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# Optimization of Lean and Agile Supply Chain Management Practices in the Aviation Industry

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# Optimization of Lean and Agile Supply Chain Management Practices in the Aviation Industry

## Cover Page Footnote

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The concept of lean supply chains and agile supply chains have recently evolved to streamline and optimize the continuous flow and flexible fluctuations in customer demand throughout the entire supply chain. In the last decade, organizations involved in supply chain management addressed the importance of integrating lean supply chains with agile supply chains. This study will identify current practices in the implementation of integrated lean and agile supply chains in what is evolving as *leagile* supply chains.

Table 1 displays the four evolutionary timeline transition phases of supply chain spanning from the early 1980s to the late 1990s. The supply chain timelines include the early 1980s, late 1980s, early 1990s, and late 1990s. The evolution of supply chain comprised of several criteria that distinguished each phase. Aside from the supply chain timeline evolution markers, additionally, five criteria were included to distinguish the differences for each timeline. The supply chain philosophy included product, market, and customer concepts. This philosophy also included practices which emphasized lean and agile methods, and early stages of attempting to establish operational leagile practices. The market winner criteria from an organizational operational perspective to gain competitive advantage and market success placed emphasis on quality, cost, availability, and lead time over the span of the four phases. The market qualifiers, as seen from the perspective of customers for purchase order prioritization consideration, ranged among cost, availability, lead time, and quality factors.

**Table 1**

*Supply Chain Transition from Product to Customer riven Operations*

| **Supply chain evolution phase** | **I** | **II** | **III** | **IV** |
|---|---|---|---|---|
| **Supply chain time marker** | **Early 1980s** | **Late 1980s** | **Early 1990s** | **Late 1990s** |
| **Supply chain philosophy** | Product driven | Market oriented | Leagile supply chain | Customer driven |
| **SC type** | Lean functional silos | Lean supply chain | | Customized leagile supply chain |
| **Market winner** | Quality | Cost | Availability | Lead time |
| **Market qualifiers** | (a) Cost<br>(b) Availability<br>(c) Lead time | (a) Availability<br>(b) Lead time<br>(c) Quality | (a) Lead time<br>(b)Quality<br>(c) Cost | (a) Quality<br>(b) Cost<br>(c) Availability |
| **Performance metrics** | (a) Stock turns<br>(b) Production cost | (a) Throughput time<br>(b) Physical cost | (a) Market share<br>(b) Total cost | (a) Customer satisfaction<br>(b) Value added |

*Note*. Adapted from Christopher and Towill (2000).

In the early 1980s the supply chain philosophy was mainly product driven, with lean functional silos, and as Total Quality Management was evolving at the same time, quality was the market winner. The market qualifiers were prioritized by cost first, then availability, and lead time. Key performance indicators emphasized stock replenishment and production costs. In the late 1980s the supply chain philosophy transitioned to a market oriented and lean supply chain type with cost as the market winner. The market qualifiers were prioritized first by availability, then by lead time, followed by quality. Key performance indicator metrics were placed on throughput time and physical cost.

In the early 1990s, the supply chain philosophy transitioned to mainly to a market driven, with an attempted leagile supply chain type and with product availability as the market winner. The market qualifiers were prioritized by first, lead time, then quality and followed by cost. Key performance indicator metrics were placed on market share and total cost. In the late 1990s the supply chain philosophy transitioned to customer driven emphasis, with a customized leagile supply chain, at an early, primitive operational stage. The market winner was lead time reduction, in an attempt to expedite production completion times. The market qualifiers were prioritized, first by quality, then cost, followed by product availability which did not always fulfilled demand. Key performance indicator metrics emphasis was placed on customer satisfaction and value added, which was usually followed by increased subsequent product pricing.

Figure 1 below, shows market qualifiers and market winners for lean and agile supply chains as a result of a study performed in the year 2000 to show the engineering of leagile supply chain at the time. Notably, there are similarities compared to the 2000 study by Christopher and Towill in Table 1 above, in the market qualifiers and market winners for both lean and agile supply chains, combined, assuming that lead time is a subset of service level with the same effect. Notably, there are differences in the organizational attribute's categorization of market qualifiers and market winners between the lean and agile supply chains, which pose a question mark, if for example, what is the current trend of prioritization of market qualifiers and market winners in a leagile supply chain network strategy.

**Figure 1**

*Market Qualifiers and Market Winners for Lean and Agile Supply Chains*

| | **Market Qualifiers** | **Market Winners** |
|---|---|---|
| **Agile Supply** | **1. Quality**<br>**2. Cost**<br>**3. Lead Time** | **1. Service Level** |
| **Lean Supply** | **1. Quality**<br>**2. Lead Time**<br>**3. Service Level** | **1. Cost** |

*Note*. Adapted from Mason-Jones et al. (2000)

Table 2 below depicts a comparison of the distinguishing attributes of both lean and agile supply chains as published by Mason-Jones et al. (2000). These distinguishing attributes are in turn driven by the differentiating product or market characteristics of both lean and agile supply chains vary according to supply and demand drivers. As time progressed with the lessons learned from lean supply chains and agile supply chains separately, a dialogue among supply chain stakeholders began in an effort to combine or find a happy medium between lean and agile, thus the coined term for *"leagile"* has emerged. The problem has soon become apparent that "one size does not necessarily fit all" as an approach to integrating differentiated supply chain networks published by Beck et al. (2000). The second most important question then arose as a result of this integrated leagile mode of thinking, as to which attributes, variables, and types of data make more sense to prioritize from most important to the least important ones, in order to be able to create the ideal leagile supply chain network.

**Table 2**

*Comparison of Lean and Agile Supply Chains*

| **Distinguishing attributes** | **Lean Supply** | **Agile Supply** |
|---|---|---|
| Typical Products | Commodities | Fashion goods |
| Marketplace demand | Predictable | Volatile |
| Product variety | Low | High |
| Product life cycle | Long | Short |
| Customer drivers | Cost | Availability |
| Profit margin | Low | High |
| Dominant costs | Physical costs | Marketability costs |
| Stockout Penalties | Long-term contractual | Immediate and volatile |
| Purchasing policy | Buy materials | Assign capacity |
| Information enrichment | Highly desirable | Obligatory |
| Forecasting mechanism | Algorithmic | Consultive |

*Note*. Adapted from Mason-Jones et al. (2000).

Dependent on the stakeholders' management structure in the supply chain network, will be a determining factor in the success or failure of implementing new proven methods as emphasized in Montgomery et al (2011). The tools and techniques identified for use in the implementation of an organized approach to quality management, control, and improvement, must be fully supported by the managing decision makers in the organization. There are many reasons causing fluctuations in demand, evident by both increased and decreased purchasing activity, some of which are attributed to varying pricing, seasonal changes, and product availability.

## APROACH

This research study was conducted to provide theoretical and practical research methods and practices that could dynamically be modified to help identify what attributes, variables, and types of data are needed to analyze optimal approaches in order to show how to blend a *lean*, continuous, flow approach, with the ability to accurately forecast *agile,* flexible, fluctuations in customer demand. The study will be developed in a way that will promote the concept of ideal futuristic "*leagile"* supply chain networks, for consistent tactical and operational outcomes spanning from producers to consumers, and every stakeholder involved throughout the supply chain management processes. One approach discussed by McMahon (2010) presented case studies of integrating an organization's capability maturity model integration methods with agile development for realizing the benefits of more mature organizational processes.

A key take-away from these case studies would be to analyze the lessons learned by documenting what has worked well, what mistakes to avoid, and especially what improvement methodologies can further be optimized, in the quest to implement the ideal leagile supply chain network without interruptions. Another approach as discussed by Chrissis et al (2011) accommodates other modern approaches as well, including the use of agile methods, lean six sigma and architecture-centric development. However, differences exist in successfully implementing a combination of lean and agile supply chains as it is becoming more evident that the "one size does not fit all" paradigm holds true.

The approach to completing this initial phase of the research study, is to identify which attributes, variables, and types of data are needed, in order to be able to create the ideal leagile supply chain network processes. The current trend of prioritization of market qualifiers and market winners in a leagile supply chain network will then be identified and applied to measurable outcomes that could be used to further optimize the supply chain network with the analysis of several identifiable key performance characteristics, from a strategic, tactical, and operational planning levels. The quantitative model seeks to identify the optimal solution by efficiently and effectively meeting fluctuating customer demand.

It is important to note the continuous improvement derived from the Japanese mindset of Kaizen, which encourages organizational change and continuous improvement, by improving work quality, removing waste, and aiming for accurately forecasting fluctuating demand in order to adequately be prepared to provide the necessary supply. One of the most effective known ways to reduce waste, is to employ a lean manufacturing technique known as Poka-Yoke which focuses on error proofing and strives to prevent waste from occurring, beginning from the manufacturing cycle stages with the use of systems, tools, visual cues, and by continually implementing extra precautionary safety measures.

The researchers in this study employ a usable model consisting of three manufacturing plants and four warehouse distribution centers. The model may easily be replicated and/or modified, to meet specific fluctuations in customer demands, and ensure adequate product supply, as these demand fluctuations arise, at any given point in the ordering time cycle. The model is set up for a typical purchase of avionics parts that must meet certified ISO 9000 and 9001 quality standards. The ISO standards are developed and published by the International Organization for Standardization. The ISO 9000 and 9001 standards are a validation proof that the procured ISO 9000 and 9001 certified parts meet certain quality standards and continuous improvement processes which are inclusive in any quality management system adhering to international standards. The model is structured so that aviation parts from two manufacturing plants, are transported to three distribution warehouse centers made available for purchasing and delivery. The quantitative model consists of several mathematical equations that take into account, quarterly production capacity, and quarterly demand forecast. Assuming product availability, cost minimization is the main objective in the transportation of goods from origin to destination, in the optimal decision-making process. The model depicts a network representation of the supply, demand, and- transportation costs per unit.

Emerging technologies in additive manufacturing make it possible to replace needed avionics and aerospace parts using 3-D printing. It is estimated that the value of aerospace parts of commercial aircraft in 2019, was valued at USD 467.4 billion (Grand View Research, 2020). Additive manufacturing of avionic parts need to be make-to- order with a short turn-around time in order produce spare parts to fulfill fluctuating demands. With 3D printing technology, there is no need to keep inventory other than the raw materials needed to print the parts.

3D printed avionic parts must be approved and certified by FAA prior to maiden flight.

The model replicates three additive manufacturing plants located in Sunnyvale, CA, Melbourne, FL, and Phoenix, AZ, using high technology polycarbonate 3D printing to manufacture aircraft windows.

The windows are then shipped to four assembly plants located in Everett, WA, Huntsville, AL, Savannah, GA, and Charleston, SC.

Table 3 indicates the production capacity of window units of the three additive manufacturing plants:

**Table 3**

*Quarterly Units Production Capacity*

| **Origin** | **Additivve Manufacturing Plant** | | |
|---|---|---|---|
| 1 | Sunnyvale, CA | | 1,000.00 |
| 2 | Melbourne, FL | | 3,000.00 |
| 3 | Phoenix, AZ | | 6,000.00 |
| | | **Total** | **10,000** |

Table 4 below, is warehouse distribution centers quarterly demand forecast.

**Table 4**

*Quarterly Units Quarterly Units Demand Forecast*

| **Destination** | **Warehouse Distribution Center** | | **Quarterly Units Demand Forecast** |
|---|---|---|---|
| 1 | 1 Everett , WA | | 2,000 |
| 2 | 2 Huntsville, AL | | 4,000 |
| 3 | Savannah, GA | | 1,000 |
| 4 | Charleston, SC | | 3,000 |
| | | | |
| | | **Total** | **10,000.00** |

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Table 5 are transportation costs per unit shipped to the warehouse distribution centers.

**Table 5**

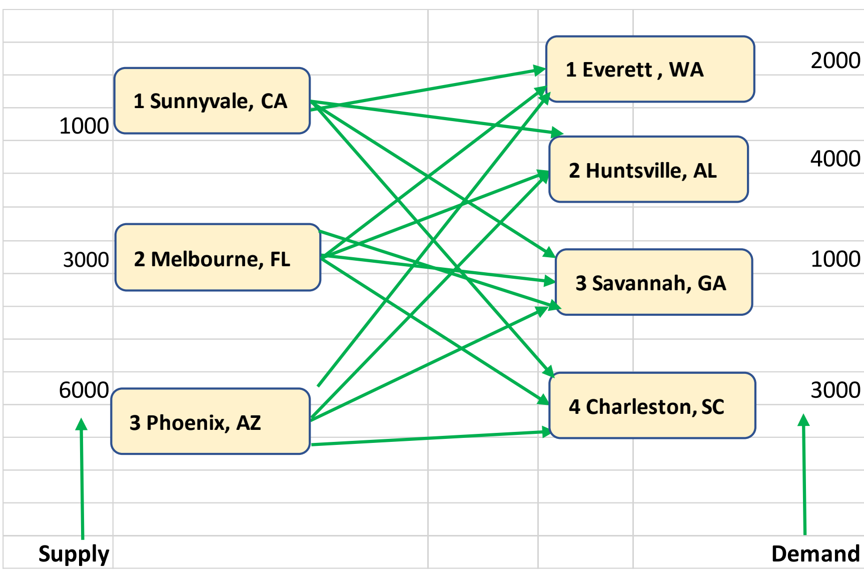
*Unit Transportation Cost of Additive Manufactured Windows Model*

| | | Destination | | |
|---|---|---|---|---|
| Origin | Everett | Huntsville | Savannah | Charleston |
| Sunnyvale | 12 | 15 | 18 | 20 |
| Melbourne | 16 | 14 | 8 | 10 |
| Phoenix | 11 | 13 | 17 | 19 |

Figure 2 depicts the network diagram of the twelve total distribution warehouses where the additive manufactured windows are shipped.

**Figure 2**

*Network Diagram of the 3D Printed Polycarbonate Windows Vista*




## Mathematical Model

Let $x_{ij} =$ number of units shipped from origins i, (1-Sunnyvale, 2-Melbourne, 3-Phoenix) to destinations j (1-Everett, 2-Huntsville, 3-Savannah, 4-Charleston)

We want to minimize the transportation cost of windows shipped from Sunnyvale:

$$12x_{11} + 15x_{12} + 18_{x13} + 20_{x14}$$

Transportation costs for windows shipped from Melbourne:

$$16x_{11} + 14x_{12} + 8_{x13} + 10_{x14}$$

Transportation costs for windows shipped from Phoenix:

$$11x_{11} + 13x_{12} + 17_{x13} + 19_{x14}$$

Supply Constraints:

$x_{11} + x_{12} \leq 4000$ Savannah Supply
$x_{21} + x_{22} \leq 5000$ Melbourne Supply

Destination Demands:

$x_{11} + x_{21} = 2000$ Everett Demand

$x_{12} + x_{22} = 3000$ Savannah Demand
4000 Huntsville Demand
$x_{13} + x_{23} = 4000$ Charleston Demand

**Figure 3**

*Optimal Solution of Transportation Cost AM windows Model*

Transportation Results

: Unit Transportation Cost of Additive Manufactured Windows Model Solution

| Optimal cost = $122000 | Destination 1 Everett | Destination 2 Huntsville | Destination 3 Savannah | Destination 4 Charleston |
|---|---|---|---|---|
| Origin 1 Sunnyvale | 1000 | | | |
| Origin 2 Melbourne | | | 1000 | 2000 |
| Origin 3 Phoenix | 1000 | 4000 | | 1000 |

For this particular study, the model results indicate an optimal objective value function solution of a cost amount totaling $122,000 from the three origins to the four destinations.

It is of significant importance to establish a continuous improvement approach in order for the supplier(s) to have the capability to fulfill the various fluctuating customer demand on time and within optimal cost decision making practices. Risk mitigation strategies and contingency planning should be employed to better prepare suppliers for avoiding unforeseen supply chain disruptions.

**Need for Proactive Approaches in a Post Pandemic environment to avoid Supply Chain Disruptions**

Lean (and the related lean six sigma (LSS) methods, have been used for decades in supply chain optimization (Antony et al., 2017) and were commonplace in the pre-pandemic environment. To be sure, the recent global pandemic shined a light on the need for more adaptable lean and agile supply chain methods. In the post-pandemic environment, authors (such as Inanov, 2021; Shi et al., 2021), point out that the supply chain disruptions have caused many to rethink the use of classical lean manufacturing with a focus on supply chain resilience. Other (such as Alamelu, et al, 2022; McMaster et al., 2020) describe the need for an agile supply chain and value-based focus. Combining lean and agile as *leagile* in this post-pandemic environment capitalizes on the value of two methodologies for the future.

This proactive approach in this paper, rather than a reactive one, has the benefits of methodically analyzing the problem, involving a variety of skilled researchers and practitioners, and testing proposed solutions. While the principles of proactive models in supply chain are not new (such as Ahmadi-Javid & Seddighi, 2012; Roy et al., 2020), the recent pandemic has emphasized the need for methodical advances in supply and demand optimization methods to avoid crisis mode solutions.

**Plans for Future Research Development**

This research study will lead to future, high impact, science and technology research projects as current trends in lean and agile supply chain networks continue to evolve, including technological progress in the area of additive manufacturing. Specifically, the study of lean and agile supply chain networks, has strong potential to generate substantial interest and potential funding from an organization that is on the verge of cutting-edge technologies, processes, and methods, that will be demanded upon modern global supply chain networks. The topic of *leagile* supply chain networks is beginning to generate considerable inquiries among supply chain network stakeholders, in an attempt to transform existing supply chain network operations into ideal, futuristic leagile supply chain networks with maximum competitive advantage, optimized for cost minimization, and profit maximization.

The main focus of an extension to this research study, would be to identify the ideal leagile supply chain network from an operations management perspective, involving all stakeholders. Flexible and adaptable supply chain networks, aim to minimize disruptions in the organizations' logistics and supply chain management operational strategies for optimized organizational scenario analysis and performance to maximize profit and minimize cost. The researchers believe that additional funding will be necessary, to modify and apply the model developed in this study, to other areas, such as defense, aviation, aeronautics, aerospace, healthcare, and in any field where logistics and supply chain network processes are in place.

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