Master's thesis

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A literature review and analysis of Lean supply elements in Engineer-To-Order (ETO) setting.

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Preface and Acknowledgment

This master's thesis is written for the Department of Industrial Economics and Technology Management (IØT) at the Norwegian University of Science and Technology during the spring 2020 semester. The thesis is individually conducted and authored by Anoop Mupparichalil, who is currently enrolled as a student in the final semester of MSc Project management.

The targeted audience is the thesis supervisor, evaluators, academicians, and firms operating in Engineer- to-order setting. The purpose of this paper is to explore what literature says about lean supply and elements of lean supply in ETO setting. As the student who is currently pursuing a master's degree in Project Management, this report is aimed to elaborate upon knowledge learned during the study program.

Further, l would like to thank professor Ann-Charlott Pedersen who was my main supervisor and Leandro dos Santos who was my co-supervisor for their valuable time and guidance.

July 2020. Anoop Mupparichalil

Abstract

Purpose

The purpose of the thesis is to discuss what extend the study about lean supply in Engineer-to-order (ETO) was carried out and the relevance/applicability of Lean Supply and elements of lean supply in ETO setting.

Design/methodology/approach

The thesis is literature analysis, and, first, I introduced the lean supply and different elements of lean supply. Second I introduced the ETO setting and lean in ETO setting. Further, I did a research review of relevant articles on lean supply in ETO setting. From this, I prepared a framework on what to analyze from the literature review. Further, I analyzed the article vertically, and then what the articles discuss the element of lean supply, such as lean supplier development, Just-in-Time(JIT), and long term relationships.

Findings

It was identified that the studies on lean supply in ETO were relatively recent. Further on the relevance and applicability of lean supply and elements of lean supply, it was observed that, with customization of the practices of lean supply elements, the lean supply could be adopted in the ETO setting. However, the lean supply practices such as lean supplier development, JIT, long-term relationships are seen not adopted, as is similar to the mass-production industry in the ETO setting.

Research limitations/implications / Practical implications

In this research, all the 12 elements of lean supply were considered to analyze. This can limit the extent of generalization of validation of the finding. Further, the research was carried out based on literature analysis, and the literature were selected by the narrative method, and some manual inclusions and exclusion were carried out, which might limit the reproducibility of the selection of articles considered for review.

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Abbreviations

AHP	Analytic Hierarchy Process
APM	Action Plate Method
ATO	Assemble to Order
BP	Best Practice /Best Process /Best Performance
CODP	Customer Order Decoupling Point
CRM	Customer Relationship Management
ETO	Engineer-To-Order
HRM	Human Resource Management
HV/LV	High Volume/ Low Volume
IP	Intellectual Property
JIT	Just-In-Time
LP	Lean Purchasing.
LS	Lean Supply
MCT	Manufacturing Cycle Time Reduction
MTO	Make to Order
MTS	Make to Stock
OMCD	Operations Management Consulting Division.
PDA	Plant Development Activity
QC	Quality Control
RCA	Route Cause Analysis
RFID	Radio Frequency Identification
SD	Supplier Development
SMED	Single Minute Exchange of Die
SRM	Supplier Relationship Management
TPM	Total Productive Maintenance
TPS	Toyota Production System.
TQC	Total Quality Control
TQM	Total Quality Management
VMI	Vendor Management Inventory
VSM	Value Stream Mapping

1 Introduction

The global competition in today's market and associated challenges have impelled many firms to explore new management approaches in order to improve the firm's competitiveness and efficiency To understand the overall framing of this thesis and its relevance, it is important to briefly discuss the challenges associated with conventional supply system.

In a conventional supply system, a purchase decision is mainly based on quoted price and thus supplier tend to give a low bid to secure business order aiming to increase the price in the future orders with negotiations. This eventually leads to price increase to customer and thus a low price bid becomes higher price (Womack et al., 1990b). Similarly, in conventional supply system some suppliers may withhold critical information from buyers to have the advantage in negotiations or extending the same product to several customers with relatable/similar needs (thus often leading to production/non-compatibility issues during assembly). The counter tactics employed by the buying firm in such situations include involving multiple suppliers, which often lead to trust issues and conflicts (both with internal and external suppliers – from fear of losing the business or order volume). Thus in effect deteriorating the buyer-supplier relationship (Womack et al., 1990b). Another downfall of such conventional systems occurs when the buyer is bound to only one supplier due to complexity in the overall production process. In such scenarios, there might be changes to some parts or the whole production process, thus necessitating renegotiations with the supplier and need to establish close relationship between both the parties. However, certain suppliers maybe reluctant to such negotiations or to opening up their facilities for collaborations (from fear of IP issues and business advantage among others). Thus, adversely affecting the whole process quality and deliverable. In short, the conventional supply system poses a number of challenges while put into practice and is further aggravated due the complexities in ETO projects that form the major focus of this thesis. Hence, the following chapters of this thesis investigates the concept of lean in addressing these challenges.

From the above explanation, it is quite convincing that there are limitations to the conventional supply system. Moreover, there is a need for a better system which can possibly eliminate all the limitation of conventional supply. Lean supply is widely regarded as one of the efficient systems which address most of the limitations of conventual supply, where there is ensured compatibility of parts/components supplied, where there is a better relationship with the supplier and improved trust, better control of the cost of the procuring products/items, better quality and delivery control of the procured items, improved and incorporating failure rectification system (Womack et al.,

1990b). Sako (2004), in their study of supplier development in the Japanese automotive industry, discusses the concepts of lean supply in the context of supplier development though did not use the term Lean supply explicitly. According to Dos Santos et al. (2020), lean supply consists of elements of Supply Management, Logistics, Supply Chain Management, Lean Management, the Toyota Production System. Process and production enhancement and their continuous improvement beyond the boundaries of a lean firm are the typical focuses of Lean supply. Lean supply techniques focus on external integration and extended value streams that add value to products and services to sustain the competitiveness of a lean firms and value chains (dos Santos et al., 2020). More about lean supply and elements/characteristics of lean supply are discussed in theoretical background chapter 2.2.

The aim of this master thesis is to focus on the lean extension beyond the boundaries of a lean firm in a particular manufacturing approach, which is Engineer-to-order (ETO). As part of the semester assignment of the master's study program (Mupparichalil, 2019), a study about the pertinence of lean supply and lean supplier development in different sectors and manufacturing approaches, other than mass production, became apparent. Lean supply is observed to be consisting of 12 key elements, 1) Delivery practices (JIT systems, pull production), 2) Problem solving & continuous improvement 3) Flow Integration and system supply 4) Supplier involvement in product development 5) Customer focus 6) Supplier quality assurance 7) Effective communication with Information sharing 8) Relationship type: collaboration & partnership 9) Relationship horizon: long-term collaboration 10) Few suppliers in the supply base 11) Multi-criteria supplier selection 12) Supplier development & support (dos Santos et al., 2020). Lean supplier development is one of these 12 elements.

In the previously mentioned project thesis (Mupparichalil, 2019), I addressed lean supplier development activities, and suppliers' motivation/involvement in lean supplier development activities, within a limited scope. That thesis consisted of a review of various literature on lean supplier development and relational aspects of supplier and buying firm. Moreover, the performed literature search showed a wide range of articles with a keyword of 'lean supplier development' in different electronic databases. There were different articles and studies about lean supplier development in mass production firms. That study also gave the impression that there is a gap in the study about 'elements of lean supply, especially 'lean supplier development' in the context of products typified as low volume, highly customized product manufacturing environment, such as ETO manufacturing. Particularly, there were no explicit 'case studies' found for ETO setting

(similar to mass production firms) about 'lean supplier development' in the literature search performed with the keyword 'lean supplier development'.

Womack et al. (1990), in his book, presented lean as the next paradigm of manufacturing beyond mass production. The Toyota production system (TPS), which was based on two basic systems, 'cost reduction through elimination of waste and full utilization of workers capabilities', was generally considered to be the best-known example of lean. However, Toyota's success, where lean management is inspired by, was mostly from their group of firms operating under similar market and product technology solutions which include a limited product offering with little to no customization, production in high volume resulting in repetitive manufacturing, and a relatively stable or predictable demand (Lander and Liker, 2007). So, firms operating in high variability, low volume environments, or offering products on a build to order or have highly engineered, are often seen struggling to relate their business with Toyota's system when attempting to apply lean, especially to the novel circumstances (Lander and Liker, 2007). According to Lander and Liker (2007), the reason for this is mainly the way companies are viewing the Toyota production system and how they are trying to approach implementation.

According to Netland and Powell (2016), lean in one setting may be anti-lean in another setting, and variation is a bothering situation for lean, also applying lean under more variation is the goal in successful lean innovation. Besides, Lander and Liker (2007) mentioned, the only way to develop true Toyota-style systems in environments vastly different from those for which the lean solution has already been developed, is to apply the same principles that people in Toyota have used to shape what is recognized today as TPS. 'Applying the same thought process to a novel environment will result in a Toyota-style system customized for the particular conditions the firm faces' (Lander and Liker, 2007, p3683). This implies the lean supply and elements of lean supply, such as supplier development, can be argued to be implemented in the ETO setting. Lean supplier development is one of the elements of lean supply (dos Santos et al., 2020). Hence, all these observations prompted to investigate this aspect in the current thesis; thus, elements of lean supply studies in engineer-to-order (ETO) is considered to be an area to explore. Delivery practices (JIT systems), and long term-relationship are two other lean supply elements which are much discussed in the mass production setting. These two elements are very much coupled with lean supplier development. A lean supply system establishes primarily on the basis of the relationship (Womack et al., 1990b). Similarly, JIT (Just-in-Time) is a key aspect and which was one of the primary reasons to have supplier developments, especially in automotive industries in Japan (Sako, 2004).

So, when lean supplier development in ETO setting becomes an area to explore, JIT and long-term relationship is also an area of interest to explore because of the close influences. Thus, within the scope of this thesis, these two elements of lean supply are to be considered of area interest.

This thesis will investigate what extent literature says about lean supplier development, JIT, long-term relationship in the ETO setting. Further, I will explore the available information in the literature regarding the applicability of some of these lean supply elements in the ETO setting. For the investigation, I will perform a search of literature which are related to 'lean supply' in ETO context. After selecting a sample of relevant literature, I will review this literature to explore relevant information, which is pertinent for lean supplier development, JIT, long-term relationship for ETO. For that, it is aimed to use electronic databases for literature, which includes published articles.

1.1 Research question

The research performed in the project thesis (Mupparichalil, 2019) was within a limited scope, which included a limited number of articles for the review. So, in this research, more material/documents, including prominent textbooks, published articles will be reviewed to investigate further about lean supplier development, JIT, long-term relationship in ETO setting. To explore the gap of study in the elements of lean supply such as lean supplier development, JIT, long-term relationship in ETO, it is required to explore more literatus which are focused on this area. This study will limit to information available in the published article to investigate how much and what extend is written in literature about this. Hence, the research question in this thesis is:

Q1. What the literature says about lean supply elements such as lean supplier development, JIT, long-term relationship in ETO setting?

By doing research on the topic in this thesis, it is aimed to touch on the areas about the lean supplier development, JIT, long-term relationship difference of ETO and high-volume production. The next subsection will describe the background for this research: the lean supply setting

1.1 Background: the lean supply setting.

Nowadays, lean is widely discussed not only across different functional areas of traditional mass-production manufacturing firms but also in different kinds of industry sectors. Although many business concepts have emerged and have proven to be relatively short-lived and modish, lean is displayed as maintaining a notable position for decades. Womack & Jones (1997)'s study and

literature contributed to learning on extending the scope of lean beyond just manufacturing, by extracting the essence of lean into principles pertinent to any organization. According to Netland and Powell (2016), as shown in Figure 1, the lean principles/philosophies are diffused across the firm/enterprise and into new industry sectors over the period, and it keeps continuing at a rapid pace.

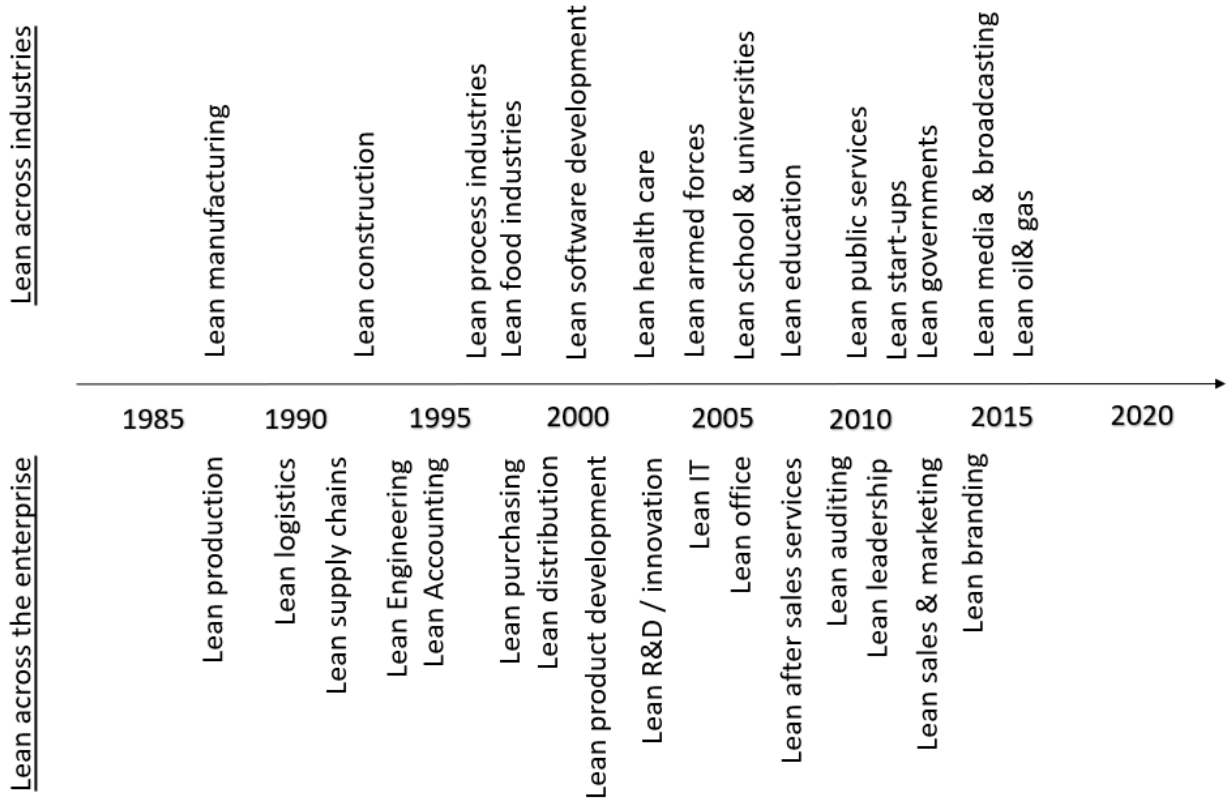

Figure 1. The spread of lean thinking across the enterprise and select industries (Netland and Powell, 2016a)

Part of such diffusion of lean philosophies contributed to extending lean within and beyond boundaries of firms/enterprises and into their interfaces in different dimensions. Womack and Jones, (1997) mentioned that the lean principle could be applied beyond a firm's boundaries to maximize value to the buying firm. Many firms, got encouraged after the inspiring study of Womack & Jones (1994), and after adopting lean implementation programs to eliminate internal waste, firms concentrated on improving extended value streams by involving supplier counterparts. Jones & Womack (2002) mentioned that the extension of lean programs should include practices that involve suppliers in finding and reducing problems that affect internal and external processes. To obtain the full adoption of lean in the suppliers, it is vital that suppliers

members share the same lean knowledge, and their production systems are synchronized (Dyer and Nobeoka, 2000a).

Firms incorporated lean supply are observed to achieve their intended objectives in improving competitiveness and efficiency. The affair of lean has emerged and mostly associated with firms characterized as high-volume production. Over the past two decades, much has been discussed on supplier developments of mass production firms, and many articles are published (Bortolotti et al., 2016; MacDuffie and Helper, 1997; Sako, 2004).

In the context of products typified as highly customized, engineer-to-order, the firm's product, and process scenarios are different from mass production. Studies on a lean extension beyond the boundaries of a lean firm are seen relatively unexplored in literature in such contexts. While doing the literature review for my project thesis (Mupparichalil, 2019), it was observed, there is a presumption that typical lean supply scenarios seem not be apposite in ETO setting (where firms operate in volatile markets, and the product flexibility is vital and offered to its customers). ETO manufacturing is generally known for its long lead times due to the time required for engineering, procurement, besides the production and delivery lead time. Additionally, the nature ETO manufacturing consists great deal of uncertainties in supply and demand aspects, which has a direct effect on purchasing functions. It is considered imprudent for ETO manufacturing firms to purchase and stock as well as produce and stock solely based on forecasts. This aspect considerably pushes the customer order decoupling point (CODP) upstream and increases the supply lead time (Netland and Powell, 2016a). It is generally perceived that, in different industry sectors, lean supplier development, JIT, and long-term relationship are considered a viable approach to address such challenges, especially on lead time and inventory build-up. However, the information on elements of lean supply such as lean supplier development, JIT. Long-term relationship in ETO setting are identified as an area yet to explore.

1.2 Structure

The study begins with an introduction in chapter 1, explaining the conceptualization of the topic of the study. Chapter 2 takes through various theoretical backgrounds pertinent to the topic discussed which includes the concept of lean, waste related to industries and lean concept in the perspective of supply. Also, discussions about backgrounds of our area of interests: Lean Supplier development and Lean in ETO industry is elaborated. Afterwards the chapter 3 establishes and justify the methodology and framework in which the research is carried out. The strategy used for

selecting the literature to be reviewed is explained in this chapter. In chapter 4, the literatures are reviewed and analyzed and a holistic discussion of JIT, long-term relationships, knowledge transfer, standardization, modularization and supplier development are conducted. Chapter 5 narrows down the analysis of the study with the finding and relevant discussions. Chapters 6 & 7 consists of limitations and recommendations apposite to the study respectively. And the chapter 8 is the list of reference used.

2 Theoretical Background

2.1 Lean

Lean, according to Netland and Powell (2016, p10) 'is a way of looking at organizations, a philosophy, and a system of interconnected processes and people who are striving to continuously improve how they work and deliver value to customers'. 'Doing more with less' is what literature specifies about the word 'lean', such as delivering things for a customer by means of minimal resources in all respect (Netland and Powell, 2016a,Liker,1997)

The philosophy of lean first emerged from the Toyota production system as they endeavor to decrease the time frame between the reception of order from customer and shipment of product while eliminating the waste (Rose, 2011). Lean thinking and lean practices are derived from business practices at Toyota, which facilitated Toyota to achieve superior performance, quality, lower cost, and efficiency. They are not merely tools for production operation in the automobile industry, rather than they are a wider ranging framework for developing better productive value creation system, and it can be applied in different categories of industry sectors and affairs (Netland and Powell, 2016a). Lean help to achieve better performance by developing the problem-solving skills with the support of hands-on management system, thus lean is a mean for an individual as well as organizational learning. As per liker Liker, (2004), continuous improvement and respect for people are deemed as the two pillars or core values of lean in Toyota. 'Continuous improvement' depicts the idea of constantly exploring for a better way to work. And 'respect for people' depicts giving consideration to all who/what the firm deal with, which include employees, customers, society, environment so on and so forth, and improve themselves continually. Moreover, firms envision it as an attitude to give respect or taking into consideration of all while dealing with different areas of their operation, which includes even the first stage 'design' to the final stage of customer service, and the way to achieve this is by developing people (Netland and Powell, 2016a). The Toyota house is shown in the Figure 2 below, which illustrates the core values.

Figure 2.2 The Toyota Way 2001 house

Source: Liker (2015).

Figure 2 The Toyota House *(Jones and Womack, 2002)*

According to Shah and Ward (2007), lean production is an interlinked socio-technical system to eliminate waste by improving on supplier, customer and internal consistency simultaneously. Lean production consists of practices derived of guiding principles of lean, which are consolidated to form practice bundles. The practice bundles focused on internal processes essentially consisted of TQM (Total Quality Management), TPM (Total Productive Maintenance) and JIT (Just-in-Time) for performance enhancement and HRM (Human Resouce Management) for its 'respect for people' principle. Netland and Powell (2016a), Shah and Ward (2003), says implementing these practices simultaneously is one of the ways to bestow lean capability for a production company. However, to become a lean manufacturer this would not suffice. There is a need for continuous improvement across all these practices. An illustration of how these practices and continuous improvement are interlinked is shown below.

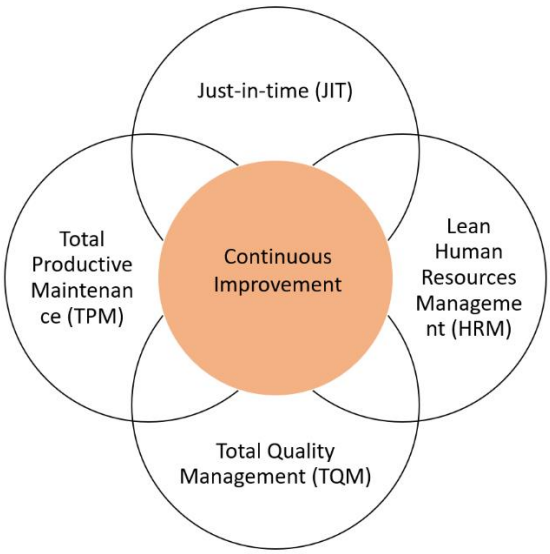

Figure 3 The five elements of lean production.

Externally lean principles are applied to processes consisting of supplier and customer with objectives of achieving active customer involvement and long-term effective relationship with suppliers. Lean purchasing (LP), customer involvement and partnership, supplier involvement and development and standardization are the basic practice bundle for this objective (Birkie and Trucco, 2016a)

2.1.1 Wastes

Womack et al. (1990b), in their book, specifies the Japanese words Muda meaning: any human activity which absorbs resources but creates no values. Fujio Cho, former President of Toyota, defined waste as ‘‘anything other than the minimum amount of equipment, materials, parts, space and worker’s time, which are absolutely essential to add value to the product’’ (Suzaki, 1987, p. 8). In lean, the concept of waste is quite often misunderstood. Waste is not just an action or object but anything that hinders achieving the perfect process i.e., the process which provides the best customer satisfaction (Netland and Powell, 2016b). Harris et al. (2016) describes the type wastes occurring in a firm as overproduction, waiting, transport, inventory, over-processing, motion, defect. He further adds one more waste, which is knowledge. These eight wastes are discussed below.

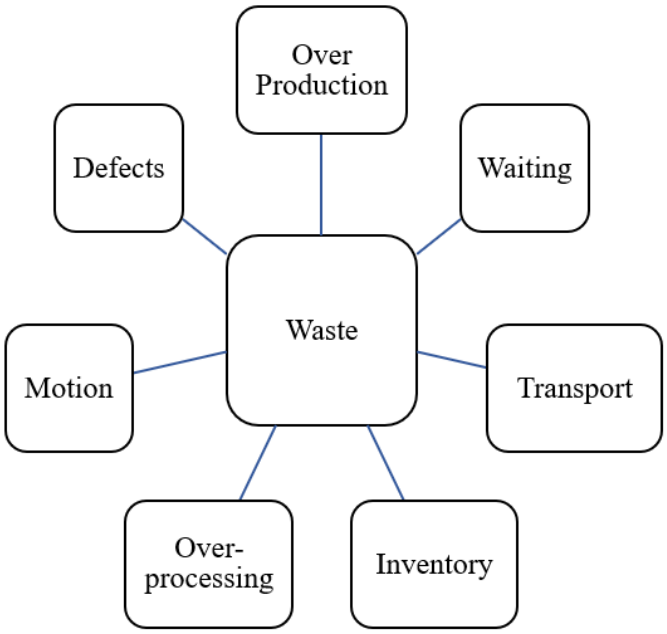

Figure 4 Waste (Harris et al., 2016)

Overproduction: Occurs when there is excess or faster production than the demand, which can result in excess inventory, cost, and increase in lead time. This can even make ripples in supply-chain disrupting suppliers' performance for meeting the firm's overproduction requirement.

Inventory: Maintaining inventory is of great importance for a firm. It helps to helps to compensate fluctuation in the process line. However, holding inventory is costly, and it consumes more labor and time. So, a firm with high inventory may not be an efficient one. To achieve lean, the inventory level should be leveled and controlled at an optimum level.

Motion: Any motion of the inventory or operators, which is not in line with the Just-in-time system translates to waste. This can happen due to poor housekeeping, no proper standardization of processes, lack of training or good ergonomics.

Waiting: this waste occurs when there is a disruption in the flow of material along the supply chain, which puts some process on hold. This can jeopardize the due date, and sometimes compensating these waiting times with other processes even leads to overproduction, which increases cost. A supply base with reliable suppliers can help reduce such waste.

Transportation: Any movement of material that adds no value to the final product is a waste. Unless there is a pre-planned stop, material going through the supply chain should not stop anywhere. Unnecessary movement consumes time, space and may cause damages to the product.

Over-processing: When a product is under processed or over-processed beyond its required specification, it can become a waste. For example, a purchasing agent who was trained by his predecessor gets the generation-to-generation knowledge, may use an outdated process while dealing with the supplier because he deems his way as the way it is done, which can cause unnecessary delays which in-turn are reflected as the fault from the supplier side. This process doesn't add any value but is a loss to the firm's efficiency.

Defects: Any processing product or final product that is not as per the requirement at the first time it is processed is known as a defect, and there rises a need for someone to go and fix the defect. When a defect is found, the real problem is not the defect itself, but the process that resulted in a defect. A defect anywhere along the supply chain can affect the value flow to the customer.

As an eighth waste (Harris et al., 2016) mentions is 'knowledge', which means the lack of transfer of knowledge along the supply chain. Many times, in firms, knowledge is only shared on a need-to-know basis. A system with free knowledge sharing is vital for imparting lean capabilities.

The core idea of lean production is to use various lean practices to achieve a streamlined, high-quality system that produces the final product as per the demand with little or no waste. The lean approach makes value-creating actions in the best sequence while increasing efficiency. It can be said that lean is the way to do more with less.

2.1.2 Principles of Lean

Lean production may seem as a set of tools, but for Toyota, where lean emerged from their unremitting focus to achieve efficiency. Liker (2004) perceived the Toyota system as a set of principles rather than tools. Ohno (1988) & Ōno and Mito (1988) (as cited in Lander and Liker 2007) who developed most of the lean tools, in his conceptualization, he remained to a philosophical level in its presentation. Womack and Jones (1996) narrowed down lean thinking and presented five principles as

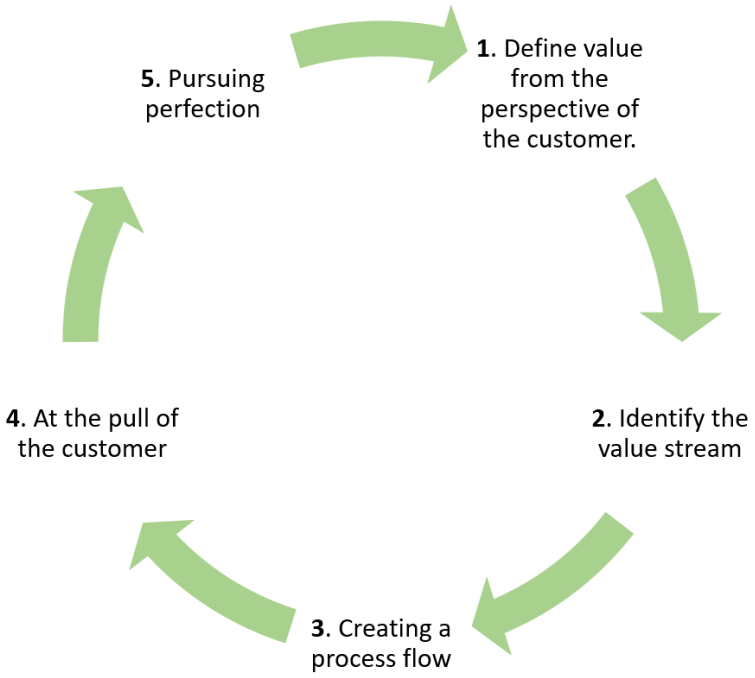

Figure 5 The five lean principles.

The principle starts with 1) defining the value form the customers perspective, 2) then identifying the value stream by disseminating each step involved in the processes from conceptualization to the final product.3) and creating a process flow which basically consists path for products to move seamlessly without any non-value adding activities, simultaneously 4) achieving pull system thereby producing only what is required. Furthermore, all these are carried with the aim of 5) pursuing perfection for continuous improvement in the value stream (Womack and Jones, 1997b).

Defining these five principles gave a framework for implementing lean, and some commentators realized that lean is behavior-driven and developing a mindset for solving problems rather than starting with lean tools straight away (Spear and Bowen, 1999; Hines et al., 2004, 2011; Liker, 2004; Spear, 2009 Birkie et al., 2017). However, in order to achieve a Toyota style system, a thorough understanding of the lean tools is required. In TPS, Jidoka was a quality management tool. Likewise, different tools have been developed, which are used in combinations to bring lean in an industry.

Bhasin & Burcher (2006), in their article, explains different tools firms use to become lean. Firms practicing the lean concept generally instigate to embrace most of it or all of these, rather than solely one or two.

Technical Requirements/Tools:

i. **Continuous improvement/kaizen:** An approach of continual improvements in quality, cost, delivery and design.
ii. **Cellular manufacturing:** A system of grouping facilities to reduce time in transport, waiting and process.
iii. **Kanban:** As method of managing production and continual delivery.
iv. **Single piece flow:** Scheme of one complete product at a time.
v. **Process mapping**: A method of mapping of order execution process.
vi. **Single minute exchange of dies (SMED):** A way of eliminating delays in change-over time on machines.
vii. **Step change/kaikaku:** An approach of making radical change of an activity to eliminate waste.
viii. **Supplier development:** Practice of developing suppliers for mutual benefits.
ix. **Supplier base reduction**: Strategically reducing the number of suppliers.
x. **Five S and general visual management:** Schemes to increase the efficiency of production/office milieu.
xi. **Total productive maintenance (TPM):** A method of using maintenance rules to improve the reliability, consistency and capacity of machines.
xii. **Value and the seven wastes:** Concept of value for right price and right time, based approach.

A supply system that can provide its products and services with consistent delivery, the right quality, and the best cost, otherwise can be called a 'lean supply system' is favorable for a smooth supply chain. Any uncertainties or failures from a supplier can result in a disruption in supply chain and waste. Hence, tools mentioned by Bhasin and Burcher (2006), supplier development & supplier base reduction to develop leanness in the supplier have gained prominence.

2.2 Lean Supply

2.2.1 Lean supply paradigm

In contrast to conventional supplier systems, in lean supply system, the lean buying firm selects all the required suppliers on the basis of past relationships and a proven record of performance, not just through the bidding process to lowest bidder, and typically involves relatively fewer suppliers in each project (Womack et al., 1990b). The supplier companies selected in this way, are typically long-term members of buying firms supplier group or has been supplying same product/part to other projects of buying firm, and so they are relatively easy to designate. The lean buying firm may designate a whole component to such suppliers, like assigning of a module, and

such suppliers are categorized as first-tier suppliers (Womack et al., 1990b). This supplier is responsible for the delivery of the complete module to the buying firm's facility/factory, which may quite often include the responsibility of engineering the product also. And the first-tier supplier may have a team of second-tier suppliers which are independent companies, and these companies can have even more supplier companies in the third-tier or fourth-tier of the supply chain pyramid (Womack et al., 1990b).

In order to protect proprietary technology or to the consumer's perception of the product, the lean buying firm doesn't delegate to the supplier the detailed design of some parts/components considered vital to the success of the final product. Even though, in the lean supply system, interchange of sensitive information takes place flawlessly, including the supplier's production cost and quality. This is possible mainly because, in the lean supply system, there is a rational framework exists for determining cost, price, and profits. Such frameworks directs the both parties to work together for mutual benefit rather than having a suspicious relationship with one another (Womack et al., 1990b). A basic contact directs almost all the relationships between supplier and buying firm in the lean supply system. It is literally an expression of the buying firm's and suppliers' long-term commitment to work together. However, this contract also acts as a means to establish rules for determining prices, quality assurance, ordering and delivery, material supply, and property rights (Womack et al., 1990b).

2.2.2 Characteristics/Elements of lean supply

i. System of establishing and jointly analyzing cost in lean supply:

First, the lean buying firm sets a target price for their final product/module and then, with the suppliers, works backwards, figuring how the product/module can be produced for this price while agreeing for a reasonable profit for both the buying firm and the suppliers. It is designed on an idea of " final selling price minus" system unlike the conventional "supplier cost plus" system (Womack et al., 1990b). Harris et al., (2016) used a different term called 'true cost' in his book for determining the cost. To achieve the set target cost, both the lean buying firm and the supplier use techniques such as value engineering. In this the cost of each stage of production is analyzed and each factor that could reduce the cost is identified. Once the part is under production, in lean production, value analysis technique is used to attain further cost reductions. These savings can be achieved by kaizen or incremental improvements, the redesign of the part or introduction of new tooling(Womack et al., 1990b). In the lean supply system, the supplier ought to share a great deal

of its proprietary information about production techniques and costs. The buying firm and the supplier together evaluates the details of supplier's production process, seeking for ways to improve quality and cut cost. In return, the buying firm must regard the supplier's need to earn a reasonable profit. These kind of cooperation and agreements between the buying firm and supplier on sharing profits encourages the supplier to improve the production process, because it guarantees that the supplier holds all the profits generated as result of any sort of own cost-saving initiatives, innovations and kaizen activities (Womack et al., 1990b).

ii. Continually declining prices:

A second feature of lean supply is decreasing prices recurrently over the life of a model (Womack et al., 1990b). While a typical buying firm assume that bidder's price are low and they expect to recover their investment by increasing the prices in the subsequent years, a lean buying firm assume— or rather know— that the initial price, whether low or high, is an estimation of both cost and profit of the supplier. Besides, the lean buying firm is also familiar about the learning curve in making practically any product/item. In this case, the lean buying firm knows that the prices reduce in the following years, even though cost of resources such as raw-materials and labor wages increases (Womack et al., 1990b). The buying firm and the supplier go through joint discussions and negotiation process to access the issue of savings. Both parties agree on the cost reduction plan over a certain period of production and life of the product. They base such discussion and negotiations on the fact that any extra cost savings (other than the agreed savings) which are derived by the supplier will go back to the supplier (Womack et al., 1990b). Womack et al. (1990b) expresses, in the lean-supply system this is the key mechanism for motivating the suppliers to involve in continuous improvement. By agreeing to share the revenue from joint activities and allowing the suppliers to retain the revenues from extra initiatives they undertake, the buying firm give up the right to control the benefits of the supplier's ideas. As a result, the buying firm benefited with better collaborations along with motivation for innovations and cost saving proposals from supplier. The lean supply system, therefore, improves the relationship between the supplies and the buying firm with mutual trust and cooperation (Womack et al., 1990b).

iii. Just-in-time delivery of products in lean supply:

The way by which the products are delivered to the buying firm in lean supply system is different from the conventional supply system. In most of the leading lean buying firms, the components are directly delivered to their production facility without any specific inspections from the

suppliers. In lean firms, this is normally achieved by just-in-time and pull system. Although, the system is highly susceptible to fluctuations in the delivery and on any faulty products.

The unpredictability in the order volume from the buying firm forces a supplier to pile up stocks unessentially. This is to meet the order requirement throughout all-time with prompt deliveries. For meeting the all-time order requirement, the supplier needs to either make the part/component or keep raw material in stock (Womack et al., 1990b). On the other hand, a lean buying firm gives visibility to future orders and any potential changes in orders to suppliers. In the occasions, If the order variations are to persist long term, the buying firm supports the suppler in finding alternative options or other business. The buying firm shows a commitment and refrain from bringing back the business in-house to keep its employees occupied. Both parties possess a notion of understanding of working together to share the bad time and a good time. Buying firm considers the supplier firm to be their assets to a great extent and their workers as their part and own employees (Womack et al., 1990b).

iv. Quality control by eliminating route cause of defects:

In a lean supply system, quality control (QC) is very effective (Womack et al., 1990b). The QC department of the buying firm comes into action on the occasions of any defective part that is found in the deliveries. Further, they go through a thorough investigation using the route cause analysis (RCA) method, the "5 why's" by collaborating with resources from the supplier firm. "5 why's" is a method of seeking answers for the question 'why the problem/defect occurred' from one finding to its cause and the continue seeking cause until the final route cause is found. Thus, using this method, in a bilateral problem-mitigation mission, the buying firm and the supplier firm traces the leading cause of the defect and come with measures that will prevent such errors from occurring in the future (Womack et al., 1990b).

On the other hand, in the conventional supply system, a typical supplier may not allow the buying firm to involve in their activities and may not offer access to their production facilities. Whereas, the lean supply agreement allows the buying firm's personnel to visit the supplier's facilities. The repeated occurrence of such problem mitigation missions eventually helps the supplier firm to learn better manufacturing and improve their processes. Process improvements eventually lead to cost reduction and thus increased profit margins (Womack et al., 1990b).

v. Improved Buying firm – supplier firm relationship (long-term relationship):

Suppliers know that if they show commitment and efforts to perform well, the buying firm acknowledges it and ensure they make a fair return on their investment. When it comes to knowledge sharing, suppliers conceive it as when knowledge sharing happens; it benefits to improve the performance of whole group members. This eventually contributes to having a culture of mutual support, innovation, and knowledge development among supplier counterparts. What matters is the final product, and which might be the final assembled product which the buying firm is selling. Thus, suppliers act on self-interest and actively involves in mutual problem-solving through the supplier groups (Womack et al., 1990b).

In lean supply, it is quite typical to have certain parts "sole-sourced" for large complex systems that require massive investments in tools, but relatively less so for simpler parts. On the other hand, in order to not affect the buying firm's operation in any case, they usually divide such simpler parts order between two or more members of their supplier group. The buying firms don't take this step to drive prices down; rather, they do it to prevent anyone from letting down on quality or delivery reliability (Womack et al., 1990b). If a supplier falls short on quality or reliability, the buying firm does not dismiss the supplier. Instead, the buying firm shfts its business volume to other suppliers. Among lean buying firms, this has been found a form of punishment is highly effective in keeping everyone on their toes while sustaining the long-term relationship essential to the system (Womack et al., 1990b).

Lean buying firms sometimes fire their suppliers, but not erratically**.** Suppliers are never kept in the dim light about their performance; instead, some lean buying firms use to have supplier grading systems. The suppliers get a certain score on the basis of the number of faulty/defective parts/components found on the production/assembly line, the percentage of on-time deliveries in the proper quantity and sequence, and performance in reducing costs. The suppliers often compare their scores with those of their competitors, make discussions on the findings, and features problem areas for attention, quite often with the help of personnel allotted from the buying firms. The scoring system is not just a statistical workout. It also evaluates the supplier's attitude and their readiness to improve. Only if there is no sign of improvement with the supplier; in the end, they will be considered for firing (Womack et al., 1990b).

Thus, a lean buying firm typically pursues a long-term agreement that establishes a rational framework for analyzing costs, establishing prices, and sharing profits, instead of a 'price-

determined' link with outside supplier and bureaucracy intricated in house supply divisions (Womack et al., 1990b). So, this makes all counterparts focus on improving constantly to maintain their performance by being completely open with each other, without fearing that their competent will take advantage of such an openness situation for their own benefits. In the already established lean buying firms, the relationship between suppliers and buying firms is not built primarily on trust, but on the mutual interdependence cherished in the agreed-upon rules (Womack et al., 1990b). It means it keeps everyone striving constantly to improve performance. Because lean firms are so successful in devolving much of the responsibility to suppliers, they need to do relatively less by themselves than in a conventional buying firm (Womack et al., 1990b). Typical Japanese lean buying firms such as Toyota, on average, do detail-engineering on only 30 percent of the parts in their products, and the suppliers engineer the rest. When there are more outside suppliers, it requires larger purchasing staff for the buying firm (Womack et al., 1990b).

2.3 Lean supplier Development

In order to utilize the benefits of the lean supply system which has improved relationship between buying firm and supplier, the best cost in piece price, improved quality products, and so on the supplier counterpart also need topossess similar knowledge and knowledge about lean, lean capabilities. To attain these the suppliers need to be developed to impart the lean qualities and needs to be developed to have lean capabilities (Dyer and Nobeoka, 2000a; Harris et al., 2016; Womack and Jones, 1997b). However, supplier development in general will be discussed in the coming chapter.

2.3.1 Supplier Development

The state of art and related work about Supplier development were previously reviewed, and an identification of the relevant background material were carried out in the project preceding this thesis (Mupparichalil, 2019). No relevant new material was found during the work on this current thesis. The presentation from the project report is included below

<< According to Sako (2004), supplier development is method, utilized by a buying firm to improve its supplier's capabilities. Or in other words, it is the buying firm's initiatives to transfer or replicate its in-house production or organizational capabilities into extern boundaries of the firm (Sako, 2004). Besides, one of the purchasing function's underlying objectives is to maintain a network of resourceful suppliers. The current competitive market environment drives a firm´s focus on their core competencies; thus, they become more dependent upon suppliers. In order to

compete, firms must ensure that their suppliers' capabilities and performance are superior than the capabilities and performance of the firm's competitors (Krause, 1997). Also, the firms are required to develop and maintain relationships with a competent and capable network of suppliers in order to survive in the international market. For establishing such networks and extracting maximum value from them, as well as to enhance the capabilities needed for meeting growing competitive challenges; the buying firms should get involved in supplier development (Chidambaranathan et al., 2009).

According to Krause (1997, p34) supplier development is "any effort of a firm to increase performance and/or capabilities to meet the firm's short-term and/or long-term supply needs" . Supplier development ranges from restricted efforts, such as simple supplier evaluation and a request for enhanced performance, to extensive efforts, such as providing to training the supplier's personnel and investing in the supplier's operation. Supplier development (SD) is considered to be one of the three choices that can be adopted for managing the problems faced by buying firms in their supply networks (Wagner, 2006). The supply network problems may include a non-competitive supplier base, low-grade performance of the existing supplier, the inability of current suppliers to support the strategic development of a firm, or unavailability of capable suppliers in a certain market. The three ways to handle these issues include:

i. Vertical integration: To set up manufacturing competency in-house (Guan and Rehme, 2012).
ii. Supplier switching: To carry out a search for alternative suppliers, which are more capable (Monczka et al., 2015).
iii. Supplier Development (SD): To assist the supplier in enhancing the performance of products and services, or improving the capabilities of suppliers (Harris et al., 2016). >>

Traditionally, suppliers used only little input as necessary from the customer side, as long as the customer demands on product specifications were met. But in the 1980's, in the U.S, the manufacturing industry witnessed a paradigm shift in supplier management practices. Firms cut down the number of direct suppliers and started to establish more healthy and cooperative relations with the remaining suppliers. This paradigm shift could be viewed as the establishment of supplier development in the industry. For example, the Toyota Supplier Support Centre in Lexington, Kentucky promoted lean manufacturing concepts for supplier companies (Hartley and Choi, 1996). Furthermore, now these trends, due to the competition in global as well as domestic

markets, shorter product life cycles, demand for higher quality and lower prices, are ever-increasing and are likely to continue (Krause, 1997).

Hartley and Choi, (1996) cites, working along with the suppliers and buying firms are benefiting by enhancing quality, cutting down cycle time, and cost in the process. Also mentions a manager's experience at General Motors, who was part of a supplier development project with more than 2000 suppliers reports improvements such as a 50 percent increase in supplier productivity, 75 percent in lead time reduction, 70 percent inventory reduction during their one-week workshop. A supplier's internal organizational policies can hinder self-improvement; here, a customer can play a major role. The involvement of customers can legitimize the need for improvement.

A supplier development initiative of a buying firm includes activities to enhance supplier productivity in the cost, quality, service or delivery performance, or upgrade supplier's abilities to the buyer's requirement (Krause et al., 1998; Wagner, 2010; Friedl and Wagner, 2012). Firms are known to use various supplier development methods. They could include introducing competition to existing supplier base, evaluating existing suppliers for further development, raising performance expectations, offering future benefits, training and educating suppliers, personnel exchange among supplier and buyer firms, or investing directly in the supplier (Krause, 1997).

Based on the commitment of the buying firm, supplier development approach can be either indirect or direct. When a buying firm commits in an indirect supplier development, it invests no or limited resources to the supplier. But in case of direct supplier development, the commitment is more; thus the buying firm plays an active role and invest a considerable amount of resource in the supplier (Krause et al., 2000; Monczka et al., 1993; Wagner, 2011). The supplier's approach can also be considered as reactive or strategic based on the time it invests in a supplier. A reactive approach is when there appears a lack of expected supplier performance, but in a strategic approach, the buying firm proactively involves in supplier development with the aim of a long term strategic partnership (Ahmed and Hendry, 2012).

For the best output, the selection of suppliers to be developed should be a strategic decision rather than a reactive one. Scholars have opined that a potential candidate for supplier development will be the one with a strategic partnership like relation with the buying firm (Araz and Ozkarahan, 2007; Talluri and Narasimhan, 2004; Wagner, 2011). Another criteria considered include the cost involved and the criticality of the components in the transaction (Hartley and Choi, 1996).

Effectiveness of supplier development needs to be assessed periodically to get a long-term benefit from such commitment. I.e., with all these efforts, there is still a need for a strong follow up from the customers/buying firm's side Prahinski and Benton, (2004) while investigating Supplier evaluations and communication strategies for supplier performance enhancement, found that the buying firm cannot expect continuous improvement from supplier side if the buying firm does not follow up in their supplier development initiatives (Ahmed and Hendry, 2012).

Hartley and Choi (1996) states, buying firms are reducing their direct supply base, which in turn makes them more dependent on the remaining few suppliers. To alleviate risk in such a scenario, buying firms try to indulge in a long-term relationship with these suppliers. And many suppliers, even though trying to improve their performance, with a limited resource they get caught up in their daily activities. So, a customer/buying firm driven supplier development can effectively improve a supplier's efficiency. Hines (1994) states that supplier development brings "supply chain responsiveness" and enables "the mechanisms to facilitate improvements up and down the supply chain.". The buying firms can enrich their suppliers with their abundant knowledge, skills, and experience, which will, in turn, become profitable for the buying firm through improved performance of the supplier. And the supplier also benefits as it helps cost reduction and an upper hand with its competitors. In the long run, an efficient and responsive value chain composed of fewer, reliable partners with good relationships may prove to be critical for all parts of the value chain.

2.3.2 Switch to a lean Supplier:

It is widely acknowledged that switching suppliers to get new capabilities might lead to lose of all the benefits associated with long-term supplier relationships. Sako (1992) pointed out, trust between supplier and customer is essential to achieve these benefits, so switching supplier not only deteriorate the relationship with the existing supplier but also with other suppliers who is in the network. Besides, the most efficient lean suppliers may have standing commitments to other customers, which might make them less receptive to a newcomer. Finally, the customer might end up having fewer sourcing options if it waits to generate a larger pool of lean suppliers rather than acting to improve the capabilities of existing suppliers (MacDuffie and Helper, 1997).

2.3.3 Steer Your Supplier to a lean supplier (Good Consultant or Partner):

A lean buying firm has pivotal role in encouraging its suppliers to develop lean capabilities by oneself or offer support of consultants or partners other than interfering directly with the supplier's

internal operations (MacDuffie and Helper, 1997). It is not always easy to transfer the knowledge of lean production across organization. Primarily it requires a "hands-on" approach whereby key principles are taught by observing how problems are handled in real-life scenario. Thus basically it can be concluded that, a lean buying firm compared with alternatives has superior knowledge about lean production and a greater capability to motivate suppliers to learn (MacDuffie and Helper, 1997).

2.3.4 Supplier and Partner:

Harris et al (2016) presents a distinction between suppliers and partners:

Suppliers are any organization that provides a component, product, or service needed to support the successful and profitable manufacturing of your company's products. Generic definitions would include adjectives like manufacturer or producer; in-service support like subcontractor, provider, or source; and material brokers, materials like retailer, wholesaler, merchant, and vendor. Much as these descriptions sound impersonal, so is the relationship (Harris et al., 2016).

On the other hand, a partnership relationship is not impersonal. A partner becomes a collaborator with whom we join forces and work together to the benefit of both. A partner brings to the table knowledge and expertise in his or her processes and products. Since most manufacturers are not vertically integrated from raw material to finished products, business partners must be utilized to provide those resources. Mutually beneficial relationships will provide stronger partnerships (Harris et al., 2016).

Some of the benefits in moving from the classic supplier mentality to a partnership strategy listed in Harris et al (2016) article are,

- Simple, focused, and responsive order processing
- Industry-best lead times
- Highly flexible production processes
- Consistent shipments and coordinated deliveries
- Perfect quality
- Production flow accelerating cash flow
- Mutually profitable partnerships

2.3.5 The lean Supplier Development in practice

From the discussion of lean supply, it is apparent that, implementing lean philosophies in manufacturing firms, pushes firms to hold less inventories, cut lot sizes, and increase flexibility, whereas in the classical setting firms ought to possess high inventories, large lot sizes and hold reduced flexibility (Harris et al., 2016). When supplier selection is based on the piece price, it often leads to have supplier base spread across globally, regardless of geographical location of buying firm. Certain firms advocate lowest piece price philosophy deemed to be seen distinguished as a diversified supply base has relatively lower dominance and fewer chances of hurting the buying firm, which may be a paradox in the reality (Harris et al., 2016). In Figure 6, it illustrates different suppliers for one single part or *part A*. In this model a single supplier can influence the firms production, which means that the firm has dependency on suppliers to some extent (Harris et al., 2016). When the firm replaces suppliers with single supplier or limited suppliers for one part/product, the volume order become relatively larger to such suppliers and the buying firm become major buyer to supplier. In the case illustrated by Figure 7 where the buying firm is a preferred buyer of the supplier, supplier begin to act responsibly towards quality issues, equally on on-time deliveries and others. This scenario allows for a win-win situation for both supplier and buyer, with both parties working together for the success, and any success may likewise be shared by both parties.

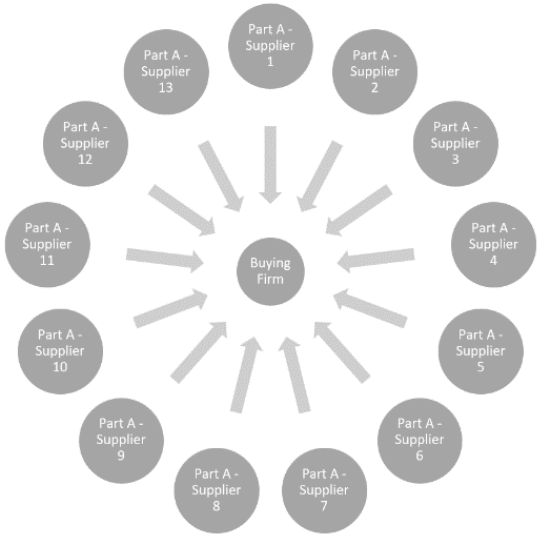

Figure 6. Buying firm and suppliers in classical supplier development (Harris et al., 2016)

Figure 7. Buying firm and suppliers in lean supplier development (Harris et al., 2016)

As in the model illustrated in the Figure 7, when the supplier for one product is limited, it will create a mutual dependency and hence generate a long-term relationship between both firms. Both parties need to take decisions that are best for the whole supply chain rather than silo thinking (Harris et al., 2016). This brings firms to embrace the contemporary business management paradigm, as stated by Lambert (2008), organizations now operate within supply chain, rather than competing as autonomous enterprises. According to Harris, such cooperation contributes in having improved efficiency in transportation of part/product from supplier to buyer, lower requirement of inventory levels, efficient packaging and internal material movements (Harris et al., 2016). >>

Barla (2003) also opined, to accomplish employment of lean supply, the supplier base shall be reduced. As per Barla (2003) in general, the supplier base can be reduced in three ways:

- reducing the number of suppliers for each part,
- reducing the number of suppliers for each family of parts, and
- outsourcing fewer parts.

2.3.6 Lean supplier development of Japanese firms

Supplier development in Japanese automotive industry has been widely considered as typical example of lean supplier development and as model in for several industries for framing their supplier development programs. Toyota, Nissan and Honda have their own unique way of supplier development programs which includes short-term fixes to instill 'maintenance capability' and long term development of 'evolutionary capability' (Sako, 2004). Dyer and Nobeoka (2000b) in their article discussed the lean supplier development initiatives undertook in Toyota extensively. In Toyota's supplier development program they extended lean to their suppliers by teaching them the activities of TPS (Toyota Production System) and TQC (Total Quality Control). TPS is a system focused on the elimination of waste, exposes quality issues through line stoppages and forces the management to fix the root cause of the problem (Sako, 2004). The program was instilled through Toyota's Purchasing and Planning Division and Operations Management Consulting Division (OMCD). Sharing of knowledge, both characterized as tacit and explicit is considered the key in Toyota´s approach towards supplier development (Dyer and Nobeoka,

2000b). Some of the effective lean supplier development methods practiced by lean buying firms Toyota are listed below.

- Supplier Association
- On-site consulting
- Problem solving teams
- Supplier learning teams
- Employee transfers
- Performance feedback; process monitoring.

i. Supplier Association:

As explained earlier in the section 2.2 (lean supply paradigm), supplier associations are typical characteristics of lean supply and lean buying firms. In case of Toyota, the firm where the concept of lean has emerged, had different supplier associations based on different tier of suppliers and supplier's geographical location, and so on. Such associations are primarily intended to promote 'mutual friendship' and the 'exchange of technical information' between the buying firm and its suppliers (Dyer and Nobeoka, 2000b). They conduct general meetings, plant tours periodically and these activities facilitate to develop ties among members and the sharing of *explicit knowledge* through multilateral knowledge transfers among the members of association (Dyer and Nobeoka, 2000b).

ii. On-site consulting

This method implies a system of having consulting teams to facilitates knowledge sharing by providing direct 'on-site assistance to suppliers. Typically involves sending consultants (network-level resources accessible to all members) to the supplier for a period of time (one day to many months), depending on the nature of the problem. The consultants possess valuable production knowledge and assist in quality improvements, productivity improvements, inventory reductions and so on (Dyer and Nobeoka, 2000b).

iii. Problem solving teams

It regards as the practice of forming problem solving teams to address the emergent problems arises in the supply network. Such teams can be from within various divisions of the lean buying firm and possibly even other from suppliers. By this they can collectively bring their knowledge

to bear to 'fix' the problems. The team basically identify the root cause(s) of the problems and take measures to solve it from the originating level (Dyer and Nobeoka, 2000b).

iv. Voluntary learning teams (jishuken/PDA core groups)

Voluntary study groups are formed from the key suppliers for the purpose of assisting each other in productivity and quality improvements. Such groups are formed based on geographic proximity, competition, similarity of production processes and so on. They work for the benefit all in the group, the basic idea is to help each other increase productivity in areas of common interest. These group of suppliers visits each other's plant and jointly develop improvements suggestions. In such joint learnings, the group involve learning that is 'hands on' and 'on site' (context specific) which are particularly effective at tacit knowledge transfer (Dyer and Nobeoka, 2000b).

v. Interfirm employee transfers

Transferring employees across the firms in the value chain and to suppliers is an important way to create network identity and transferring knowledge. In Toyota, they do transfers temporary as well as permanent depending on level. It is also mechanism to learn the suppliers perspective and problems they experience in production and processes. At time some supplier might be lacking some particular skills or knowledge with their workforce, and in such occasions the transferred employee can aid with the knowledge from the buying firm, using their system and technology (Dyer and Nobeoka, 2000b).

vi. Performance feedback; process monitoring.

In case of Toyota, they regularly measure the performance of suppliers with the intention to identify improvement areas and suggest what can be done to improve. This can be a continuous process of in the form of yearly auditing. These monitoring and giving feedback encourages and motivates suppliers to improve in the shortcomings (Dyer and Nobeoka, 2000b).

2.4 Lean in ETO

2.4.1 ETO

For decades, lean production has been effectively applied in many firms producing high volumes of standardized products. However, firms that operate in dissimilar settings have yet to expose an appropriate model for following the lean practices, adapted and adjusted to the diverse characteristics demonstrated by producers of, for example, highly customized, engineer-to-order products. Engineer-to-order (ETO) refers to the strategy by which design, engineering, and

production do not commence until after a customer order is confirmed. In terms of the product-process and production characteristics of this type of environment, the products are customer-specific, highly customized items produced in low volumes (often one-of-a-kind), and processes are typically non-repetitive yet labor-intensive, often demanding highly skilled labor (Powell et al., 2014). Firms with a typical ETO manufacturing environment used to have different stakeholder's involvement, including customers, in the different processes from the concept design phase, follows it through the detail engineering as well as the production and the testing phases (Kjersem et al., 2015). The scope of such participation is to maintain the possibility of changing features of the products while under construction or manufacturing, and that results in a one-of-a-kind product at the end of each project. Most of the products build through an ETO approach start as a conceptual frame for a future possible service, but during the building project, things frequently change, and the final product can look quite different from the starting idea (Kjersem et al., 2015). This implies that the design/engineering/production phases in an ETO must be flexible and adaptable to this dynamic system where changes may occur at any time (Little et al., 2000). Therefore, planning and controlling processes/activities in an ETO project must cope with a dynamic system, the product complexity, and the included information uncertainty. A system in which can have changes anytime can be defined as a dynamic system (Kjersem et al., 2015). According to Kjersem et al. (2015) in such ETO environment, the complexity of the product is given by, i) the structure of the goods flow, ii) the number, combination and the complexity of the parts that are needed to the end product, iii) the number of the running projects that each department is involved in. Similarly, the uncertainty of an engineer-to-order project is mainly interpreted by the amount of information necessary to perform a task compared with the already available information in the project organization (Kjersem et al., 2015). As per Forrester (1958) there are mainly three uncertainty factors specific to engineer-to-order manufacturing.

i. uncertainty of product spec, where changes can occur,
ii. volume and mix of future demand (the supplier firm might not know when will the buying firm place a new order which affects the forecast of the material and people),
iii. uncertainties in the process of manufacturing where parts of the product are relatively unknown.

2.4.2 Lean in ETO – how lean principles are applied in ETO

Powell et al., (2014) in his study, enlightens more on aspects of lean in firms of highly customized products or products and processes consisting of higher levels of variation and lower volumes, such as one-of-a-kind products. They assert that, in order to develop lean working practices in such scenarios, the fundamental lean principles be re-examined as low volume, high variety (e.g. ETO) producers exhibit neither mass consumption nor continuity of demand. They then defines the lean ideal as "providing customers (both internal and external) with exactly what they need to accomplish their purposes, with no waste; where we define waste as anything that incurs a cost of any kind, the elimination of which does not reduce the value delivered" (Powell et al., 2014, p 572).

Morgan and Liker (2006) in their book, describes about lean principles in the context of 'product development' which stand very close relevance with ETO product manufacturing as in both cases it typically has a high degree of customer specific design and engineering activities. The main idea of the principles is to lessen variation in product development whilst preserving creativity. In Toyota, they creates a higher level of flexibility by standardizing lower-level tasks in different aspects. Morgan and Liker (2006) suggests that there are three broad categories of standardization at Toyota:

i. Design standardization: use of common architecture, modularity and reusable or shared components;
ii. Process standardization: in order to reduce variability found in having many non-standard low levels tasks;
iii. Engineering skill set standardization: to make easier knowledge modelling and knowledge representation.

In terms of 'design standardization' and 'component modularity', Persson and Ahlström, (2006) suggests that successful modularization provides a company with three benefits:

- It allows a company to economically increase product variety that can be offered to customers;
- It increases a company's ability to respond to various demands from dynamic competitive environments, thereby creating strategic flexibility;
- It allows reduced task complexity and enhances the ability to complete tasks in parallel.

So, standardization and modularization are identified as key elements for success in pursuing the lean ideal in ETO manufacturing companies.

Powell (2014) proposed a set of principles that shall enable ETO manufacturers to pursue the lean ideal.

i. Defining Stakeholder Value
ii. Leadership, People and Learning
iii. Flexibility
iv. Modularization
v. Continuous Process Flow
vi. Demand Pull
vii. Stakeholder- and Systems Integration
viii. Transparency
ix. Technology
x. Continuous Improvement

Powell (2014) suggest a stake holder value should be defined from the perspective of all major stakeholders, rather than purely the customer. ETO firms shall adopt the perspective of all major stakeholders to incorporate what they need to accomplish their purposes, with no waste. Further the focuses shall be on the softer side of lean, and includes leadership, people and learning. Flexibility is another principle Powell (2014) proposes, in traditional lean production the emphasis seems to lie in the application of standardization and repetition to achieve efficiency. The next principle is modularization, as a modular design allows an organization to combine the advantages of standardization (e.g. lower costs associated with higher volumes) with those of customization (e.g. greater variety of product / service offerings). Improved flow is enabled as a result of greater flexibility and the standardization created from the use of a modular approach, thus Powell (2014) suggest that, where possible, production should take place in response of actual customer demand, which leads to the number six principle, demand pull. Demand pull implies that products be processed more in a "just-in time" fashion rather than the typical push approach. A further enabler of continuous process flow and demand pull is stakeholder- and systems integration, which means adopting a system view of the entire supply network, with systematic cross-functional and inter-organizational integration that includes all the major stakeholders. For such integration to be successful, the entire network must be transparent, thus there is an emphasis on the use of visual controls and sharing of key indicators amongst stakeholders which is principle eight. It is apparent that the design, engineering and production of such highly customized products requires a greater level of technology deployment than more standardized environments, therefore technology is also

considered as a major enabler of operational excellence in ETO manufacturers. Further, continuous improvement is a vital part of the application of lean in any setting which is listed as 10th principle.

2.4.3 CODP and ETO

The CODP (Customer order decupling point) separates the part of the material and information flow that is based on firm customer orders from the part that is based on forecasts and speculation. In general, there are four different strategies distinguished based on different CODP positions: Make-to-stock (MTS); Assemble-to-order (ATO); Make-to-order (MTO); and Engineer-to-order (ETO) (Netland and Powell, 2016a; Powell et al., 2014).

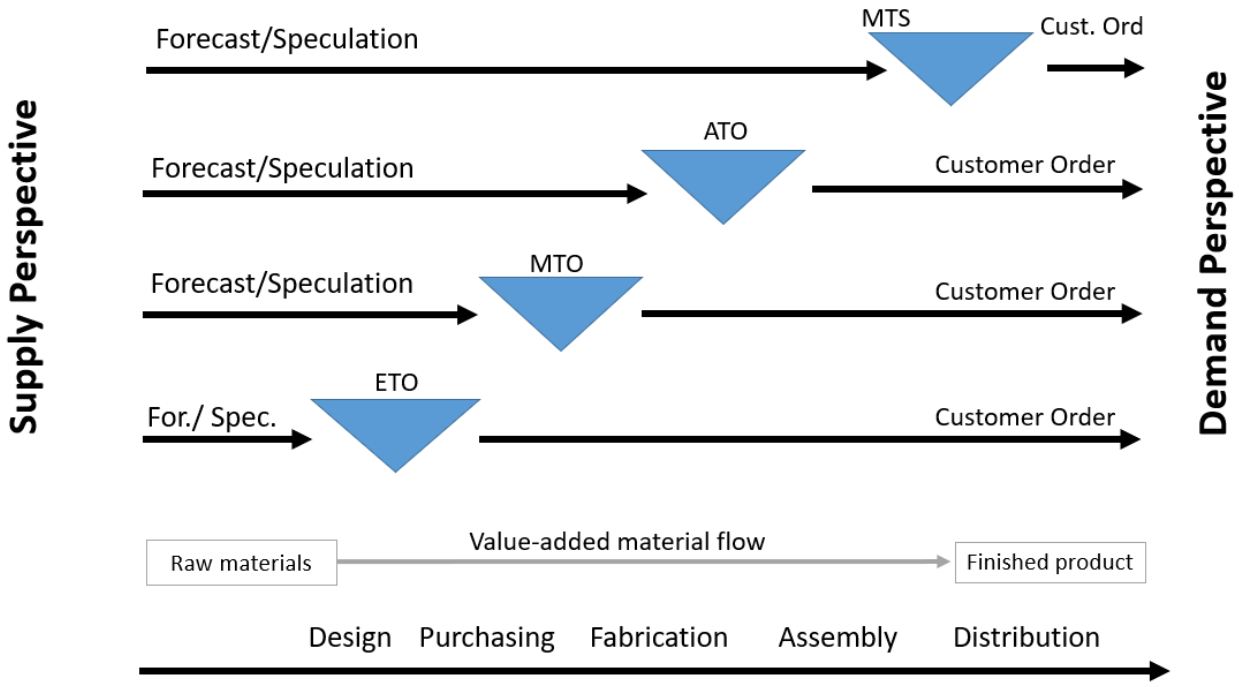

Figure 8 positioning of the CODP in each of the four main strategies, relative to each other (Netland and Powell, 2016a; Powell et al., 2014).

Firms typically desire to become less reliant on the use of forecasts, which results in shifting the CODP towards left. On the other hand, when they want to reduce the lead time, it makes them to require shifting CODP towards the right, to move it closer to the market and customer. For the firms offering ETO/MTO products, the lead time is vital, and shorter lead times make them more competitive. The typical nature of ETO/MTO products such low volume, high variety environments, makes firms rely on forecasts, and it eventually becomes challenging in the reduction of lead times using typical lean flow techniques (Powell et al., 2014).

The earlier CODP means that a higher degree of customization can be offered in an engineer-to-order setting, though at the cost of longer lead times and increased uncertainty (Powell et al., 2014). ETO manufacturers endure uncertainty across different dimensions, including uncertainty in process specification uncertainty; product specification and mix; and volume uncertainty. Because of the extent of uncertainty experienced by engineer-to-order manufacturers, planning and control become more complex and difficult for these companies. This is particularly true when we further consider the concept of uncertainty in terms of lean, where the success of lean in the traditional sense has been built on the elimination of uncertainty and variation through demand- and production leveling (Powell et al., 2014).

I have in the chapter 2 described the theoretical background of this thesis. The next chapter will deal with the methodology.Methodology

The goal of this chapter is to discuss the research methodology where it explains how the research is devised in order to answer the research question, and what kind of methods are chosen and why they are chosen. An appropriate research design will be used to devise the research. According to Bryman (2016) a research design provides a framework for the collection and analysis of data. In the following section, first, the research methodology is explained, and then why the particular methodology has been chosen.

2.5 Research methodology

According to Bryman (2016) a literature review is used to gather information from the work done by others in the same field by reviewing scholarly articles. Further, using existing works of literature on the research topic can be used as a means for developing arguments about the relevance of the research and where it leads (Bryman, 2016). By doing literature review research, according to Bryman (2016) the following list is adapted to the thesis topic. In this thesis, it intended to cover a similar way, if not all, at least some of it.

What the literature says about lean supply aspects such as lean supplier development, JIT, long-term relationship, in the ETO setting?

- What is already known in the area of lean supply aspects/elements (lean supplier development, JIT, long-term relationship) in ETO setting.
- What are all the theories and concepts are pertinent to lean and lean supply aspects/elements (lean supplier development, JIT, long-term relationship) in ETO setting

- Are there any contrasting information or controversies?
- Are there any findings that are inconsistent relating to lean supply aspects/elements (lean supplier development, JIT, long-term relationship) in ETO setting?
- Any unanswered questions in lean supply aspects/elements (lean supplier development, JIT, long-term relationship) in ETO setting.

If the process of literature reviewing is giving more uncertain outcome or which is relatively unpredictable and might not know what direction it leads, it can be categorized as narrative reviews (Bryman, 2016). In this, the reviews are relatively less focused and having more wide range in scope compared to systematics reviews. In addition to that, narratives reviews are less explicit about criteria for inclusion or exclusion of studies (Bryman, 2016).

In the thesis, it is aimed to review literature in lean supply/supplier development, and the outcome is unknown and uncertain. The research question 'what the literature says about lean supply aspects/elements (lean supplier development, JIT, long-term relationship) in ETO environment', can also be observed as not leading to a specific direction. On the other hand, the question opens a wide range in scope, which eventually makes the selection of studies for review to be less explicit. So, based on the nature of the study, a narrative literature review approach is found to be the most suitable method for this thesis. Thus, the narrative literature review method, with elements of a systematic review is adopted in this thesis and explained in the next section.

Moreover, here are two types of research approaches as per Bryman (2016), deductive and inductive. In the deductive approach, a researcher, based on what is known about in a domain and of theoretical considerations in relation to that particular domain, deduces a theory that must then be applied to empirical study, i.e. theory to observations/findings. Whereas in an inductive approach, a researcher gathers the conclusions of his or her findings for the theory that prompted the whole exercise and then fed back the stock of the theory i.e. observations/findings to theory (Bryman, 2016). In this thesis, the study can be characterized as a deductive as the observations and findings from the literature review will be used to derive a theory by gathering the conclusions.

According to Brotherton (2015), a scientific research derives as 'exploratory, descriptive and explanatory'. Exploratory research typically aims to explore a subject that is relatively unexplored or known very little. In this, a researcher wants to surface the key issues from the subject and a basic understanding as a starting point for further research. As a result, exploratory researches are usually qualitative as in an exploratory phase, and there is no need to be precise or accurate.

This study here can be primarily presumed to be exploratory, as the outcome is unknown, and the study is conducted by the analysis of literature in the given area of lean supply/lean supplier development and is the source of information. Further, in the research, an investigation is envisioned in what literature says about ETO production and lean supply/lean supplier development. In the given specific context also, the research outcome cannot be predicted and hence can be considered as exploratory type research. According to Bryman (2016), exploratory research can be investigated using literature reviews as a secondary research method.

2.6 Research strategy

Bryman (2016) explained systematic review practices could be incorporated in narrative reviews. In certain narrative review studies, systematic review practices suite if the searches require a mechanical approach to reviewing literature to provide transparency about how the searches were conducted and how comprehensive is literature searches (Bryman, 2016). He also added this approach is likely a good choice, especially when reviewers work on their own where there is no one to assist for keyword selection, assessment quality, etc., unlike as group in a typical systematic review. In this study, however a narrative approach is found to be most suitable as inclusion and exclusion of literature shall be based on relevance and at times manual selection also may require.

Literature search: In this study, the electronic database is the prime source of published literature. For that, NTNU university library platform Oria, public platforms such as Scopus and Google scholar, are identified as suitable platforms. Further bibliographies of books, articles that are already considered for review, or already reviewed in the project thesis (Mupparichalil, 2019) are also a source of literature. Different textbooks and articles were discussed for the preparation of reports for the project thesis (Mupparichalil, 2019), and these technical documents are found to be a guiding source of information. From the project thesis (Mupparichalil, 2019) the reviewed works of literature were referring to many articles, textbooks and also it listed the collection of records in the bibliography, so as the current thesis is in the similar area of research, many literatures from project thesis are considered to be included.

Research question search:

As the next step of the search to address the research question, a search is performed with the below given string,

‘Lean supply supplier ETO "engineer-to-order"’

This gave 1040 results, which is a large number, and required articles needed to be manually selected further on. Here also manual search was to be performed to pick the document to shortlist for the final selection of review. Thus, abstracts were read, and relevant documents that are pertinent to the research question are chosen. By doing this, the result was narrowed down to 57 published articles.

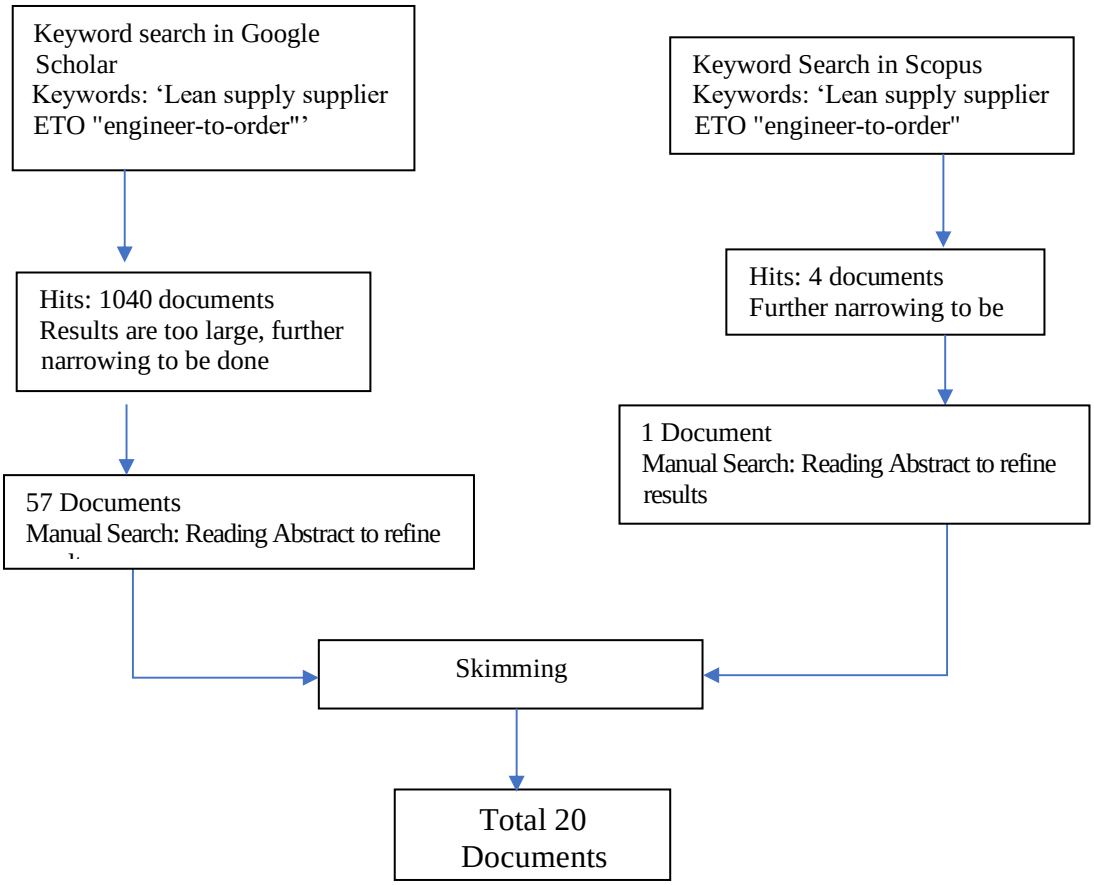

Figure 9 Literature Search flow chart.

Further, a search was performed in Scopus to address the same research question, with the keyword similar to what it was used for Google scholar. The keyword used was 'Lean supply supplier ETO "engineer-to-order"'. The search result gave 4 documents. The same inclusion philosophy is repeated in results from google scholar, and already found document are given weightage in selection. Added to that, a manual selection was performed, and the list is narrow is to 1 article.

For the final selection to the articles for detailed analysis, the second-round manual selection was performed form the combined list of google scholar and Scopus (57 google scholar + 1 Scopus = 58 results). For that, the articles were skimmed for evaluating the relevance and quality of the

literature. The relevant documents which were pertinent to the research question were chosen. From the manual selection, 20 articles were finally selected for the detailed analysis.

Inclusion and exclusion criteria: As the research question explain, the thesis focuses on a study in the area of lean supply aspects/elements (lean supplier development, JIT, long-term relationship). Hence primary inclusion criteria in the literature search were any articles, textbooks that were pertinent for the study of supplier development, JIT, long-term relationship in lean organizations. The literatures used for writing project thesis (Mupparichalil, 2019) were given priority as they were searched using keyword 'lean supplier development', and the selection of literatures included refining the results by reading abstract and later the whole text. Lean as such is a philosophy which is employed in various type of organizations and industries. Different lean management practices are employed in different sectors and industries, for example, medical, computer science, government administrative organizations, engineering construction and production firms and so on. In this thesis, the study is limited to the sectors, engineering construction, and production firms because the research question is addressing lean in ETO, which comes under the engineering construction and production sector. So, the second inclusion criteria were any article on lean supply/ supplier development, which were related to the area of engineering, construction, and production were to be chosen for the selection for review. Finally, the literatures on lean and ETO shall be given priority in inclusion when searching for the articles for addressing the research question.

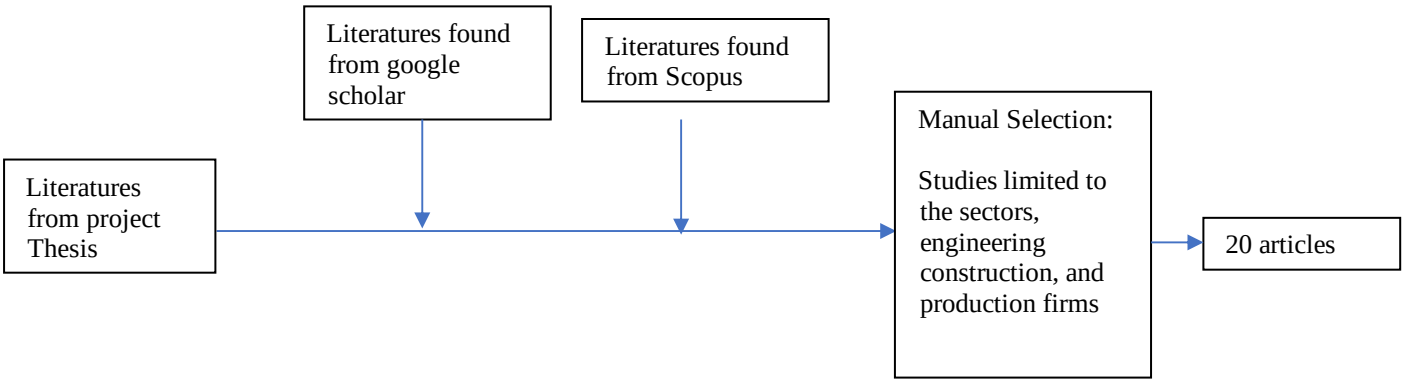

Figure 10 inclusion exclusion of article

Based on the all afore mentioned criteria and procedure of selection 20 articles are selected and are listed and further assessed based on the framework given in next chapter, 3.3.

2.7 Framework

In the chapter 2, theoretical background, different aspect of lean, lean supply, lean supplier development, and lean in ETO are discussed. Based on the discussion, a framework is developed to evaluate the selected articles to investigate how extend lean implementation in the external process improvement of a lean buying firm is studied. Lean supply is a broad term with an its elements (listed below) are investigate to what extend they are discussed in the article. By investing these elements, it can be assessed the applicability of lean elements lean supplier development, JIT and long-term relationship in lean ETO. Though Lean supplier development is one the element of lean supply, it has given focus as the reason prompted for this study is from the previous study conducted on lean supplier development. Powell et al. (2014) expressed that JIT, is can be achieved by the use of Standardization/ Modularization/ Prefabrication. So, it is a term that is always coupled with JIT and will also be looked in to. Further knowledge transfer/information; flow/Training & Learning are also coupled with long-term relationships; these aspects are also taken into consideration.

The below-given aspect are investigated in the articles.

- JIT
- Standardization/Modularisation/Prefabrication
- Long term relationship
- Knowledge transfer/information flow/Training & Learning
- Supplier development

The articles are reviewed and information about these aspects in ETO setting are discussed in the analysis part.

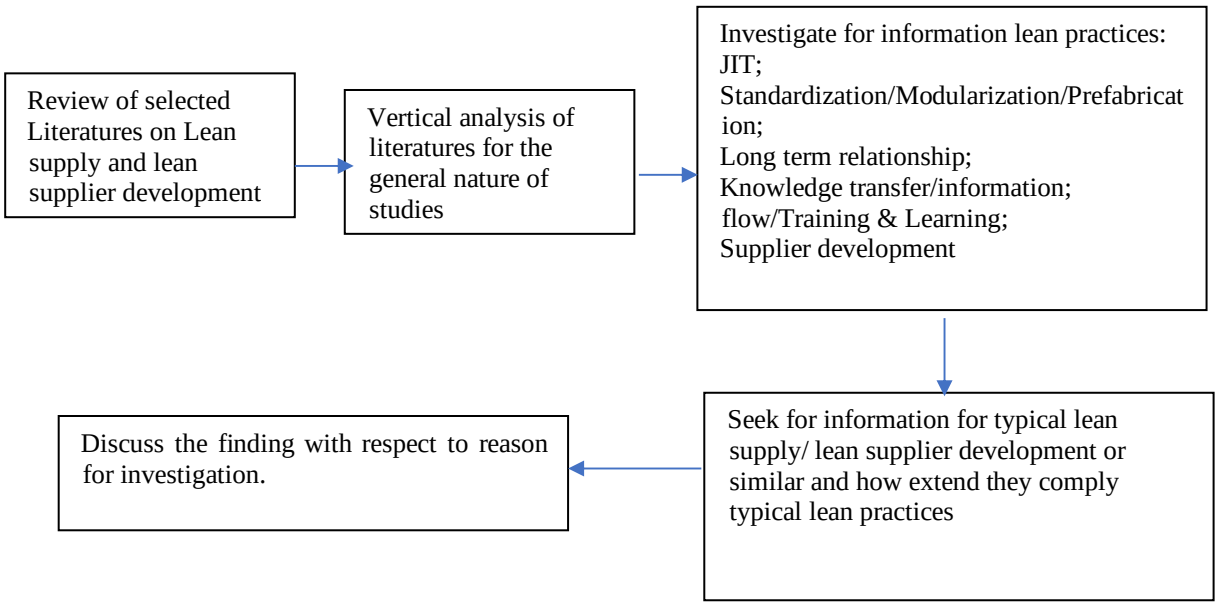

Figure 11 Illustration of assessment framework

Table 1 List of documents selected for review

Sl.no	Category	Title	Author	Method	Region	Themes	Themes in lean supply
1	Article	A supply chain flexibility framework for engineer-to-order systems	(Gosling et al., 2013)	Case study	Cardiff, UK	ETO & supply	Supply chain flexibility (strategic supplier flexibility)
2	Article	Application of vendor rationalization strategy for manufacturing cycle time reduction in engineer to order (ETO) environment	(Seth and Rastogi, 2019)	Case study	India-Qatar	ETO & supply chain	Vendor rationalisation for manufacturing cycle reduction in ETO firm
3	Conferenc e e	Defining the lean and agile characteristics of engineer-to-order construction projects	(Gosling et al., 2007)	Conceptual	UK	Lean & Agile in ETO	Comparison of lean and agile approach in supply chain in ETO.
4	Article	On-site oriented capacity regulation for fabrication shops in Engineer-to-Order companies (ETO)	(Matt et al., 2015)	Case study	Bolzano, Italy	ETO & Prefabrication	JIT-delivery (material flow) , JIT-regulation circuit (information flow) using Prefabrication/modularisation
5	Conferenc e paper	Increasing productivity in ETO construction projects through a lean methodology for demand predictability	(Dallasega et al., 2015)	Case study	Italy	ETO & demand predictability	JIT and synchronization of demand and supply
6	Conferenc e Paper	Lean in high variety, low volume production environments − A Literature Review and Maturity Model	(Buetfering et al., 2016)	Literature Review	Germany, Netherlands , Norway Belgium	Lean in HV/LV & its application	Comparison of supply chain structures of different HV/LV models
7	Article	Linking product modularity to supply chain integration in the construction and shipbuilding industries	(Pero et al., 2015)	Case study	Italy-Germany	ETO & Modularisation	Modularization & supply chain integration
8	Article	Managing uncertainty in purchasing in engineer-to-order manufacturing	(Halse et al.,n.d.),2015	Case study	Norway	ETO & supply	Flexibility in supply chain
9	Article	Modelling Supply Chain Management Processes in Engineer-to-Order Companies	(McGovern et al., 1999)	Case study	Tyne, UK	ETO & supply chain	Long-term relationship, knowledge sharing
10	Article	Need for innovation in supplying engineer to-order joinery products to construction case study in Sweden	(Forsman et al., 2012)	Case study	Sweden	ETO & supply chain	Long-term relationship, knowledge sharing, modularisation/prefabrication
11	Article	Principles for the design and operation of engineer-to-order supply chains in the construction sector	(Gosling et al., 2015)	Case study	UK	'FORRIDG E' in ETO	JIT, Information flow, learning and training, supply chain integration
12	Article	RFID technology for increasing visibility in ETO supply chains: a case study	(Pero and Rossi, 2014)	Case study	Italy	ETO & Supply chain	Information sharing using RFID
13	Conferenc e paper	Strategic Organizing of Piping Supplies for Ship Construction	(Engelseth andLe,2017)	Case study	Norway	ETO & supply chain	Relationship, JIT
14	Article	Supplier Involvement in Product Lifecycle Management of Construction Firms	(Cheng-Wen Lee,2008)	Analytical-structural	Taiwan	ETO & supply	Relationship, Supplier involvement
15	Conferenc e paper	Supplier's selection strategy for mass customization	(Mukherjee et al., 2009)	Analytical (AHP)	India	ETO & supplier selection	Supplier selection Methods
16	Article	Sustaining performance under operational turbulence the role of Lean in engineer-to order operations	(Birkie et al., 2017)	Case study	Italy-Sweden	ETO, lean implementation & performance of lean in ETO	Relationship, Customization, JIT, Flexibility, MCT
17	Conferenc e paper	Towards a collaborative approach to sustain engineer-to-order manufacturing	(Amrani et al., 2010)	Conceptual	France	performance ETO & collaboration	Relationship, CRM, SRM
18	Article	Understanding dynamism and complexity factors in engineer-to-order and their influence on lean implementation strategy	(Birkie and Trucco, 2016a)	Case study	Italy-Sweden	ETO complexity & dynamism	JIT; Standardisation; Customer involvement and partnership
19	Article	Adaptation of the value stream mapping approach to the design of lean engineer-to order production systems A case study	(Matt, 2014)	Case study	Italy	ETO, VSM	VSM
20	Article	Engineer-to-order supply chain management A literature review and research agenda	(Gosling and Naim, 2009)	Literature Review	UK	ETO & supply chain	Lean and agile in ETO

3 Literature review & Analysis

In order to explore what literature, say about lean supplier development or similar concept on ETO setting, this section presents a study based on literature review. Literature search was performed, and further from the combined shortlisted articles, both abstract and conclusion were read and also, the articles were further skimmed for evaluating the relevance and quality of the literature. Based on that 20 articles were chosen for review to seek information / any studies about lean supplier development in ETO. For that finally 20 relevant articles were reviewed in detail for looking information about the concept of lean supply and lean supplier development to find what extend it is explored. While reviewing the articles, references to more relevant articles were found. Thus, after reviewing the 20 articles, these were later included to the list by substituting already selected article which are found less relevant.

The list of articles selected for review for research question is given Table 1.

3.1 Overall Literature Characteristics

A summary of overall characteristics of studies/reviewed literatures are discussed in this section. The literatures are characterized on the basis of method of study, industry of study, region and year of study for assessing the pattern and knowing the general trend. As articles for review were selected on the basis of relevance of information it discusses, most of the articles are assorted from different journals, hence a categorization was on the basis of sample is of interest in different journals.

i. Year of publication.

Among the reviewed articles in this thesis, except one, 19 of them were published in last two decades. Out of that 13 of them are from last recent years, and not more than 5 years old. A representation of studies per year from 1999 to 2020 is depicted in Figure 12.

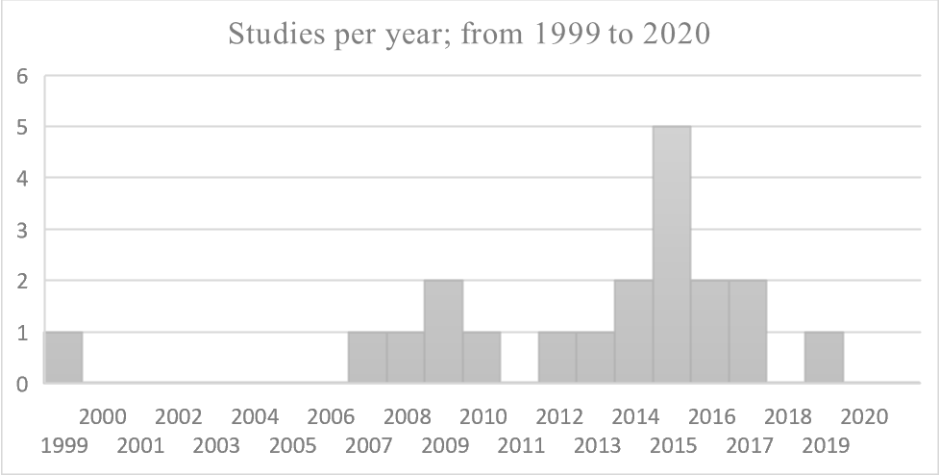

Figure 12 Representation of year of publication

As observed, most of number of studies were conducted in the year 2015 and years surrounding. This implies most of the studies are of recent years, but it has reduced recently (2019 and 2020). And it further gives an impression that lean implementation for external process improvement is of recent interest, and it could be that newer articles are not yet published.

ii. Geographical region of researches/studies.

The research was dominated with studies from Europe (90%), the remaining 10% were from Asia. There was not study from Americas and Africa. Most of the studies were from either UK or from Italy. There was one from India and one from Taiwan to be name as contribution from Asian continent and lacks any from Japan. A pie chart of studies with respect to geographical location is given below.

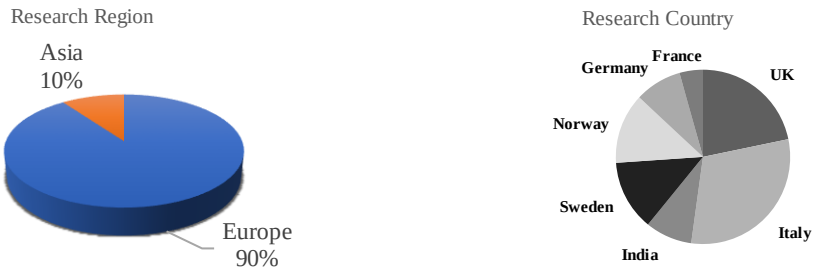

Figure 13 Research Geographical region.

This shows that the interests for study on lean implementation for external process improvement is more in Europe than in rest of the world. It can be assumed that this could be because more researches are documented and published in European region in this sector rather than mere interest

on this topic because it cannot be said that the ETO projects and products are less in other regions, it is quite common in different regions of the world. This disparity can be explained in light with the statement of Netland and Powell (2016), they mentioned, the production cost in low-wage countries are relatively low and so traditional high-volume, low-variety production with relatively low-profit margins might have migrated to such low-cost regions. Moreover, knowledge-intensive, customer-specific developments and products would have gotten the attention in the place in high-cost regions.

iii. **Research methods and Industry sectors which researches are conducted:**

Out of selected 20 articles when reviewed, 15 of them are case studies, 2 of them are literature reviews, 2 are conceptual and one is analytical. Some articles employed both literature reviews and case studies. Researches were mostly dominated in construction industry (e.g. Gosling et al., 2013, 2007; Cheng-Wen Lee, 2008; Dallasega et al., 2015; Forsman et al., 2012; Gosling et al., 2015; Matt et al., 2015; Matt, 2014; Pero et al., 2015), however some studies were done in mechanical manufacturing industries working with various kind of mechanical component, process equipment manufacturing, and so on (e.g. Birkie and Trucco, 2016; McGovern et al., 1999; Pero and Rossi, 2014; Seth and Rastogi, 2019). Besides, couple of researches were done in Maritime industry and Oil and Gas industry as well (e.g. Birkie et al., 2015; Engelseth and Le, 2017; Halse et al., n. d.; Pero et al., 2015). Overall literatures were of from various ETO industry sectors and hence it gives very generic impression while assessing the outline. It can be assumed that construction industries possess relatively less sensitive intellectual properties (IP), and so researchers were able to get access to case companies in construction industry quite easier than other industries such as Oil & Gas, ship building. Further the safety and hazard requirement of construction industries are also relatively less compared to hazardous product manufacturing industries and so on. So, it can be argued that, this is could be one of the reason most of the studies concentrated on construction industries.

3.1.1 Themes discussed in the articles

After having reviewed the whole 20 articles, it was investigated how and what extend the themes which mentioned in framework are discussed in the articles. For that all the articles are read in detail in search of information pertinent for themes and the following observation is developed.

The supply-chain/lean-supply themes that are discussed in the literature are **JIT** (Birkie et al., 2015; Birkie and Trucco, 2016; Dallasega et al., 2015; Engelseth and Le, 2017; Gosling et al., 2015; Matt et al., 2015)**, Long term relationship** (Amrani et al., 2010; Birkie and Trucco, 2016; Cheng-Wen Lee, 2008; Engelseth and Le, 2017; Forsman et al., 2012; McGovern et al., 1999)**, Knowledge transfer/information flow/Training & Learning** (Forsman et al., 2012; Gosling et al., 2015; Matt et al., 2015; McGovern et al., 1999; Pero and Rossi, 2014), **Modularization/Prefabrication** (Birkie et al., 2015; Birkie and Trucco, 2016; Matt et al., 2015; Pero et al., 2015)**, Supplier development** (Birkie and Trucco, 2016; Gosling et al., 2013; Hal se et al., n.d;Seth and Rastogi, 2019)**.** The concepts and ideas presented about these themes in the review articles are discussed next.

i. JIT (Just-in-time)

From the reviewed articles, different authors opined on different aspects/applications/notions of JIT in the ETO setting.

Matt et al. (2015) discusses the concept of JIT in prefabrication/modularization in the construction industry. According to Matt et al., (2015), demand for prefabrication should be pulled from the installation site as construction progresses, to manage any unpredictable situations efficiently. Matt et al. (2015) explain a modified type JIT, which is appropriate for the ETO setting. As the demand predictability is very uncertain in the ETO setting, implementing JIT similar to mass production setup would likely be not improving the efficiency of the supply chain in an ETO setting. Introducing a supermarket for the prefab component as in Figure 14 (which will be used in an ETO project at the construction site) can address different challenges in an ETO setting. By introducing a prefabrication component supermarket, the CODP is moved downstream. The fabrication unit for the prefab component considers the CODP as the demand at the prefab component supermarket. Furthermore, the supermarket makes the prefab component ready for final assembly and delivers to the site based on the requirement from the site, as and when construction progresses. Thus, the supermarket divides the decoupling point, one at the supermarket for the fabrication yard of prefab component and second at the site where the prefab components are delivered just-in-time. Here the concept of JIT, which literally contributes to having zero inventory, is not 100% complied. However, the philosophy of JIT is used to address different challenges, including lead time reduction, supply chain/manufacturing flexibility.

Benefits due to economies of scale can be availed at the prefabrication yard in this setup, at the same time, punctuality for components at the construction site can be ensured in this setup. Further, the concept addresses remedies to storage at the construction site, and issues related to uncertainties arise in demand.

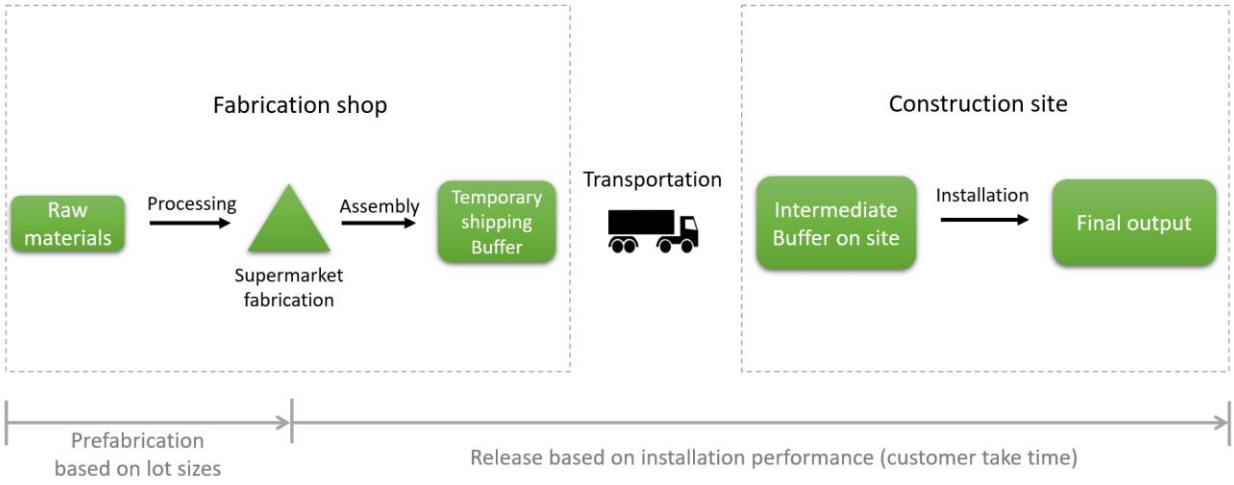

Figure 14 Concept of supermarket *(Matt et al., 2015)* .

Dallasega et al., (2015) did the research on the same ETO project that Matt et al., (2015), and further came up with some additional suggestions. Their study was mainly focused on the synchronization of different activities of an ETO project, and they concluded that synchronization (of engineering, fabrication, and installation) is vital for solving problems with project interruption. Dallasega et al. (2015) also refers to prefabrication and having a prefab component supermarket as an option for availing JIT in the construction project. Besides, Dallasega et al. (2015) expresses, with an effective synchronization, the demand predictability can be improved, and the JIT philosophy can be better utilized.

Gosling et al. (2015) in their research also expresses the way to adopt JIT in the ETO setting is using prefabrication, pre-casting methods in the construction industry. So instead of manufacturing at site, components that can be supplied as prefabricated, pre-casted (such as facades, pre-cast concrete blocks) can be delivered to the construction site as JIT, and the demand is pulled based on the requirement. However, the dynamic environment of ETO project set-up makes this difficult, and Gosling et al. (2015) mentioned RFID based tracking system could make a difference in this as the material flow information becomes transparent.

Engelseth and Le (2017), in their study discusses about an ETO project in shipbuilding industry. In their study, they unravel how JIT was used in the piping product supply for a shipbuilding project at the shipyard. A ship/vessel, which is a very complex ETO product, consist of different assemblies/units, and some of them are customized, and some of them are standard items. Apparently, pipes and valves are generally bought from suppliers brought to the site, and further assembled to the complex units at the fabrication stage. In the project in the case study, the standard pipes and valves were delivered by a wholesaler to the sites in the JIT model by applying Vendor Managed Inventory (VMI) principle. Between the buying firm and supplier, it existed a close relationship and continuous information flow. From the beginning of the project, the information sharing was done flawlessly between two parties. Stock availability delivery time from supplier, production plan, demand forecast and so on from buying firm were communicated by two firms. Further consumption at site and demand requirements were constantly passed to suppliers. Thus, the supplier was able to deliver the product in JIT mode. In this project, at some level of the value chain, inventory of items are availed. However, in a possible level, lean philosophy JIT is used but not the same as in mass manufacturing firms where there are zero inventory and direct supply of item from the production facility to fabrication/assembly unit of buying firm.

Birkie and Trucco (2016), in their study about the influence of dynamism and complexity in lean in the ETO system, mentions that JIT in one of the case company (which is a supplier to lean buying firm) was not able to fulfill the requirements flawlessly. This was because frequent changes resulted in having in not continuously the orders. However, by improving the production planning, they could manage to mitigate it to some extent; however, the parts were to be stored in the warehouse. Which, in turn, again comes to the partial fulfillment of JIT philosophy.

From different examples seen in the literature, it gives the impression that, in the ETO setting, JIT cannot be applied in the same way as it used to be applied in a mass-production setting. However, the philosophy can be used, and with some adjustments in the value chain and the advantages of JIT can be utilized. So, by having a buffer/supermarket/warehouse of inventory in the middle or somewhere in a suitable position in the value chain, JIT can be utilized for delivering products to the end customer. By having JIT coupled with modularization/prefabrication, the CODP can be moved downstream to some extent.

ii. Long term relationship

From the reviewed different articles, many authors expressed the 'long-term relationship' between buying firm and supplier serves as an opportunity to mitigate many challenges occurring in lean implementation in the ETO setting (Forsman et al., 2012) the same is discussed in this section.

Forsman et al. (2012) made invaluable contributions in these aspects in their research, where they did a case study on the ETO construction industry and opined on buying firm supplier relationship affairs. Forsman et al. (2012) enhanced knowledge about the barriers of efficiency in supplying ETO solutions to the construction industry. Forsman et al., (2012)'s study concentrates on lean thinking and information management in the construction sector and points towards the need for longer-term procurement relations and efficient communication of information among various parties involved. This could improve the efficiency of supplying ETO products in the construction industry. Forsman et al. (2012) in his research case study unearths wastes occur in ETO construction project. From the case study, under-processing (deficiencies in information or lack of information and materials forwarded through the value stream which is leading to cause inefficiency in downstream processes), increase of lead time due to lack of concurrent engineering as result of lack of continuous information flow, defects or unreliability of geometrical information of supplied products, lack of coordination and synchronization in the supply chain were found to be as some of the wastes or causes of wastes. With the help of modern information technology platforms, it is possible to make improvements in planning and coordination, assembly information, and spatial stages of construction, thus leading to increased levels of off-site prefabrication, decreased assembly time, and increased predictability of on-site work; all of which would lead to reduced waste and improved efficiency matrices. Further, Forsman et al. (2012) advocate procurement models based on more long-term relations than individual project levels of the contract. One of a kind projects and the contractual nature among their stakeholders in the construction sector are some of the culprits to limited long-term relations in the procurement of sub-suppliers. The fragmented nature of the construction industry hinders the adoption of innovative and productive technologies that were successfully implemented in other industries. Forsman et al. (2012), from the case study, proposes that a procurement model based on a more long-term relationship with a supplier than temporary project level procurement would be a much desirable strategy to increase the efficiency. By having better coordination through a close

relationship, concurrent engineering and efficient knowledge accumulation can also be achieved (Forsman et al., 2012).

Birkie et al. (2015) also mentioned a similar view as Forsman et al. (2012) in terms of long-relationship. In the case study, a company that worked with suppliers as partners managed to gain a better negotiation position and thus cost reduction. In the company, the buying firm openly discusses the price with suppliers considering the market situations, and they both worked together for the price reduction. This might not be possible in a conventional supply system where supplier tends to be opportunistic and aims to look for max gain regardless of situations. Similarly, in one of the case company suppliers were given access to the shop floor so that they were able to supply the parts without getting a request for a part. Because of having a long-term relationship, the suppliers of one of the case companies shared their production plan to the buying firm (case company); thus, the shop floor was kept informed about the expected delivery of parts.

Birkie and Trucco, (2016), also expresses on long-term relationship aspects and states in their research, based on a case study, in the case company, the customers maintained a partnership like a relationship with the supplier from the very beginning stage such as product conception stage and which helped them in accommodating late changes without additional expenses. Further, in some ETO projects, the customers bring in some components for final assembly for the test of the final product (testing is under a supplier's scope), and any delay in delivery of such item causes an impact on the delivery schedule of the final product. By having a local presence and close relationship with customers, supplier could manage to align such component requirement from the customers side and manage to address the complexities.

McGovern et al. (1999) mentioned demand uncertainty is one of the limiting factors for any development of a long-term relationship between buying firm and supplier. And in their case study, they mentioned firms started realizing the importance of more collaborative relationships, especially with key suppliers. The operational benefits associated with this kind of collaboration and strategies for collaboration are to develop an improved understanding of customer requirements, reduction in lead time, manage the uncertainty associated with demand requirement and so on. McGovern et al., (1999)'s study is older compared to the rest of the case studies discussed here, however, the author has addressed similar challenges like other authors also expressed.

Engelseth and Le, (2017), also mentioned that the motivation for ETO firm to have a long-term relationship was coupled with uncertainty reduction. The study was in the shipbuilding industry and very recent. The case companies were showing an increased willingness to invest in relationships to mitigate issue related uncertainty.

Further, Cheng-Wen Lee (2008), in his study in the construction industry, found that the degree of buyer-supplier relationship has a positive impact on product life cycle management. The study primarily talks about supplier involvement in the ETO project, which is one of the typical lean supply characteristics.

From the above examples, it can be understood that long-term relationship has similar benefits in the ETO system with respect to the mass production setting. Different authors emphasized on a different benefit of long-term relationship; however, better access and cooperation is what is found the common opinion of authors. It can be observed that a partner like a relationship is not referred in any of the cases. Many aspects that were seen in a partner like a relationship in mass-production industries is unseen in cases discussed.

iii. Knowledge transfer/information flow/Training & Learning

In the matter of knowledge transfer, information exchanges, training, and & learning, many articles bring various opinions that are pertinent to an ETO setting. Most of them are coupled with the relationship between the buying firm and supplier counterparts.

Forsman et al., (2012) emphasize on flawless information exchange between buying firm and supplier counterpart and also promotes the use of information management technologies to minimize wastes as well as effective information flow among various stakeholders in construction projects. The information needs to be accurate, achievable, accessible, and understandable for all parties involved to achieve higher productivities. Efficient information transfer through the value stream is needed, and modeling this information to make it easier to take in and understand is a key issue. The limitations in the available information cause uncertainties that slow down the pace of the ETO project. This limits organizational learning. Increased education in Lean principles throughout this supply chain in order to increase awareness of this phenomenon and to create a platform for continuous improvements would constitute a useful innovation. Increased efforts of the joinery-product suppliers in 3-D modeling and generation of exploded views are likely to

enhance ETO project efficiency. Further use of information technology tools for increased visualization and efficient knowledge transfer is also believed to be useful in this context. Forsman et al. (2012) in the study finally comments that standardization in processes and communication is vital for an ETO firm to increase efficiency, and in the case company, they proposed it as an improvement area in the case company. Also, in the case of problem-solving, it was found the problems are solved as they emerge, and thus there was no practice of route cause analysis. Thus, the actual problems are not detected, and also there is no organization and inter-organizational learning culture, which then prompted to have the problem to occur repeatedly.

As it is known that flawless information flow and knowledge sharing is a characteristics of lean supply system. From the examples about the case studies shows a mixed outcome, some studies recommend improving the existing information flow and knowledge sharing system by implementing lean principles completely. Further, the practice of inter-organizational learning and quality management using route-cause analysis is observed to be not practiced much. Similarly, a knowledge-sharing/information exchange/learning with the long-term relationship is not seen established.

iv. Standardization/Modularization/Prefabrication

Standardization and modularization as we know literally benefit to bring the decoupling point closer to downstream as some of the activity such as engineering is more or like are already done, and the remaining activity is a fabrication. When it comes to prefabrication, the fabrication of items is also done, and the item is ready to be delivered to the site on a JIT basis, whereby the CODP is further brought to downstream. There are different case studies found in the reviewed article which talks about standardization/ modularization and prefabrication.

Birkie and Trucco, (2016) express that, the ETO case companies in their research, utilized the benefits of standardization techniques for their products. One of the case companies standardized the processes and products by defining the quality gates, developing a classification of products into families and sizes, establishing preparation of work procedures and guidelines. The second case company utilized standardization techniques for the usage of common processes and common component platforms.

From the study conducted by Forsman et al. (2012), they commented that increasing the level of prefabrication in the ETO system is much desirable. In their study, the case company used prefabricated products for the construction industry. By this, construction activities are moved out of the site and delivered the product to the site in JIT mode. And thus, by this, the case company benefited with decreased assembly time and better predictability of on-site work.

Matt et al. (2015) conducted their research, especially on JIT delivery of prefabricated products to the site. Prefabricated steel components and pre-produced metal components are fists stored in a supermarket and then delivered directly to the site depending on demand-pull. So, at the site the item is delivered without any delay. It used to be two types of orders, one from the site for delivery of the prefabricated item, another one order prefabrication to store in the supermarket. By this, the supplier can take advantage of economies of scale and further all kinds of advantages on transportation.

Pero et al. (2015), in their study, expressed that modularity has a positive impact on supply chain performance as it can contribute to the reduction of lead time. At the same time, he commented modularity gives a lower degree of flexibility in design changes and customization. Pero et al. (2015) also stated that a modular solution allows us to take advantage of economies of scale, which means modularity can eventually contribute to cost reduction of the final product.

Utilizing the technique of making products into modules and sourcing the whole module from the supplier, including engineering of the module, is a typical technique used in the lean supply paradigm. In TPS, Toyota utilized the concept of modularization and modularized products in their cars by involving suppliers in the product design and completed product delivered to the assembly unit (Womack et al., 1990a). In the ETO environment, it can be seen from the reviewed articles that, the firm utilized this technique wherever possible. Also, tried to take advantages through standardization, modularization, and then prefabrication. However, unlike mass production environment, the whole process of modularization and delivery of modules has been adjusted/customized based on the nature of the ETO environment. It can be surely seen that the lean philosophies on modularization are adopted with modifications based on the environment.

v. Supplier development

From the reviewed articles, authors opined on different aspects of supplier development. The lean supplier development initiatives, with all its typical characteristics, were seen hardly ever in the reviewed studies.

In the case study conducted by Forsman et al. (2012) it was observed the supplier companies of joinery products worked together under one brand, which is common for all suppliers to sell the product in the market. There was a network of suppliers, however, as the volume of their enterprises were relatively small; hence not much of innovation was present. Forsman et al. (2012) mention that such networks could actually cooperate and work together on research and development. There was no information on whether the buying firm has any role in the formation of the supplier network. Forming a supplier network is a lean supplier development model; however, in the typical lean supplier development model, the buying firm usually takes the lead of such associations and networks.

Authors Gosling et al., (2013) and Seth and Rastogi, (2019) discusses about supplier development theme by introducing different strategies used for supplier development in ETO setting. They are,

1. Strategic vendor/supplier flexibility
2. Vendor rationalisation

Strategic Vendor/Supplier Flexibility: Different articles touched the term flexibility, the applicability of flexibility in lean supply implementation in ETO.

Gosling et al., (2013) discusses about Supply chain flexibility (strategic vendor/supplier flexibility); and according to Gosling et al., (2013), flexibility is an 'effective response' to uncertainties occurring in process, supply, demand, and control. Correspondingly uncertainty in the supply chain is a circumstance where lack of necessary information and control makes decision making hard for a firm. Gosling et al. (2013) discusses about strategic flexibility in supply chain and argue that it is a pragmatic approach for ETO setting as the nature of ETO setting comes with various sort of uncertainties. The author says the supply chain strategy for different supply chain structures should be configured to match its context as the position of CODP is located at various levels in different supply chain structures. This implies a one size supply chain structure does not fit for all so as for an ETO supply chain setting (Gosling et al., 2013). For implementing strategic

flexibility in the supply chain, it shall be done in four steps, first classify supply chain to distinguish its structure (such as ETO or similar other), second identify and analyze the uncertainties in the supply chain, third optimize the pipeline and finally develop the strategic flexibility. Gosling et al. (2013) describe the Pipeline as the delay between a generated purchase order and the delivery of the ordered item, and shorter pipeline lead time contributes to bolsters competitive advantage. In a typical ETO setting, where the products are generally the outcome of projects, its nature itself can introduce uncertainties into a pipeline. Thus, one size pipeline design does not fit on all settings, so the pipeline strategies shall also be different for different settings (Gosling et al., 2013). As part of pipeline optimization, techniques such as using input-output diagrams, process flowcharting, group problem-solving in pipeline etc. were employed. Each pipeline was taken individually and assessed for improvement. And the identified uncertainties were addressed. This whole exercise resembled to value stream mapping in lean practices. Further, to develop strategic flexibility, the supply system and suppliers needed to be developed (Gosling et al., 2013). For that, the suppliers were classified into tiers. Gosling et al. (2013) classified them as strategic partners, preferred suppliers, approved suppliers. In addition to that, the buying firm based on the tier class of supplier/vendor the vendor flexibility development programs were devised. For strategic partners, formal trainings were given to develop capabilities in required areas. Further other tier class suppliers were approached in a different strategy. In the case study in the research, ideas similar to TPS system supplier development, such as working as a team, considering supplier as partner approach, demotion, and promotion based on performance monitoring, were also seen used in this development process. It can some extend be noticed that some of the lean philosophies are used in these environments, but not all. In this development, different approaches resembled to lean practices; however, they are not fully complying with lean practices. A combination of the idea of value stream mapping and supplier development, to some extend, can be referred here in this case study.

Halse et al. (2015) similarly discusses about the relevance of uncertainty in the supply chain and about purchasing flexibilities for such uncertainty situations. And presents a case study of maritime industry in northwest Norway to elaborate on purchasing flexibility. Halse et al. (2015) opined there are purchasing flexibility, vendor flexibly and knowledge flexibility.

Vendor rationalization: According to authors Seth and Rastogi, (2019, p2), "vendor rationalization generally is referred as an approach of reducing the total number of vendors to cut costs and minimize coordination hassles, and thus introducing supply efficiency so that vendor base can further be refined, optimized and can be made more effective".

In article Seth and Rastogi, (2019) came up with a case study on 'application of vendor rationalization strategy for reducing suppliers for manufacturing cycle time reduction (MCT) in ETO setting' and proposed that rationalization of supplies and necessary strategic alignments can considerably lessen supply risk, costs, manufacturing, and delivery cycle time and co-ordination challenges associated with ETO environment. From the study the authors stated that vendor rationalization is not just about supplier base reduction, instead, it is developing vendor base, which can give the best business scenario and fit to the buying firm. By assessing the affairs such as what the firm is buying, from which supplier, and what type and quantity, associated risks to incorporate, type of reviews to undertake on design, manufacturing issues, supports offered on the products and cost for it, the vendor rationalization is pointing to a practice of some periodic changes and strategic alignment for supplies and vendor bases.

The Seth and Rastogi (2019) says the vendor base shall be developed by not only on the basis mathematical modeling of vendor evaluation/prioritization, instead each purchase item/component needs to be assessed for its nature, and a grouping shall be done based on Kraljic's matrix. This can be beneficial for cross-functional integration of components, which is an essential requirement in an ETO product/ project setting. Further to achieve this, the supplier bases shall be developed on the basis of a co-operative business partner arm-in-arm relationship. The author proposes a radical change in buying firm supplier relationships, such as changes from playing multiple vendors to one another for the best price and also purchasing on the basis of low piece price. Instead of the traditional way of rating the vendors/suppliers and making a purchasing decision based on prioritization from such ratings, the buying firm should make purchase decisions on the basis of the complexity of the component /item by doing value engineering to the product and process. By this, the buying firm can limit the number of vendors for complex items/components. In short, Seth and Rastogi (2019) convey the purchasing decisions shall be on the basis of each component/item, and vendors shall be rationalized on the basis of this to achieve better manufacturing cycle time in an ETO setting.

The idea explained in the article also points out concepts of lean supply, such as supplier/vendor base development, long term relationship with the supplier such as a co-operative business partner, purchase decision on the basis of the item to be purchased and not on piece price, value engineering and so on.

This section analyzed the selected literature seeking information on what literature mentions about lean supply elements, which we are investigating, and in the next section, we will evaluate and discuss the finding the analysis

4 Findings and Discussion

4.1 Findings

After having reviewed the 20 selected articles, various aspects of the lean supply system and lean supplier development were investigated in the article. To what extend the article discusses the aspect of lean supply system and lean supplier development or any practices used in the lean supply system and lean supplier development, the articles we reviewed for information relevant to JIT, long-term relationship, knowledge transfer/information exchange/learning and training, Standardization/modularization/prefabrication, and supplier development. Out of that, the below-given number of articles either directly talks or mentions about the given theme. Different articles talk or mention more than one topic.

JIT - 5 articles

Long-term relationship -6 articles

knowledge transfer/information exchange/learning and training – 5 articles

Standardization/modularization/prefabrication – 4 articles

supplier development – 3 articles

There were a few explicit studies on JIT implementation in ETO system, and most of the authors came to similar conclusions about JIT in ETO. Which states that JIT technique can be used in ETO setting however not in the same manner as it used to be implemented in mass production, but a slightly modified form with an addition of inventory of already fabricated/manufactured products which are more or less standardized and then deliver to site when there is a demand-pull. So, this can work with two pulls from the customer; one is the real need at the site as when the construction/manufacturing progresses, second one based on the future requirement forecast

which depends on the project/product requirement forecast of the customer to end-user. As multiples authors opined a similar model, we can say that this is a very practical option and can be utilized as a paradigm in the ETO setting for taking advantage for different kinds of industries.

Moreover, the case studies reviewed, mostly construction industries were utilizing this technique 3 off them, and 1 off a mechanical unit manufacturing industry and another one shipbuilding industry. However, regarding the requirement of inspection of items delivered at customer, there was not enough information found in the case studies discussed. Only one author (Forsman et al., 2012) mentioned in one of the case company when they had issues of quality and time consumption for measurement at the site, they brought in lean supply system with prefabrication and JIT and further improved their technical communication regarding the specification requirement etc. with supplier and then demanded to adhere to quality requirement. And the author proposed this as a recommendation for improvement for firms operating in similar setting.

Relationship between buying and supplier firm are discussed by 6 authors in their articles though, and the general perception is that long-term relationship among buying firm and supplier firm is seen not typical like what it was observed in lean mass production firms. Forsman et al., (2012) came up with a suggestion from his study that long-term relationship is vital for ETO projects, which can help to eliminate wastes (under processing, increased lead time, defects, lack of coordination) in the ETO projects and thus increase the overall efficiency. Birkie et al. (2015) expresses a long-term relationship gives them a better negation position and helped in mutual cost reduction. In the same study, because of long term relationship, access to the shop floor of buying a firm and sharing the production plan of the supplier firm were happened. These practices are quite often seen in a lean firm with long-term relationships. Birkie and Trucco, (2016) expressed, the companies in the case study were able to collaborate better any late changes to the design was manageable without additional expenses to buying firm. McGovern et al. (1999) mentioned, demand uncertainty is one of limiting factors for any development of a long-term relationship between buying firm and supplier; however, the author mentioned firms realized this and strategically improved collaboration with the key supplier to improve these aspects. On the other hand, Engelseth and Le, (2017), mentioned that the motivation for ETO firm to have long-term relationship was coupled with uncertainty reduction. McGovern et al., (1999) study is relatively older and the recent studies has a clearer observation on benefits of long-term relationships. From

the literature analysis, it can be observed that different authors discuss the different aspect of the long-term relationship; generally, it can be perceived that not much information is available to say that the long-term relationship between buying firm and supplier are similar like in lean mass production manufacturing. This gives the impression that firms are in the exploring phases of benefits of long-term relationships; it has to be established further to achieve the full benefits.

Some authors in their study mentioned about the knowledge transfer/information flow/Training & Learning that occurred in the firms which they used for case studies. There seems to be no dedicated study found in knowledge transfer/information flow/training among the reviewed articles. Out of 20 articles, 3 articles talk about knowledge transfer/information flow/Training & Learning. Forsman et al., (2012) expresses improved information sharing with a long-term relationship as a suggestion to improve the efficacy of ETO construction projects. Knowledge transfer/information flow/Training & Learning practices are seen in the lean supply paradigm and are relatively less explored in studies discussed in the articles.

There are 4 studies in 20 articles reviewed discusses about Standardization/ modularization/ prefabrication. This implies the interest in this topic in ETO is relatively more among researchers. All authors Birkie and Trucco, (2016); Forsman et al., (2012); Matt et al., (2015); Pero et al., (2015) has common view regarding the relevance of Standardization/ modularization/ prefabrication, and it's positive impact on reducing lead time and facilitating JIT. Pero et al. (2015) opined, although modularization has positive impacts on ETO projects/products, it has a lower degree of flexibly in design changes and customization.

Supplier development was discussed by three authors in their studies, especially contributions of Gosling et al., (2013) and Seth and Rastogi, (2019) were standing out. It can be noted the interest in supplier development studies were relatively less, that is 3 studies out 20 studies were only having information about supplier development. Also, at the beginning of the research, there was an earlier finding that there were no explicit case studies found on the supplier development in ETO. To some extent, it can be argued true because there was no article found with such a title. So, it is quite obvious to have such an impression. However, the detailed study of selected artless unraveled the pertinence of that claim. When we compare the supplier development, discussed in the articles with lean supplier development, it is complying to some extend, but not all practices are implemented. As we know typical lean supplier development program of mass production

firms such as Toyota, Nissan, and Honda, they all had explicit supplier development agendas for their suppliers, and they worked out it as supplier development programs such as TPS in Toyota, Best practice in Honda, supplier development in Nissan.

When we observe the studies in ETO, we can say that some of the lean supplier development practices are adopted. For example, in the case study, which Forsman et al. (2012) conducted, the suppliers used a form of network to brand their products. Having a supplier network is a typical feature of the lean supply system. And in TPS, Toyota used to lead to have such supplier networks and promote any sort of innovations through these bodies. In the given study, there is no evidence given that supplier networks were led by any buying firm. However, the idea of the supplier's network was in practice. Similarly, in the study of Gosling et al. (2013), the author discusses about the flexibility in supply chain and expresses supplier/vendor flexibility is key to utilize the lean in ETO to benefit with its real potential. He suggests that one size supply chain structure does not fit in all settings and hence the supply chain strategy and pipeline line strategy for the different structures shall be configured to match its context.

Gosling et al. (2013) further state to achieve this, the supplier in the value chain needs to be developed to gain relevant lean qualities. For that classification supplier to tiers and further into strategic partners, preferred suppliers approved suppliers were done. This approach is one of the practices in lean supplier development. As it is a typical practice among renowned lean firms to have tier class for customers and then bring them under a strategic relationship. Further, working as a team, considering supplier as a partner approach, demotion, and promotion based on performance monitoring were also seen used the case company to achieve the flexible supply chain system. Supplier association, on-site consulting, problem-solving teams, learning teams, employee transfers, performance monitoring & feedbacks are some of the practices Toyota used for their supplier development (Dyer and Nobeoka, 2000b). Hence it is quite explicit that the case company in the case study of Gosling et al. (2013) took advantage of lean supplier development practices.

However, when we take a deep look into the lean supplier development aspects, many of its practices are used, and some are not used. Such as supplier association, joined price calculation, route cause analysis, etc. are not mentioned in the case study. This gives an outlook that the firm which Gosling et al. (2013) has used for the case study has started using lean supplier development; however, it has to still explore different aspects of the concepts and practices. Which gives an

impression that the approach sounds pragmatic with some adjustments, and again it needs further development to achieve the full benefit. When it comes to the study done by Seth and Rastogi (2019), they proposed vendor rationalization as a solution for many challenges associated with manufacturing cycle time in the lean supply chain in ETO by conducting the case study. Vendor rationalization, which they proposed, consisted not just base reduction but also developing vendor base. The supplier base shall be developed, improving the relationship with supplier and considering them as partners. The supplier selection was then on the basis complexity of the component and note on the basis of price. This approach they proposed that establishing a supplier base on the basis of complexity of product and relationship with the supplier is an approach in lean supplier development.

Apparently, this was what the core in lean supplier development as per Harris et al. (2016) the supplier selection should be on the basis of the components total cost, not just the piece price. By reducing manufacturing cycle time, the buying firm is getting repeat orders at a shorter lead time than what it was before. This implies there are organization learning and continuous improvement in the setup on manufacturing process and making the whole process efficient. On the other hand, in a conventional supply, repeat orders cannot be expected, so continuous improvement and organization leaning does not happen. However, the approach used lean supplier development it can be seen not to the full extent of practices used, which was discussed in the previous case and so on.

To sum up, the articles reviewed consist of relevant information about the lean supply element on lean supplier development, long-term relationship, JIT, Standardization/ modularization/ prefabrication and knowledge transfer/ information exchange/ learning and training which we are discussing. This leads to the relevance and applicability of lean supply elements in ETO setting, and this will be discussed in the next section.

4.2 Discussion

One of the reasons which prompted the current study is the words of Lander and Liker (2007) on the applicability of TPS in a different system. According to Lander and Liker (2007), the only way to develop true Toyota-style systems in environments vastly different from those for which the lean solution has already been developed is to apply the same principles that people in Toyota have used to shape what is recognized today as TPS. “Applying the same thought process to a

novel environment will result in a Toyota-style system customized for the particular conditions the firm faces" (Lander and Liker, 2007, p3683).

While preparing the project thesis (Mupparichalil, 2019), it was noted there was no explicit case study found among lean literature on lean supplier development in the ETO setting. This study was within very limited scope, including literature analysis. It was quite obvious to be inquisitive and explore further to find the gap of study, which was primarily noticed, especially when it is looked in line with what Lander and Liker (2007) expressed on TPS.

Further, there were different authors opined on the applicability of lean supply and lean supplier development concepts in ETO. Dallasega et al., (2015,p2) stated, "since supplier lead times are, for the most part, much greater than the possible accurate foresight regarding construction work completion, a Just in Time (JIT) delivery of Engineered to Order (ETO) components from production to the construction site is not possible". Gosling and Naim (2009) questions the applicability of lean in ETO and similar industries and also expressed that ETO firms shall have strategic characteristics of agility. Birkie and Trucco (2016) also remarked that "despite widespread research and publication on lean, there is dearth of evidences addressing peculiarities of implementation in different business environments including capital goods manufacturing ETO".

When we approach the information found (regarding external lean process improvement of ETO firms) from the literature analysis in this thesis, in light with the statement of different authors regarding the applicability of lean in ETO firms, it is seen than there are many contrasting studies. Birkie et al., (2015,p17) expressed, "Lean is ultimately aimed at reducing variability and waste in the value-adding processes. As such, it could be well employed by ETO firms that could use it to run otherwise cumbersome activities in a customized but organized manner". This kind of customization was observed in different case studies given in the reviewed articles. JIT philosophy is very well used in a case company given in the study of Matt et al. (2015) but in a customized mode. There they introduced a supermarket of prefabricated items, and then, to the construction site, they delivered depending on demand-pull on a JIT basis. For achieving such customized JIT, the typical lean practices of standardization/modularization/prefabrication are very well employed. The customized JIT and used standardization/modularization/prefabrication are discussed by different authors as well. Similarly, regarding supplier development, developing supply

counterpart on the basis of principle strategic supplier/vendor flexibly and vendor rationalization is seen employed by case companies discussed in studies (Gosling et al., 2013; Seth and Rastogi, 2019). These two studies can be argued to be brought under supplier development as one author talks about customization of the pipeline for supplier relation and development on, and the other author talks about customization of procurement based on component/product to be procured. The finding on supplier development regarding strategic supplier/vendor flexibly is matching with the claim of Gosling et al., (2007). Gosling et al., (2007,p803) stated, "developing flexibility and market sensitivity, in the case of the ETO supply chain, appears to be of greater importance than developing stability and efficiency". The main research question is, 'What the literature says about lean supply and supplier development in an ETO setting? So, it was quite uncertain initially about this aspect as it was not much known from the previous study (project thesis) (Mupparichalil, 2019). Thus, after having the literature search and then a detailed review of selected literatures, it was found that some studies on lean supply and lean supplier development in ETO were existing. However, apparently, these studies were discussing the lean supply and lean supplier development concepts that are customized to incorporate in ETO. So, different authors brought up case studies and concepts which are very pertinent for lean supply and lean supplier development in ETO setting. However, it was found that, these concepts and cases were not exactly similar to lean supply and lean supplier programs of TPS or similar. Thus when we see this in light with the statement of Lander and Liker, (2007), it can be argued that their claim is valid for lean supply and lean supplier development in ETO. Applying the principle and thought process the Toyota has used to ETO environment can result from having the ETO firm a Toyota-style system customized for the particular conditions. (Gosling et al., 2007).

In terms of long term relationships, Forsman et al. (2012) mentioned, the typical culture in the construction industry is run the project using a temporary organization. And this culture would likely affect in relationships with suppliers as well. In such a construction project, the project progress is given the highest priority. This culture limits the development of long-term relationships. Further, Forsman et al. (2012,p21) commented, "a strategy to approach major customers to create long-term agreements with mutual incentives for increased efficiency in the process would be desirable". The other authors also did not mention any sort of partner-like relationship existed in any case company. So, this can lead to the impression that long-term relationships idea are seen as not matured like what was observed in typical lean firms. Similarly,

knowledge transfer/ information exchange/ learning and training are always coupled with relationships. Though there was the information of limited knowledge transfer/ information exchange/ learning and training, there was not enough information found in the reviewed articles to argue that in ETO, it is well established. The finding on a long-term relationship and knowledge transfer/ information exchange/ learning and training are within limitation as the reviewed articles were chosen based on the relevance of lean supply and lean supplier development.

So, to conclude, lean ETO is argued to be not favorable strategy by some authors, at the same time some time, some authors argue that it can very well be used by customizing the lean practices. As an outcome of this study, the second argument is looking more factual that the findings are more aligned to that claim. This applies to lean supply practices and lean supplier development. However, there is a lack of studies in this area, especially in lean supplier development. So, more researches are to be done to have further information.

5 Limitations

The research is a literature review, and the typical limitations associated with such researches exist in this thesis also. In the research, the author used a narrative method and, the manual exclusion and inclusion of literature, could not have given the best outcome, which is, however, unintentional. Further, the number of literatures included in the review is limited; however, it is assumed that it is within the acceptable limits of the scope of the thesis. In terms of long-relationship knowledge transfer/ information exchange/ learning and training aspects, it can be argued that the literature search for information in lean supply, lean supplier development articles cannot be accepted as a flawless method. So, in this thesis, it is stated, this as a limitation, as the literatures were mostly selected focusing on the lean supply and lean supplier development.

6 Conclusions

The thesis was developed to investigate information on the available studies about lean supply and the elements of lean supply in the ETO setting. Although there are different elements for lean supply, three elements were mainly focused on this research. That are lean supplier development, JIT, and long term relationship. In order to answer the research question, “What the literature says about lean supply elements such as lean supplier development, JIT, long-term relationship in ETO setting?”, first to pave a theoretical background, the concept of lean and lean supply was addressed, elements of lean supply were presented, and then ETO setting and lean in ETO was evaluated.

Second, a literature search was conducted on lean supply in ETO with a focus on lean supplier development in particular. 20 articles were selected for review, and these articles were analyzed to seek information which are pertinent for the elements of lean supply in ETO industry.

The selected articles were vertically analyzed first to know the general perspectives of researches/studies conducted in this particular area. From that, it was found, most of the studies were recent, of five years old, and were conducted in the European region. The case studies found in the literature were mostly from construction industries. There were very limited studies from

Asia and no studies from the American continent. Studies on JIT and was relatively explicit compared to other elements. There was no single study with a title lean supplier development/ supplier development in the ETO setting; however, studies on supplier/vendor flexibility and vendor rationalization were explaining concepts of lean supplier development.

Further, from the information evaluated from the reviewed articles, on lean elements, the relevance/applicability of lean supply and element of lean supply in ETO become apparent. Discussion on Lean supplier development, long-term relationship, JIT, Standardization/ modularization/prefabrication and knowledge transfer/ information exchange/ learning, and training were assessed and found that the articles discuss these elements in different extents. Five authors discussed JIT, and most of the authors agreed on the method of using JIT with an intermediate inventory (called as product/component supermarket by some authors) of modularized/prefabricated products. Whereby the product can be delivered to the work/construction site on a JIT basis through there is an inventory somewhere in the value chain. In terms of the longterm relationship, six authors mentioned the long-term relationship, and there were mixed opinions. However, it is observed from the case studies discussed in the literature that the idea of long-term relationships in ETO firms is seen not so matured like what is there in the typical lean mass production firms. Similarly, knowledge transfer/ information exchange/ learning, also are in the seen very little discussed. Concepts of lean supplier development were seen as discussed by three authors. Supplier/vendor flexibility and vendor rationalization, which can be viewed as customized lean supplier development, was the method mentioned in the case studies in the reviewed articles.

So from the cases discussed in the reviewed articles, we can reach to a conclusion that the lean supply elements are employed in different ETO firms but in a customized manner. So with this, it

can be said that the relevance and applicability of lean supply and lean supply elements in ETO settings are likely conceivable with customization. This lead to an agreement with what Lander and Liker (2007,p3683) said, “on lean, applying the same thought process to a novel environment will result in a Toya-style system customized for that particular condition the firm faces”.

This study in the thesis enlighten the aspects of lean supply in ETO and contributes to the development of perception on lean supply in ETO industry. A similar study was not seen apparent, or if already occurred, the contribution from this study could be added to the collection knowledge along with the existing studies. Similarly, the study can give a general perception of lean supply in ETO for lean firms operating in the ETO setting. The study can be considered as a starting point for ETO lean firms that are considering exploring lean supply. Further, it leads to future researches as the current study, not exploring the extent of studies on all 12 elements of lean supply. So it is an area to explore for future researchers.

7 Recommendation

More researches need to be done on the area of lean supply practices utilization and supplier development in ETO. Some recommendations include developing standard processes of supply set up for product groups. For example, when a façade is to be supplied for a construction project, by having research with multiple case studies, it can be concluded that at what point of the project, the demand occurs. So, the suppliers can foresee the demand based on the production plan and ensure the JIT availability of products at the site. For this, already established case studies can be used as examples to produce standard practices for the industry type and product type. Similarly, in the supplier development practices, by having researches and case studies, a generalization can be introduced on what sort of products and categories of products and their supply system can be considered under the supplier development portfolio of the particular industry. For example, in the case study of Engelseth and Le, (2017), pipes are found to be an item that can be delivered to the site in the shipbuilding industry. So, if the whole process of this value chain if studied and understood and then suppliers are developed to take advantage of the lean supply system completely. So, each pipeline shall be carefully assessed and evaluated, and based on the study standard procedures on that particular product in that particular industry can be developed. Such knowledge can be shared with all industries which undertake similar projects. There can be shipbuilding in different shipyards. However, a knowledge developed in one shipyard by a

company on the pipeline of a product and its supply might not be available to companies operating in a similar environment in the same region. Altogether it is for the sake of science and increasing the efficiency of the whole sector. So, such knowledge sharing, and practices shall be standardized and distributed to companies operating in similar environments. Such efficiency increases can keep the industry sector of that particular region over the competitors from a different region. If the companies are reluctant to disseminate the knowledge, research institutes should take the responsibility to produce more studies in these aspects and publish the knowledge for the sake of contribution to science.

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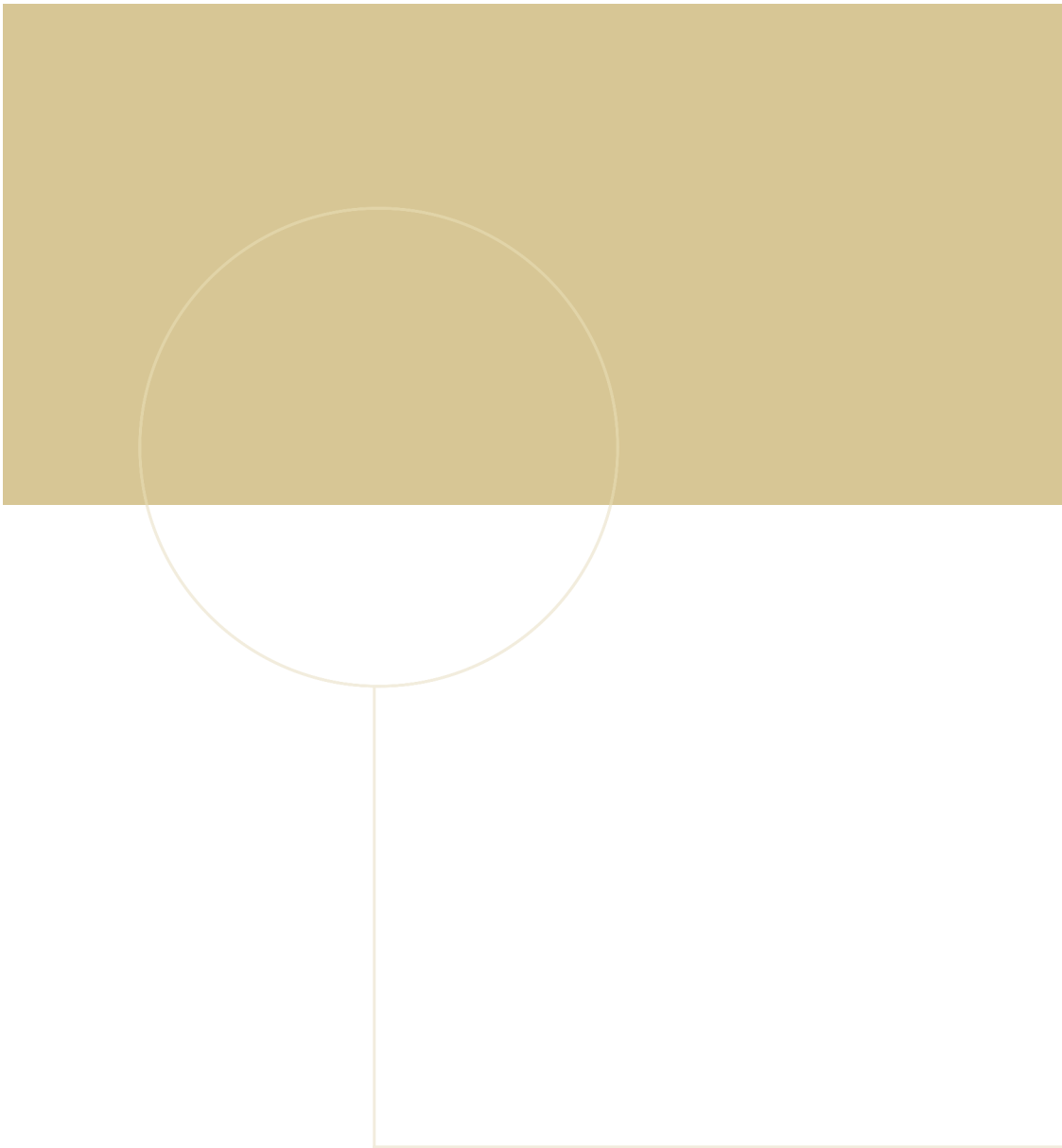

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