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Investigation about the Lead Time Variability at Warehouse

A Case Study of the Central Warehouse of Company Y

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Abstract

The lack of previous studies regarding the understanding of distinction and relationship between effective and efficient measurements of supply chain performance led this report to create a framework based on various literatures of the two concepts, including Potočan (2006)'s claim on the sources of conflict in content understanding, implementation of methodologies and management of organizations' operations. By initiating the analyses on the lead time deviation in the Company Y, a major manufacturing company for commercial vehicles, and its influence on various performance measurements at different levels, the connection is endeavored as the lead time being an effective measurement and other time dependent measurements being efficient ones. With the complex nature of aftermarket service and its significant market share in automotive industry, the lead time is crucial to maintain the availability of spare parts and keep the stock at a desired level. Deviations of the lead time occurring at various links and nodes of the supply chain can have a significant impact on the service level and overall customer satisfaction. This report attempts to find out the existence of lead time deviation within the fragment of the supply chain followed by its successive impacts on safety stock and service level by quantitative analyses. Subsequently, the study tries to connect the reasons of such phenomena, explored by conducting qualitative analyses through interviews and field observations, to the framework developed. Finally, the constructive conclusions and suggestions made for further research analyses regarding how to stabilize the lead time deviation in the receiving process and how to connect performance indicators in different functions, processes and sub-processes vertically in the organization and horizontally in the supply chain. Additionally, the importance of increased transparency, traceability and reliability of supply chain in the focal company to compete in today's aggressive business environment is emphasized by applying a combination of technologies such as GPS devices, RFID technology and extended information system integrations.

Keywords: Aftermarket Supply Chain, Lead Time Variability, Warehouse Management

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List of Abbreviations

Abbreviation	**Explanation**
ALT	Actual receiving lead time
ETA	Estimated receiving time of arrival
ELT	Expected receiving lead time
FTL	Full truck load
IS	Information system
LTL	Less than truck load
LT	Lead time
POS	Point of sales
RFID	Radio Frequency Identification
RLT	Receiving lead time
SKU	Stock keeping units
SML	Service market logistics
TLT	Total lead time
WMS	Warehouse management system
WO	Warehouse Operations

1. Introduction

In this chapter background of the thesis is discussed and research questions are formulated that this report intends to answer. Delimitation of the study is also described and finally, a thesis structure is presented to give the readers an overview of the whole report.

Competing against time is the principle of taking timely completion of supply chain tasks to a higher level which benefits the supply chain operations both internally and externally. This is done by reducing the total lead time of goods to satisfy customers' needs as a competitive advantage over competitors (Harrison and Van Hoek, 2008). Nowadays, the market competitions and the dynamic business environment often require continuous improvement of the supply chain to handle large number of orders with greater variety in shorter response time. As one of the essential components of the supply chain, warehouse plays an important role as a buffering system to accommodate variability caused by factors in the process of production, transportation and distribution. On the other hand, more innovative practices, such as JIT (Just-In-Time), cross-docking, barcoding, radio frequency identification (RFID), automation process and warehouse management systems (WMS), have been implemented to reduce the level of such variability (Gu et al. 2007). But, this does not mean the uncertainties along the supply chain have diminished. In fact, there are uncertainties from various sources, both from outside and inside the supply chain, affecting the lead time of warehouse operations on strategic, tactical and operational level. The sources of those uncertainties can be unpredictable like natural disaster or predictable as planned machine maintenance, which must draw managers' attention on a daily basis (Gong and Koster 2011). Therefore, the main focus of this article is not only about the investigation of why but also to concentrate on what are the issues, and how to reduce them without sub-optimizations.

1.1 Background

Warehouses play a key role in modern supply chain and determine the success, or failure, of businesses today. The very existence of keeping inventories in a various type of warehouses is mainly because of the mismatch between supplier lead times and customer expectations, which alternatively cannot be achieved cost effectively by direct transport. Strategically, it may be beneficial to hold inventories to a certain level within the supply chain to response efficiently towards volatile market demands, separating the lean manufacturing activities from the downstream activities (Baker and Canessa, 2007). In addition, it may be more cost-effective to build up inventory as an offset to reduce costs elsewhere in the supply chain. For instance, obtaining purchasing discount for larger quantity orders, building seasonal stock and coping with demand peaks in advance, avoiding stock-outs in order to deal with production shutdowns, natural disasters, etc (Rushton et al. 2014). Furthermore, there is an opportunity to reduce the total cost by consolidating product orders at the warehouses when required to be delivered to same and nearby delivery points, i.e. break-bulk and make-bulk consolidation services. It is very crucial for the smooth and high-level operations of such warehouses which have commitments of same-day or next-day delivery for their customers with speedy, accurate, reliable, and damage-free services (Baker and Canessa, 2007).

Any warehouse should be designed to fulfill the specific requirements of the supply chain of which it is in part (Rushton et al. 2014). According to van den Berg and Zijm (1999), three types of warehouses are production warehouse, distribution warehouse and contract warehouse. Production warehouses are used to store the raw materials, semi-finished or finished products in a production facility. On the other hand, a distribution warehouse is a warehouse that is used to collect products from different suppliers to deliver to a number of customers. The contract warehouse is operated by a third party.

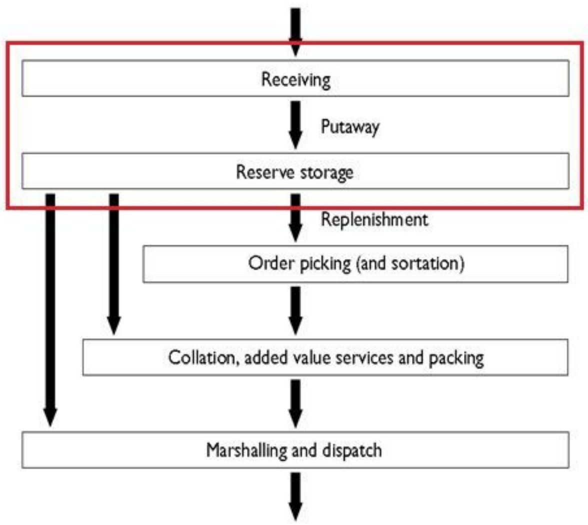

Figure 1: Typical warehouse functions (Rushton et al. 2014, p.260)

The typical warehouse functions include receiving, reserve storage, order picking, sortation, quality control, other added value services i.e. packaging and dispatch (Figure 1). Among which, receiving involves the physical unloading of incoming transport, inspection of the package or the quality, and recording of the received good into the computer systems. From that, the goods are put away in the warehouse. Subsequently, in the reserve storage function, goods are normally taken up to the shelves in the large storage area. When required those goods would either go directly to dispatch (i.e., in the form of full pallet or special package after repackaging) or to replenish an order picking (Rushton et al. 2014).

This study focuses on the lead time variability for inbound processes at the central warehouse of Company Y. A case study was conducted for the aftermarket supply chain of this focal company, a major manufacturer for commercial vehicles. The aftermarket supply chain manages the after sales services such as supplying and distributing the service parts, accessories and other related services after the sales of original product by the manufacturer to the consumer and is different than normal manufacturing supply chain. Thus, the type of the warehouse in aftermarket often can be considered as a distribution warehouse. It is often difficult to manage the aftermarket supply chain as a lot of uncertainties are concerned primarily due to unpredictable demand patterns and high number of stock keeping units (SKUs) (Cohen et al., 2006). Due to these complex characteristics, the warehouse management in the aftermarket experiences additional challenges than the other types of warehouses. Essentially, the measures needed to be taken to effectively manage these uncertainties as the sales of original products can be directly affected depending on how good the after sales service is of a company and because it is a major area to make profits. Maintaining a stable lead time is crucial in aftermarket supply chain to ensure good customer service as it is connected to the total operating time of a vehicle and it is undesirable to keep customers, who are in urgent need of parts, in wait, as it would cause the vehicles to lose the operating time. Therefore, it is safe to assume that the deviations in the lead time are not something desired. But, such deviations still occur in many parts of the supply chain. The internal warehouse problems such as late receiving and delays in moving goods from dock to stock make it even more challenging for the whole chain to deliver required level of service to the customers. Therefore, this study took an attempt to find out the causes and impact of the lead time deviations in the inbound process or more specifically the lead time in parts receiving process at the warehouse.

1.2 The purpose of the thesis

The purpose of this thesis is to find out the root-causes and impacts of unreliable receiving lead time and present viable suggestions for stabilizing such phenomenon.

1.3 Research question

In this study, investigations would be carried out to identify if the deviations follow any patterns or for which type of parts deviate the most and the underlying reasons of those instabilities. Naturally, what impact this deviation has on the other components of the supply chain would also be investigated. Another interesting area would be to investigate if there is any lack of integration regarding the performance measurements and the information system(s) between the business functions. To serve the purpose of the study, following research questions have been formulated:

- *Why do the actual receiving lead times deviate from the expected receiving lead times at the central warehouse?*
- *What impact does this deviation have on the other components of the supply chain?*

1.4 Delimitation of the study

While deviations can occur in various parts of the supply chain (i.e. supplier, transport, inbound or outbound), this study only focus on the inbound part of the total lead time or more specifically receiving lead time at the warehouse. This study does not take into consideration the deviations occurring in other parts of the chain as that would not be feasible to cover within the given timeframe. Also, only the central warehouse for European market has been taken into consideration.

1.5 Thesis disposition

The main chapters of this study were divided into five parts: Introduction, Theoretical, Empirical 1, Empirical 2 and Conclusion. The thesis outline is illustrated in Table 1. In the first part, authors have presented the background of the problem and research questions were formulated in continuation of that. In the second part, literature, relevant to the thesis topic, was reviewed and a theoretical framework has been constructed based on the derived knowledge from the literature. Additionally, an overview of the methodology used in this study was given in this part. Issues regarding reliability and validity of the study were also discussed in the methodology chapter.

The *empirical* part of the study was divided into two segments. In the third part of the study - *Empirical 1* - quantitative analyses have been conducted using the secondary data collected from the internal database of the Company Y. This has been done to realize the extent of the problem that exists in the focal company and the impacts of that problem in other parts. In fourth part of the study -*Empirical 2* - a case description has been presented based on the interviews and observation. In this part, an attempt has been made to find out the underlying reasons behind the existing problem, which were presented as findings.

In the final part, some concluding remarks were provided relating the findings obtained from the third and fourth part of the study. In the end of this final part some recommendations were provided for Company Y to resolve the situation and some suggestions have been made for further research.

Table 1: Structure of the thesis study

Part 1 *Introduction*	•Introduction
Part 2 *Theoretical*	•Literature Review •Theoretical framework •Methodolgy
Part 3 *Empirical 1*	•Statistical Analyses of Lead Time •Safety Stock Analysis
Part 4 *Empirical 2*	•Case Description and Findings
Part 5 *Conclusion*	•Conclusion •Recommendations and Future Research

2. Literature Review

An overview of the literature studied is presented here. The chapter starts with describing the aftermarket characteristics and how it is distinct from other business market. After that it touches upon the hierarchical paradigm of warehouse management and planning process, and depicts the concept of operational efficiency and effectiveness. It also includes the importance of having suitable and integrated information system for different levels of a company. The chapter ends with some relevant theories describing the impact of the lead time variability on the safety stock level.

2.1 Aftermarket

Aftermarket, also known as secondary market is concerned with the manufacturing, supplying and distributing the spare parts, equipment, accessories and related services such as repairing, maintenance etc. after the sale of original product by the manufacturer to the consumer. Aftermarket parts can be manufactured by a third-party company at a high volume and can be made to fit the specifications of different varieties of original products (Delbridge, 2017). According to Ehinlanwo and Zairi (1996, pg. 41) "All activities done to maintain the quality and reliability of the car carried out after the customer has taken delivery with the goal of ensuring customer satisfaction". Morschett (2006) states industrial customer services include wide range of activities such as spare parts, maintenance, repair, training, installation of parts, warranty and so on and that can be called as after sales service.

The past literatures have included spare parts management, maintenance and repair activities as the main components of aftermarket and after sales services (Tavakoli et al. 2015). Nonetheless, the role has changed in terms services such as spare parts supply, part installation, commissioning, training and technical support, diagnosis, inspection, consultancy, instructions, product modification, software services, warranty schemes, complaints management and support, reverse logistics, financing, leasing, operating models etc. (Patelli et al. 2004). In short, a new business chain known as aftermarket supply chain or after-sales services supply chain starts just after the end of manufacturing supply chain.

There are some significant differences between the manufacturing and after-sales service supply chain. Some the basic characteristics of both chain and differences between them have been identified by Cohen et al. (2006), which has been summarized in Table 2.

Numerous opportunities exist in aftermarket business. For example, it is a high margin business and accounts for a large chunk of profits. A study revealed that GM earned relatively more profit from $9 billion after-sales revenue than $150 billion revenue from car sales (Cohen et al. 2006). According to Cohen et al. (2006), this is the golden age of services and while every company must transform itself into service business, most company fails to effectively realize the potential of aftermarket services business. When the business begin offering solutions (i.e. selling spare parts and other after-sales services) instead of selling products, the aftermarket can become huge source of revenues and profits. Cohen et al. (2006) suggested companies to stop pushing the products in the market and to start delivering value instead, which the consumers get from using the product. While customers in automotive market don't expect their vehicles to be completely invulnerable from breakdown, they do expect manufacturers to fix things quickly when it happens. Thus, after-sales services can enhance customer satisfactions and stabilize the long-term revenues by providing strategic and competitive advantages (Tavakoli et al. 2015).

Table 2: Differences between manufacturing and aftermarket supply chain (Cohen et al. 2006)

PARAMETER	MANUFACTURING SUPPLY CHAIN	AFTER-SALES SERVICE SUPPLY CHAIN
Nature of Demand	Predictable, can be forecasted	Always unpredictable, Sporadic
Required Response	Standard, can be scheduled	ASAP (Same day or next day)
Number of SKUs	Limited	15 to 20 times more
Product Portfolio	Largely homogeneous	Always heterogeneous
Delivery Network	Depends on nature of product; multiple networks necessary	Single network, capable of delivering different service products
Inventory Management Aim	Maximize velocity of resources	Pre-position resources
Reverse Logistics	Does not handle	Handles return, repair, and disposal of failed components
Performance Metric	Fill rate	Product availability (uptime)
Inventory Turns (The more the better)	Six to fifty a year	One to four a year

At the same time, it is highly challenging to effectively manage the aftermarket supply chain. The demand pattern for spare parts is very difficult to predict and it has high number of SKUs (stock keeping units). Aftermarket supply chain must support all the products that the company has sold in the past as well as those it currently makes and each generation of product has different parts. So, the number of SKUs can be 20 times higher for the aftermarket than the manufacturing functions deal with (Cohen et al., 2006), and considerable efforts and resources are needed on the strategic management and effective operational implementations of after-sales service (Tavakoli et al. 2015).

2.2 Warehouse management

In the past, warehouses were seen mainly as stockholding points, attempting to match supply to demand and acting as a buffer between different actors among the supply chain. Stock visibility along the supply chain was limited and information flow was very slow, resulting in companies holding more stock unnecessarily. Productions in those days were supply-driven with manufacturers producing products in the hope of retailers to stock them and of consumers to buy them. In today's market with expensive land, buildings, labor and energy costs, together with the introduction of concepts such as just in time (JIT), efficient consumer response (ECR) and quick response (QR), companies are continually looking for how to minimize the amount of stock levels and speed up the throughput with capacity increase and automation process development. The use of tools such as postponement – where products are finalized in the warehouse instead of production sites – are also becoming popular. However, in our society, the market environments and customer demands are not always predictable and therefore, there is a great deal of stock holds at various stages within the supply chain, including different types of warehouse. Plus, this phenomenon has been further entailed by increased consumer demand for greater choices of product ranges and sizes in the combination of online stores and self-services (Richards, 2017).

Fulfilling the continuous flows of the supply chain, the smooth operation of warehouse management often comes with challenges; reducing warehouse operation costs while increasing service levels; achieving perfect order (on time, in full, no quality issues, with correct paperwork); shorter lead times while keeping stock availability; delivery through multiple channels (especially when customers engaging their shopping activities via omni-channels); keeping pace with smaller and frequent orders; substantial increases in stock keeping units in order to meet with the proliferation of product lines; greater fluctuations in demand side such as seasonality, new product introductions, and the usual demand peaks; increasing labor costs and skilled-labor availability; long-extended information system integrations to ensure data transferred correctly and increase supply chain visibility (Richards, 2017). Combining those challenges with the special characteristics of aftermarket products, managing activities, resources and procedures of aftermarket warehouses can get even more tricky (relatively higher SKUs and lower inventory turns hence higher inventory holding costs) and should require more attention from top management. Plus, from our understanding, the focal company is gaining a higher profit margin from its sales on spare parts and aftermarket services, and consequently it is reasonable enough for the concerns over and the strong needs to investigations and solutions on the issues related but not limited to the variability of dock-stock cycle time at the central warehouse.

2.2.1 Warehouse planning process

Miller (2002) points out that the importance of maintaining effective and efficient warehouse operations as an important component of multi-functional areas within the integrated supply chain and recommends the use of a hierarchical paradigm (Figure 2), which in turn should fit into overall production and distribution planning scheme of a company's supply chain. This planning paradigm not only incorporates the operational level of activities, processes, policies and decision-makings, but also includes tactical and strategic level of planning. Moreover, the efficacy of such a hierarchical warehouse planning relies heavily on a well-designed feedback loop that allows for more successful decision-makings at all levels, for example, by conveying information and knowledge about issues and infeasibilities of warehouse operations based on existing resources from bottom-up approach and by providing insights and missions of the company's long-term plans by top-down approach.

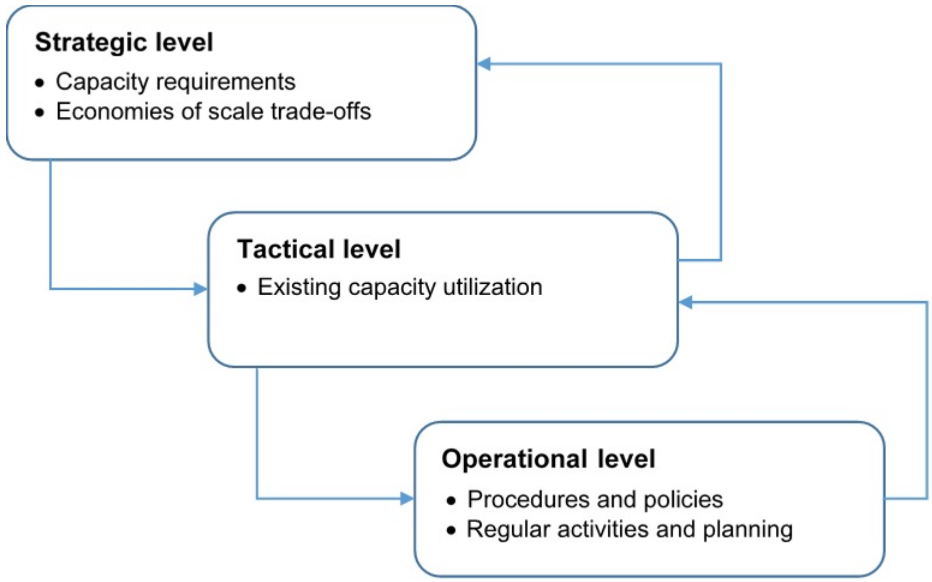

Figure 2: Hierarchical warehouse planning (modified from Miller, 2002, p160)

Furthermore, at the strategic level, the planning and decisions regarding the overall mission of the warehouse network should be made and among which capacity requirements and economies of scale trade-offs are key interrelated determinant, i.e. the investment decisions on the level of automation and IT system can significantly impact warehouse capacity and total costs. The decisions about the warehouse capacity are of storage and throughput capacity requirements.

At the tactical level, a firm must focus on how to utilize the existing resources in the most efficient and effective means, i.e., planning activities over a planning horizon (monthly and/or longer) while determining the associated labor level and equipment utilization and capacity balancing against the demand for warehouse operations etc. Additionally, decisions of relatively minor purchasing on additional warehouse assets can occur in this planning process. However, the major infrastructure issues and investment decisions, which cannot be resolved at the tactical planning level, should be taken up to the strategic level. Miller (2002) also makes a clear statement that the absence of this feedback approach will result in sub-optimizations which would affect the overall performance of the supply chain.

At operational level, regular and detailed warehouse activities, scheduling and planning take place, i.e., making procedures and policies and updating them, short-term labor scheduling and assignments of items (packages, pallets, and other types of unit loads) to storage locations (random or fixed locations, or both). In some occasions, the non-routine activities could happen unexpectedly at the operational level, which should draw most critical attentions and must be reported back to the tactical level for observations. When the line managers find themselves consistently experiencing those unplanned activities in need of excess storage and handling capacities, it could be a sign of warehouse capacity issues which should be sent back to the tactical level for solutions. If the tactical level find them hard to solve, then they should be passed onto the strategic level for total network improvements. Notably, higher the planning level, more aggregated and specialized feedbacks would be. Therefore, the hierarchical planning and scheduling approach of warehouse management help companies to reach their goals and missions throughout the integrated supply chain network.

2.2.2 Operational efficiency and effectiveness

Any system’s performance is judged by its output against its input(s); a higher output to input ratio is a measure of the system’s efficiency and effectiveness. Companies often spend a great deal of resources in their logistical operations for the movement, storage and handling of goods and information across their supply chains. Therefore, it is essential to plan, monitor, control and improve the performance of the logistical operation including the warehouse management to achieve a specific set of corporate goals and strategies by reducing costs and satisfying their customers (Sople, 2008). Potočan (2006) also recognizes the dependence of the organization's existence and development on the achievement of necessary efficiency and effectiveness of its operations and behaviors; adequately using the available resources for the creation of the products and/or services while meeting the needs and requirements of customers at the same time.

Jacobs et al. (2014) makes a clear distinction between the two concepts of Efficiency and Effectiveness followed by Productivity (Figure 3). Having an efficient process is to produce a product or provide a service by using the smallest input of resources, or simply put, resource utilizations with the aim of minimum waste, hence the popular quote “do things right”. Whereas an effective process is related to the value creation for customers with the ability to achieve a desired objective or goal, which is often described as “do the right things”. Moreover, Effectiveness against Efficiency equals Productivity, meaning “doing the thing in the right way”. Therefore, maximizing effectiveness and efficiency at the same time often creates conflicts, i.e., in the grocery store, being efficient means using less staff as possible while being effective is to minimize customers’ waiting time. Without recognizing the value of the customers’ time would result in dissatisfaction of customers, especially if there is a long queue of customers waiting before the checkout line. However, using checkout-counters with staff and self-service mixed seems to solve this issue.

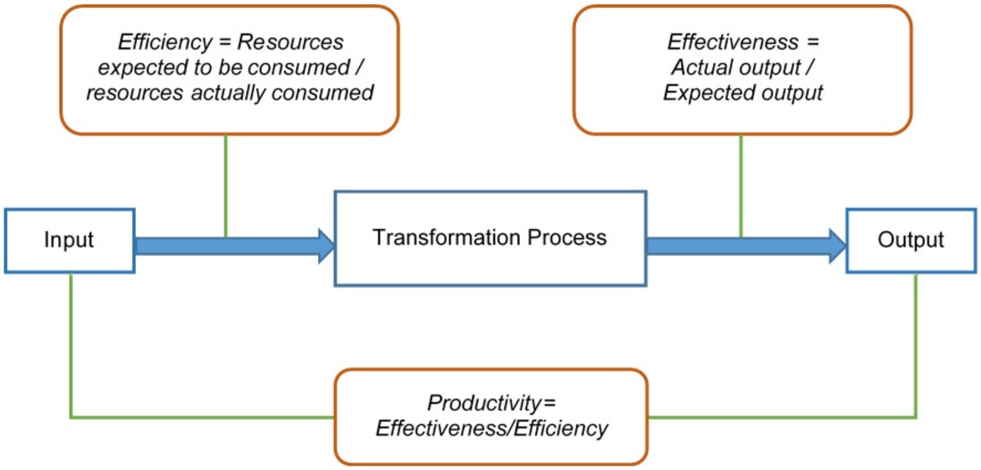

Figure 3: Productivity, Effectiveness and Efficiency (Jacobs et al. 2014, p59)

Yet, Potočan (2006) describes the above goal (output) approach of effectiveness is more complex, often abstractly defined, subjective, and therefore, more difficult to measure since those goals need to be defined hierarchically and have multiple characters in accordance with the company's structure, which in the end might create conflicts within the company horizontally and/or vertically in the short run. He also claims that there are various definitions of operational efficiency and effectiveness among organizations and scientific fields which also entail more conflicts in content understandings, implementations of methodologies and the management of organizations' operations. The differences are based on criteria, such as investigation approaches (broad or narrow), study aspects (individual or interdisciplinary), the study scopes (entity or part of the entity), etc. Consequently, the efforts made for efficiency and effectiveness within the organization further facilitate the conflicts to emerge openly and clearly from the initial fictitious state, reflecting non-optimality, unsuitability, inappropriateness of different organizational functions, their relations (internal and external) and synergies. Therefore, the definition of the two concepts and their relations hold great significance to the company and the researcher prior to the investigation of conflicts caused by achieving efficiency and effectiveness. Furthermore, the author favors the synergetic implementations of efficiency and effectiveness in the long run for the company in question, enabling a holistic treatment of the appropriateness of its operations and behaviors, meaning the two concepts are independent, but they are linked together and interdependent in their applications, and the conflicts are temporary which could be harmonized with common objectives.

Jacob et al. (2014) explains that in a company, a major focus to the operation and the supply chain is the operational effectiveness which relates to the core business processes, spanning over the different business functions from purchasing, manufacturing, warehouse management, inventory management, transportation, etc. In the meanwhile, the operation and supply chain strategy is concerned with a broad range of policies and plans for the guidance of using the resources needed to implement the corporate strategy. Consequently, the operation and supply chain strategy must be integrated with the corporate strategy and the operational effectiveness should be achieved by performing activities and processes in a way that implements strategic priorities at minimum cost. In Potočan (2006)'s opinion, the above approach is called the contingency approach in which the managers and researchers determine a segment of the organization they consider the most significant for achieving the effectiveness of the company's operations, then go about it as holistically as possible. For this reason, the treatment for the conflicts arose focuses on inputs, processes and outputs. He proposed two alternative approaches which are more balanced, namely, the stakeholder's value approach and the competing values approach. The former concerns the achieved level of stakeholders' demands and satisfactions while the latter associates with the assumptions that the organization goals are determined and evaluated by the owners, top and middle management. The main advantage of the stakeholder's value approach is the equal treatment of internal and external success factors (Table 3), which could also include criteria in environment and social responsibility. Table 3 indicates that this new approach emphasizes the importance of measuring effectiveness with multiple criteria in an equal consideration.

Table 3: Examples of effectiveness criteria of the stakeholder's value approach (Potočan, 2006)

Stakeholders	Effectiveness Criteria
1. Owners	Financial return
2. Employees	Salaries, working conditions, training, supervision
3. Customers	Quality of goods and services, on-time delivery
4. Suppliers	Smooth financial transactions, mutual benefits and development
5. Government	Obedience to laws and regulations
6. Society	Contributions to local community

Note: Stakeholders varies in terms of size and variety in different organizations. This table only presented some general examples.

Although, the competing value approach may sound narrowly characterized in terms of competitive values and benefits in the company's operations, the scope covers two dimensions.

First one relates to the target areas including internal evaluations (adequate implementations of operations from managerial perspective) and external evaluations (how the results of relevant operations are assessed by the environment, i.e., customers and markets). The second one is related to the flexibility and stability of organizational structure (Figure 4).

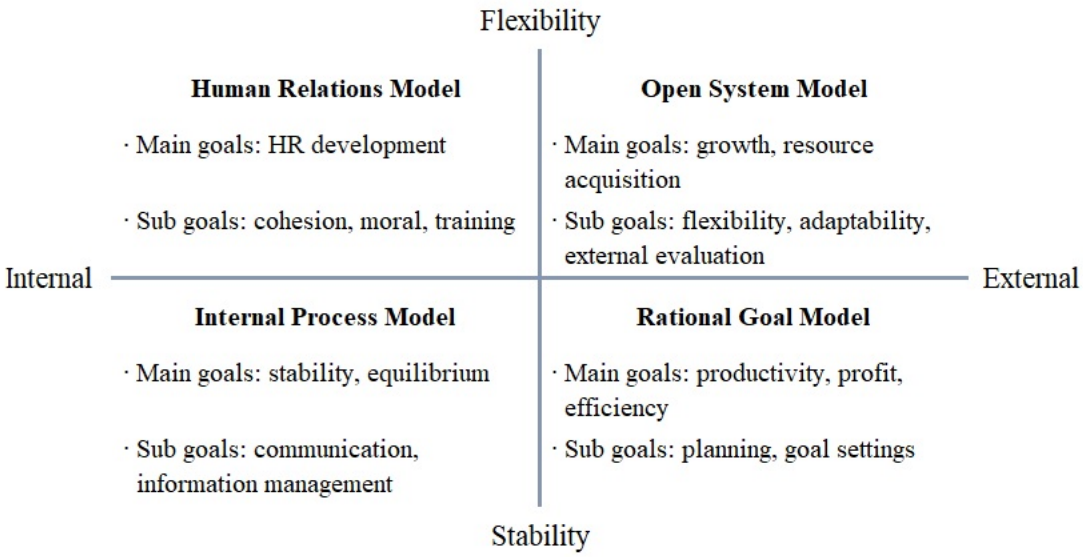

Figure 4: The competing values approach for effectiveness evaluations (Potočan, 2006)

The proposed framework of effectiveness under the competing values approach consists of four models where each quadrant holds values competing with ones diagonally opposite to them. The Human Relations Model focus on human resource development such as training and supervision, which is in contrast with the Rational Goal Model which focuses on productivity, planning and goal settings. Similarly, the Open System Model concentrates on growth, flexibility and adaptability towards the external environment while the Internal Process Model is about management control and communication (Ikramullah et al. 2016). The justification for this approach is that the different competitive values and benefits should coexist in the business practice. The above two alternative approaches present the foundation for the definition of the relations between effectiveness and efficiency in the non-conflict character emphasizing a holistic treatment of the organization's operations with harmonious and synergetic implementations. Thus, effectiveness relates to the holistic treatment of the most significant factors (conflicts, success, demands), their relations and synergies in the organization whereas efficiency represents a partial aspect of that treatment with a supplementary role as other aspects (culture, tacit knowledge, leadership, motivation, etc.) in the company (Potočan, 2006).

Based on those discussed above, the effectiveness and efficiency of the warehouse operations, as an important constituency of the supply chain, should be defined clearly before conducting the investigation regarding the lead time variability between the processes of receiving and putaway in this study. The significant implication is that the lead time among other factors should be treated as an effective measurement for the mission of the central warehouse, because it concerns with the factors such as customer's satisfaction of on-time delivery, time-dependent internal processes and activities, flexibility and adaptability of external market response, etc. Therefore, the lead time should have a governing function as a strategic guidance and indication for the various efficiency measurements such as resource utilization, procedures and policies etc. In other words, the effectiveness measurements of the warehouse operations should be viewed, defined and treated on the strategic level whereas the efficiency measurements should be done so on the tactical and operational level, but this does not exclude the objective reality concerning the important governance of effectiveness measurements towards efficiency measurements on the tactical and operational level.

2.2.3 Performance measurements in the warehouse

Forslund (2007) defines various steps for performance measures management; set objectives and strategies, matrices definitions, target settings, measures and analyses, evaluations, then the actions to improve the processes. Naturally, there are also numerous reasons to measure the warehouse performance. Warehouses need to operate within standards in terms of service level and cost or time. Failure to meet these standards will make the warehouse inefficient and might create bottlenecks or can have adverse impact on the effectiveness of the whole chain (Rushton et al., 2010). Also, they need to ensure customer satisfaction through service improvement and need to maintain a culture of continuous improvement (Richards, 2018). Measuring performance against the industry's best in class and against the customers' expectation can help to continually improve the performance. It can also help to avoid additional cost such as cost of error, cost of lost sales etc. Moreover, measuring performances can be useful to discover and investigate potential issues before they become major problems and take appropriate actions accordingly. However, it is important to understand both customer requirements and limitations of the warehouse to ensure a balanced service level. So, monitoring performance against the criteria that are important to the customers and the criteria that are important to the company, both should be in focus. Best measures therefore should be governed by customers' requirements, but aligned with company's resources (Richards, 2018).

The performance measure also should be well defined and aligned with each level of management discussed earlier in this chapter (2.2.1). For example, Key performance indicators (KPIs) and performance measures for strategic and tactical level should be aligned with the company's business strategy, objectives and with other KPIs within the company. And performance metrics for operational level should be aligned with these upper level KPIs. KPIs for strategic and tactical level might often be too wide for the operational level staffs and they may face difficulties to understand what are needed to be done by them when these KPIs are not met. So, it should be ensured that these upper level KPIs are translated appropriately for the operational level staffs that are dealing with everyday activities. These can be done by developing short term metrics for operational level and then by giving training to the staff. According to Richards (2018), It is important to train the operational level staff about these metrics because they also need to know how these metrics are derived and why they are important. They need to be made aware of the reasons behind these metrics and that they will also become beneficiaries of an improved operation.

Typically warehouses try to achieve a number of objectives simultaneously such as gaining reliability through on time dispatch and order accuracy, cost minimization etc. To ensure that the warehouse is operating effectively, it is therefore common to monitor a range of performance measures. These measures can include KPIs with wider scope such as service level which are more concerned with the overall performances of the warehouse and then function specific metrics such as inbound or outbound metrics. Some relevant performance measures for this study have been adapted from the work of Warehouse Education and Research Council (WERC, n.d.) and have been listed out in Appendix A.

2.3 Information system in the supply chain

An information system (IS) is defined as an interacting structure of people, equipment and procedures, which work together to collect, store, and manage data and make relevant information available for planning, implementation and control. The very purpose of the IS is to collect data and transform them into valuable information which then would be presented to the users in an appropriate way for managing the organization. In the meanwhile, the socio-technical perspective of an organization takes the social system (regarding people as main component) and the technical system (tools and equipment) into consideration and the success of an organization often relies on how well the two systems are integrated as the IS as being the part of the organization must bridge the two parts. As mentioned in section 2.2.1, the planning and decision-making processes can be divided into strategic, tactical and operational levels. Consequently, the ISs are needed to support those decision-making processes by reducing time to collect information and perform advanced calculations. Therefore, having suitable ISs on those different levels in the focal company are of great advantages for today’s complex and fast-moving world (Figure 5). Meanwhile, the justifications for different types of systems corresponding to the different levels are different; an operational support system is a prerequisite requirement for any organizations, a management support system is there for the utilization of a company’s existing resources, a decision support system is needed for the identification of new business opportunities and a strategic planning system is used for discovering competitive advantages. Expectedly, as the planning and decision-making processes move up the hierarchy of this paradigm being more unstructured, the characteristics of the IS would be more summarized while the opposite direction in the hierarchy would entail more detailed information, especially on the operational level, which would in turn be used to feed the upper level system with relevant data. (Flodén, 2013)

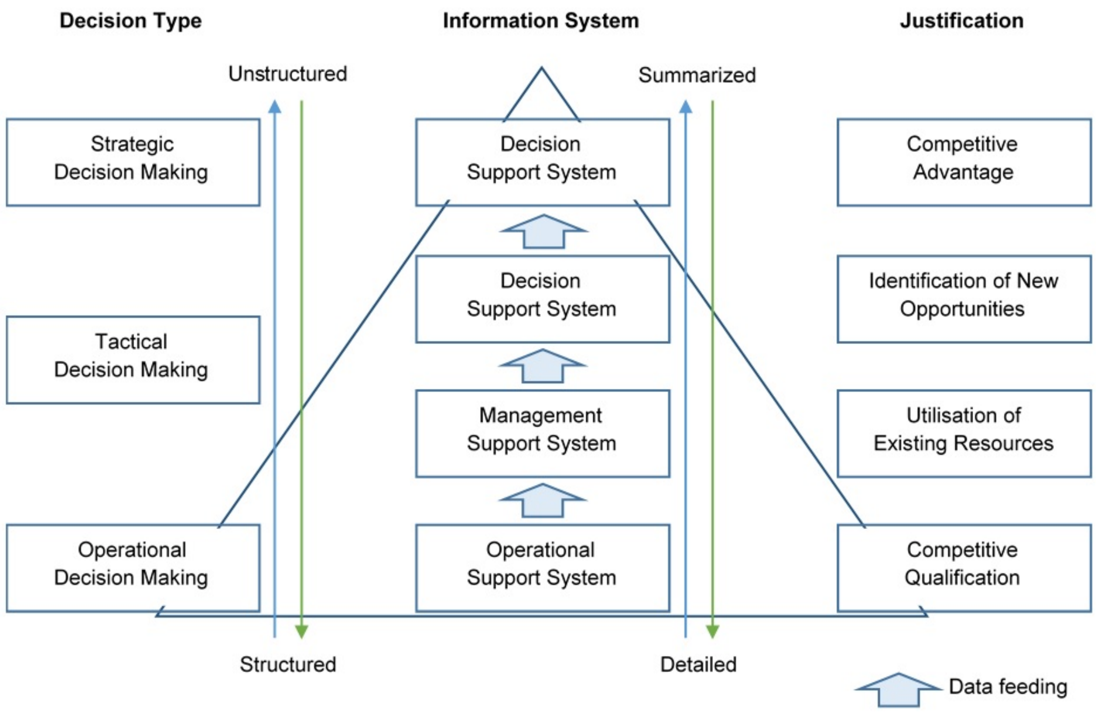

Figure 5: Decision types, information systems with relevant justifications (Flodén, 2013, modified)

Supply chain management (SCM) within an organization deals with control of material and information flows, structural and infrastructural processes relating to transformation of the materials into value-added products, and delivery of finished products through suitable channels to customers in order to maximize customer value and satisfaction (Narasimhan and Kim, 2001). Moreover, SCM can help the company to enhance its competitive advantages by integrating the internal functions such as marketing, manufacturing, warehouse management, transportation, etc. and effectively linking them to the suppliers and customers through advanced information technology and systems (Narasimhan and Kim, 2001; Bowersox and Daugherty, 1995). Kaya and Azaltun (2012) further emphasized the importance of communication and information sharing among the different nodes of the supply chain for achieving effective decision and processes as they are inter-dependent. Gonzálvez-Gallego et al. (2015) found a positive relation between two factors, business performance and information communication technology (ICT) capabilities (abilities to use ICT in business activities to share information, make transactions, coordinate tasks and activities and collaborate with customers and suppliers), and implied that companies nowadays are still far from effective supply chain integration with both suppliers and customers due to less integrated ISs, although merely investing and having integrated IS would not lead to better business performance and special attention are needed for intangible ICT assets such as training. Their analyses were based on the data collected from the companies of Spanish and Portuguese origins, but they claim that the results could be generalized within OECD member countries since their economic and technological development are similar. Furthermore, Woxenius (2012) suggested a solution of using the combination of GPS (global positioning system) device and RFID (radio frequency identification) technology for measuring Directness KPIs and improving transport chain (which together with logistics chain can form up the supply chain, see his article) performance. Interestingly, his suggestion could very well be applied for increasing visibility and traceability of good flows along the supply chain which would reflect the operational efficiency of links and nodes of the supply chain as GPS device can provide information about the distance and whereabouts of goods in the links and RFID can capture data of the nodes in which goods have passed.

2.3.1 RFID technology

To further elaborate the efficient data capturing and increasing the visibility and traceability of good flows along the supply chain, use of RFID can be discussed here. While bar codes are the most common form of capturing data by automation, RFID is being increasingly applied in supply chains for the tracking of unit loads, for carton identification and for other purposes at item level. The technological development of RFID is being considered very important in the field of supply chain as it significantly reduce the number of touches and time needed for capturing and transmitting the data. Automatic identification is enabled by this technology using radio frequency tags, data readers, host stations and integrating software. The tag that is attached to the unit loads, has a microchip and an antenna and can store and transmit data when in proximity of the reader. The reader sends the data to the host stations that contains the application software after retrieving them from the tag by means of radio waves and the data can then relay to the server or other logistics information system. Although RFID tagging is still more expensive than the bar coding, continuous reduction of price of both tags and readers makes it a smarter data capturing option along the supply chain (Rushton et al., 2014). Tagging the parts in the consignment prior to the shipping would enable the receiving process automated and would help to reduce the number of error dramatically as there will be less human intervention. RFID readers in most cases can alter the information stored in the tag and these readers can be either at fixed locations or portable such as hand held devices. Installing readers and host stations at different locations such as near the receiving doc and gate or near the storage area would help to increase the visibility of inbound process in real time and reduce the number of human error. Further using RFID technology might pave the way for future automation or adaptation of more advanced technology by enabling to identify an item to a database where more comprehensive data is stored. For example, it might enable a conveyor based sortation system to identify the goods automatically and then retrieve the routing instructions from the database (Richards, 2018).

2.4 Lead time variability and safety stock

As this study focus heavily on lead time variability and how it impacts the service level, understanding the interrelation between lead time and safety stock and how this relation influences the service level are equally important; maintaining sufficient inventory level to avoid stock outs while ensuring determined service level. At the same time, carrying excess inventory will increase the amount of tied up capital. So, a balance is needed between inventory carrying cost and service level. When the stock of specific items is depleted, the order must wait or be canceled. If the order is held and filled later after the items being replenished, it is referred as backorder. In worst case scenario, the order can get cancelled and stock outs can occur which would result in lost sales. The extra amount of inventory that is carried to avoid such kind of stock outs is safety stock (King, 2011).

While the logistics management tries to guarantee the desired level of stock service at lowest possible cost and risks, several unpredictable factors influence the supply chain and create uncertainties. Thus, the continuity of service can be broken by disturbance in a stage of supply chain (Korponai et al., 2017). According to Ponte et al. (2018), lead time greatly affects the ordering decision for all types of firms and interacts with various sources of inefficiencies in supply chain such as variability of customer demand. On the other hand, highly variable lead time entails dealing with higher level of uncertainty. Other sources of uncertainties can arise from various other sources within supply chain such as late delivery, late receiving, stocks with inappropriate quantity or quality, etc. Korponai et al. (2017) suggests that safety stock can cover the effects of these uncertain factors within the supply chain by avoiding stock shortages and maintain desired service level.

Safety stock can be needed to give a certain level of protection against variability in demand or variability in lead time or both. But first the service level should be determined. According to Korponai et al. (2017), service level is the extent of acceptance regarding the shortage and it can be determined with the relation to number of periods allowing the shortage and the total number of period analyzed. It is mathematically expressed as below (Korponai et l., 2017)

$$SL = 1 - \frac{P_s * t}{T}$$

, where

$SL = service\ level,$
$P_s = number\ of\ periods\ allowing\ shortage,$
$t = length\ of\ the\ given\ period,$
$T = length\ of\ complete\ examined\ period.$

From the value of SL, a Z value can be obtained from the standard normal distribution table. Alternatively, the service level can be explained as the maximum allowed level of probability for the stock-shortage occurrence and Z value is the corresponding Z score of that standard normal distribution. King (2011) suggests to use this way of finding the corresponding Z value which then be applied to determine the safety stock level for maintaining the desired service level and hedging a certain level of protection against variability in demand or variability in lead time or both.

According to King (2011), if variability in lead time is not present and lead time is predictable then the safety stock is needed only to give protection against variability in demand. Then the equation for safety stock would be

$$Safety\ Stock = Z * \sqrt{\left(\frac{PC}{T_1}\right)} * \sigma_D \qquad (2.1)$$

, where,
$Z = Z\ score,$
$PC = performance\ cycle\ time\ or\ lead\ time,$
$T_1 = time\ increment\ used\ for\ calculating\ standard\ deviation\ of\ demand,$
$\sigma_D = Standard\ deviation\ of\ demand.$

However, if variability in lead time is present and is of primary concern then the safety stock equation becomes as

$$Safety\ Stock = Z * \sigma_{LT} * D_{avg}$$

, where,
$Z = Z\ score,$
$\sigma_{LT} = standard\ deviation\ of\ lead\ time$
$D_{avg} = average\ demand$

If both demand variability and lead time variability are present and are independent, then statistical calculations can be combined to obtain a lower safety stock level (King, 2011) as follows:

$$Safety\ Stock = Z * \sqrt{\left(\frac{PC}{T_1} * \sigma_D^2\right) + \left(\sigma_{LT} * D_{avg}\right)^2} \qquad (2.2)$$

The equation (2.2) indicates that a high variability in lead time will result in a high level of safety stock which will eventually push the inventory carrying cost upwards. On the other hand, if required level of safety stock is not calculated accurately and maintained properly then potential risks of stock shortage will increase as safety stock will not be able to cover all the uncertainties and thus in turn may lead to lower service level.

3. Theoretical Framework

Based on the derived knowledge from the literature review, a theoretical framework has been constructed in this chapter.

In this study, an attempt of the interdependent relationship between the effectiveness and efficiency measurements on different level of organizational structures has been made according to the literature reviews discussed in Chapter 2. The lack of previous studies in the management science as well as the scarcity of common understanding regarding the relations of the two concepts under discussion has provided an insight towards their definitions and the distinctive relationships, which could be a new way of viewing them in the future research studies and the treatment of their evaluations in any organizations. The following is an example for the foundation of the framework in this study with an exploratory approach.

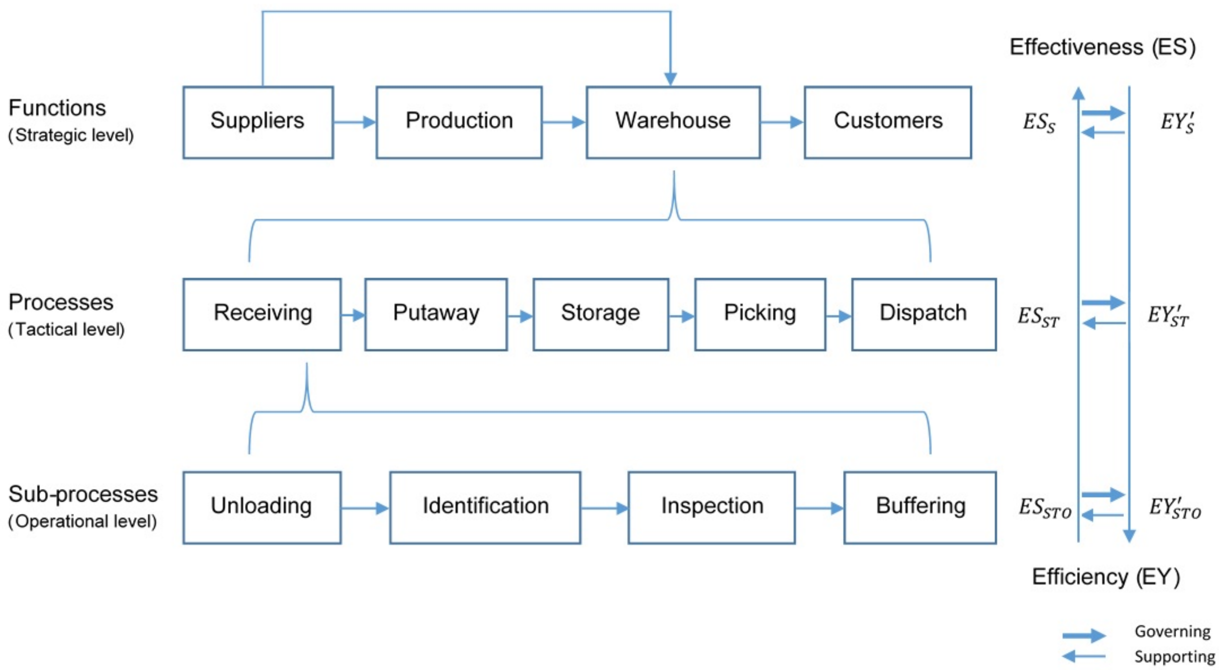

Figure 6: Examples of interdependent relations of effectiveness and efficiency measurements

Figure 6 is developed based on the literatures of warehouse planning hierarchy (Figure 2), operational efficiency and effectiveness, information system in the supply chain (Figure 5) with the combination of the supply chain structure of the aftermarket service in the focal company. It can be observed that the example given is the typical supply chain with different functions focusing on feeding the material flows to the warehouse in the aftermarket business. First, the suppliers send most of the finished products to the warehouse directly for deconsolidation and other value-added activities while some parts and components (unfinished products) need to be received at the production plant for assembly then fed to the warehouse as product lines. The order lines received from both the suppliers and the production plant are transformed into product lines with added values and delivered to the customers.

Being consistent with this report, the lead time are taken as an effective measurement which distributed among four functions[1] (on the strategic level). Moreover, the warehouse functions are consisted of five typical processes (on the tactical level); receiving, putaway, storage, picking and dispatch where the lead time is further divided. Furthermore, the receiving processes have sub-processes (on the operational level) of unloading, product identification, quality inspection and buffering with the disseminated receiving lead time. Meanwhile, the efficiency measurements are also divided into different levels followed with other factors or aspects combined such as leadership styles, cultures, motivations and tacit knowledge. Notably, the efficiency relates to the utilizations of resources, internal processes and activities, thus the corresponding measurements differ from each other horizontally and vertically in the organization. Therefore, it could not be aggregated on higher levels or disseminated to lower levels as the lead time or any other effective measurements which could be defined in numerical forms. But the efficiency measurements can be summarized and specialized (on higher levels) or detailed and narrowly-focused (on lower levels). With these assumptions, the following equations can be achieved:

$ES_{LT} = total\ lead\ time$

$ES_{LT} = ES_1 + ES_2 + ES_3$

$ES_3 = ES_{31} + ES_{32} + ES_{33} + ES_{34} + ES_{35}$

$ES_{31} = ES_{311} + ES_{312} + ES_{313} + ES_{314}$

, where ES_3 represents the warehouse lead time, ES_{31} is the receiving lead time and ES_{311} equals to unloading lead time and so on.

And inspired by Potočan (2006)'s conclusions on the relations of effectiveness and efficiency measurements, the lead time should also equal to the mathematical functions of the relevant efficiency measurements and other factors combined as follows:

$ES_{LT} = f(EY_S', EY_S'', EY_S''', \ldots, \Theta_S)$, and subsequently,

$ES_3 = f(EY_3', EY_3'', EY_3''', \ldots, \Theta_3)$,

$ES_{31} = f(EY_{31}', EY_{31}'', EY_{31}''', \ldots, \Theta_{31})$,

$ES_{311} = f(EY_{311}', EY_{311}'', EY_{311}''', \ldots, \Theta_{311})$,

[1] Due to the simplicity of the formula and the relevant explanation, the transportation time is omitted.

, where EY'_S, EY'_3, EY'_{31}, EY'_{311} and Θ_S, Θ_3, Θ_{31}, Θ_{311} are corresponding efficiency measurements and other factors[2] of the supply chain, the warehouse, the receiving process and the unloading sub-process. Noteworthy, the efficiency measurements on each level can be multiple and should incorporate all time-dependent variables, measurements and criteria, i.e., for the warehouse lead time, ES_3, the corresponding efficiency measurements are expressed as $EY'_3, EY''_3, EY'''_3, \dots$, considering their time-dependency. Therefore, combining the above formulas, the total lead time can be expressed in the following mathematical expressions:

$$ES_{LT} = \sum_{S=1}^{3} f(EY'_S, EY''_S, EY'''_S, \dots, \Theta_S) = \sum_{S=1}^{3}\sum_{T=1}^{M_S} f(EY'_{ST}, EY''_{ST}, EY'''_{ST}, \dots, \Theta_{ST})$$

$$= \sum_{S=1}^{3}\sum_{T=1}^{M_S}\sum_{O=1}^{K_{ST}} f(EY'_{STO}, EY''_{STO}, EY'''_{STO}, \dots, \Theta_{STO})$$

, where $S = 1,2,3$, $T = 1,2,3, \dots, M_1, M_2, M_3$, and $O = 1,2,3, \dots K_{1M_1}, \dots K_{3M_3}$. It is worth mentioning that the supply chain in this example consists of three different level, namely, strategic, tactical and operational and the elements on each level differs hence the size differences with T and O. For example, based on Figure 6, $M_3 = 5$ (represents 5 processes of the warehouse function), $K_{31} = 4$ (represents 4 sub-processes of warehouse receiving process), thus K_{3M_3} can be equal to K_{35} which represents the number of sub-processes for the dispatch process. Table 4 compiles the summary of the elements used in the expressions above. Therefore, the general expression for any given effectiveness measurement can be expressed as follows:

$$ES_X = \sum_{S=1}^{N} ES_S = \sum_{S=1}^{N}\sum_{T=1}^{M_S} ES_{ST} = \sum_{S=1}^{N}\sum_{T=1}^{M_S}\sum_{O=1}^{K_{ST}} ES_{STO} \tag{3.1}$$

and

$$ES_X = \sum_{S=1}^{N} f(EY'_S, EY''_S, EY'''_S, \dots, \Theta_S) = \sum_{S=1}^{N}\sum_{T=1}^{M_S} f(EY'_{ST}, EY''_{ST}, EY'''_{ST}, \dots, \Theta_{ST})$$

$$= \sum_{S=1}^{N}\sum_{T=1}^{M_S}\sum_{O=1}^{K_{ST}} f(EY'_{STO}, EY''_{STO}, EY'''_{STO}, \dots, \Theta_{STO}) \tag{3.2}$$

[2] Other factors may differ on different working environments and levels like the corresponding efficiency measurement.

, where the supply chain has N functions, $\sum_{S=1}^{N} M_S$ processes, $\sum_{S=1}^{N}\sum_{T=1}^{M_S} K_{ST}$ sub-processes, ES_S, ES_{ST}, ES_{STO} represent effectiveness measurements while EY'_S, EY'_{ST}, EY'_{STO} and Θ_S, Θ_{ST}, Θ_{STO} are corresponding efficiency measurements and other factors on each levels.

Table 4: The summary of elements used in mathematical expressions

Level	Components	Effectiveness Measure (lead time)	Efficiency Measure	Other factors
Top	Supply chain	ES_{LT}	EY'_S, EY''_S, EY'''_S	Θ_S
Strategic	Supplier	ES_1	EY'_1, EY''_1, EY'''_1	Θ_1
	Production	ES_2	EY'_2, EY''_2, EY'''_2	Θ_2
	Warehouse	ES_3	EY'_3, EY''_3, EY'''_3	Θ_3
Tactical	Receiving	ES_{31}	$EY'_{31}, EY''_{31}, EY'''_{31}$	Θ_{31}
	Putaway	ES_{32}	$EY'_{32}, EY''_{32}, EY'''_{32}$	Θ_{32}
	Storage	ES_{33}	$EY'_{33}, EY''_{33}, EY'''_{33}$	Θ_{33}
	Picking	ES_{34}	$EY'_{34}, EY''_{34}, EY'''_{34}$	Θ_{34}
	Dispatch	ES_{35}	$EY'_{35}, EY''_{35}, EY'''_{35}$	Θ_{35}
Operational	Unloading	ES_{311}	$EY'_{311}, EY''_{311}, EY'''_{311}$	Θ_{311}
	Identification	ES_{312}	$EY'_{312}, EY''_{312}, EY'''_{312}$	Θ_{312}
	Inspection	ES_{313}	$EY'_{313}, EY''_{313}, EY'''_{313}$	Θ_{313}
	Buffering	ES_{314}	$EY'_{314}, EY''_{314}, EY'''_{314}$	Θ_{314}

Matching the characteristics of information system in section 2.3, this framework can provide some useful information; the effectiveness measurement can be aggregated when reaching higher levels or disseminated vice versa; the efficiency measurement(s) has no features as the corresponding effective measurement, but can be specialized and summarized on the strategic level, detailed and narrowly-focused on the operational level. Additionally, the effectiveness measurement can either be expressed at the same level of the efficiency measurement(s) and other factors or can be equated by more detailed lower level efficiency measurement(s) and other factors. This also supports Potočan (2006)'s claim of non-conflict characters of the two types of measurements, where the effective measurement governs the efficiency measurement(s) while the efficiency measurement(s) supports the effective measurement.

In addition, Table 5 shows an example of some measurements and metrics of warehouse operations (discussed in section 2.2.3) and corresponds those with the two concepts, effectiveness and efficiency (discussed in section 2.2.2), in different hierarchical level of planning (section 2.2.1), with alignments to the discussion on formulas (3.1) and (3.2). A list of the common warehouse performance measurements has been included in Appendix A. As this study focus on the lead time variability at the warehouse and the scope is limited to investigating the performance of warehouse in terms of lead time, these specifications have been made only from lead time perspective.

Table 5: An example of compilation about the warehouse performance measurements

Level of Planning	Components	Effectiveness	Efficiency
Strategic	Supply chain functions	Total lead time	Availability percentage, service level
Tactical	Warehouse processes	Warehouse lead time	Perfect order completion index
Operational	Sub-processes	Receiving lead time, put away lead time, dock to stock cycle time etc.	Inbound metrics, i.e., supplier orders received per person-hour, lines received and put-away per hour etc.

Notably, it is reasonable to state that the focal company has a successful flow-oriented corporate management and organizational structure over the years pursuing its corporate values of focusing on strong business performance and customer success. Thus, the above approach of establishing such a theoretical framework, using lead time, can also be placed under the context of the supply chain management where its core components are the time- and space- related arrangements of the goods flow between supply, manufacturing, distribution and consumption (Hesse and Rodrigue, 2004). This could be further examined and enhanced by the information flow from the suppliers to customers through advanced information technology and systems covering vertical hierarchy of an organization and horizontal operation of logistics and transport chains (together form up the total supply chain).

4. Methodology

In this chapter, authors provide an overview of the research design or framework for conducting this study. It also includes the methods used for collecting the data. Issues regarding reliability and validity to assess the quality of the study are also discussed in this chapter.

4.1 Research design

The purpose of this study is to find out the root causes and impact of unfavorable events within the aftermarket supply chain of a specific organization. So, this study focuses on the contemporary events of that focal company within the industry and mainly search for "why" of those events. While there are several ways of doing a research such as experimental, survey, histories, archival analysis, case studies etc., researchers should carefully consider the advantages and disadvantages of each before choosing one specific method for conducting the research. Yin (2003) suggests distinguishing the advantages and disadvantages of each strategy depending on three conditions- (i) type of research question (ii) control of investigator over the behavioral event (ii) focus on contemporary and historical phenomena. Yin (2003) also states that when focus is on a contemporary phenomenon within a real-life context, "why" and "how" questions are posed and the investigator has little control over events, then case study is the preferred strategy. Case study can be single or multiple depending on the case. For example, a case can focus on one company or organization within an industry or several companies within the industry. Normally, "why" forms the essential or central research question in a case study, while "what happened" and "how much" or "to what extent happened" complement the central research question. In this sense, this thesis thus is a single case study, as it focuses on contemporary event of one organization within an industry and mainly search for "why" of the event. A case study makes use of interviews, observation and sometimes quantitative data can be contextually necessary.

To meet the goals and purpose of the study, three steps have been adapted initially. At first step, the literature review has been carried out and the theoretical framework has been constructed based on those literatures. At second step, data have been collected from focal company's internal database and from interviews and observations. Finally, a theoretical conclusion has been drawn from the findings of statistical analyses and interviews.

4.2 Literature review and theoretical framework

Literature review has been conducted to reinforce the future result of the study with theory and previous researches in this area. Major sources of literature were books, journal articles and other electronic sources. The literature review has been done by searching through different electronic sources such as university library website (Göteborgs Universitetsbibliotek) and other scientific databases such as ScienceDirect, Elsevier, Google Scholar etc. Another approach was to searching through the bibliography of relevant literature to find out other related articles or books for the study. The main purpose of the literature review was to gain more in depth knowledge about the phenomenon and to compile these knowledges and to construct the theoretical framework.

4.3 Data collection instruments

Data are facts about the object of study and data collection are acts of systematic gathering of the data. Data were collected for this study in two segments, secondary data were collected from the Company Y's internal database and primary data were collected through interviews and observations.

4.3.1 Secondary data collection

The secondary data has been collected mainly from different module of company databases. Modification was made to sort and organize data in correct form and to extract information from those data, as data from secondary sources were in unstructured and disaggregated form.

4.3.2 Interviews

To map the structure of the activities and to have a clear idea about the processes and sub-processes, interviews were conducted. Relevant questions were asked of the experts in each department to find out if there is any gap or lack of coordination between the functions as it is believed that it would help the study to investigate root causes of the lead time variability. A detailed list of interviewees with their job positions and respective department could be found in Appendix H. For interviews, the snowball sampling method was used. In the snowball sampling method interviewees' social network were used to further include people from different departments with experience of the phenomenon being studied for this project (Collis and Hussey, 2014). The reason of using this method of interviews is because it was believed that it would help to get relevant answer of the questions from experts, as employees of one department often does not have sufficient knowledge about the activities of other departments. However, this method can increase the possibility of interviewing people with same views. The questions for the interviews were qualitative and semi-structured.

4.3.3 Observations

For this study, participant observation method was used, where the researcher followed the activities and people involved in the phenomenon being researched. The aim of using observation was to obtain a detailed understanding of the phenomenon and the values, motives and practices of those being observed. According to Collis and Hussey (2014), there are some requirements for conducting participant observations such as the phenomenon under study has to be observable within an everyday setting and the researchers have to have access to the appropriate setting. Also, the phenomenon should be limited in size and location to be studied as a case and the research problem would have to be appropriate to investigate by collecting qualitative data from observation and other means that are relevant to the setting. The results of this participant observation were then used to construct the case description. They also facilitated relating the findings with the results obtained from statistical analyses.

4.4 Analysis and theoretical conclusion

To analyze the lead time data obtained from secondary source, descriptive statistics (mainly mean and standard deviation) and some inferential statistics were needed to explain the data in depth. As Holcomb (2016) stated, when there are large amounts of data that need to be interpreted, the descriptive statistics are used to organize and summarize them regardless of their origins of samples or populations. However, the inferential statistics are often needed for making generalizations from samples to populations such as the Anderson-Darling test for normality and the Levene's test for variance homogeneity (section 5.4 and 5.5 respectively). Among descriptive statistics, the mean is the typical measure of location on a sample and often called arithmetic average, which is denoted as $\bar{x}$. The sample mean is calculated as

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (4.1)$$

, where x_i is any given observation and n is the sample size. Another descriptive statistic for determining the dispersion of a distribution is the standard deviation. It can be thought of as the "average distance" of the observations from the mean. The standard deviation is commonly denoted as s or SD and defined as

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

, where x_i is any given observation and $\bar{x}$ is the mean with the sample size of n (Nick, 2007). The above formula is also proven to be an unbiased estimate of the population standard deviation (the denominator $n - 1$ used for dividing the sum of squares under square root). Due to the large amount of data acquired (section 5.1), it was acceptable to use the biased estimate of the population standard deviation for the descriptive statistics in paragraph 5 (not for the Anderson-Darling test in section 5.4 and the Levene's test in section 5.5), which is defined as

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \qquad (4.2)$$

, where the denominator n is used instead of $n - 1$ for dividing the sum of squares under square root (Cohen, 2008).

Moreover, based on the formulas (4.1) and (4.2), the mean and standard deviation values of the actual receiving lead time for total samples in 1 day and 4 days categories (section 5.2, 5.3, 5.4 and 5.5) and for each part number (section 5.6) were calculated with the combination of other statistics such as mode, median, range etc. Most importantly, the scatter plots of the mean and standard deviation values of each part number over different intervals based on frequencies were also generated for examining the correlation between them (section 5.6), based on the method applied by Cammarota and Rogora (2005).

Furthermore, once the lead time deviation was confirmed, it was necessary to compare the safety stock levels in cases where the lead time deviation was excluded and included respectively to see the impact of such a phenomenon on the operation of the central warehouse in this study. Therefore, the formulas (2.1) and (2.2) discussed in the literature review (section 2.4) were used in chapter 6 for the approximate estimations of the safety stock levels and thus some interpretations would be made correspondingly.

Finally, an investigation was carried out to find out from the interview and observations if the processes and activities were efficient enough to support warehouse effectiveness. If the processes and activities were to be efficient enough based on the existing warehouse capacity, then a conclusion would be made that the expected lead time for each function, which had already been specified by the strategic level, should be adjusted accordingly or investment should be made to increase the capacity such as automation, information system and technology etc. If that was not the case, then investigation would further continue to find out the root cause and give some viable suggestions for improvements.

4.5 Reliability and validity

Reliability and validity are considered as two of the most prominent criteria for evaluating and assessing the quality of business and management research. These criteria have been considered to ensure the quality of this study as follows.

4.5.1 Reliability

Reliability refers to the absence of differences in the results if the research were repeated as well as the accuracy and precision of the measurement (Collis and Hussey, 2014). This idea can in parallel be termed as dependability. Reliability or dependability is concerned with mainly two questions. First, whether the results of the study are repeatable or are the findings likely to apply at other times. Second, it also questions whether the measures that are devised for measuring the phenomena (i.e. organizational effectiveness) are consistent (Bryman and Bell, 2011). As to the case study in this report, the data extracted from the internal database is cross-checked with that of WMS which used for calculating the binning precision to ensure consistency. Regarding the question of repeatability, research methods used for the collection and interpretation of data could offer similar results if repeated, unless the organizational settings go through notable changes.

4.5.2 Validity

Validity is considered in many ways as the most important criterion of research, which is concerned with the integrity of the findings and conclusion generated from the research. The concept of validity can be further distinguished into three major types; measurement validity, internal validity and external validity (Bryman and Bell, 2011).

4.5.2.1 Measurement validity

As the name suggests, measurement validity often questions whether the measures, devised to assess a phenomenon, reflect accurately the phenomena that it is supposed to be denoting. It is also closely related with the reliability of the research. If the measures of the concept fluctuate and do not reflect the phenomena that are to be investigated, the findings of the study will be questionable and hence making the research unreliable as it will be unable to provide a valid measure of the phenomena in question (Bryman and Bell, 2011). In this study, researchers use lead time as an effective measure to link other time-dependent performance indicators within a segment of the supply chain of the selected focal company. As lead time being a core component of supply chain management, this approach could be considered feasible and fairly accurate.

4.5.2.2 Internal validity

Internal validity, which can also be termed as credibility, is concerned with the issue of causality. It questions whether a conclusion that incorporates two or more variables (i.e. x causes y, fully or partly), can reinforce that causality with fair amount of certainty (i.e. it is x that is responsible for variation in y and not something else) (Bryman and Bell, 2011). For the interviews, snowball sampling method is used so that it is possible to interact with people who have expertise in the related fields and knowledge about the phenomena. As the snowball sampling method often carries the risk of increasing the casual relationships, researchers conducted quantitative analyses first based on internal data from the focal company to maintain the internal validity and those results were then used to develop a causal relationship with the findings from the interviews to clearly understand the phenomena.

4.5.2.3 External validity

This concept, sometimes can in parallel be termed as transferability, refers to the question of whether the results and findings of a study can be generalized and likely to apply to some other context beyond the specific research context (Bryman and Bell, 2011). Although there is a great deal of concerns about the generalizability of a case study such as how findings yielded from a single case study can be applied to other general cases, the framework developed in this study might be applicable to the similar industrial settings upon the condition that it has been further tested and proved. However, the findings in this report can be exclusive to the focal company and may not be used to make unproven presumptions for other organizations or industries.

5. Lead Time Statistical Analyses

The empirical parts of this report will be presented in the order of conducting quantitative analyses (the lead time statistical analyses in Chapter 5 and the safety stock analyses in Chapter 6) first, following with qualitative analysis (case description and findings in Chapter 7). The reasoning here is to reduce the risks of the subjective casual relationships induced by the snowball sampling method and to increase the understanding of the lead time deviation beforehand regarding its place and time within the inbound process of the central warehouse.

5.1 Brief introduction of lead time data

The data used to gain an insight to the deviations of the actual receiving lead time in the central warehouse is extracted from the internal database of the focal company; in total 203,658 records dating from April 3rd, 2017 to April 19th, 2018 (the observation period). The data also consists of labels as follows:

- Part Number: A unique identification of each automotive part, 3-8 characters
- Main Supplier Number: An identification number assigned to each supplier, 2-5 characters
- Description: A short text describing the content of each Part Number
- R31 Date: The registration date of receiving a Part Number
- R32 Date: The registration date of putting away a Part Number
- Actual Receiving Lead Time (ALT): Actual receiving lead time calculated by the network day subtraction of R31 from R32 and minus 1 (network day function to exclude weekends and minus 1 to denote the same day handling as zero), and it is an integer.
- Expected Receiving Lead Time (ELT): Fixed receiving lead time from R31 to R32 in the system, expected to be handled within 1 day or 4 days

For example, Part Number 20382388 is described as a control rod supplied by Main Supplier 270, which was received at 07/05/2017 and put away at 07/06/2017 with 1 day ELT. Therefore, the ALT is calculated as 1 day (See Appendix B). Additionally, based on the observation of the given data, each part number is linked to a unique main supplier number, but the main supplier number could be the same for different part numbers, meaning there is case that the same supplier could provide different parts. Moreover, each record can be considered as an order line independent of each other where the same part number occurs several times over the observation period. Furthermore, the order line handling and the required time may differ according to the processes of unloading, identification, inspection, buffering and other value-added activities such as pre-packing, thus the separate analyses would be more ideal based on the different ELTs defined by the focal company. Finally, the order lines for each part number should be aggregated in this report to have an idea about the lead time variability and the obtained frequencies of each part number with its relation to the lead time variability since the product characteristics of each part number are the same and the time as well as the handling spent should be similar theoretically. This would be, subsequently, more helpful to observe some hidden patterns to the reasons of the lead time deviation via inferential statistics and visualizations.

5.2 Descriptive statistics of the actual lead time

The descriptive statistics are used to summarize the data in a compact form and can be presented in tables, charts and other graphical forms, which would allow for patterns to be discovered when they are not apparent in raw data (Collis and Hussey, 2013). In this case, it is a good idea to start the analyses with calculations of the mean, median, mode, range, interquartile range and standard deviation values[3] based on categories of different ELTs (Table 6).

- The mode is the most frequent occurring value in each data. In this case, it is the most frequent value among ALTs
- The median is the mid-value of a given data that has been arranged in size order, calculated by the number of ALTs plus 1 and dividing them by 2
- The mean is the arithmetic average of a given data, calculated by dividing the sum of ALTs by the number of ALTs
- The range is a simple measure of dispersion, calculated by the difference between the maximum ALT and the minimum ALT
- The interquartile range (IQR) represents the difference between upper quartile (Q3 or 75% of the data values) and the lower quartile (Q1 or 25%), showing the spread of middle 50% of the data values, which is helpful to determine the outliers when combined with the box plot
- The standard deviation (SD) is a measure of how well the mean represents the data or the deviation of the observations from the mean, which is the most important measure for the lead time variability. It is the square root of the variance which is the mean of the squared errors. (Collis and Hussey, 2013)

Table 6: The descriptive statistics of ALT by ELT

ELT	N	Mode	Median	Mean	Range	IQR	SD
1 day	119,480	0	1	1.05	205	1	2.43
4 days	84,178	0	2	2.28	257	2	3.99

Note: N represents the number of observations (ALTs)

Table 6 presents that in both categories, the mode values are smaller than the corresponding median values which are also smaller than the mean values, while the standard deviations, on the

[3] Calculations and plotting are achieved by the help of R programming software and the detailed programming codes please refer to Appendix C.

other hand, are larger than the mean values. This means the distribution for the ALT in both categories positively skewed and largely dispersed. Meanwhile, comparing the medians with ranges and IQRs, there are outliers affecting the mean, range and standard deviation values, which would be premature to make general conclusions; 4 days category have longer time for handling than that of 1 day due to the larger mean value, and at the same time, 4 days category deviates more than that of 1 day because of the higher the standard deviation (Collis and Hussey, 2013). Successively, this leads to next sections for the detection of the outliers using a box plot and testing of normality.

5.3 Detection of the outliers

Usually the length of the box when constructing a boxplot is equal to the IQR which contains the middle half of the data values. The right whisker should extend from Q3 to the maximum data value which is not farther than 1.5 times IQR from Q3 and beyond that should be considered as outliers (Jaggia and Kelly, 2016). As shown in the Table 7 and Figure 7, the outliers for 1 day category lie beyond 3 (rounding up 2.5) till 205 (maximum value), where 5,484 observations fall within that range and take around 4.59% against the total number of observations (119,480), whereas the outliers for 4 days category range from 7 (excluding 6) to 257 (maximum value), in which 2,399 observations can be spotted and should be around 2.85% against the total number of observations (84,178).

Table 7: The right whisker and the corresponding percentage of outliers by ELT

ELT	Q3	IQR	Q3+1.5*IQR	No. of Obs	Percentage
1 day	1	1	2.5	5,484	4.59%
4 days	3	2	6.0	2,399	2.85%

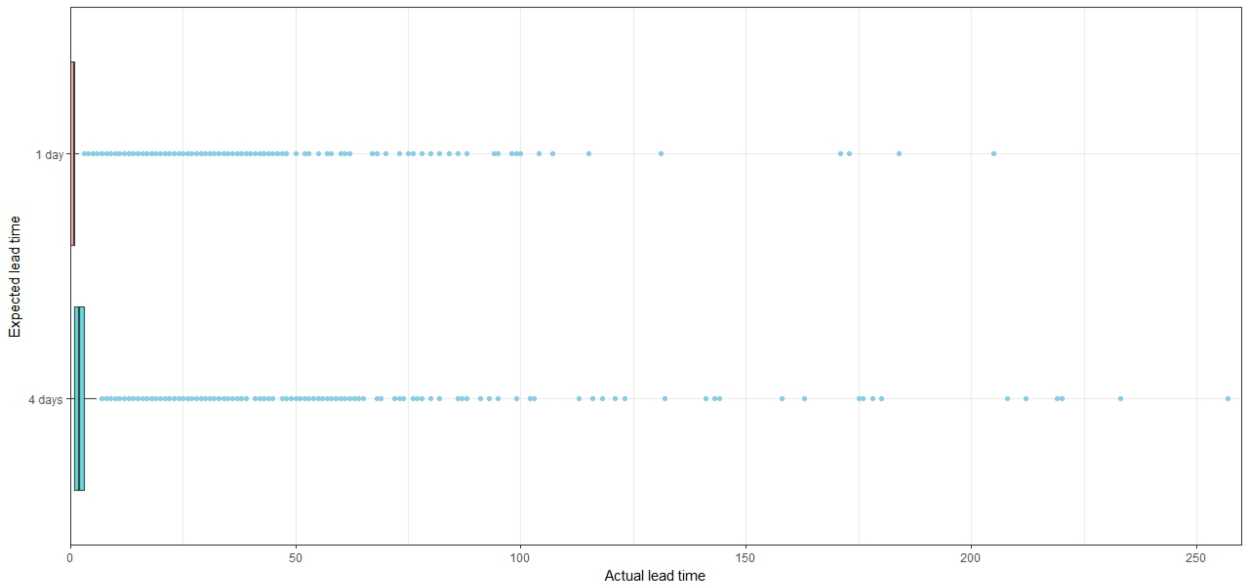

Figure 7: The boxplot of ALT against ELT

While the outliers can greatly affect statistics such as the mean and standard deviation, it is not always clear what to do with them. Reasonably, it might indicate the outliers could be stemmed from bad data due to incorrectly recorded observations in the database, which should be corrected or simply deleted. Alternatively, those outliers could be random variations depicted from the operational processes in the warehouse and they should remain within the data set (Jaggia and Kelly, 2016). As too little related information obtained about the outliers in this case, the correction and deletion approach will not be applied. But, some of those outliers will not be included in the testing of normality and the seeking of relevant distribution patterns.

5.4 Normality tests

In statistics, the frequency of occurrence of a quantity in a ratio variable (since the lead time is measured in day) and its array (the frequency distribution) that summarizes the frequencies of all values can be presented in a histogram plot, which can give a visual examination of how values are distributed and provide an aid to the interpretation of the given data (Collis and Hussey, 2013). For example, it can be shown in the mentioned plots that how many and how much percentage of those order lines are handled in day 0, day 1 and so on, assuming each order line is independent. Moreover, when the frequency distribution is asymmetric, it is believed to be skewed. The skewness is a measure of the extent to a which a frequency distribution is asymmetric. The positive value of the skewness means the tail is on the right and vice versa (the skewness of a normal distribution is 0). Furthermore, determining whether the distribution is more peaked or flatter than a normal distribution, the measure named kurtosis would be helpful. The positive value of kurtosis means the distribution is more peaked because most of the observations are clustered in the centre and vice versa (the kurtosis of a normal distribution is 0).

Additionally, Anderson-Darling test (the normality test) compares the actual frequency distribution of the sample with a theoretical normal distribution by the same mean and standard deviation. If the p value is insignificant (less than 0.05), then the null hypothesis (the sample is from a normal distribution) would be rejected (Ruppert, 2014). After excluding some outliers, considering the lead time only from the interval 0 to 10, where almost 99% of the order lines are handled for both categories, the results are shown in Table 8, Figure 8 and Table 9.

Table 8: The updated descriptive statistics of ALT by ELT

ELT	N	Median	Mean	SD	Skewness	Kurtosis
1 day	119,177	1	0.97	1.26	2.39	11.63
4 days	83,605	2	2.09	1.79	0.99	4.30

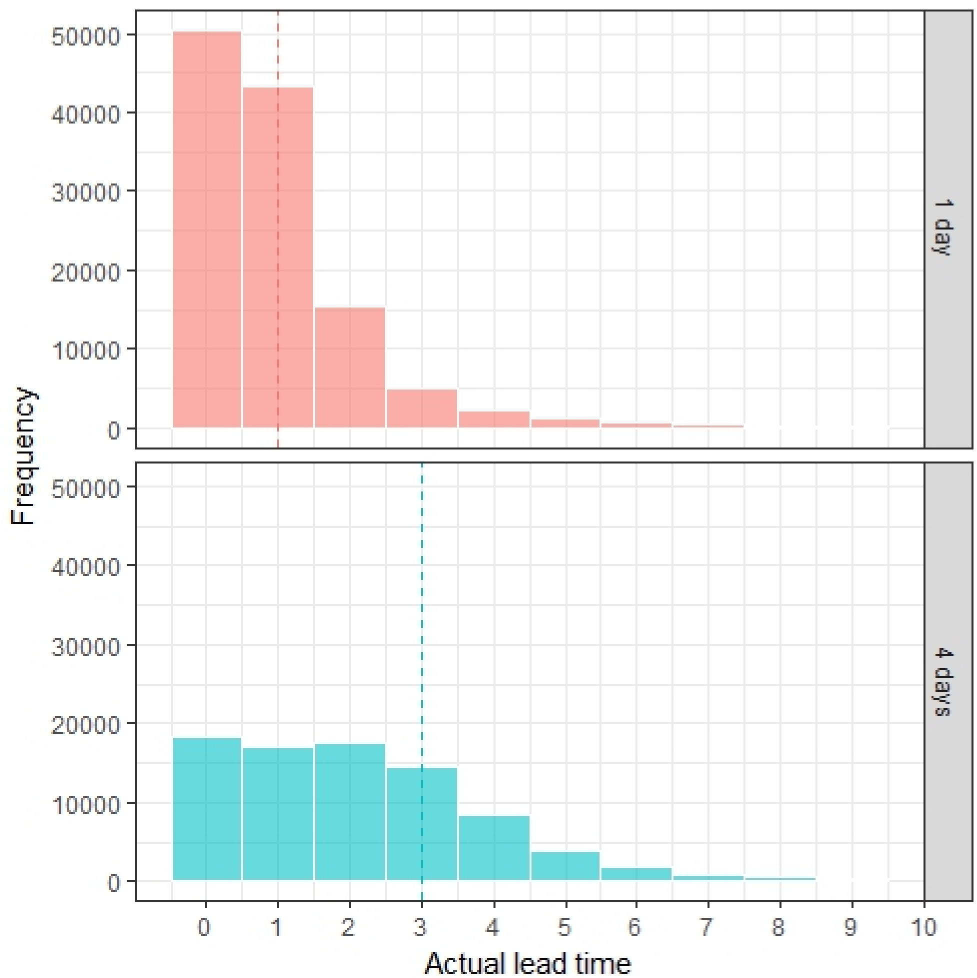

Figure 8: The frequency histogram of ALT by ELT

Table 9: The Anderson-Darling test for normality (α=0.05)

ELT	A statistic	P-value
1 day	9,586.86	0.0000
4 days	2,207.78	0.0000

Combing the results from both tables and Figure 8, there is enough evidence to conclude that the distributions of both categories are not normal, and they are more peaked and have tails on the right. Understandably, 4 days category deviates more than 1 day category due to its larger standard deviation. In addition to the previous results, 1 day category is slightly more dispersed than 4 days category based on the respective comparisons of their standard deviations against their mean values. However, further analyses and interviews are needed for explaining the reasons on this dispersion for 1 day category even if it has more number of observations, because order lines in 1 day expected lead time category are supposed to be handled shortly (note the dash lines in Figure 8 represent Q3 or 75% of the data values for each category) and smoothly. Interestingly, based on Figure 8, both histograms portrait similar shapes and trends of distributions for the categories of 1 day and 4 days, especially having much similar resemblance after the actual lead time day 5 or 6. Therefore, grouping the categories based on the actual lead time would be a good option for revealing more patterns. More importantly, a non-parametric test should be used to examine the difference of distributions and determine the boundaries of each group for the two categories.

5.5 Distribution patterns on different groups

Concluded from the previous results, the mean values cannot represent the data very well due to larger standard deviations for 1 day category and the variables (the actual lead times) are not normally distributed followed by unequal sample sizes (the number of observations). Consequently, this leaves using the median as an alternative for groupings and determinations of distribution differences. Bearing those in mind, it is reasonable to find a robust non-parametric test for variance heterogeneity between the two categories in different groups. According to Fox (2008), the Levene's test is suitable for the cases where the groups of samples are unequal in sizes and departed from normality. Particularly, the null hypothesis of the Levene's test is that the two samples are of equal variances and the median, in addition to the mean, should perform a better result applied in the test statistics when the underlying distribution of the variable is skewed.

After a several repeated experiments, two groups are formed; Group A with the lead time ranging from 0 to 6 and Group B from 7 to the rest including the outliers (maximum is 257). The

Levene's test results and associated the descriptive statistics are shown in Table 10 and the relevant boxplots, histograms and distribution density plots can be found in Appendix C.

Table 10: The Levene's test results (α=0.05) and associated the descriptive statistics in groups

Group	ELT	N	Median	Mean	SD	The Levene's test	
						Test Statistics	P value
A	1 day	118,228	1	0.92	1.10	17,322	0.0000
	4 days	81,779	2	1.96	1.58		
B	1 day	1,252	8	13.28	17.30	0.47	0.4913
	4 days	2,399	8	12.93	18.87		

Evidently, the distributions of the two categories in Group A are different due to insignificant p value comparing with α (0.05). Similar to the previous result, 1 day category disperses slightly more (comparing the respective mean to standard deviation), although 4 day categories still have large standard deviation value comparing with 1 day category. In Group B, the both categories follow similar distributions (larger p value against α resulting the acceptance of the null hypothesis of variance homogeneity, which is also supported by Group B boxplot, histogram and distribution density plot in Appendix C), meaning that each order line is treated fairly. This conclusion can also be supported by the equal median values, and the closer mean and standard deviations. On the one hand, the higher standard deviations against the mean values show that the data are more dispersed and deviated comparing with Group A. On the other hand, the much larger values of the median, mean and standard deviation, also in comparison to Group A, should require additional examinations regarding the performance of the receiving and putaway processes (inbound) in the warehouse.

5.6 Lead time variability for each Part Number

As the same part number represents the same product characteristic or description, it would demand same handling time and process theoretically. Hence, the aggregation of order lines for each of part number are essential to see whether the related mean and standard deviation have any correlation and to examine whether the lead time variability differs on the frequencies of different part numbers within each group formed in the previous section. For example, Part Number 10523 from Group A, is a castle nut supplier by Main Supplier 929, appeared 3 times (frequencies) within the observation period, while the related mean value and the standard deviation are calculated respectively as 0.67 and 0.47. Although, it is proven to be the case that the mean values cannot represent the data very well for 1 day category in Group A as well as both categories in Group B, it is a common attempt to investigate variability using mean and standard deviation to get an insight for understanding the phenomena. Moreover, because some part numbers have higher frequencies than the others, it would be logical to assign those frequencies to their respective intervals (with which the number of part numbers are comparable), i.e., Part Number 10523 (with a frequency of 3 times) is assigned to interval [2, 4) (See Appendix D). Once the part numbers on Group A and Group B are plotted separately based on the designed frequency intervals, there should be enough evidence to draw conclusions on aforementioned presumptions. Therefore, the scatter plot between the mean value and standard deviation is more appropriate to demonstrate the extent of the lead time variability in different groups (Figure 9 and Figure 10), a method used by Cammarota and Rogora (2005).

To this point, it is obvious from the two scatter plots below that the actual lead time deviates and disperses largely in Group B, which reflects the same result from the previous section. Additionally, combing the results of two figures and Table 11, 4 days category have higher deviations than that of 1 day category in Group A, mostly between 0 and 4 days (95.6%), whereas the observations for 1 days category in the orange color tend to deviate between 0 and 2 days (93.0%), concentrating on the down-left side of the observations for 4 days category in the blue color. This result could indicate that the process capacity for 1 day category might need further investigation and improvement or the defined expected lead time might have to be changed from 1 day to 2 days. Most importantly, regardless of the frequency intervals, the standard deviation tends to have a positive correlation with the mean, inferring the higher its variability longer the average lead time of a given part number in both groups.

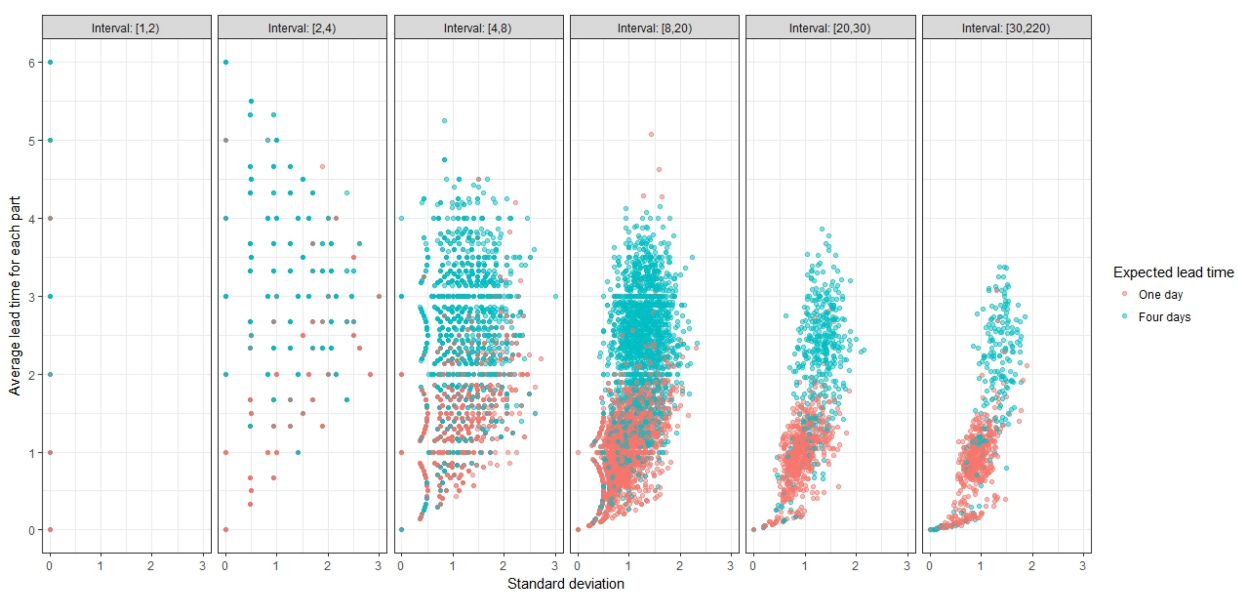

Figure 9: The scatter plot of the standard deviation against the mean of ALT by ELT

Table 11: The cumulative percentage of part numbers handled by ELT for Group A

	0	1	2	3	4	5	6
1 day	38.9%	83.1%	93.0%	96.1%	97.7%	98.8%	100.0%
4 days	13.5%	37.6%	69.3%	88.9%	95.6%	98.3%	100.0%

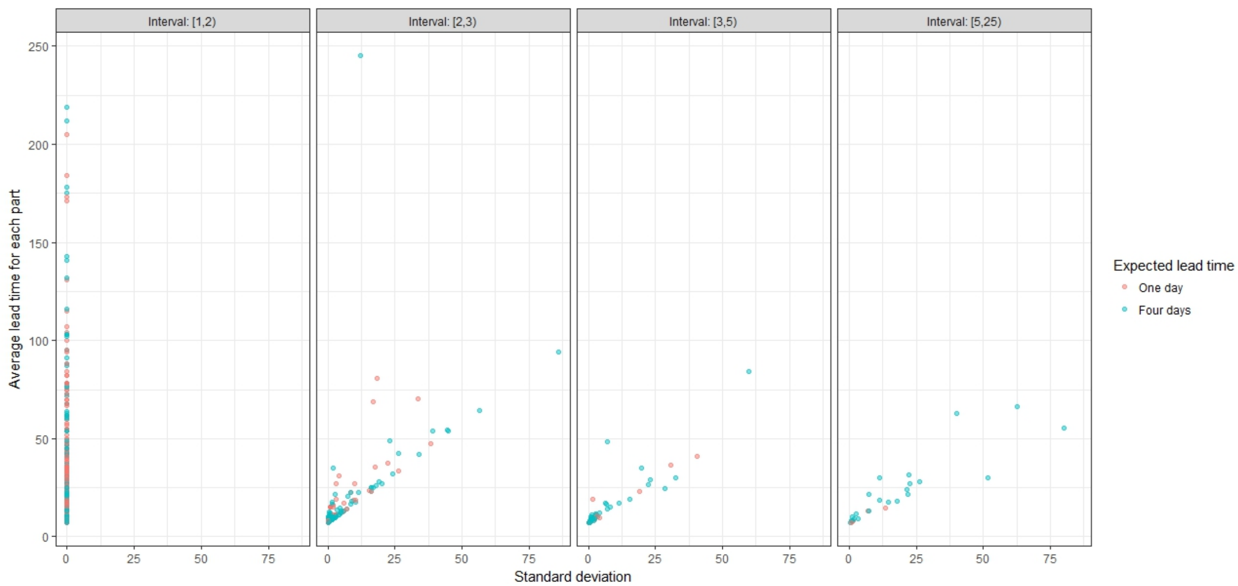

Figure 10: The scatter plot of the standard deviation against the mean of ALT by ELT

6. Safety Stock Analyses

In this chapter, the safety stock levels for both categories are estimated theoretically, respectively using functions (2.1) and (2.2) from section 2.4 to grasp an understanding regarding the impacts of the lead time deviations.

6.1 Brief introduction of demand data

The demand data is provided by Interviewee 5, who is responsible for forecasting the inventory level of the central warehouse. It is also extracted from the internal database of the focal company and dates from April 3rd, 2017 to April 19th, 2018, the same way as the lead time data. The data also consists of labels as follows:

- Part Number: Same as the lead time data
- Total Lead Time (TLT): The total amount of lead time, including order lead time, administrative process lead time, supplier lead time, transport lead time and receiving lead time, which is fixed in the system and measured in weeks
- Average Demand (AD): Customers' average demand in a period which is equal to 4 weeks
- Standard Deviation of Demand (SDD): Standard deviation of customers' demand in a period
- Service Level (SL): Target service level for each part number

The relational combination of the demand data with the existing one with mean and standard deviation of actual receiving lead time (Appendix D) is achieved by linking them via their respective part numbers (see Appendix F for merging data).

6.2 Safety Stock Estimation

The forecasting method applied in the focal company only considers the demand variability for estimating the safety stock level (Interviewee 5 and Interviewee 6). However, as this study develops to the point of showing the receiving lead time variability in chapter 5, especially in section 5.6, it is important to compare the results of different methods (with and without the lead time variability), namely using formula (2.1) and (2.2), and to show the impacts of unstable lead time towards the service level and the safety stock level.

Firstly, it is also critical to converge the unit measures in lead time which should be on same dimension for comparison. Since Interviewee 5 states that the inventory levels are estimated in a period (time increment used for calculating mean and standard deviation of demand) which is equal to 4 weeks and 20 working days, the unit harmonization should be applied for the rest of the elements used in the formulas, e.g. weeks and days will be converted into periods (see Table 12).

Secondly, although it has been proven that the actual receiving lead time does not follow normal distribution, the focus of the analyses in this section is to demonstrate how lead time variability affects the safety stock and the service level, assuming normal distribution be postulated and relevant Z score is calculated by inserting SL value to the Excel function, NORM.S.INV (), which returns the inverse of the standard normal cumulative distribution with 0 mean and 1 standard deviation (Interviewee 5). This approach here can be an indication or an insight for future research employing the exact distribution function.

Table 12: Unit conversion methods by dividing factors

Element	Unit	Dividing factor	Reasoning
TLT	Week	4	1 period equals 4 weeks
AD	Period	1	Same unit
SDD	Period	1	Same unit
SL	Period	1	Same unit
ELT	Day	20	1 period equals 20 days
AALT	Day	20	1 period equals 20 days
SDALT	Day	20	1 period equals 20 days

Note: AALT- Average actual receiving lead time, SDALT: standard deviation of actual receiving lead time

Moreover, the calculations can be divided in two parts; considering only demand variability as the company usually does applying formula (2.1) and allowing both demand and lead time variability in formula (2.2) (Appendix G);

In formula (2.1),

- TLT is considered as PC and T_1 equals to 4
- No conversion needed for SDD which is σ_D

In formula (2.2),

- $\left(\frac{PC}{T_1}\right)$ equals (TLT/4-ELT/20+AALT/20) as it is assumed that lead time only varies in the inbound process and the other parts remain stable
- No conversion needed for SDD which is σ_D
- SDALT/20 is σ_{LT}
- No conversion needed for AD which is D_{avg}

Furthermore, to be consistent with the findings in section 5.6, the results should also show different categories with 1 day and 4 days as follows (Table 13):

Table 13: Safety stock levels in a period with different methods

Category	Result of (2.1)	Result of (2.2)	Change in %
1 day	1,990,549	2,082,992	4.64
4 days	2,273,075	2,235,365	-1.66
Total	4,263,624	4,318,357	1.28

The above result from Table 13 clearly indicates that the lead time deviation in the inbound process in the central warehouse does affect the overall safety stock level by 1.28% increase, but it seems the contribution is derived from 1 day category in the contrast to the negative percentage from 4 days category. This discrepancy could be argued that the order lines in 1 day category deviate between 0 to 2 days, well exceeding the defined 1 day expected lead time, whereas the order lines in 4 days categories are handled well below 4 days, which is illustrated in Figure 9 and Table 11. In addition to that, the total lead time may need to be extended 1 day extra for 1 day category for a safe guard against the lead time deviation and for satisfying the target service level. Nevertheless, the lead time variability in the inbound process not only has an impact on the safety stock level in the warehouse but also decrease the service level conversely if it is not taken into consideration, not to mention the deviations stem from other parts of the TLT such as order lead time, administrative process lead time, supplier lead time and transportation lead time. Moreover, it is worth to mention that according to Interviewee 5, the demand data is provided by the dealers monthly and updated weekly (or more frequently for some parts) instead of point of sales (POS) from the end customers. This might further complicate the accuracy of the forecasting results regarding the inventory level in the company, especially in the central warehouse. Therefore, supply chain visibility should be the focus for the company in the future with information system integrations extending from suppliers to end customers.

7. Case Description and Findings

Data collected from interviews and internal documents are covered in this chapter. An overall view of Company Y's after-sales service market logistics (SML) and how the departments are connected, are provided here. Different types of flows and the inbound processes for these flows have been illustrated here also. This chapter also presents an analysis based on this case description and literature study. Findings from statistical analysis have also been used as important discussion topics during the interviews. By this, an attempt has been made to realize the connections between the different components of the aftermarket supply chain of the focal company and to identify the probable causes of deviations that have been found in statistical analysis and thus answer the first research question.

7.1 Company Y's Service Market Logistics

Company Y's service market logistics (SML) develop, manage and optimize service parts availability and distribution and thus tries to secure customer's uptime, where uptime is the solution provided by the focal company that increases the operational hours of the vehicles. The main aim of the SML is to provide world class after-sales services to customer by focusing on delivery precision, quality, continuous improvement and cost efficiency.

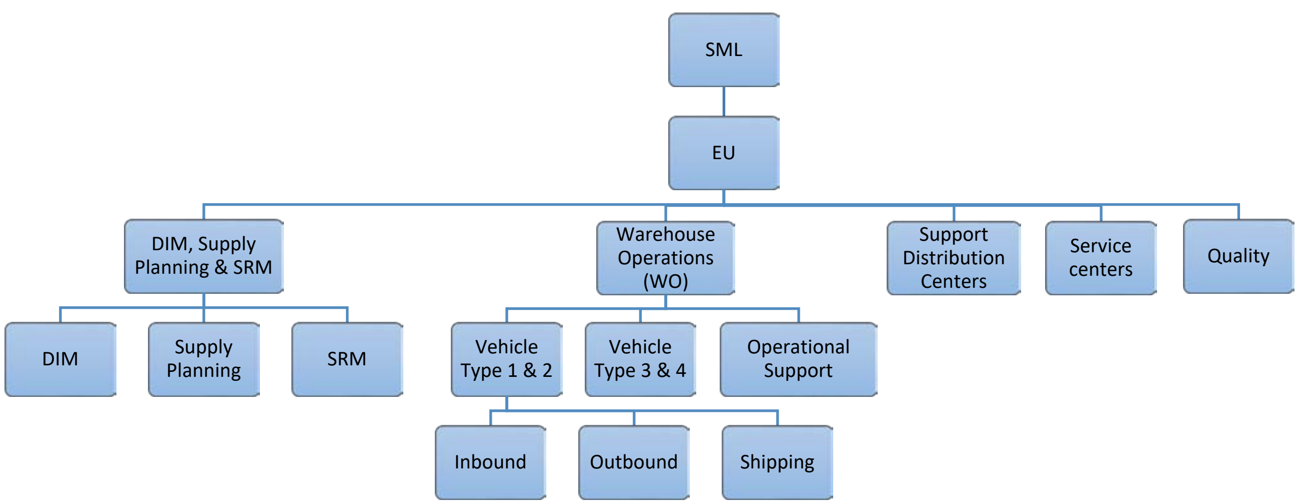

Figure 11: Organizational structure of Company Y's SML (Source: Internal Documents)

SML serves all the different brands (vehicle types) and business areas within Company Y and is divided based on regions such as European Union, North America, South America, Asia Pacific (APAC), and Japan. As the scope of this study only limits to the European market, the operations within the SML's EU segment has been covered here (Figure 11). There are different departments of aftermarket supply chain within the EU segment commonly referred to as "EU" and these departments are divided into sections such as DIM (Dealer Inventory Management), Supply Planning and Supplier Relation Management (SRM), Warehouse Operations at central warehouse, Support Warehouses, Service Centers, Quality etc.

DIM, Supply Planning & Supplier Relationship Management (SRM) is further divided into separate departments such as Supply Planning, Dealer Inventory Management (DIM), SRM etc. On the other hand, Warehouse Operations are divided based on brands such as commercial Vehicle Type 1 & 2, commercial Vehicle Type 3 & 4, and Operational Support etc. This study covers the operations and activities of the first two departments within the EU segment which are *Supply Planning* and *Warehouse Operations*. More specifically it takes a closer look at the interrelations between the activities of Supply Planning and Warehouse Operations department. To understand how the activities of these two departments interrelate, it is important to have an overview of the Company Y's whole aftermarket supply chain. Company Y's SML intends to secure the availability of spare parts near the customer locations and refer the dealers of spare parts as the end customer. So, Company Y's aftermarket supply chain comprises thousands of nodes worldwide as dealers and service centers and several central and support warehouses to serve those dealers. Central warehouses are supposed to cover the whole range of parts. Figure 12 will give an overview of the whole aftermarket supply chain.

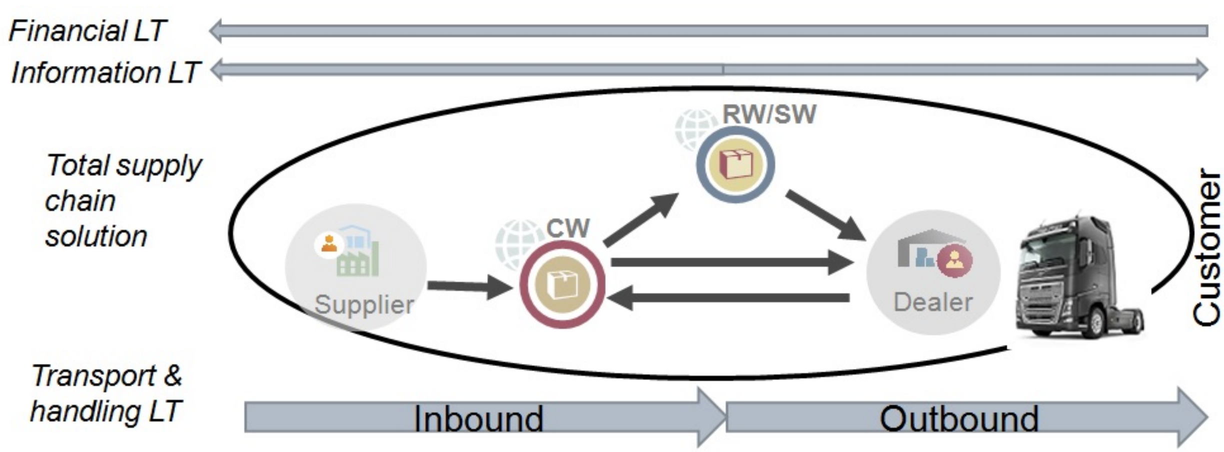

Figure 12: Company Y's aftermarket supply chain and lead time (Source: Internal Document)

Supply *Planning* is responsible for managing the availability and flows of parts to the warehouse. So, their responsibility is to provide availability of parts in the distribution system. Therefore, *Supply Planning* usually decides which parts would go to warehouse and in what volume. So, the interaction with suppliers and transportation of parts to the central warehouse cover a big part of *Supply Planning's* responsibility. And by this, *Supply Planning* focus on providing availability to maximize the uptime of the end customers where uptime is the solution provided by the company, which increases the operational hours of the vehicles (Interviewee 1, 2018). To maintain the availability in the distribution system, *Supply Planning* replenish the inventory based on the forecast and reorder point. The forecast is updated at the end of every period (four weeks) based on the latest demand information. On the other hand, the reorder point is determined based on replenishment frequency, economic order quantity and safety stock. The order size is determined by the economic order quantity. This reorder point depends on two factors, lead time and demand from the dealers. The total lead time (TLT) defined by the SML consists three parts; the internal lead time which consists both order processing time and manufacturing time by the suppliers, transport lead time and the receiving lead time (Figure 13).

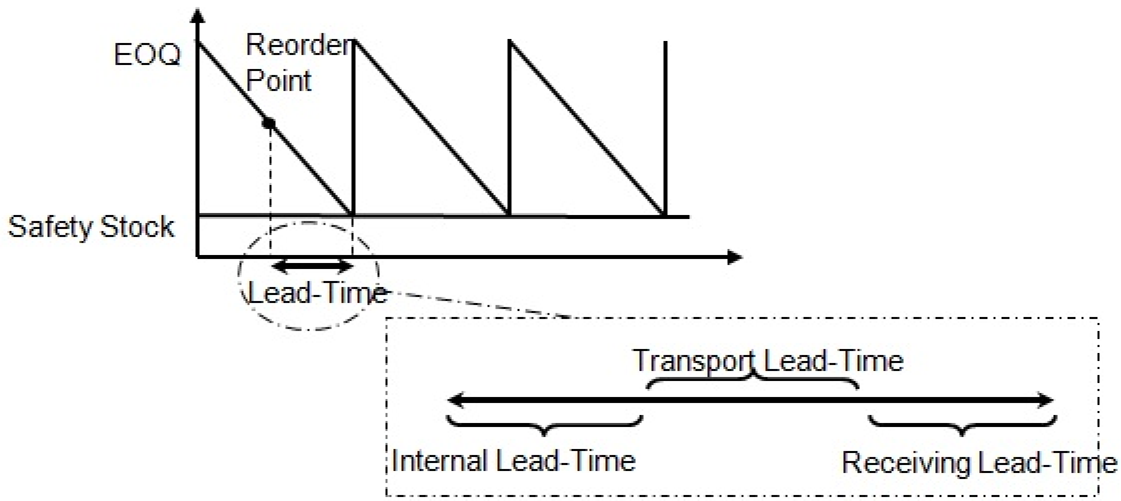

Figure 13: Inventory replenishment and Lead time (Source: Internal Document)

TLT is normally measured in weeks but it may differ for different parts. In general, the internal lead time can take up to four weeks, where the administrative processes and order processing can take one week and manufacturing of parts can take up to three weeks for the supplier. The transport lead time is generally considered as one week. The receiving lead time is calculated in days and it consists of the number of days required to complete the whole inbound process until the parts are on the shelf and becomes available in the system. In *Supply Planning's* system, the receiving lead time is set as either 1 day or 4 days for the inbound process depending on the different types of packaging activities that the goods need to go through before going to stock. This receiving lead time is also included in calculating the safety stock among other lead times; if the receiving lead time is equal or more than 3 days, it would be rounded up to a week and added to TLT. Otherwise it would be considered as one additional week in safety stock calculation (Interviewee 5, 2018). Also in *Supply Planning's* system, the lead time is used to provide an estimated time of arrival (ETA) of parts in case of an ordered part that is not available (Interviewee 1, 2018).

To measure the performance, *Supply Planning* follows different KPIs. One of the main KPIs is Part Availability, which measures the availability of parts to the dealer, i.e. the dealer got the quantity that they ordered and it measure the performance for all business areas and all warehouses, fully or partly delivered orders excluding blocked or passive parts. In a word, it measures the service experienced by the dealers from central warehouse, which is the percentage of average order lines supplied in each order. Orders are divided into order lines indicating the ordered quantity for one part. So it measures the completeness of an order on an aggregated level.

Parts Availability = (Order lines fulfilled in an order/Number of order lines in an order)*100

Another KPI is used to measure dealer readiness to serve an end customer, which is Dealer Service Index (DSI). It determines if the dealer inventory is able to meet one week's forecasted demands. It is measured by calculating the ratio of the total number parts with on-hand inventory quantity that is greater than their forecasted weekly demand quantity, over the total number of picks of inventory, based on the last 12 months' sales (Source: Internal Documents).

DSI= Sum of all parts with stock > one week demand/All parts

7.2 Warehouse Operations and Inbound process

The next link of the supply chain, which is the central warehouse, is responsible for making the parts available for the successive links within the specified time frame, in right quantity and in right quality (Interviewee 4, 2018). So, they are the one that directly work with the physical flow of goods.

The inbound flows coming to the central warehouse are differentiated based on the different types of treatment and packaging activities that the goods need to go through before going to stock. According to Interviewee 2 (2018), the inbound flows can be directed to central warehouse mainly from 3 sources as follows:

- Supplier flow: The goods come directly from suppliers in full truck load
- External packaging service provider (ExPack): Goods can either go directly to ExPack from suppliers' premises or can first come to the warehouse, and then go to ExPack from the warehouse. All the pre-packing activities are done in ExPack and when the goods come from ExPack, they are ready to be binned on the shelves.
- Katoen Natie (KTN): Goods that are less than truck load goes to a third-party logistics service provider termed as KTN for consolidation and cross docking activities. Goods are then come in full truck load from KTN to the warehouse.

So, the goods can either come directly from the supplier in full truck load, or if it is not full truck load then the parts would go to a cross docking centre (KTN) and can then come to warehouse from that cross docking centre (KTN), and third, the parts can come from a third-party packaging service provider (ExPack) to warehouse. Packaging activities are also being done inside the warehouse for some parts. These different types of flows regarding the packaging services are illustrated in Figure 14.

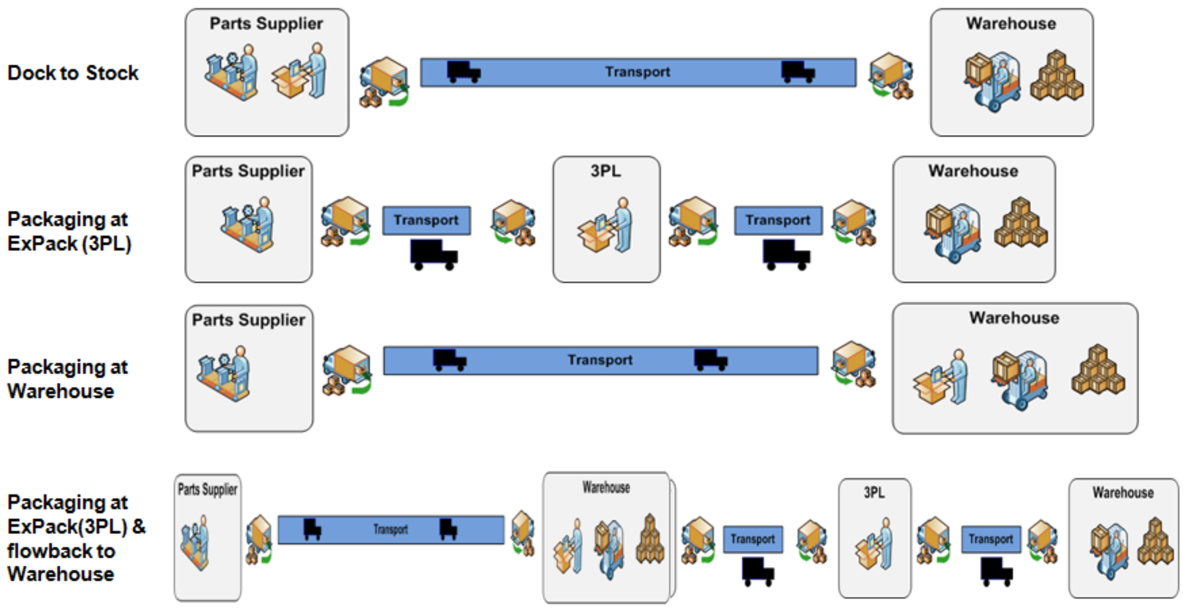

Figure 14: Different types of flow directed towards central warehouse
(Source: Internal document and participant observation)

The different packaging and other activities that the parts need to go through before being binned are described in Table 14.

Table 14: Different packaging activities (Source: Internal document and participant observation)

Direct	The suppliers of the parts are responsible to do the packaging and parts are shipped from suppliers' premises exactly how they should be binned in the central warehouse.
Re-packing	The parts are shipped from suppliers' premises in the pre-specified pallet to the warehouse. But when parts arrive to the warehouse they need to be transferred in larger pallets before storing to shelves to save valuable space in the warehouse. This activity is referred to as re-packing.
Pre-packing	The parts are shipped from suppliers' premises in large quantities in a single box or even without any box. Each of these parts need to be packed in smaller boxes separately. This activity is referred to as pre-packing
Quality Control	All new parts that are coming to central warehouse for the first time, go through quality control. Regarding the old parts, if any problem is detected with the parts during the last shipment then it gets a flag in the warehouse management system and is therefore goes through quality control during the next shipment.

After packaging activities are being done the goods become ready to be binned on the shelves. There are different teams being responsible for handling the goods throughout these packaging and quality control activities. According to Interviewee 3 (2018), these responsibilities can be divided mainly in two segments. One team is responsible to handle the goods in receiving dock and they start by unloading the goods, matching the trailer with advanced shipping notice and making sure that the correct parts are delivered by the supplier in right quantity. After that they sort the goods according to the different packaging activities and drop them in different zones specified for different flows shown in Figure 14. The other team tracks the goods that are ready for binning and then pick the goods up in reach truck and finish the inbound process by binning them on the shelves. The movements of goods are being recorded in the warehouse management system (WMS) using different codes and screens. These movements are recorded by scanning the barcode in different screens for specified parts. For example, when the goods are first received and unloaded by the first team, the barcodes are scanned and put as status zero in a specified screen using a specific code. Depending on different packaging activities that the goods have to go through and the different routes that the goods have to take for that, the receiving team can put the goods in different statuses after that, and when the goods are ready for being binned or go to the stock they put another pre-specified status, so the second team that are responsible for binning can track the goods and bin them. After binning, the person responsible for binning has to scan the barcode again in another pre-specified screen so it confirms that the goods are in stock now and becomes available in the WMS. All the scanning processes are done with hand held scanning devices that are portable as they are attached with the reach trucks. Errors during scanning processes are not uncommon in current processes due to manual scanning procedures and high amount of human intervention in each step (Interviewee 3 and Participant observation, 2018).

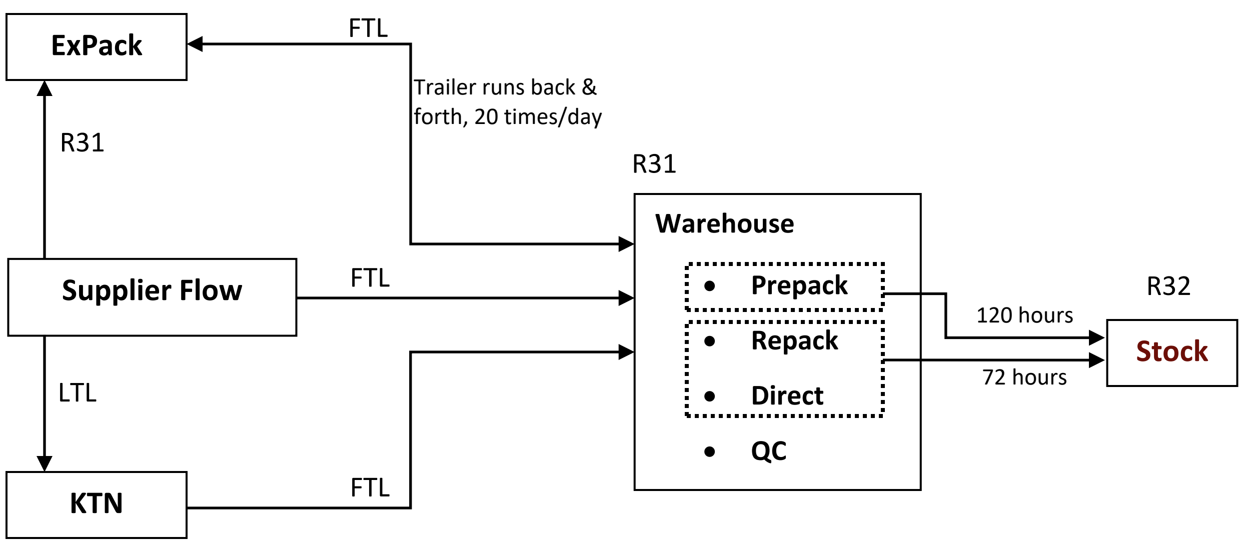

Figure 15: Inbound process for aftermarket parts (Source: Interviewee 2 and 3)

There are specified time frames, within which the parts have to be binned in the specific storage area. These time frames are followed as one of the main KPIs within the inbound and are commonly referred as binning precision. The parts that need to go to external packaging service provider or the parts that need to be pre-packed inside the warehouse or need to go through quality control have a binning time of 120 hours, and for the rest the target is 72 hours (Figure 15) (Interviewee 2 and 3, 2018).

7.3 Findings

7.3.1 KPI focused departments and dissimilarities in targets

Due to high number of stock keeping units (SKUs) and varying demand pattern, the aftermarket supply chain is highly unpredictable. So ensuring accuracy in forecasting and maintaining stable lead time is very important to provide good service to the customers. To ensure this, all the departments need to have a clear idea about the processes and activities done in other departments and the connection between KPIs followed in other departments to make the whole supply chain effective. Currently different departments focus on their KPIs and efforts are made to reach the expected target of those fragmented KPIs by each department. But as the connection between KPIs are missing, different departments often failing to capture the whole picture. For example, the parts availability is followed as the most important KPI in *Supply Planning Department* and when *Supply Planning* struggles with availability, it might be the case that too much goods are pushed in the warehouse which might create capacity constraint for the warehouse. On the other hand, dissimilarities have been found in the targets regarding the receiving lead time in different departments. Whereas WO measures its lead times in terms of hours and has set a target of 72 hours and 120 hours based on different types of flows for the inbound processes, in *Supply Planning's* system these are calculated in days and has set as a target of either 1 day or 4 days for the inbound processes depending on the different types of packaging activities that the goods need to go through before going to stock. This in turns make the lead time unstable and might affect availability and safety stock calculation, as to maintain desired level of availability and correct safety stock, stable lead time is crucial. This dissimilarity might also has a negative impact on the ETA calculation as *Supply Planning* put an ETA in the system based on their perception of the target. The effect of this can be farfetched in some cases as customers can potentially promised about a wrong date of getting their parts delivered when in reality they will get the parts on a later date. This further indicates the different departments' efforts to make the processes efficient owned by them and thus overlook the impact it would have on the other parts of the chain.

7.3.2 Complicated sorting process and increased movement during put away process

It has been discussed previously in section 5.6 that a positive correlation exist between the actual average lead time and standard deviation of actual lead time regardless of the frequency interval and deviations tend to increase. Further it was found out that distributions of both categories tend to have long tails on the right (Figure 8, section 5.4) and actual lead time for both categories tend to disperse compared based on the respective comparisons of their standard deviations against their mean values. Table 10 indicates that parts with ELT equal to 1 day has a median value of 1 which indicates that only 50% of the parts were handled within the specified target and other 50% of the observed data deviated from their target. While this can be due to dissimilarities in the targets between two different departments it can also be an indication that their process is nor capable of meeting the target of binning within 1 day. This deviation from the target can be due to extra movement of goods and existence of unnecessary touches during the receiving process.

As mentioned before in this chapter, currently there are three different types of inbound flows coming to the central warehouse and another one runs back and forth between the warehouse and external packaging service provider. In addition to this, after unloading the goods, pre-packing activities are further divided between warehouse and the external packaging service provider. This creates unnecessary movements and makes the receiving and sortation process complicated. These complicated inbound processes with different types of flows can make the whole process complex with extra movements and unnecessary touches, which can further lead to holding up goods in between the flows and thus causing delays. Eventually that might lead the binning process to deviate from the expected lead time.

7.3.3 Unreliable receiving data and Lack of transparency

The current method of data capturing in the warehouse, discussed in section 7.2, is not fully automated and involves high amount of touches regarding the scanning procedure. This increased movement of goods for packaging activities requires additional handing of goods. And scanning the barcodes in each step with hand held scanning devices generates high amount of unnecessary touches which in turns make the data capturing method prone to error. In fact, errors are not very uncommon as workers sometimes do not follow the procedures correctly. These errors can have negative impact on the availability of parts and thus can cause customers to wait for a longer period even though the goods are available in stock physically. There are other negative impacts as well such as it can induce doubt about the validity of a portion of the captured data to the other parties of the chain and thus making it difficult to maintain the transparency of the inbound process of the goods.

8. Conclusion and Recommendations

In this final chapter, some concluding remarks and recommendations have been provided for Company Y based on the analyses in the previous chapters and some suggestions have been made for further research.

8.1 Conclusion

The overall performance of receiving process in the central warehouse of Company Y is satisfactory to a certain degree within the scope of this research, given the complex characteristics of the aftermarket service. However, with aiming to reveal the underlying effect of the lead time deviations in the process studied and provide some insights about the situation, the conclusions drawn and recommendations suggested in this chapter might be helpful to understand the significance of having a mindset about the relationships between effective and efficient measurements. Because most of all, the transparent, reliable and traceable supply chain should be the ultimate goal for every organization.

But at first, the presence of the lead time deviation in the receiving process of the warehouse, followed by the discovery of the positive correlation with its mean value, are very well reflected in the safety stock estimations which should have a negative impact on service level, especially in 1 day category. These findings are then further confirmed by the extra movement of goods for consolidation and value-added activities on the operational level. Thus, special attentions might be needed for further investigations and future improvements which might seem necessary to be unfolded and shared among managers on both strategic and tactical levels.

Moreover, the expected receiving lead time defined by the company might not be reflecting the true capacity of the process in the warehouse. As the order lines handled mostly within 4 days for 4 days category, the 1 day category well exceeded the target and received around 2 days for the most part. Although, in general, claiming a room for improvements on both categories (1 day and 4 days) in the future would not be far-fetched if sales increase incrementally following the business boom and market expansions, the ambitious target without appropriate consideration, scientific support and synergy between different departments may not be in the best interest of the customers and the company itself. Therefore, it makes more sense to either simplify the process intended to reduce the variability of receiving lead time which is more likely to decrease its corresponding average lead time (because of the positive correlation between mean and standard deviation of receiving lead time) or be flexible with the target (simply changing 1 day to 2 days for 1 day category and monitoring 4 days category closely).

Furthermore, it is pleasant to notice the changes made to coordinate different warehouse processes under the brand-oriented structure for which the same team are responsible prior to the process-focused one where one team only covers one process assigned. Yet, there is still a road ahead for business process or functional operation integration. It is observed during the quantitative and qualitative analyses of this report that different functions of the company follow different KPIs which are not fully aligned with each other as gaps among targets often exist as discussed in section 7.3.1. In addition to this, there is lack of clear distinction and understanding of the relationships between effective and efficient measurements; KPIs (mostly efficient measures) are not always connected through lead time (defined as effective measurement based on the framework) hence changes in KPIs from one function or department are not reflected in other departments and the unit measure in the lead time also differs as some follow hours (in the warehouse) while others use days (in the Supply Planning team), weeks and periods (DIP team), with inadequate definitions of harmonization and conversion methods, i.e., 24 hours in the warehouse does not necessarily mean 1 day for Supply Planning team.

Finally, information system in the company does not cover both ends of the supply chain, namely, suppliers and end customers; forecasting usually depends on data provided by dealers frequently, meaning complicated forecasts with less accuracy with no direct access to actual sales data from POS. Combined with the effect from lead time deviation, this can further complicate the accuracy of forecasting inventory level in the warehouse. Therefore, the extended integrations of information system from suppliers to customers (horizontal) and from operational level to strategic level (vertical) should be of competitive advantage not only lead to successful business considering increased supply chain transparency but also to implement effective and efficient measurements for better operational performance in terms of customer satisfaction and better market response, knowing the weak links in supply chain beforehand and be responsive about fixing them.

8.2 Recommendations

8.2.1 Simplification of receiving process

One potential reason for the deviation of receiving process from the expected lead time, as indicated in section 7.3.2, can be the existence of extra movements of goods and unnecessary touches during the receiving process which eventually made the receiving process somewhat complex. These deviations can sometimes reach up to 5 or 6 days as mentioned in section 5.6 (Figure 9). To meet the ambitious target of putting goods in stock within 1 or 2 days, first these deviations should be reduced and stabilized which can be done by simplifying the whole receiving process. In the short run, by moving all the value-added activities to the external packaging service provider and eliminating the back and forth movement of goods between warehouse and third-party service provider will help simplify the receiving process. In the long term, the possible option would be to standardize the packaging activities in collaboration with the suppliers and packaging departments, so the suppliers would send the goods in standard form, although comparison should be made in that case as it might increase the transport cost and manufacturing time. On the other hand, it would help standardize and stabilize the receiving activities while achieving FTL for one supplier, except for goods that need to be put in storage without any packaging.

8.2.2 Increasing transparency and making the process reliable

To increase the transparency and reliability of the whole process, especially regarding the receiving lead time that starts right after unloading the goods, better collaborations between different departments are needed. Upgrading the data capturing and transmission methods using RFID technology discussed in section 2.3.1, and installing fixed reading stations for RFID tag near the receiving dock or gate and also inside the warehouse would help reduce the unnecessary touches in each step as well as increase the reliability of data. Additionally, sharing those data in real time with other parts of the chain would make the whole process transparent. This might also be helpful to identify errors form suppliers side and potentially would lead to the reduction of the number of errors in WMS. Integrating these technologies with the WMS might also make it possible to measure the performance indicators, such as goods received per hour, in an easier way. Sharing these performance indicators and linking them through effective measurements such as lead time with other parts of the chain will help realize if there is any capacity constraints in any part. Combining RFID tags on goods received and GPS devices embedded with consignment unit and transport mode where goods stored for travelling between different links within the supply chain should be efficient enough to increase transparency and traceability, which will provide information about the weak links and nodes of supply chain beforehand and enable responsive approach towards problem-solving. These eventually will reinforce collaboration and further develop trustful relationship between the departments.

8.2.3 Aligning KPIs and unit of measurements

Other than the dissimilarities in targets between different departments, the units used for measuring the lead time are also different as this has been found in Section 7.3.1. This might further impede the development of a coordinated system. To maintain uninterrupted synergies between the goals of different departments and to ensure overall effectiveness, it is important to align and measure the targets using the same measurement unit. On operational level, targets and KPIs could be measured i.e. in hours which should be aligned with other sub-processes while the tactical and strategic levels should have some methods implemented to convert and harmonize the unit measures accordingly. Most importantly, KPIs from different levels of the organization, with some of them being more detailed on operational level and some being summarized and specialized while moving up to the organizational hierarchy, should be connected through some specific effective measurements. This is to ensure the applicability of different KPIs designed according to the needs on different levels of the hierarchy and extend connectivity of other performance indicators so that the overall effectiveness of the supply chain is guaranteed and enhanced by the help of extended information system integration both vertically and horizontally.

8.2.4 Consideration of lead time deviation in forecasting

Due to high volume of SKUs and low inventory turn, the aftermarket supply chain tend to be unpredictable and sporadic in nature and depending only on demand forecast can hinder achieving the desired effectiveness that is needed to gain competitive advantage. In this sense, lead time is crucial to maintain the availability of parts and keep the stock at a desired level. Lead time deviations occurring at various links and nodes can have significant impact on the service level and overall customer satisfaction. As discussed in chapter 6, the lead time variability in the receiving process has not been considered when calculating the inventory level at the central warehouse, not to mention the impact of such variations stem from other parts of the chain such as order lead time, administrative process lead time, supplier lead time and transportation lead time. Therefore, it is important to take this deviation into consideration when forecasting the respective safety stock levels up to a point where the operations of goods flows are synchronized and stabilized at such a degree that deviations of lead time are negligible.

8.3 Future research

The theoretical framework used in this study has not yet been proven and developed to the point of theoretical application regardless of industry settings. The next step should include data sampling from other companies with the aim of comparison between two groups; with one having governing factors (such as lead time or cost) for other performance indicators to monitor the overall effectiveness of the supply chain and the other having no such specific understanding towards the distinction of effective and efficiency measurements. Then, the formulas in 3.1 and 3.2 need further mathematical validation before application.

It is worth mentioning that this study only covered the lead time deviation in the inbound process of the central warehouse, a segment of the aftermarket supply chain of the focal company. In future, an extended study should include all segments i.e. supplier lead time, transport lead time etc. to find out the deviations occurring in different links and nodes of the supply chain and their respective impacts on aftermarket supply chain performance.

Following the current trends of automotive industries' shift towards electric vehicle and full service leasing, there might be a game changer for managing the inventory in the aftermarket supply chain. For example, electric vehicles might have different but less number of parts compared to conventional vehicles and some parts like batteries might need special attention regarding handling, storage and recycling processes due to their sensitive characteristics. For the trending business model of leasing vehicles with full service in which the lessor has the responsibility for repairing and maintenance work of the vehicles, there might be a new way of managing the aftermarket service. Therefore, benchmarking from successful companies like Tesla (electric vehicle manufacturer) and Rolls-Royce (pioneer of "power by the hour" concept, where the lessee paid the lessor on a fixed cost basis), scientific evaluations of own organizational characteristics, customization and possible implementation of those business models should be explored accordingly.

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Appendix A – Performance measures for warehouse

According to Warehouse Education and Research Council (WERC, n.d.), below are some of the most important performance measures for warehouses.

Service level

On Time Shipments: The percentage of orders shipped at the planned time. Number of order shipped on time / Total number of orders shipped

Inventory turnover: This can be calculated by dividing the total number of units sold by the average number of units in stock.

Inventory turnover = Cost of Goods Sold / Average Inventory = Inventory Turnover

Total Order Cycle Time: The average end to end time between order placement by the customer and order receipt by the customer.

Excluding non-working days: sum of (Time order received by customer – time order placed) / Total number of orders shipped

Perfect Order Completion Index: A compilation score which measures the result each of the 4 major components of a Perfect Order: (i) Delivered On-Time (ii) Shipped Complete (iii) Shipped Damage Free (iv) Correct Documentation

% orders on time x % orders shipped complete x % orders shipped damage free orders x % orders with correct documentation as defined by customer (e.g. invoice, ASN, labels)

Backorders as a Percentage of Total Orders (Material management): The portion of total orders that are held and shipped late due to lack of availability of stock. This can be measured by lines or by units or by dollar value.

Number of order held and shipped late / Total number of orders

Inbound metrics

To improve and speed up performance, it is important to know how long it takes for each function of inbound flow to complete. Inefficiencies in the receiving dock can have negative impact on the downstream warehouse and distribution functions which can result additional cost.

According to Warehouse Education and Research Council (WERC), warehouses should focus on six inbound metrics to improve their performances.

Dock to stock cycle time (in hours): Dock to stock cycle time is one of the key metrics to measure performance of the receiving, inspection, put away and storage function of the warehouse. It is the time that is required to put away goods. Dock to stock cycle time starts with the arriving of the goods at the warehouse premises from supplier and ends when they are put away in the warehouse and registered in the warehouse management system. It is calculated by the following formula

Dock to stock cycle time = Sum of the cycle time in hours for all supplier receipts / Total number of supplier receipts

According to WERC's DC measure 2010 (Manrodt and Vitasek, 2010), while the best in class have a dock to stock cycle time of around 3 hours and the median is around 10 hours, the bottom performers have a dock to stock cycle time of more than 24 hours.

Supplier orders received (per person-hour): It measures the supplier order received and processed per person per hour within receiving function and is calculated by following

Supplier orders received (per person-hour) = Total number of supplier orders processed in receiving / Total person hours spent in the receiving operation

Lines Received and Put-away (per Hour): Measures number of lines processed and put away per person hour within receiving function.

Lines Received and Put-away (per Hour) = Total number of lines received, processed and put away/ Total person hours spent in the receiving operation

Percentage of supplier orders received with correct documents: number of orders processed with complete/ correct documentation as a percentage of total orders. Documents can include packing slips, case/pallet labeling, certifications, ASN, carrier documents or other documents as required.

Number of supplier orders that are processed with complete or correct documents/total (supplier) orders processed in the measurement period

Percentage of supplier orders received without damage: Percentage of total orders that are processed damage free within receiving functions.

Percentage of supplier orders received without damage = Number of (supplier) orders processed without damage / total number of (supplier) orders processed in the measurement period

On time receipts from supplier: Percentage of total orders that are received on time

On time receipts from supplier = Number of (supplier) orders received on time / Total number of orders received

Appendix B – Partial lead time data

The purpose of this table is to show how the data look like and the actual lead time is calculated using Excel's network days function, i.e., the cell F2 equals to NETWORKDAYS(D2,E2)-1.

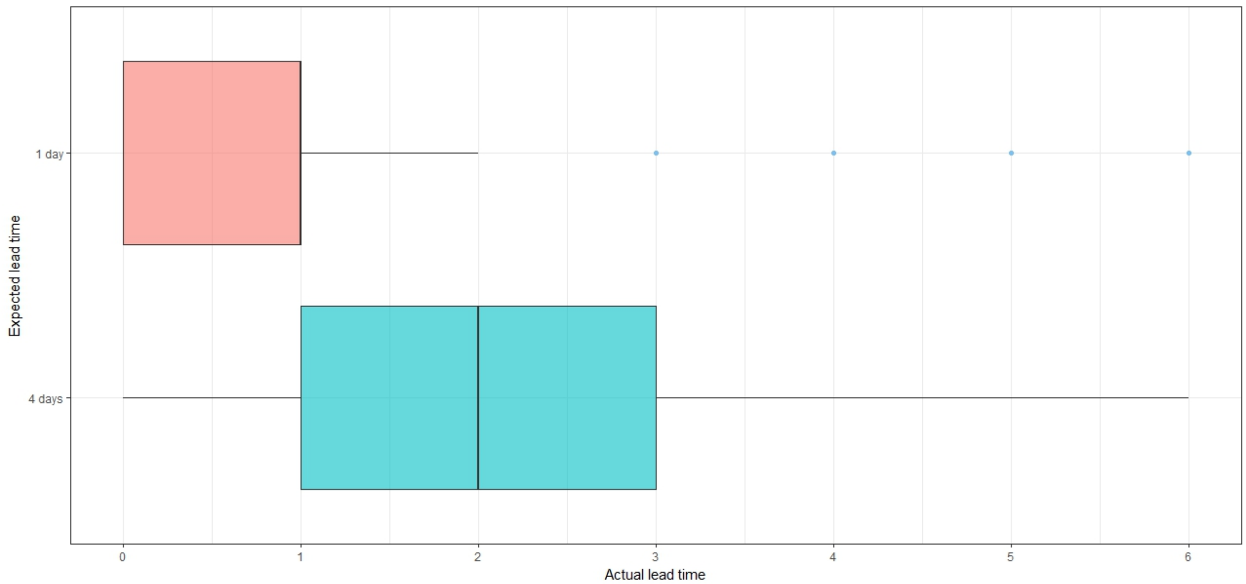
The partial lead time data table

	A	B	C	D	E	F	G
1	Part Number	Main Supplier Number	Description	R31 Date	R32 Date	Actual Lead Time	Expected Lead Time
2	20382388	270	CONTROL ROD	7/5/2017	7/6/2017	1	1
3	20382388	270	CONTROL ROD	8/18/2017	8/22/2017	2	1
4	20382388	270	CONTROL ROD	9/19/2017	9/19/2017	0	1
5	1521938	18	PRESSURE PIPE	8/22/2017	8/23/2017	1	1
6	1521938	18	PRESSURE PIPE	9/12/2017	9/13/2017	1	1
7	1521938	18	PRESSURE PIPE	10/10/2017	10/10/2017	0	1
8	20933766	31	SIGN WINDOW	4/28/2017	5/5/2017	5	4
9	20933766	31	SIGN WINDOW	6/5/2017	6/9/2017	4	4
10	20933766	31	SIGN WINDOW	7/13/2017	7/18/2017	3	4
11	20933766	31	SIGN WINDOW	10/2/2017	10/3/2017	1	4
12	20933766	31	SIGN WINDOW	11/30/2017	12/7/2017	5	4
13	20933766	31	SIGN WINDOW	2/16/2018	2/20/2018	2	4
14	11030	2288	BALL BEARING	6/28/2017	7/3/2017	3	4
15	11030	2288	BALL BEARING	7/19/2017	7/24/2017	3	4
16	11030	2288	BALL BEARING	10/13/2017	10/16/2017	1	4
17	11030	2288	BALL BEARING	12/28/2017	1/4/2018	5	4
18	11030	2288	BALL BEARING	1/10/2018	1/12/2018	2	4
19	11030	2288	BALL BEARING	1/18/2018	1/22/2018	2	4
20	1079948	45676	CONTACT	4/27/2017	4/27/2017	0	1
21	1079948	45676	CONTACT	8/30/2017	8/30/2017	0	1
22	1079948	45676	CONTACT	9/7/2017	9/7/2017	0	1
23	1079948	45676	CONTACT	9/27/2017	9/28/2017	1	1
24	1079948	45676	CONTACT	10/18/2017	10/18/2017	0	1
25	1079948	45676	CONTACT	1/5/2018	1/8/2018	1	1
26	20587258	45676	WIRING HARNESS	10/23/2017	10/25/2017	2	1
27	20587258	45676	WIRING HARNESS	11/27/2017	12/2/2017	4	1
28	20587258	45676	WIRING HARNESS	1/22/2018	1/24/2018	2	1
29	20587258	45676	WIRING HARNESS	2/26/2018	3/2/2018	4	1

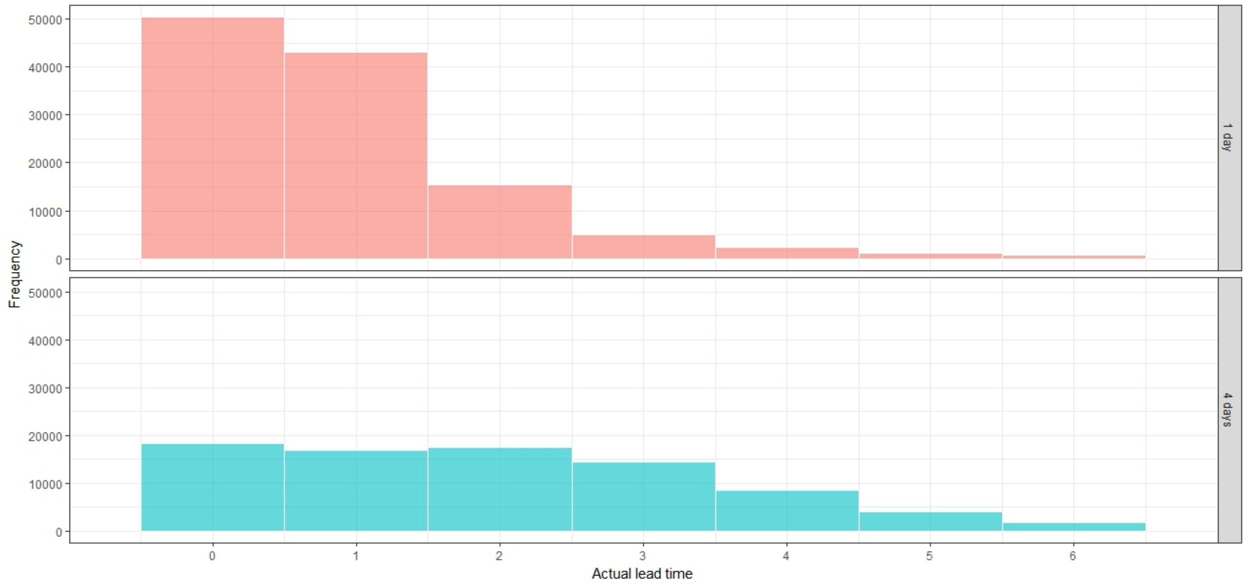
Appendix C – Plots for different groups

In Group A, the actual receiving lead time ranges from 0 to 6 days and the relevant plots are as follows:

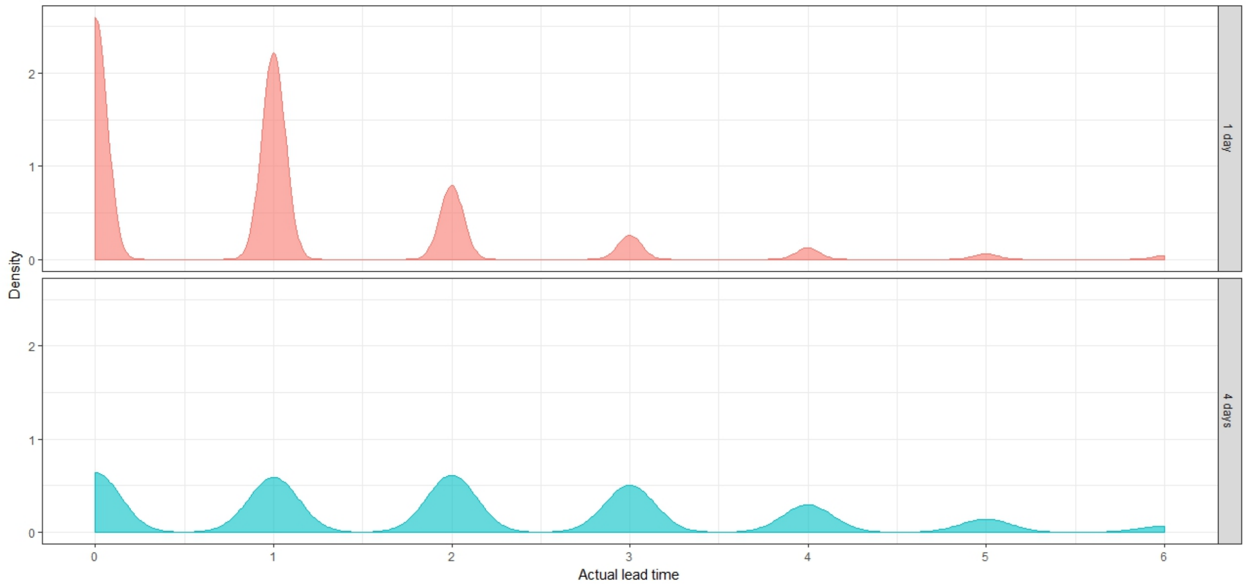
Group A boxplot



Group A histogram

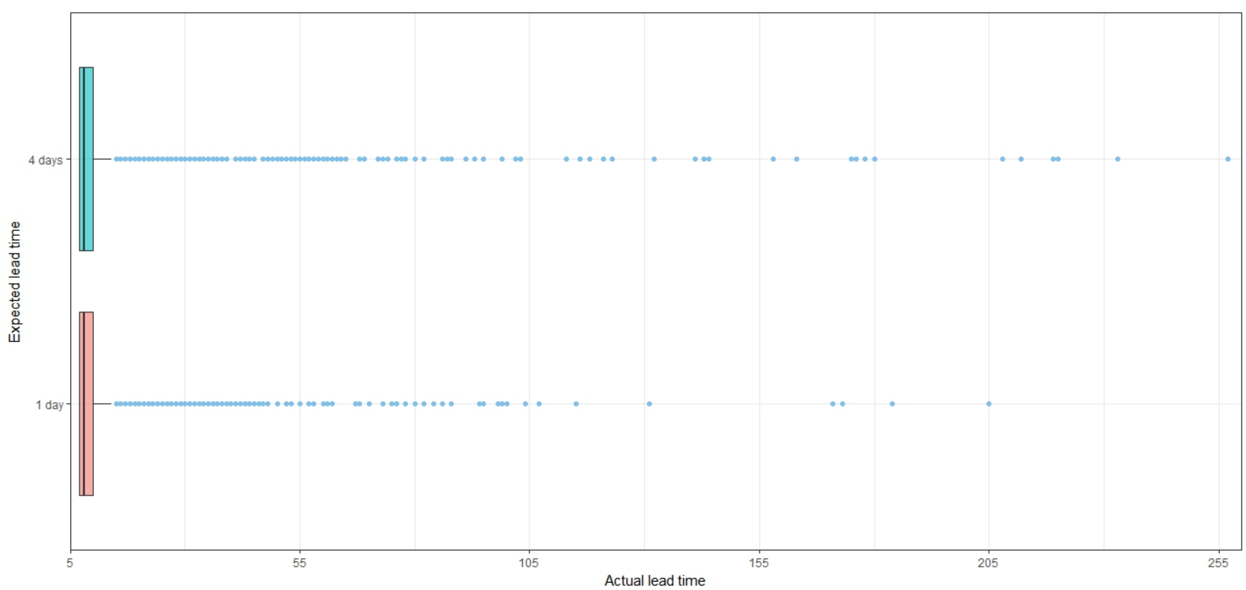


Group A distribution density plot

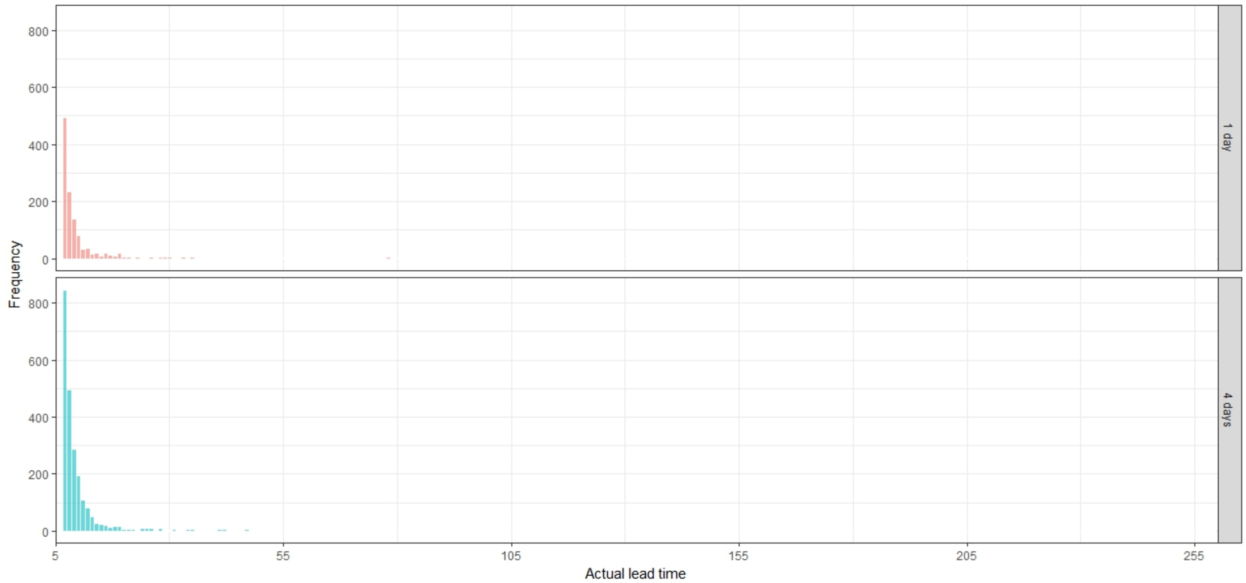


In Group B, the actual receiving lead time ranges from 7 to 257 days and the relevant plots are as follows:

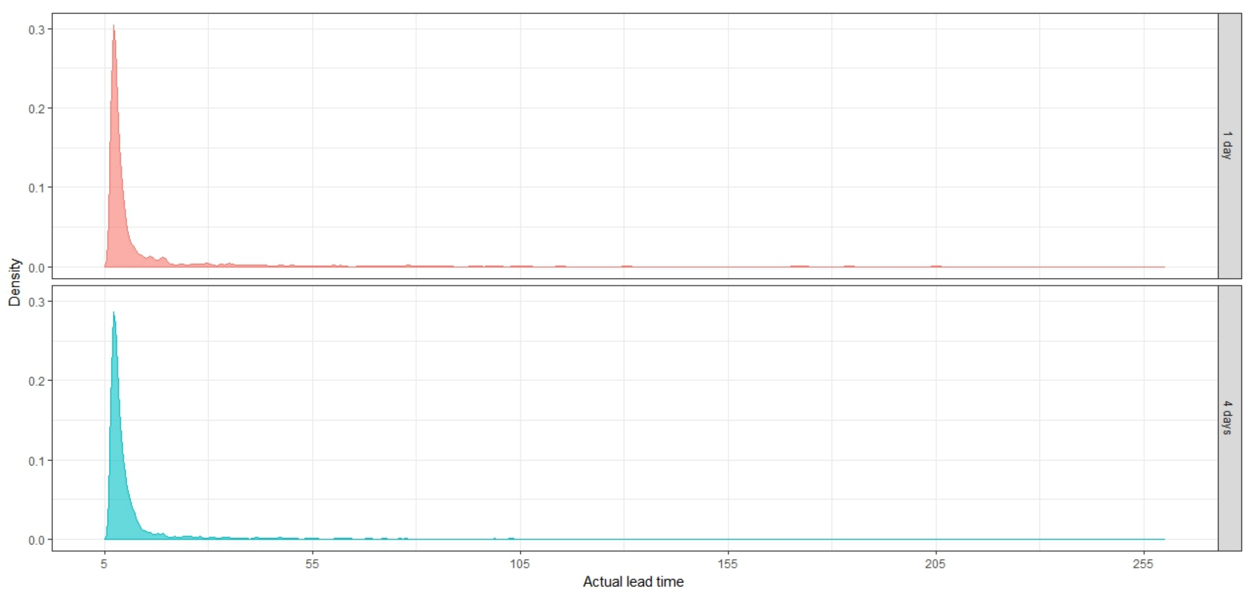
Group B boxplot



Group B histogram



Group B distribution density plot



Appendix D – Partial data for actual receiving lead time variability

The purpose of this table is to show how the aggregation of data for Group A looks like for each part number with its corresponding mean, standard deviation, frequency and frequency interval. Additionally, the frequencies are assigned to their respective intervals with which the number of part numbers are comparable as follows:

Frequency Interval	[1,2)	[2,4)	[4,8)	[8,20)	[20,30)	[30,220)
Number of Part Number	11305	9904	7532	5156	1142	890

Note: The interval is left-closed and right-open.

Group A actual receiving lead time variability table

	A	B	C	D	E	F	G	H
1	Part Number	Main Supplier Number	Description	ELT	AALT	SDALT	Frequency	Frequency Interval
2	1151785	46301	CARDBOARD BOX	4	0.05	0.31	206	[30,220)
3	1151786	46301	CARTON	4	0.03	0.20	151	[30,220)
4	1151788	46301	BOX	4	0.01	0.10	93	[30,220)
5	20961733	23114	BUMPER	4	2.21	1.05	53	[30,220)
6	20718077	13559	COLUMN LOCK	4	0.06	0.23	52	[30,220)
7	20524936	6679	PRESSURE SENSOR	4	0.82	0.68	44	[30,220)
8	1652986	2288	BALL BEARING	4	2.31	2.15	29	[20,30)
9	20764313	13553	ROLLER BEARING	4	1.79	1.09	29	[20,30)
10	21009157	16412	FUEL PIPE	4	2.50	1.38	24	[20,30)
11	20360542	2720	DOOR	4	0.85	1.24	20	[20,30)
12	1599922	124	CAP NUT	4	0.79	0.83	19	[8,20)
13	1151798	14590	BAG	4	0.53	0.78	17	[8,20)
14	1547969	1362	SHIM	4	0.71	0.57	17	[8,20)
15	20863768	6312	KIT	4	2.88	1.17	8	[8,20)
16	21156845	6837	VALVE	4	2.43	0.73	7	[4,8)
17	1075859	12543	CAP PLUG	4	1.83	1.07	6	[4,8)
18	1079319	270	BALL JOINT	4	1.00	0.58	6	[4,8)
19	1087715	44940	JACK	4	2.33	1.11	6	[4,8)
20	20572888	2720	AIR VENT VALVE	4	1.25	0.43	4	[4,8)
21	21155196	28537	REAR WALL PANEL	4	1.00	0.00	3	[2,4)
22	21157373	46682	HOSE	4	3.00	1.41	3	[2,4)
23	21158846	6837	ADAPTER	4	2.00	0.82	3	[2,4)
24	1062054	7890	ROD	4	2.00	0.00	2	[2,4)
25	1062712	1386	HINGE	4	2.00	0.00	2	[2,4)
26	1062870	6128	AIR DEFLECTOR	4	1.00	1.00	2	[2,4)
27	1543469	1728	VALVE COVER	4	4.00	0.00	1	[1,2)
28	1069697	929	WASHER	4	1.00	0.00	1	[1,2)
29	1543577	1883	SEALING RING	4	0.00	0.00	1	[1,2)

Note: ELT- Expected receiving lead time, AALT- Average actual receiving lead time, SDALT: Standard deviation of actual receiving lead time

The frequencies are also assigned to their respective intervals with which the number of part numbers are comparable in Group B as follows:

Frequency Interval	[1,2)	[2,3)	[3,5)	[5,25)
Number of Part Number	2776	217	61	27

Group B actual lead time variability table

	A	B	C	D	E	F	G	H
1	Part Number	Main Supplier Number	Description	ELT	AALT	SDALT	Frequency	Frequency Interval
2	20570092	34588	STEERING KNUCKLE	4	8.00	1.07	7	[5,25)
3	20935640	6175	BATTERY	4	18.00	17.89	7	[5,25)
4	21122541	43508	OIL SEPARATOR	4	66.17	62.55	6	[5,25)
5	20393424	6175	BATTERY	4	21.80	7.19	5	[5,25)
6	21122539	43508	OIL SEPARATOR	4	24.00	21.33	5	[5,25)
7	20522990	7635	WINDSCREEN	4	9.33	2.05	3	[3,5)
8	20576295	7635	WINDSCREEN	4	8.00	0.82	3	[3,5)
9	20589844	18911	RUBBER SEAL	4	48.33	7.04	3	[3,5)
10	20924614	21578	FILTER	4	7.00	0.00	3	[3,5)
11	1606929	16482	WASHER PUMP	4	9.00	1.00	2	[2,3)
12	1654088	6455	NEEDLE BEARING	1	7.00	0.00	2	[2,3)
13	1668459	6687	LOCK RING	4	7.00	0.00	2	[2,3)
14	20398014	1540	DOOR	4	54.00	39.00	2	[2,3)
15	20466350	47914	WIRES	4	8.00	1.00	2	[2,3)
16	21148267	41863	WINDSCREEN	4	94.00	86.00	2	[2,3)
17	21159001	1783	LEVEL SENSOR	4	11.00	3.00	2	[2,3)
18	1062030	6665	SWITCH	4	7.00	0.00	1	[1,2)
19	1062713	1386	HINGE	4	7.00	0.00	1	[1,2)
20	1063116	109	PLATE	4	8.00	0.00	1	[1,2)
21	1066947	27240	HATCH	4	8.00	0.00	1	[1,2)
22	1066959	21982	HOSE ASSEMBLY	4	7.00	0.00	1	[1,2)
23	1069044	723	FLEXPLATE	4	7.00	0.00	1	[1,2)
24	1069204	6687	LOCK RING	4	7.00	0.00	1	[1,2)
25	1076202	1933	HOSE	4	7.00	0.00	1	[1,2)
26	1078564	3370	COVER	4	11.00	0.00	1	[1,2)
27	1087722	5038	MIRROR	4	10.00	0.00	1	[1,2)
28	11418522	1165	FRICTION DISC	4	9.00	0.00	1	[1,2)
29	11022	2288	BALL BEARING	4	9.00	0.00	1	[1,2)

Note: ELT- Expected receiving lead time, AALT- Average actual receiving lead time, SDALT: Standard deviation of actual receiving lead time

Appendix E – R codes

R is a language and environment for statistical computing and graphics and it is free to download[4] and use, but comes with no warranty! R can be extended easily with packages available on its website[5], which also allows users to add additional functionality. Here are the codes used extensively in this report, feel free to copy them and use them for your research and studies!

```
install.packages("plyr")#For each subset of a data frame, apply function then combine results into a data frame#
install.packages("ggplot2")#A system for 'declaratively' creating graphics#
install.packages("car")#This package contains functions and data sets associated with the book An R Companion to Applied Regression#
install.packages("moments")#Functions to calculate Pearson's kurtosis, Geary's kurtosis and skewness#
install.packages("nortest")#Five omnibus tests for testing the composite hypothesis of normality, including Anderson-Darling test#
#Install those packages first using install.packages() and load them before using their functions! Cheer!#
library(plyr)#loading related packages#
library(ggplot2)
library(car)
library(moments)
library(nortest)
library(psych)
library(scales)#scale function for using percentage which is embedded in ggplot2 package#

nonp <- read.csv (file.choose(), header=T)#nonp is an excel csv file which contains the data discussed in the report (section 5.1)
attach(nonp)#Attaching the data to R so that it can be accessed by their column names#
summary(nonp)#Get a summary of the data#

class(ELT)#The value of ELT is identified as "integer"#
nonp$Part_No<- as.factor(nonp$Part_No)#Need to change the value of PLT to "factor"#
nonp$Part_Description<- as.factor(nonp$Part_Description)#Same as above#
nonp$Main_Supplier<- as.factor(nonp$Main_Supplier)#Same as above#
nonp$ELT<- as.factor(nonp$ELT)#Same as above#
nonp$ELT<- factor(nonp$ELT, labels=c("1 day","4 days"))#Changing the value from 1 and 4 to 1 day and 4 days#
class(nonp$ELT)#Check to see if the value changed from integer to factor#
summary(nonp)#Get a summary of the data after the changes#

ddply(nonp, "ELT", summarise, NB=length(ALT))#Getting a number of observation for each category(1 day and 4 days)#

getmode <- function(v) {
  uniqv <- unique(v)
  uniqv[which.max(tabulate(match(v, uniqv)))]
```

[4] https://www.r-project.org/

[5] https://cran.r-project.org/web/packages/

```
} #Getmode function is downloaded from https://www.tutorialspoint.com/r/r_mean_median_mode.htm #

ddply(nonp, "ELT", summarise, Mode=getmode(ALT))#Getting mode values for each category#
ddply(nonp, "ELT", summarise, Median=median(ALT))#Median values for each category#
ddply(nonp, "ELT", summarise, Mean=mean(ALT))#Mean values for each category#
ddply(nonp, "ELT", summarise, Range=range(ALT))#Range values for each category#
ddply(nonp, "ELT", summarise, IQR=IQR(ALT))#Interquartile range values for each category#
ddply(nonp, "ELT", summarise, SD=sd(ALT))#Standard deviation values for each category#
ddply(nonp, "ELT", summarise, Q3=quantile(ALT, 0.75))#Q3 values for each category#
ddply(nonp, "ELT", summarise, RightWhisker=quantile(ALT, 0.75)+1.5*IQR(ALT))#Right whisker values#
ddply(nonp, "ELT", summarise, No=length(which(ALT>3)))#Counting the number of observations where 1 day category's ALT is greater than 3#
ddply(nonp, "ELT", summarise, No=length(which(ALT>6)))#Counting the number of observations where 4 days category's ALT is greater than 6#

ggplot(nonp)+
aes(x=reorder(ELT, ALT, FUN=length), y=ALT, fill=ELT)+
geom_boxplot(outlier.colour = "skyblue", outlier.shape =19, alpha=0.6, outlier.alpha=1)+
scale_y_continuous(limits=c(0,260), breaks=seq(0,260,50), expand = c(0, 0))+
coord_flip()+
labs(x= "Expected lead time", y="Actual lead time")+
theme_bw()+
theme(legend.position="none")#boxplot for Figure 6, including outliers#


aggregate(nonp$ALT, list(nonp$ELT), quantile, probs=seq(0, 1, 0.1))#Finding out 99% of the orderlines handled within 10 days#
nonp1<-nonp[which(nonp[,3]<11),]#Creating dataset for further analyses with lead time between 0 to 10#
nonp1Q3 <- ddply(nonp1, "ELT", summarise, Q3=quantile(ALT, 0.75))#Preparing inserting the Q3 dash lines for both categories#
head(nonp1Q3)

ggplot(nonp1)+
aes(x=ALT, fill=ELT)+
geom_histogram(binwidth = 1, alpha=0.6, col="white", position="identity",
show.legend=T)+
scale_x_continuous(limits=c(-1,10), breaks=seq(0,10,1), expand=c(0,0))+
labs(x= "Actual lead time", y="Frequency")+
facet_grid(ELT~.)+
geom_vline(data=nonp1Q3, aes(xintercept = Q3, col=ELT),
linetype=2, size=0.5)+
theme_bw()+
theme(legend.position="none")#The frequency histogram for lead time interval 0 to 10 for both categories#

ddply(nonp1, "ELT", summarise, N=length(ALT))#Number of observations for both categories#
ddply(nonp1, "ELT", summarise, Median=median(ALT))#Median values for both categories#
ddply(nonp1, "ELT", summarise, Mean=mean(ALT))#Mean values for both categories#
```

```
ddply(nonp1, "ELT", summarise, SD=sd(ALT))#Standard deviations for both categories#
ddply(nonp1, "ELT", summarise, SK=skewness(ALT))#Calculating skewness for both categories#
ddply(nonp1, "ELT", summarise, KU=kurtosis(ALT))#Calculating kurtosis for both categories#
ddply(nonp1, "ELT", summarise, NT=ad.test(ALT))#Testing for normality for both categories#

nonpa<-nonp[which(nonp[,3]<7),]#Creating dataset for Group A#
nonprest<-nonp[which(nonp[,3]>=7),]#Creating dataset for Group B#

describeBy(nonpa$ALT, group=nonpa$ELT)#Calculating descriptive statistics for Group A#
leveneTest(nonpa$ALT~nonpa$ELT, center=median)#Levene Test for Group A#

describeBy(nonprest$ALT, group=nonprest$ELT)#Calculating descriptive statistics for Group B#
leveneTest(nonprest$ALT~nonprest$ELT, center=median)#Levene Test for Group B#

ggplot(nonpa)+
aes(x=reorder(ELT, ALT, FUN=length), y=ALT, fill=ELT)+
geom_boxplot(show.legend=FALSE,
outlier.colour = "skyblue2", outlier.shape =19, alpha=0.6, outlier.alpha=1)+
scale_y_continuous(limits=c(0,6), breaks=seq(0,6,1))+
coord_flip()+
labs(x= "Expected lead time", y="Actual lead time")+
theme_bw()#Boxplot for Group A#

x11()#Opening a window for a new plot#
ggplot(nonpa)+
aes(x=ALT, fill=ELT)+
geom_histogram(binwidth = 1, alpha=0.6, col="white", position="identity",
show.legend=T)+
scale_x_continuous(limits=c(-1,7), breaks=seq(0,6,1), expand=c(0,0))+
labs(x= "Actual lead time", y="Frequency")+
facet_grid(ELT~.)+
theme_bw()+
theme(legend.position="none")#Histogram for Group A#

x11()
ggplot(nonpa)+
aes(x=ALT, fill=ELT, col=ELT)+
geom_density(alpha = 0.6)+
scale_x_continuous(limits=c(0,6), breaks=seq(0,6,1))+
labs(x= "Actual lead time", y="Density")+
facet_grid(ELT~.)+
theme_bw()+
theme(legend.position="none")#Distribution density plot for Group A#

x11()
ggplot(nonprest)+
aes(x=reorder(ELT, ALT, FUN=length), y=ALT, fill=ELT)+
```

```
geom_boxplot(show.legend=FALSE,
outlier.colour = "skyblue2", outlier.shape =19, alpha=0.6, outlier.alpha=1)+
scale_y_continuous(limits=c(5,260), breaks=seq(5,260,50), expand=c(0,0))+
coord_flip()+
labs(x= "Expected lead time", y="Actual lead time")+
theme_bw()#Boxplot for Group B#

x11()
ggplot(nonprest)+
aes(x=ALT, fill=ELT)+
geom_histogram(binwidth = 1, alpha=0.6, col="white", position="identity",
show.legend=T)+
scale_x_continuous(limits=c(5,260), breaks=seq(5,260,50), expand=c(0,0))+
labs(x= "Actual lead time", y="Frequency")+
facet_grid(ELT~.)+
theme_bw()+
theme(legend.position="none")#Histogram for Group B#

x11()
ggplot(nonprest)+
aes(x=ALT, fill=ELT, col=ELT)+
geom_density(alpha=0.6)+
scale_x_continuous(limits=c(5,260), breaks=seq(5,260,50))+
labs(x= "Actual lead time", y="Density")+
facet_grid(ELT~.)+
theme_bw()+
theme(legend.position="none")#Distribution density plot for Group B#

GroupA <- read.csv (file.choose(), header=T)#Creating another new data after aggregating values for each part number#
attach(GroupA)
names(GroupA)
summary(GroupA)

GroupA$Part_No<- as.factor(GroupA$Part_No)
GroupA$Part_Description<- as.factor(GroupA$Part_Description)
GroupA$Main_Supplier<- as.factor(GroupA$Main_Supplier)
GroupA$ELT<- as.factor(GroupA$ELT)
GroupA$ELT<- factor(GroupA$ELT, labels=c("One day","Four days"))
summary(GroupA)

Interval<- cut(CPN, breaks=c(1,2,4,8,20,30,220), right=F)#Creating frequency interval#
data1<-data.frame(GroupA, Interval)#Merging the frequency interval with Group A data#
View(data1)#Viewing the new data please see Appendix E#
summary(Interval)#Summarizing the frequency intervals and the respective observation numbers for each part number#
```

```
ggplot(data1)+
aes(SDALT, AALT, col=ELT)+
geom_point(position="identity",alpha=0.5)+
scale_y_continuous(limits=c(0,6), breaks=seq(0,6,1))+
labs(x= "Standard deviation", y="Average lead time for each part",
col="Expected lead time")+
facet_grid(.~ Interval, labeller=label_both)+
theme_bw()#Figure 8, the scatter plot of the standard deviation against the mean for Group A#

#Same steps for Group B#
GroupB <- read.csv (file.choose(), header=T)
attach(GroupB)
names(GroupB)
summary(GroupB)

GroupB$Part_No<- as.factor(GroupB$Part_No)
GroupB$Part_Description<- as.factor(GroupB$Part_Description)
GroupB$Main_Supplier<- as.factor(GroupB$Main_Supplier)
GroupB$ELT<- as.factor(GroupB$ELT)
GroupB$ELT<- factor(GroupB$ELT, labels=c("One day","Four days"))
summary(GroupB)

Interval<- cut(CPN, breaks=c(1,2,3,5,25), right=F)
data2<-data.frame(GroupB, Interval)
View(data2)
summary(Interval)

ggplot(data2)+
aes(SDALT, AALT, col=ELT)+
geom_point(position="identity",alpha=0.5)+
labs(x= "Standard deviation", y="Average lead time for each part",
col="Expected lead time")+
facet_grid(.~ Interval, labeller=label_both)+
theme_bw()#Figure 9#

#Cumulative percentage of parts handled by 1 day and 4 days categories for Group A #
ddply(GroupA, "ELT", summarise, One=percent(sum(AALT<1)/length(AALT)))
ddply(GroupA, "ELT", summarise, Two=percent(sum(AALT<2)/length(AALT)))
ddply(GroupA, "ELT", summarise, Three=percent(sum(AALT<3)/length(AALT)))
ddply(GroupA, "ELT", summarise, Four=percent(sum(AALT<4)/length(AALT)))
ddply(GroupA, "ELT", summarise, Five=percent(sum(AALT<5)/length(AALT)))
ddply(GroupA, "ELT", summarise, Six=percent(sum(AALT<6)/length(AALT)))
ddply(GroupA, "ELT", summarise, Seven=percent(sum(AALT<7)/length(AALT)))
```

Finally, I would like to thank my wife, Kaya and my family back home in Karamay, China for their support. I also would like to thank Dr. Cao Qi for his help in guiding me with statistical analyses. I sincerely wish good health and fortunes to all my relatives, friends and colleagues, especially to my Dad. Get well soon Dad!!! I love you all!!!#

Appendix F – Partial data for demand and lead time for each part

	A	B	C	D	E	F	G	H
1	**PN**	**TLT**	**AD**	**SDD**	**SL**	**ELT**	**AALT**	**SDALT**
2	1062028	3	19.38	8.54	0.98	1	0.50	0.76
3	1062030	3	8.85	5.64	0.98	4	3.25	2.17
4	1062052	3	18.38	21.20	1.00	1	1.50	0.50
5	1062567	3	30.08	20.98	1.00	1	1.25	1.09
6	1062568	3	32.15	19.33	1.00	1	0.75	0.43
7	1062569	3	28.92	19.54	1.00	1	0.50	0.50
8	1062570	3	18.92	13.00	1.00	1	1.00	1.00
9	1066762	6	32.69	19.18	0.50	1	0.68	0.86
10	1066823	6	19.69	3.15	1.00	1	1.50	0.50
11	1066831	4	23.38	45.29	0.92	1	0.94	0.80
12	1066857	4	467.38	649.23	0.50	1	1.94	2.08
13	1069504	9	38.08	22.88	0.99	1	1.50	1.50
14	1069507	4	2.77	1.60	0.97	4	2.25	0.83
15	1069508	4	2.38	1.91	0.94	4	3.33	2.05
16	1069509	5	74.15	30.90	0.98	1	0.91	1.08
17	1134091	5	53.69	22.61	0.70	1	3.33	2.62
18	1134385	5	130.54	28.45	1.00	4	1.33	0.47
19	1134445	4	103.46	15.87	0.99	1	0.78	0.88
20	1134566	2	157.54	19.70	1.00	1	2.22	2.35
21	1134748	13	0.62	0.96	0.55	1	4.00	2.00
22	1134815	12	119.92	85.21	0.98	4	2.20	1.17
23	1139717	4	0.77	3.54	0.50	4	2.67	2.05
24	1139721	7	0.08	0.28	0.50	1	2.50	2.50
25	1139752	7	0.08	0.29	0.50	4	5.50	2.50
26	1151786	3	8237.54	2158.04	0.50	4	0.03	0.20
27	1151787	3	9989.92	2410.02	0.97	4	0.03	0.27
28	1151788	3	475.77	149.55	0.60	4	0.01	0.10
29	1151789	3	476.77	127.54	0.60	4	0.04	0.42

Note: PN- Part number, TLT- Total lead time, AD- Average demand, SDD: Standard deviation of demand, SL: Service level, ELT- Expected receiving lead time, AALT- Average actual receiving lead time, SDALT: Standard deviation of actual receiving lead time.

Appendix G – Partial safety stock results

	A	B	C	D	E	F	G	H	I	J
1	PN	TLT’	AD	SDD	Z	ELT’	AALT’	SDALT’	SS in (2.1)	SS in (2.2)
2	102726	1.75	340.62	95.4	2.37	0.20	0.01	0.02	298.55	282.64
3	10523	2.00	51.62	23.16	2.65	0.05	0.03	0.02	86.86	86.56
4	1062018	1.00	3.31	2.36	0.13	0.05	0.05	0.05	0.30	0.30
5	1062027	0.75	32.00	11.56	1.96	0.05	0.00	0.00	19.62	18.96
6	1062028	0.75	19.38	8.54	2.00	0.05	0.03	0.04	14.76	14.58
7	1062030	0.75	8.85	5.64	2.12	0.20	0.16	0.11	10.36	10.30
8	1062052	0.75	18.38	21.2	2.88	0.05	0.08	0.03	52.84	53.73
9	1062053	0.75	22.15	17.57	2.75	0.05	0.05	0.00	41.81	41.81
10	1062054	0.75	21.38	21.75	2.75	0.20	0.10	0.00	51.76	48.18
11	1062055	0.75	20.08	22.51	2.75	0.05	0.05	0.00	53.57	53.57
12	1062097	1.25	22.62	8.67	2.75	0.05	0.05	0.00	26.64	26.64
13	1062127	1.00	1.54	1.12	2.29	0.05	0.05	0.00	2.57	2.57
14	1062130	0.50	18.54	8.38	2.37	0.05	0.03	0.03	14.02	13.71
15	1062134	1.00	7.85	5.15	2.12	0.05	0.05	0.00	10.92	10.92
16	1062136	0.75	4.15	2.05	1.55	0.05	0.00	0.00	2.76	2.67
17	1062137	0.75	7.00	3.28	1.55	0.05	0.06	0.02	4.42	4.46
18	1062374	1.25	0.38	0.51	0.00	0.05	0.06	0.04	0.00	0.00
19	1062551	1.00	6.08	2.01	1.51	0.20	0.10	0.00	3.04	2.89
20	1062567	0.75	30.08	20.98	2.75	0.05	0.06	0.05	49.93	50.54
21	1062568	0.75	32.15	19.33	2.75	0.05	0.04	0.02	46.00	45.65
22	1062569	0.75	28.92	19.54	2.75	0.05	0.03	0.03	46.50	45.76
23	1062570	0.75	18.92	13	2.75	0.05	0.05	0.05	30.94	31.04
24	1062601	4.75	3.23	2.92	0.00	0.20	0.05	0.00	0.00	0.00
25	1062636	0.75	291.08	46.72	2.33	0.05	0.05	0.04	94.13	97.80
26	1062712	2.25	11.85	4.53	2.12	0.20	0.10	0.00	14.41	14.08
27	1062713	2.25	13.08	7.27	2.12	0.20	0.15	0.12	23.12	23.09
28	1062801	1.00	1.23	1.39	0.00	0.05	0.10	0.05	0.00	0.00
29	1062870	1.00	2.15	1.51	0.00	0.20	0.05	0.05	0.00	0.00

Note: PN- Part number, TLT’- Converted total lead time, AD- Average demand, SDD- Standard deviation of demand, Z- Z score, ELT’- Converted expected receiving lead time, AALT’- Converted average actual receiving lead time, SDALT: Converted standard deviation of actual receiving lead time, SS in (2.1)- Safety stock result using function (2.1), SS in (2.2)- Safety stock result using function (2.2)

Appendix H – List of Interviews

Interviewee	Department	Position	Date
Interviewee 1	Supply Planning	Manager	2018-03-22 2018-03-26
Interviewee 2	Warehouse Operations	Operational Resource Planner	2018-04-11
Interviewee 3	Warehouse Operations	Team leader, Inbound	2018-04-12
Interviewee 4	Warehouse Operations	Manager, Operations Vehicle Type 1 & 2	2018-04-12
Interviewee 5	Demand and Inventory Planning	Demand and Inventory Planner	2018-04-18
Interviewee 6	Material Management and Theoretical Optimization	Supply Chain Data Modeling Expert	2018-05-02

**The list of interviewees is in ascending order based on the date of the interviews*

Appendix I – Interview Guide

Below you'll find 3 different sets of questions for different profile/personnel (Each interview should take approximately 60-75 minutes)

Warehouse Management (Tactical level management)

Expected Profile

A contact who would be able to give us a holistic overview about the processes and all the sub-functions in the central warehouse; and, would be able to give us an idea about how the processes in the warehouse are managed and are aligned within the SML's internal supply chain.

Required time: 60 minutes

Questions:

1. What are the main goals/objectives of the warehouse?
    a. What kind of role does the warehouse play for making the whole supply chain effective?
    b. How do you think they are aligned with the company's overall strategic objectives?
2. Could you give us some general ideas about the processes and network of flows in the warehouse?
    a. How many teams/sub functions/departments are there in the warehouse?
    b. How are their responsibilities divided?
3. Do you have any flowcharts/steering documents about the warehouse operations?
4. What are the main KPIs/ performance measures that are followed in the warehouse?
    a. Are there separate KPIs/performance measures for inbound and outbound flows? (inbound metrics/outbound metrics)
5. Do you think these KPIs are aligned with the overall strategic goals of the warehouse?
6. Do you think these specific KPIs clearly translate the goal of the WO to operational level employees?
7. Could you tell us about your view on the effectiveness and efficiency of your warehouse operation?
    a. Do you consider these as two separate concepts?
    b. Do you think the effectiveness of your warehouse should govern the efficiency of the warehouse operations?
8. Do you benchmark and evaluate your performance?
9. How the ASN (advanced shipping notice), that is sent to warehouse prior to the arrival of goods, are managed and used?
10. How are the cross-docking activities managed in the warehouse?
11. Recently Company Y is facing a lot of issues regarding divations in receiving lead time in the warehouse. In your opinion, what can be the reasons behind this?

12. How do you manage information sharing with other departments within Company Y’s internal supply chain)?
13. Do you think the operations in the warehouse matches its capacity?
14. Do you think that there are needs for improvements and investments?

Warehouse Operations (Operational level management)

Inbound Flow

Expected Profile

- At least one person (preferably team leader) working with inbound flow and binning activities in the central warehouse (mainly inbound flow from suppliers).

Required time: 60 minutes

Questions:

1. Could you please give us a general Idea about the inbound flows/receiving processes of the parts (starting from the point when the parts arrive at the warehouse)?
2. How are shifts and staffs managed within the warehouse?
    a. Does ASN play any role during planning of resources and manpower allocation?
3. How do you decide which parts need to go through inspection before binning and which parts can be directly binned without inspection?
4. How are the goods sorted after unloading? (Immediately or during binning process?)
5. How do the binning activity (put-away process) initiates?
6. Do you use batch binning (similar parts based on classification factors are binned together)?
    a. If you do not have enough parts/products for a full batch what do you do with them?
7. How long the goods can wait in receiving area?
8. How are the goods handled while binning from receiving area?
9. How does a specific part/product get suggestion for storage space (enough space to be binned and where to be binned)?
    a. When there's not enough space for binning what do you do?
10. When is a product classified as “binned” in the system?
    a. How do you do it? (manually/automatic?)
    b. How is this communicated to the successive department?
11. For inbound flow, there are specific “receiving lead times” for each specific parts. How do you manage this “receiving lead time”?
    a. How often do you face deviations for the receiving lead time? (in case of supplier flow)

    b. In your opinion, what are main reasons behind these deviations?

12. How the prioritized flows (relating to back-order) are managed?
    a. Do you think the prioritized flow (relating to back-order) creating congestion or hindering regular activities?
    b. How do you manage regular work when there are too many prioritized orders?
13. How is performance regarding inbound flow being measured in the warehouse? (productivity/ Dock-to-Stock cycle time?)
14. How do you align your processes and activities with the overall efficiency of the warehouse operation in general?
15. How do you communicate with higher level management and your colleagues on operational level?
    a. Do you receive improvement suggestion from bottom-up often? To which extent?
    b. How about the top-down instructions?
    c. In your opinion, if any improvement were to taken, which part of the process it should be? How?
16. Could you tell us about your view on the effectiveness and efficiency of different sub-processes such as receiving, inspection, binning, etc.?
    a. In your opinion, how do you make these processes more effective?

Material Management, Theoretical Optimization

1. What is the current setup of the warehouse and its relation with RDC in North America and South America?
    a. Does the warehouse serve as the main distribution center for the company?
    b. If it is yes, do you have any plan to change it?
2. How do you make connection with the lead time and KPIs within the supply chain?
    a. What are the connections there? Which KPIs are connected to the lead time?
3. Do you plan to use actual sales data in the EDI system and share them with other departments within the supply chain?
    a. For example, reducing the impact of forecasting by using actual sales data or simply replacing them?
    b. Focusing more on reducing the lead time uncertainties to meet the actual demand, instead?
4. Why standard deviation of LT is not taken into consideration when calculating Safety Stock. (because it’ll clearly affect the Safety stock and service level)
5. Are you aware about the receiving lead variability at the warehouse? What is your thought about this?
    a. How is it affecting the Service level?