uppal, M., Huang, S. H., & Dismukes, J. P., Designing supply chains: Towards theory development, *International journal of production economics,* Vol., no., pp. 223-238, 2006.

Wade, S. (2017). How Amazon's Wooing Of Chinese Sellers Is Killing Small American Businesses. Retrieved from https://www.forbes.com/sites/wadeshepard/2017/02/14/how-amazons-wooing-of-chinese-sellers-is-hurting-american-innovation/#dd3cd321df25

Wang, K., Luo, H., Liu, F., & Yue, X., Permutation flow shop scheduling with batch delivery to multiple customers in supply chains, *IEEE Transactions on Systems, Man, and Cybernetics: Systems,* Vol., no., pp. 1826-1837, 2017.

Wang, P., Zhu, Z., & Huang, S. (2013). *A new Meta-Heuristic technique for engineering design optimization: seven-spot ladybird algorithm.* Paper presented at the 2nd International Symposium on Computer, Communication, Control and Automation.

Wang, X., He, M., & Jiang, H. (2015). *A discrete firefly algorithm for routing optimization of milk-run.* Paper presented at the 5th International Conference on Advanced Design and Manufacturing Engineering.

Watkins, J. H., MacKerrow, E. P., & Merritt, T. M. (2010). *Simulating the Afghanistan-Pakistan opium supply chain*. Retrieved from

Weber, C. A., Current, J. R., & Benton, W., Vendor selection criteria and methods, *European Journal of Operational Research,* Vol., no., pp. 2-18, 1991.

Wedyan, A., Whalley, J., & Narayanan, A., Hydrological cycle algorithm for continuous optimization problems, *Journal of Optimization,* Vol., no., 2017.

Wicher, P., & Lenort, R. (2013). *The ways of creating resilient supply chains.* Paper presented at the Proceedings of Carpathian logistic congress.

Wieland, A., & Marcus, W., Carl, Dealing with supply chain risks: Linking risk management practices and strategies to performance, *International journal of physical distribution & logistics management,* Vol., no., pp. 887-905, 2012.

Wiengarten, F., Humphreys, P., Gimenez, C., & McIvor, R., Risk, risk management practices, and the success of supply chain integration, *International journal of production economics,* Vol., no., pp. 361-370, 2016.

Wikner, J., Bäckstrand, J., Tiedemann, F., & Johansson, E. (2015). *Leagility in a Triad with Multiple Decoupling Points.* Paper presented at the IFIP International Conference on Advances in Production Management Systems.

Womack, J. P., Jones, D. T., & Roos, D. (1991). *The machine that changed the world: the story of lean production*: Harper Collins.

Wong, C. W., Wong, C. Y., & Boonitt, S., How does sustainable development of supply chains make firms lean, green and profitable? A resource orchestration perspective, *Business Strategy and the Environment,* Vol., no., pp. 375-388, 2018.

Wu, Q., Wang, X., He, Y., Xuan, J., & He, W., A robust hybrid heuristic algorithm to solve multi-plant milk-run pickup problem with uncertain demand in automobile parts industry, *Advances in Production Engineering & Management,* Vol., no., pp. 169-178, 2018.

Xie, L., Zeng, J., & Cui, Z. (2009). *General framework of artificial physics optimization algorithm.* Paper presented at the 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC).

Xu, H.-Y., Fu, X., Ponnambalam, L., Namatame, A., Yin, X. F., & Goh, R. S. M. (2015). *A model to evaluate risk propagation considering effect of dynamic risk information sharing and multi-sourcing in supply chain networks.* Paper presented at the 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM).

Yadav, S. R., Dashora, Y., Shankar, R., Chan, F. T., & Tiwari, M. K., An interactive particle swarm optimisation for selecting a product family and designing its supply chain, *International Journal of Computer Applications in Technology,* Vol., no., pp. 168-186, 2008.

Yadav, S. R., Mishra, N., Kumar, V., & Tiwari, M. K., A framework for designing robust supply chains considering product development issues, *International Journal of Production Research,* Vol., no., pp. 6065-6088, 2011.

Yang, J., & Pan, J. C., Just-in-time purchasing: an integrated inventory model involving deterministic variable lead time and quality improvement investment, *International Journal of Production Research,* Vol., no., pp. 853–863, 2004.

Yang, X.-S. (2012). *Flower pollination algorithm for global optimization.* Paper presented at the International conference on unconventional computing and natural computation.

Yang, X.-S. (2010). A new metaheuristic bat-inspired algorithm *Nature inspired cooperative strategies for optimization (NICSO 2010)* (pp. 65-74): Springer.

Yang, X.-S., & Deb, S. (2009). *Cuckoo search via Lévy flights.* Paper presented at the 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC).

Yapici, H., & Cetinkaya, N., A new meta-heuristic optimizer: Pathfinder algorithm, *Applied Soft Computing,* Vol., no., pp. 545-568, 2019.

Yi, H., & Sarker, B. R., An operational policy for an integrated inventory system under consignment stock policy with controllable lead time and buyers' space limitation, *Computers & Operations Research,* Vol., no., pp. 2632-2645, 2013.

Yin, Z., & Wang, C., Strategic cooperation with a backup supplier for the mitigation of supply disruptions, *International Journal of Production Research,* Vol., no., pp. 4300-4312, 2018.

Yuan, H.-x., & Wang, X.-q. (2013). *Design of Lean Supply Chain for Real Estate Operations.* Paper presented at the International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings.

Zahiri, B., Torabi, S. A., Mohammadi, M., & Aghabegloo, M., A multi-stage stochastic programming approach for blood supply chain planning, *Computers & industrial engineering,* Vol., no., pp. 1-14, 2018.

Zarand, G., Pazmandi, F., Pál, K., & Zimányi, G., Using hysteresis for optimization, *Physical review letters,* Vol., no., pp. 150201, 2002.

Zarei, H., & Rasti-Barzoki, M., Mathematical programming and three metaheuristic algorithms for a bi-objective supply chain scheduling problem, *Neural Computing and Applications,* Vol., no., pp. 1-21, 2018.

Zhang, Y., Wang, Y., & Wu, L., Research on demand-driven leagile supply chain operation model: a simulation based on anylogic in system engineering, *Systems Engineering Procedia,* Vol., no., pp. 249-258, 2012.

Zhao, W., Wang, L., & Zhang, Z., Atom search optimization and its application to solve a hydrogeologic parameter estimation problem, *Knowledge-Based Systems,* Vol., no., pp. 283-304, 2019.

Zhou, L., Xu, X., & Deng, S., A multi-objective programming approach for designing complicated logistics network, *International Journal of Logistics Systems and Management,* Vol., no., pp. 419-437, 2011.

Zhu, Q., Shah, P., & Sarkis, J., Addition by subtraction: Integrating product deletion with lean and sustainable supply chain management, *International journal of production economics,* Vol., no., pp. 201-214, 2018.