Implementation and Introduction Barriers of Industry 4.0 with Canadian Lean Mature Aerospace Manufacturing Companies

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Mise en œuvre et introduction obstacles de l'industrie 4.0 avec les entreprises canadiennes de fabrication aérospatiale matures

Vahid TAGHAVI

RÉSUMÉ

Le processus de fabrication a considérablement changé au cours des dernières années et le lean est l'une des méthodologies qui a joué un rôle important dans les modifications. Le Lean est une méthodologie révolutionnaire qui a émergé dans l'industrie automobile. Les entreprises Lean réussissent à réduire les coûts en éliminant les déchets. Peu à peu, de nouvelles méthodologies sont devenues populaires dans différents secteurs industriels. L'industrie 4.0 est une autre méthode innovante qui vise à faire passer le processus de fabrication à des niveaux supérieurs grâce à l'utilisation des technologies de l'information.

De nos jours, certaines entreprises combinent lean et industrie 4.0 pour obtenir des produits de niveau supérieur. Les entreprises canadiennes, particulièrement les entreprises aérospatiales, sont très motivées à utiliser les nouvelles technologies, comme en témoigne le Rapport d'activité 2015 d'Aéro Montréal. En 2015, ils visaient à mettre en place un nouveau cadre stratégique et opérationnel pour la réalisation de projets visant à amener le secteur aérospatial d'aéro Québec à un niveau supérieur. Par conséquent, un certain nombre d'entreprises de fabrication aérospatiale au Canada mettent en œuvre l'industrie 4.0 et certaines de ces entreprises adoptent également le lean. Les entreprises sont confrontées à un vaste domaine d'obstacles avant de mettre en œuvre l'industrie 4.0 et pendant le processus, tels que les coûts de mise en œuvre élevés, le manque d'installations et d'approches appropriées, et le manque de connaissances sur l'industrie 4.0. Cette thèse vise à étudier la tendance à l'industrie 4.0 parmi les entreprises manufacturières aérospatiales canadiennes allégées. En outre, les obstacles auxquels les entreprises sont confrontées avant et pendant la mise en œuvre de l'industrie 4.0 seront évalués.

Mots-clés: Production allégée, Fabrication allégée, Industrie 4.0, Obstacles à la mise en œuvre et à l'introduction, Entreprises manufacturières aérospatiales Canadiennes

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ABSTRACT

The manufacturing process has dramatically altered during past years and lean is one of the methodologies that played an important role in alterations. Lean is a revolutionary methodology that emerged in the automotive industry. Lean companies succeed in decreasing costs by removing waste. Gradually, new methodologies became popular in different industrial sectors. Industry 4.0 is another innovative method that aims to drive the manufacturing process to the higher levels via using information technology.

Nowadays, some companies combine lean and industry 4.0 to achieve higher level products. Canadian companies, especially aerospace companies are highly motivated to use new technologies, as it is apparent in the 2015 Activity Report of Aéro Montréal. In 2015, They aimed to implement new strategic and operational framework for doing projects to get aero Quebec aerospace sector to a higher level. Therefore, a number of aerospace manufacturing companies in Canada implement industry 4.0 and some of these companies adopt lean too. Firms face a vast domain of barriers before implementing industry 4.0 and during the process, such as high implementation cost, lack of facilities and proper approaches, and lack of knowledge about industry 4.0. This thesis aims to investigate the tendency to industry 4.0 among lean Canadian aerospace manufacturing companies. Also, the obstacles which companies face before and during the implementation of industry 4.0 will be evaluated.

Keywords: Lean production, Lean manufacturing, Industry 4.0, Implementation and introduction barriers, Canadian aerospace manufacturing companies

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABREVIATIONS

TPS	Toyota production system
LP	Lean production
CI	Continuous improvement
I4.0	Industry 4.0
CPS	Cyber-physical systems
IoT	Internet of things
LM	Lean manufacturing
WIP	Work in process
VSM	Value Stream Mapping
SMED	Single-Minute Exchange of Dies
DFMA	Design for Manufacture and Assembly
LESAT	Lean enterprise self-assessment tools
IoS	Internet of service
MES	Manufacturing Execution System
ERP	Enterprise Resource Planning
IIoT	Industrial Internet of things
AGV	Automated guided vehicle
C1	Company number 1
C3R3	Third response from company 3
B1	Barrier number 1

INTRODUCTION

The ability to produce customized products is a competitive advantage in the globalized world because of the consumerism of the present day. Consumerism leads to the variety of demand in the products so, manufacturers have to be ready to answer the different types of customer demands instantaneously. The methodologies that have the ability to produce personalized products and respond to higher demands act as game-changing strategies. Toyota production system (TPS) or lean production (LP) is one of the methodologies that can deal with this complexity. TPS aims to reduce waste in the manufacturing process from receiving the order to delivering the product to the customer to minimize lead time in a continuous improvement (CI) environment. Toyota corporation becomes the most efficient company in the automotive sector via this innovative manufacturing methodology.

As aforementioned, these days, customers do not accept goods with low quality, long lead time, and lack of diversity because of the alteration in the global market. Costumer demands increase and traditional manufacturing systems cannot respond to the new levels of the demand. In consequence, methodologies like LP are vital for competition in this competitive market. Although lean principles are developed by large companies, small and medium-sized companies can use the lean benefits.

Industry 4.0 (I4.0) is another method to handle the increasing complexity in the manufacturing process. I4.0 combines wireless and Internet to connect machines, products, and employees through Cyber-physical systems (CPS), Internet of things (IoT), and Cloud computing technology. I4.0 aims to increase the speed and flexibility of the manufacturing process and the quality of the products. Some lean companies currently implement I4.0 principles, and different results are brought out by combining LP and I4.0. There is no consensus between scientists about the linkage between lean and I4.0. Companies have been facing various types of difficulties in implementing I4.0 before and during the process. Through the current thesis, this issue is under investigation in lean Canadian aerospace manufacturing companies. Generally, the thesis investigates the proclivity to the adoption of I4.0 at the aeronautical manufacturing sector in Canada and the barriers that prevent companies from implementing I4.0. It also evaluates the problem they face during the process.

Background

Before the year 1908, the methodology for producing cars was only craft production; in this method, the whole parts of the car were assembled by one person and replacing the components was difficult because there was not any defined standard. Henry Ford introduced mass production in 1908 by ford model T. It was a revolutionary methodology and vital changes happened in the automobile industry; in consequence, the production speed increased dramatically (Taghavi & Beauregard, 2020). Scientists believe mass production is the second industrial revolution.

Ford Company was the leader of the automakers in 5 decades until TPS emerged. Although, some scientists claim Ford was the first company that reaped the benefit from just in time and lean manufacturing (LM) concept. Kiichiro Toyoda and Taiichi Ohno had a visit of the USA to learn mass production. They found out mass production was full of waste and unadoptable in Japan. They used Ford's ideas to introduce TPS in 1950. Toyota succeeded in increasing profitability and it became famous for effectiveness by implementing TPS. They succeeded to remove waste in the manufacturing process from receiving the order to delivering the products.

After three previous industrial revolutions, I4.0 was introduced by the German government in contribution to a group of scientists from different fields to enhance the industrial sectors in Germany in 2011. They aimed to introduce an approach to improve the world of technology by using the Internet and other equipment. During the process of improving I4.0, scientists determined that the Internet is more powerful than initially believed. Finally, scientists completed I4.0 in 2014 to utilize the full potential of this methodology and the companies outside of Germany began to implement it. During past years, more managers have been convinced to implement I4.0 to pave the way for more efficient manufacturing.

Research Problem

According to the title of this thesis, the difficulties related to the implementation of I4.0 in Canadian companies in the aerospace manufacturing sector are the fundamental problems that will be addressed. The aerospace manufacturing sector is a vital industry in Canada and survivability in this sector plays a vital role in the country's economy; hence launching new approaches would be beneficial. The problem of the research is divided into three sub-problems as follows:

First sub-problem concerns how much the inclination to I4.0 among lean mature Canadian aerospace manufacturing companies is and what the reasons related to possible unwillingness in managers are. Second sub-problems are those that hinder lean mature companies to start implementing I4.0, and the final sub-problem is related to difficulties that corporations which implement I4.0 face during the process.

Research Objective

This master thesis investigates the tendency to I4.0 implementation among lean mature Canadian aerospace manufacturing companies. Moreover, the candidate evaluates the problems which companies meet in terms of implementing I4.0. Respectively, the barriers are divided into two categories, depending on whether the companies have implemented I4.0 or not.

The first category is in the lean mature aerospace manufacturing companies in Canada that have not applied I4.0. The barriers in this category are those which prevent companies from applying I4.0 that are called introduction barriers in this research. Therefore, investigation of this group eventually leads to finding the reasons behind the reluctance to implement I4.0.

The second category is related to the lean mature Canadian aerospace manufacturing companies which currently apply I4.0. This group includes the barriers which hinder companies during their transformation to I4.0 and are named implementation barriers in this research.

Research Hypothesis

Referring to the research objectives, three hypotheses exist during the current investigation.

- The tendency to I4.0 is more in the companies which have currently adopted it, in comparison with the companies that do not apply I4.0 technology.
- The number of major implementation barriers are less than introduction barriers because the companies which adopt I4.0 have got over some barriers and would experience less challenges.
- The level of implementing I4.0 and tendency to I4.0 practices are more in lean mature in comparison with non-lean.

Statement of Contribution

These days, our world is getting Computerized more and more, and the rule of computer technologies becomes more vital; hence harmonizing with that is crucial in the industry, especially in the aerospace sector. The main contribution of this investigation is designing a framework to encourage aerospace manufacturing companies to integrate new approaches like I4.0 with lean production via concentrating on I4.0 inhibitors. Through familiarity with implementation and introduction barriers, companies will know what awaits them in the way of digitalization. Also, by measuring lean maturity and the level of I4.0, this paper can help companies overcome those barriers.

Scope of the Project

Aerospace manufacturing industry is one of the biggest parts of the economy in Canada. Manufacturing companies produce different kinds of products such as aircraft, helicopters, and space products. Several well-known aeronautical firms such as Airbus, Boeing, and Bombardier work in Canada and the central part of their products are exported around the globe. During past years, significant efforts have been made to implement lean in aerospace manufacturing firms in Canada; for example, a 1.3 million-dollar grant allotted to the research in aerospace in Montreal in 2014 and currently, most of the aeronautical corporations adopt

LP. Then the scope of the research is limited to lean Canadian aerospace manufacturing corporations.

As I4.0 is an emerging science, there is no clear information about how many lean Canadian companies in the aerospace manufacturing sector implement I4.0, so the statistical population and sample size may be small. Also, the research will be done in a specific region and the results cannot categorize the broader population; for example, aerospace manufacturing corporations worldwide. Furthermore, companies that have high-level experience in adopting lean, will face fewer barriers for adopting I4.0 because in some way, lean companies are learning organizations and flexibility is one essential characteristic of learning organizations. Flexibility provides the organizations with the capacity to adapt to the external conditions and be ready to implement new approaches.

Research Questions

According to the title of the thesis, the research questions for this thesis are defined as follows:

- How much is the tendency to implement I4.0 among lean mature Canadian aerospace manufacturing companies? This question will lead to determining the level of the tendency to I4.0 practices.
- What barriers prevent lean mature Canadian aerospace manufacturing companies from applying I4.0 (Introduction barriers)? The targeted companies are those which do not initiate adopting I4.0 practices. The challenges that highlight with them will consider as the barriers which prevent companies to start adopting I4.0 technologies.
- What are the barriers which lean mature Canadian aerospace manufacturing companies meet during their I4.0 implementation process (Implementation barriers)? In this question, the companies which adopt I4.0 practices will investigate to determine what type of hiders companies face during the routine implementation process of new technologies.

Organization of the Thesis

This thesis contains four chapters which were written after the introduction section. The first chapter is a literature review that investigates related resources to the title. Chapter 2 is the research methodology, which is about how the project was done and it explains how data is gathered, analyzed, and validated. Chapter 3 presents the results of the study in detail. Fourth chapter discusses about study for example the validity and reliability of the study. Finally, conclusion section has a whole view of the research process. This chapter explains the opportunities and recommendations for future researchers.

CHAPTER 1

LITERATURE REVIEW

In this chapter, the candidate aims to review the papers related to the title of the research. The literature review comprises introducing lean, lean principles, and lean tools. Furthermore, this section covers different experiences of implementing lean in various industries and the focus is the aerospace industry. In the following, the concept I4.0 and its components such as Cyber-physical-services, Internet of things, Internet of services, and Smart factory will be introduced. The literature review also includes a similar investigation in the field of implementing I4.0 in different industrial sectors. Implementation and introduction barriers of I4.0 and the linkage between LP and I4.0 will be explained in the last parts of the literature review.

1.1 Lean Production

The term LP was introduced for the first time by Krafcik (1988). Krafcik introduced LP according to the TPS that Taiichi Ohno and Kiichiro Toyoda implemented in Toyota corporation. Although some scientists believe Ford company was the birthplace of LP due to the continuous flow of parts throughout the massive plant. LP was identified around the globe by the book *The machine that changed the world* that was the consequence of the vast research done by a group of American scientists led by James Womack to study manufacturing methodologies in the automotive industry in 1990. They achieved brilliant results and the investigation proved that Toyota is the most efficient company in the automotive sector.

For the first time, LP was implemented in the automotive industry, but other industries found it beneficial as well. Nowadays, lean spread worldwide and is being utilized in offices, hospitals, and post offices. Also, the military and aerospace sector in some countries enjoyed the benefit of lean. Kochan, Lansbury, and MacDuffie (2018) divided lean automotive factories around the world to four types, as illustrated in table 1.1.

Table 1.1 Lean automotive factories

	Factory type	Characteristics
1	Stable and Lean	First adopter of lean, especially Japanese factories that completely enjoy the benefit of lean.
2	Rapid move to Lean	Factories that started lean implementation a few years ago and now have several years of experience in mass production, for example, European companies and other regions like Korea.
3	Sticking-with-tradition	US and Canadian factories that returned to traditional methodologies. They made partial progress on quality and productivity.
4	Hybrid	Factories that implemented combination of lean and mass production worldwide.

Lean focuses on change for the better, but it does not follow quick improvement instead, the philosophy behind lean is that tasks should be done with the slow and steady purpose (Pereira, 2009). Taiichi Ohno said, "the slower but consistent tortoise causes less waste and is much more desirable than the speedy hare that races ahead and then stops occasionally to doze. TPS can be realized only when all the workers become tortoises" (Krijnen, 2007).

The primary objective of TPS is to eliminate waste in order to decrease costs and improve productivity (James P Womack, Jones, & Roos, 2007). LP eliminates waste or the Japanese word Muda is related to all activity from receiving the order to delivering products to the customer. There are two types of Muda; type I is any activity that does not create value but is necessary for the function of the process in its current form. Type II is any activity that does not create value and can be eliminated without affecting the products. LP removes each activity that does not add value to the products base of TPS recommendations. Also, LP aims to remove Muri (Unreasonable work) and Mura (Uneven workload) too. Seven kinds of waste are defined as shown in figure 1.1 that should be removed such as Transportation, Inventory, Motion, Waiting, Over-processing, Overproduction, and Defects. When LP was implemented in Europe, non-utilized talent was defined as the 8th waste.

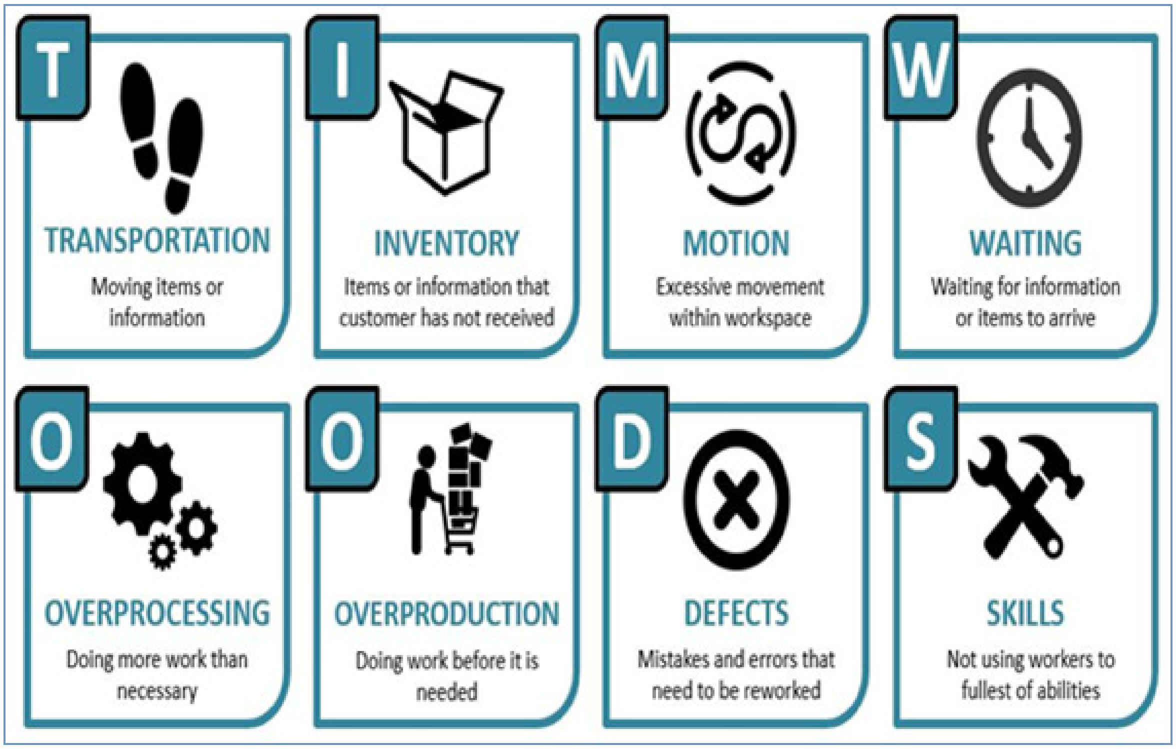

Figure 1-1 The 8 wastes of TPS
Taken from Contributor (2019)

Transportation is the unnecessary movement of products, information, or materials from one place to another. Inventory is storing materials and documents more than they are needed. There are three types of inventory: Raw materials, Work in process (WIP), and Finished goods. The inventory cost appears in the amount of space they occupy and the impact on lead time and cash flow. Garre, Bharadwaj, Shashank, Harish, and Dheeraj (2017); (Muslimen, Yusof, & Abidin, 2011) believe inventory is the biggest waste in the manufacturing process and after removing this waste, others will disappear continuously. Motion refers to the kind of movement of employees that are non-value-added, for example, the movement to reach products or adjustments. Waiting occurs when there are not the right parts, information, and instructions needed to complete the task. Over-processing means using more than is needed to complete the task or doing more work on the products than your customer values. Overproduction appears when more products are manufactured sooner than the next step or when the customer is ready for it. Overproduction is one of the worst wastes because it magnifies all the other wastes except for the over-processing. The product or paperwork errors are called defects. It is also the missing or incorrect products that need rework, resource, and materials to fix. Unitarizing talent is known as unused talent of the workers. It shows up when the role of management is separated from employees.

1.2 Lean Principles

LP contains five principles as J. Womack and Jones (1996) defined in the book lean thinking as follows: Value, Value Stream Mapping (VSM), Flow, Pull, and Perfection. These principles are called five steps to lean and considered a road map towards creating customer value, removing waste, and continuous improvement. These principles are a guideline to create a successful future with our actions today (Murman et al., 2016).

Frank, Dalenogare, and Ayala (2019) described the summary of lean principles as follows: "defining the value from the customer perspective, mapping the value stream process to achieve the predefined value, creating the flow along the value chain, establishing pull system and pursuing perfection". This thinking encourages many organizations to adopt lean principles totally or partially (Staats, Brunner, & Upton, 2011). Although lean principles positively influence improvement in numerous cases (Li, Rao, Ragu-Nathan, & Ragu-Nathan, 2005), in consequence of misunderstanding of how lean principles work, the number of failures is high (Shah & Ward, 2007). In order to enjoy the benefit of LP, these principles have to be precisely implemented. figure 1.2 shows an arrow containing lean principles. In the following the candidate provides a precise explanation of these principles.

Value is the first principle of lean and identified from a customer's perspective. It should be defined from the customer's point of view, and it represents what the customer needs, and at what price and what time the customer needs it. The companies should produce their products based on the value from consumer's point of view; otherwise, the manufacturing process will create a tremendous amount of waste.

VSM helps companies fully understand what is going on over the production process. It is a helpful step and it provides the opportunity to determine the value-added and non-value-added activity in order to increase productivity. Managers have to focus on the entire manufacturing process, not only on one single point, and the value stream provides this chance.

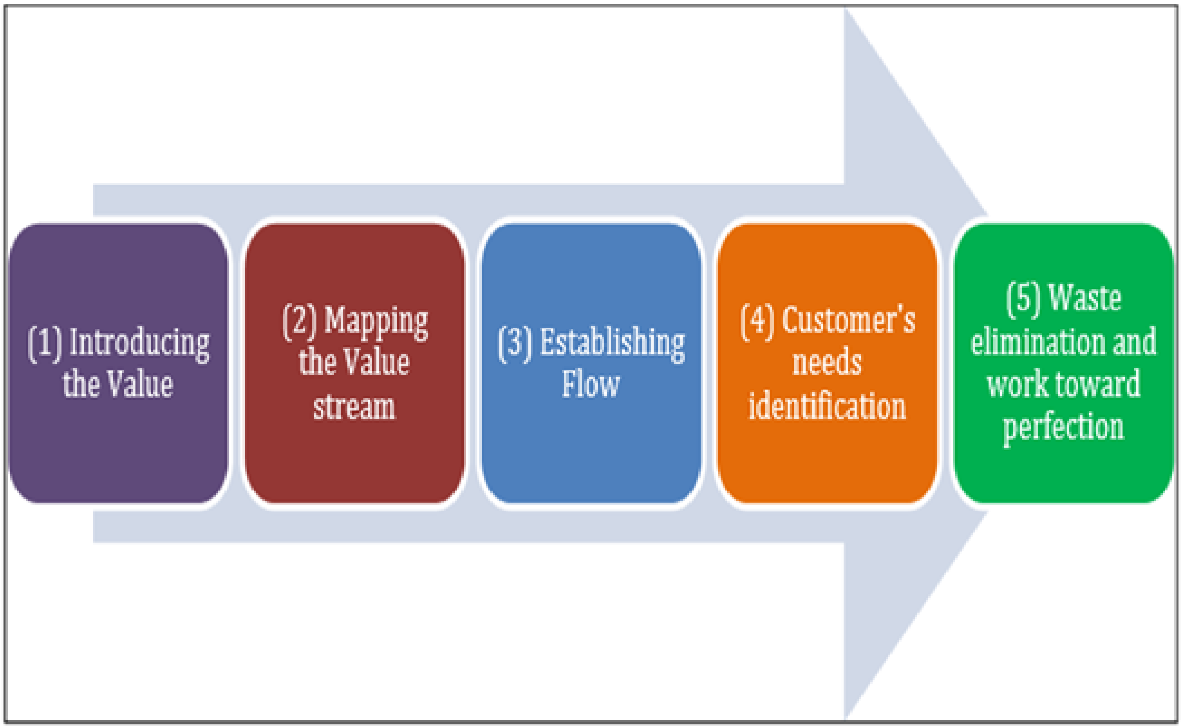

Figure 1-2 Lean production principles
Taken from James P Womack and Jones (1997)

After analyzing VSM, determining waste and removing them, it is the time for the third step of LP, named flow. Flow is keeping the manufacturing process, from the customer order to the delivery of the product nonstop. Taiichi Ohno mentioned that the starting point of creating flow is to reduce the timeline from receiving an order until delivery through eliminating non-value-added activity (Liker, 2006; Ohno, 1988). Understanding and removing the root cause of inhibitors is important in improving the flow of product (James P Womack & Jones, 1997). The objective of flow is to move products during the process without any interruption and any risk on quality and customer satisfaction. Moreover, flow aims to drastically reduce product throughput time and human effort and increase movement velocity through a series of innovations. If the production process stops in consequence of defects, inventory, or waiting, they should be marked as waste and removed (Jalili Marandi, 2018). In order to implement this step, companies should use single unit flow, avoid batch processing and focus on level loading (Heijunka).

After initiating the manufacturing process flow that decreases the time between order and delivery, the fourth principle of LP is pull. It means to let the customer pull products from the producer by using the Kanban card, instead of pushing the pre-manufactured product to the client. Nothing will be manufactured upstream until there is customer demand downstream (James P Womack & Jones, 1997). This strategy removes inventory and overproduction, so companies manufacture enough product at the right time to meet customer demands. In fact, without pull, lean thinking does not materialize.

Suppose a company implements the first four principles of lean production. In that case it succeeds to remove the numerous amounts of waste. But LP is an endless process and to complete lean, the four previous steps should be constantly improved by perfection (James P Womack & Jones, 1997). Perfection achieves via developing kaizen spirit in every employee and planning manufacturing process. Instead of 100% percent improvement in one step, kaizen focused on a hundred of 1% improvements from everyone, everyday, and everywhere. During perfection, the process is analyzed to increase value and remove waste, and it tightens the flow frequently.

1.3 Lean Tools

Lean tools and techniques play an essential role in the lean environment. Scientists defined several tools for lean and Bhasin and Burcher (2006) found out that for using the exclusive benefit of lean for a long time, the organizations should implement most or all of the lean tools, instead of one or two techniques. Some lean tools such as Kaizen, 5S, Kanban, and VSM are more prevalent in the aerospace sector. The Candidate provides explanation of these tools in detail in the following paragraphs.

1.3.1 5s

5S is one of the main tools of the lean and it includes 5 tips for improving workplace performance. 5S is utilized to create order and tidiness at a worksite in order to achieve efficient production and it is also a step towards changing the work environment. 5S is a team effort, it should be a culture, and it should be embraced by the entire organization. 5S is the foundation for CI in lean implementation. Without 5S, an enterprise encounters waste, and their clutter will exist everywhere on the floor. The name 5S is derived from the five stages named Sorting, Systemizing, Shining, Standardizing, and Securing the new standards (Ortiz, 2016). Furthermore, some scientist add Safety and Support (Maintenance) as the 6^{th} and 7^{th} S.

The sorting process focuses on providing what is relevant for the current activity, whatever is not relevant to the job has to be removed from the work area via using the system called red and yellow labels. The philosophy behind sorting is to remove unnecessary goods. So, they do not occupy space, no extra transportation and motion are needed, there is no excessive search time for tools (Ortiz, 2016), and it does not cause any accident. During the system, first of all, employees should keep all items that are needed daily including tools, gauges, and materials, then remove unnecessary clutter. Next, workers should sort out all unnecessary items, keep utilizing all of them a few times a month, in boxes with yellow tags. Also, keep using items a few times a year, in boxes with red tags, assign numbers R1, R2, R3 …; Y1, Y2, Y3 … to the boxes, and maintain a spreadsheet file with details of items and quantities. After that, boxes should be sorted out, yellow boxes should be closer and red ones should be farther from the workplace. When an item is retrieved, the spreadsheet should be updated and the number of retrievals should be counted yearly.

Finally, once a year, the worker should check the spreadsheet, if a yellow box can be retagged to red and if a box with red tag is not touched for two years in a row, it should be disposed or a yearly white elephant sale should be conducted. The sorting objective is to remove the dedicated time for searching and moving materials and tools (Liker, 2006). Fast decisions are expected in the sorting step because the majority of work will be done in the second step (Ortiz, 2016).

After implementing 1st S, the worker are left with items that are needed daily, and the task is to create a location for the whole essential items (Ortiz, 2016). Over the systemizing process, the focus is on an efficient location or if storing is necessary, this also means to configure a place for each item closer to its usage. The objective is to arrange for an easy retrieval and remove the necessity to search for the item. The mindset that strives for is that there should be a place for everything and everything should be in its place (Hobbs, 2003).

After implementing two previous tasks, the next step is shining that aims to clean up the work environment. Baban, Fertuck, and Vermilye (2009) defined it as keeping every-things swept and clean. Some reasons for carrying this out involve uncovering faults and deficiencies that can hinder efficiency. Cluttered workplace acts the same as the excessive WIP and hides the problems such as rejected materials, spare parts, and incomplete units (Hobbs, 2003). Also, it serves to create a more pleasant and spotless workplace by identifying and eliminating the causes of dirt and grime by focusing on the source of the mess. The task should be done by dividing the area into zones and defining responsibilities for cleaning, also, the tools and equipment must be owned by an individual.

The next step of 5S is referred to as standardizing and the target of the process is to ensure that three previous steps have been done perfectly and the process does not go back to the way it was before 5S (Baban et al., 2009). Standardizing teaches employees what has to be done and when and how it has to be done. It focuses on the best work method and removing each uncertainly from employees. It also encourages successful implementation at other stations in question, helping to make all station similar in their application of 5S.

The final step is known as sustain, and it aims to put in place a system for CI through providing training, awareness, and attitude in employees (Hadfield, 2006). 5S should not be static; everyone should be looking for a new and better way to organize the workplace and eliminating waste daily. Managers act as leaders in this section because they have access to the bigger vision of the whole process (Hobbs, 2003). During this step, managers have to make sure that employees are empowered to implement 5S. 5S should not be something that is done to them; it should be something done by them. Sustain makes 5S a way of life towards long term goals.

1.3.2 Kaizen

Kaizen is a Sino-Japanese word that means change for a better or CI (Lillrank, 1995). Kaizen is about the normal situation; as a measure to prevent waste by achieving continuous small improvements. Kaizen applies to all enterprise processes; so, it's one of the main tools of a lean, and improvement is absorbed into the process. Kaizen is for everyone, everywhere, and every day and it focuses on reducing or eliminating waste, thereby improving productivity, quality, time to make profit, and customer satisfaction.

Kaizen is conducted as an event involving workers and quality experts. Employees are the best actors and the best judges in conducting the kaizen events. It needs direction by quality experts, otherwise, it may not result into the expected results. The quality expert acts as the Kaizen leader, and all workers are actors. Kaizen is often conducted as a 1-day to 5-day event and concentrates on a particular process for improvement (Productivity Press. Development, 2002), for example, a Kaizen event for Single-Minute Exchange of Dies (SMED), Design for Manufacture and Assembly (DFMA), 5S, and VSM.

In order to implement Kaizen event, a business case should be prepared which contains, current state, future state, cost, and benefit. García-Alcaraz, Oropesa-Vento, and Maldonado-Macías (2017) believed that, from a quantitative view, Kaizen has the positive impact on the following items:

- Reducing setup time or changeover time.
- Improving workplace performance.
- Increasing delivery performance.
- Reducing inventories.
- Reducing machine failures.
- Eliminating bottleneck.
- Walking distance reduction.

Kaizen goals should be smart, specific, measurable, actionable, and timely; also, they should be aligned with the business objectives. There are five basic steps of Kaizen that should be implemented completely to achieve expected goals.

Management support should be provided to Kaizen event and managers should be kept informed of improvement; also, involving everyone, especially the workers is vital. Some items like completing all actions on time, simulating the changes, and observing improvement are success factors in kaizen event (Goyal, Agrawal, Chokhani, & Saha, 2019).

1.3.3 Kanban

Kanban is a Japanese word that literally means signboards or signs in the context of production (Gross & McInnis, 2003). The philosophy behind Kanban card is the authorization of the movement and production in the manufacturing process. Taiichi Ohno believed Kanban is the nerve system in the lean environment. He introduced Kanban based on the methodology implemented in American supermarkets for product replenishment (Gross & McInnis, 2003). Kanban is a card attached to the actual goods to control the production process to remove excessive inventory. The original aim of Kanban is to stop overproduction in the machine-shop which creates large inventory and costs much money (Leopold & Kaltenecker, 2015). It aims to authorize production by providing visual signal to control movement and minimize WIP in the system. Low-level WIP comes to the advantage of shorter cycle time, faster throughput, and less wasted time. Also, low-level inventory leads to exposing production problems. A term called the river of waste was introduced in LP. It is a useful analogy that shows how waste can hide within the organizations. The river is like an organization that is filled with rocks or waste and when the water level and resources in the organization are high, the rocks or waste go unseen, but when the water or resources in the organization are lower, the rocks or waste appear in form of obstacles and problems blocking the flow of value. Then once the company has a better understanding of what and where waste is, the solutions can be provided easily. Therefore, Kanban is on the pillar in lean house.

1.3.4 Value Stream Mapping

VSM is one of the lean tools to analyze the present situation and design the future situation. It aims to show where you are, how to add value and eliminate waste. Liker (2006) believes VSM is not a simple tool to draw a picture in order to find waste; actually, it is a philosophy of how to create improvement. VSM is a planning activity and involves selecting a value stream process, mapping the current state, utilizing lean tools to map the future state, and adopting the Plan-Do-Check-Act process to achieve targets. The company can map the grouping of products or services with similar processes such as a product family. It's better to choose the high-growth or high-volume product family to do VSM, and having all product flows on a single map is too complicated.

VSM includes several steps that have to be implemented in order: First of all, a team group has to be selected to manage the implementation. The selected team should spend several hours on the floor to map the current state; it involves walking through the process and documenting it, using a paper and pencil to visualize and understand the flow of material and information and finding inhibitors of the flow (Liker, 2006). Hobbs (2003) says team members should document the process starting with the shipping step in reverse, in fact starting with the last step allowing team members to look at the material flow from the customer perspective. The team should then apply lean principles to create a future state with less waste; typically, it shows higher productivity, shorter lead times, and smoother flow. Next, an action plan should be created to implement the future state; this might involve several Kaizen activities. Finally, over the next six to twelve months, the plan should be implemented (Plan-Do-Check-Act) and frequently monitored to be sure of achieving future state.

In addition to the tools mentioned above, lean companies benefit from more tools that are briefly presented as follows:

Design for Manufacturing and Assembly: It is a design methodology that aims to simplify the manufacturing and assembly process, such as minimizing the complexity of components and operations. The objectives of using this method are cutting down the production cost by focusing on cost-effective materials and machines and also reducing the number of parts to achieve simpler assembly process.

Single Minute Exchange of Dies: It is a system used to decrease equipment changeover time sharply. SMED is a helpful tool in achieving rapid changeover in the manufacturing process.

Jidoka: Jidoka is referred to an approach that prevents a defect continuing to downstream. In fact, when a defect shows up, the manufacturing process is automatically stopped and asks to get it fixed.

Heijunka: It is a tool that adjust production rate based on demand fluctuation. It is a tool utilized in order to decrease Mura and Muda. Heijunka or level loading is vital for production efficiency in TPS and LM.

Just in Time: JIT focuses on providing the right items in the right place at the right time in order to control the movement of materials to minimize WIP. JIT is one of the pillars of lean house which aim to reduce the seven kinds of waste in the lean environment.

Andon: It is a signaling system used to inform employees when the equipment breaks down and help is needed to provide the solution for the issue.

Total Productive Maintenance: Total Productive Maintenance focuses on proactive and preventive maintenance to maximize the equipment operational time.

Total Quality Management: It is a method used in order to monitor the quality of the product and services.

Six Sigma: Six Sigma is a quality improvement technique for production or service process. Six Sigma is a group of methods and tools which attempt to identify and remove the causes of defects to achieve zero defect.Lean Production in Aerospace

The past hundred years have brought exponential growth in power and technology throughout the aerospace industry, leading to higher customer expectations in quality, cost, and delivery. Especially over the past two decades, the global competition was brought to this industry as

James-Moore and Gibbons (1997) believed competition is in delivery, quality, productivity, and also reducing inventory and costs. In order to meet or exceed the expectation of today's customers, aerospace companies used LM as a game-changing strategy as it was done in the automotive industry in Japan (J. Womack & Jones, 1996). Rajenthirakumar and Thyla (2011) mentioned that aerospace companies focus on cost reduction through eliminating waste and increasing the quality of the product which are the same objective of lean in other industries. On one hand, scientists believe lean is designed for the automotive industry that has high-volume process, hence transferring it to a low-volume environment like aerospace would be challenging (Crute, Ward, Brown, & Graves, 2003). On the other hand, J. Womack and Jones (1996) believe there are numerous successful examples of lean adoption in various sectors worldwide, so difference in volume is not a barrier in implementing lean. Furthermore, Crute et al. (2003) determined issues are more visible in the production plant and management roles.

LP is popular in the aeronautical industry as it has been implemented in UK aerospace and some manufacturing companies like Airbus, Boing, and Rolls Royce plc. Additionally, the academic sector supported lean improvement in the USA and UK. A study was done in 1993 aimed to analyze the adoptability of lean in the military aircraft industry in the US called Lean Aircraft Initiative (Mathaisel & Comm, 2000). US Air Force and about twelve industrial companies participated in the research. The study aimed to find the relevance of lean value to the US defense spacecraft and clarify the level of interest in launching initiative approaches and interpret the operation approach. The research results showed that in order to have a successful operation, LP should be engaged in all links in the manufacturing chain and all links should be prepared for it. LP also helps firms to fit by their values (Mathaisel & Comm, 2000).

Thomas, Francis, Fisher, and Byard (2016) determined a tremendous improvement in performance due to implementing lean Six Sigma in the aerospace sector. They reported that build time was reduced by 20.5%, delivery time by 26.5%, value-added time by 5%, and Non-value-added by 44.5 %. The majority of scientists believe LP is a complex and Non-stop journey and companies should work precisely to gain brilliant outcomes.

Overall, the candidate has provided explanation of lean tools and principles to show the power of this methodology. Somehow, it could be claimed that LP is an inseparable part of the manufacturing companies, and it is widely spread in different industries. Some corporations have been implementing lean with other methodologies simultaneously to achieve better results or cover the issues related to lean implementation. One of these methodologies is the fourth industrial revolution that is the variable in this research.

1.4 Lean Maturity

In Reference to the title of this study, the first step is to find lean companies in aerospace industry in Canada. In this regard, a method named Lean enterprise self-assessment tools (LESAT) will be used. LESAT was developed by the Lean Advancement Initiative at the Massachusetts Institute of Technology, and it examines the level of lean and readiness to make changes in the manufacturing process. The LESAT tool groups lean practices in 3 different sections: leadership, life cycle, and infrastructure, and each section contains many lean practices. It has a level range from 1 (Lowest level) to 5 (Highest level) and totally assesses 54 lean items. The description of each level range was introduced by (Nightingale, 2001) as follows:

- **Level 5.** The best lean practice exists and a complete approach is implemented across the whole enterprise.
- **Level 4.** CI with sustained results is a routine approach in the enterprise.
- **Level 3.** There is a systematic approach with adequate sustainment that is established in most areas.
- **Level 2.** There is general awareness and some informal practice with a brief degree of effectiveness established in a few areas.
- **Level 1.** There is some knowledge about lean and some improvement practices exist in a few areas.

1.5 Industry 4.0

The industrial ideologies experienced three previous revolutions such as, Mechanization, Electrification, and Information (Zhou, Liu, & Zhou, 2015). As illustrated in figure 1.3, the first one is mechanization that emerged in using water and steam power in mechanical production which began in the 18th century. The second revolution was in the 20th century during which industry altered with the invention of electricity. Electricity changed the world and facilitated the manufacturing process. In consequence of electricity, mass production was introduced and manufacturing lines emerged. The manufacturing process accelerated through mass production and it could respond to increasing demand caused by population growth after world war II (Zhou et al., 2015). The third industrial revolution was identified by using programming and mechanical robotic arms for mechanical automation. Computers have been used to bring automation to the manufacturing process and the big part of the process has been done by computers. Rifkin (2014) believes that industrial revolutions happened in consequence of new energy regimes and communication; also, he introduced a communication-energy matrix to explain each industrial revolution.

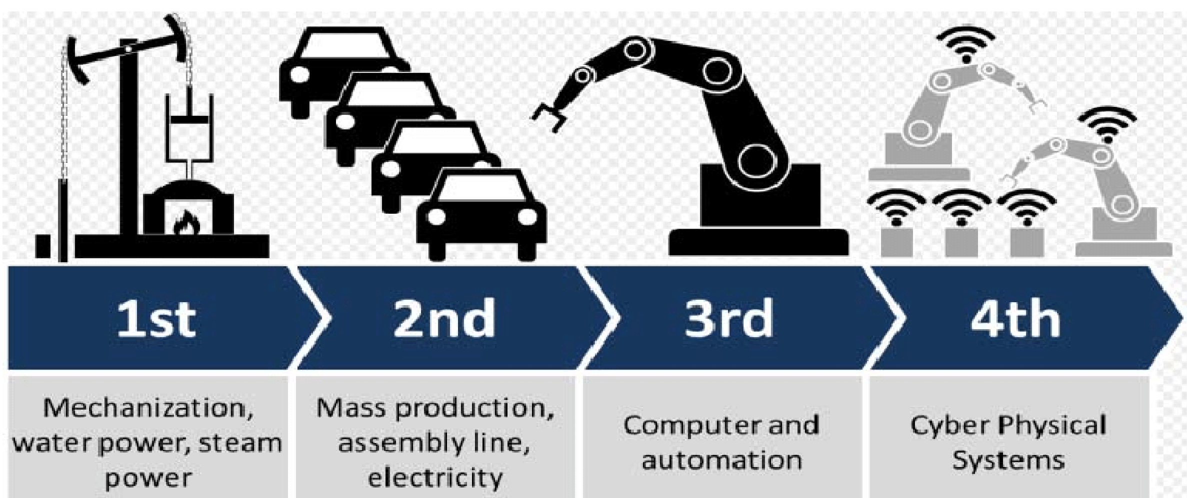

Figure 1-3 Summary of characteristics of the industrial revolutions
Taken from Chute and French (2019)

I4.0 is the fourth industrial revolution that offers a highly flexible and digitized manufacturing process. I4.0 is referred to the transformative technologies that make a gigantic alteration in the industry through utilizing the new version of smart connected machines and intelligent robots. The viewpoint of I4.0 is not at the individual computerized machine; it looks at the whole network of the computers. The concept I4.0 is supported with four basic components Cyber-physical systems, Internet of things, Internet of service (IoS), and Smart factory (Herčko, Slamková, & Hnát, 2015). CPS is a combination of sensors and actuators that communicate with each other and humans via IoT in real-time. Also, through IoS, contributors enjoy the service provided based on the Internet (Reis & Gonçalves, 2018). CPS, IoT, and IoS give this possibility to I4.0 to remove humans from decision-making process (Zhang, Li, Wang, & Cheng, 2017). Also, I4.0 has three features: Horizontal integration, Vertical integration, and End-to-End integration (Susana Duarte & Virgilio Cruz-Machado, 2017).

Suppose a fluctuation occurred in demand for a product; in the previous methods, several employees engaged in declaring demand to the production line to produce and prepare the whole system in order to transfer it where is needed. Also, if the product is maintained in inventory, it takes time to deliver product where needed because of the human engagement. This process is prolonged and the companies can not respond to the fluctuation in time. In information-technology-based systems when there is demand somewhere, the whole system determines it automatically using big data. In fact, the human decision is removed from the system, everything is automatic and the speed of the process is very high, so there is no need to maintain a big inventory. In consequence of implementing I4.0, the expenditure related to the products will decrease dramatically and the product would be more profitable.

I4.0 takes advantage of some technologies, such as Cloud computing, Radio-frequency identification, Big data, and Virtualisation security (Zhang et al., 2017). G. L. Tortorella and Fettermann (2018) and Chukwuekwe, Schjoelberg, Roedseth, and Stuber (2016) count cloud computing, 3D printing technology, CPS, IoTS, Augmented reality and big data as key drivers of I4.0.

In the I4.0 environment, machines are equipped with sensors that are connected to the network in order to transfer the data. So, the problem could be diagnosed by the machine, and someone is alerted that something is going wrong. Big data analysis Artificial intelligence and Machine learning are utilized for the sake of discovering the meaning of a huge volume of data generated by the machines. I4.0 includes the interconnected supply chains technique where ships are connected to warehouses and manufacturing lines. German Academy of Science and Engineering provides a definition of I4.0 (Bartodziej, 2017) as follows: “The technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and

Services in industrial processes. This will have implications for value creation, business models, downstream services and work organization."

The new industrial revolution offers several advantages to companies to replace old manufacturing methodologies with the new techniques available in this revolution. Corporations need to develop their skills to figure out the role of the employee in the new system. I4.0 brings robots to a higher level called cobots. Cobots are collaborative robots that employees co-share their working environment with. Figure 1.4 shows the concept of I4.0.

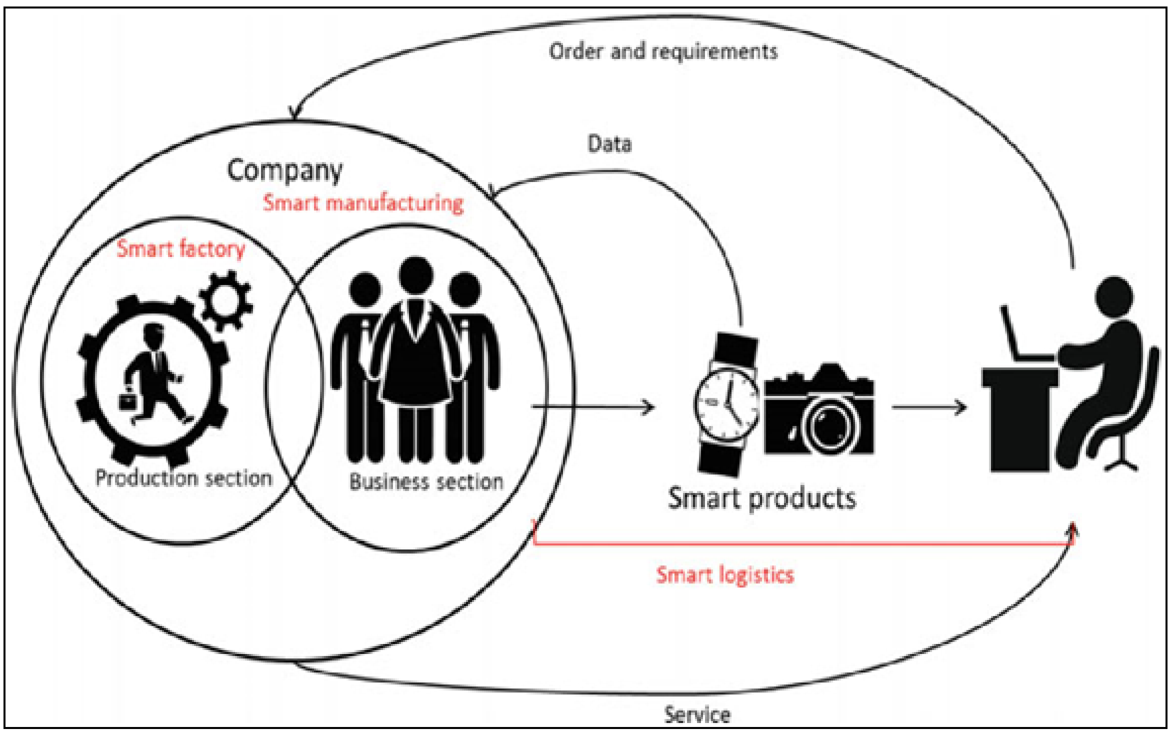

Figure 1-4 Concept model of industry 4.0
Taken from Zhang et al. (2017)

Zhang et al. (2017) said there were two segments in enterprises: production and business. The production sector is managed by Manufacturing Execution System (MES) that handles data related to the manufacturing process, also, planning, scheduling, and inventory are handled by this system. The business sector is managed by Enterprise Resource Planning (ERP) that handles supply chain management, information system, and finance. These two sectors should collaborate with each other, but this collaboration was not present in previous methodologies.

For example, if there is a breakdown in machine in the manufacturing plan, MES will fix the problem and adjust the production plan by the new situation, but ERP does not know what happened in the production sector, and it follows the original plan, so the mentioned collaboration does not build well. In the I4.0 environment this issue will not happen via using shared data in the cloud; in fact, the physical world connected to the cyber world and different sectors will be adjusted by the real condition.

In order to have information about I4.0 in detail, the candidate provides explanation of the most important key factors of it in the following subsections.

1.5.1 Cyber Physical Systems

CPS is an emerging area that refers to complicated and multi-disciplinary systems to combine cyber processing and physical components tightly through utilizing transformative research approaches insofar as to be inseparable. It gets the system to a higher level that is more reliable, flexible, and efficient (Zhang et al., 2017). Rajkumar, Lee, Sha, and Stankovic (2010) define CPS as “physical and engineered systems, whose operations are monitored, coordinated, controlled, and integrated by a computing and communicating core”. Computers, communication, and control help CPS determine the status of the physical systems alive (Alcácer & Cruz-Machado, 2019).

The new generation of machines equipped by sensors creates a huge amount of data named big data, and CPS is responsible for managing these data; hence CPS is the base for IoTS and facilitates I4.0 (Susana Duarte & Virgilio Cruz-Machado, 2017). CPS is the network set of different embedded systems with no resource constraints but with the ability to perform a large number of tasks simultaneously. Reactive computation and concurrency are two important features of CPS. Reactive computation is a feedback loop that creates an interaction between system and environment in a continuous manner. Also, there are sequences of observed inputs and outputs in the process, which have to deal with the system suitably. CPS is equipped with a control system that contains sensors and actuators which monitor and handle physical components in the manufacturing environment. A simple control system cannot perform complex tasks, hence a network of several systems named hybrid systems has been designed to achieve the task. Concurrency is another feature, and it means CPS performs multiple tasks at the same time. Concurrent processes would change information to achieve certain expected results and these operations could be synchronous or asynchronous in terms of their operation or the modalities of their operation.

CPS caught attention in different segments over the past years, and it is more popular in some segments now. Healthcare is very important where CPS is widely used, such as robotic surgery and image-guided surgery. As clearly known, it is vital to have medical devices and systems which measure things precisely so CPS is attractive in healthcare. The next application domain of CPS is in transportation, vehicles, and aircraft. There is an infrastructure-based transportation CPS for real-time monitoring the traffic infrastructures, such as traffic signals, cameras, and traffic control. Vehicle infrastructure coordinated transportation CPS for transit signal priority, queue warning for ambulances and fire trucks. Industry is one of the biggest domains of CPS (James & Cervantes, 2019); in general, manufacturing industries uses different equipment of CPS broadly.

Production lots and machines are equipped with components to make them smarter toward improving the efficiency of the production. Sensors gather data from the manufacturing environment and electronic hardware and software, analyze these data and make decisions based on these data (Alcácer & Cruz-Machado, 2019). Smarter cyber-physical manufacturing systems can perform various tasks, such as smart control, optimal resource utilization, smart diagnostics and maintenance, safety of the industrial environment, and smart monitoring of the health of these machines. For example, in terms of fault-repair, failure could be diagnosed by sensors, and then actuators activate the reparation process automatically (Mrugalska & Wyrwicka, 2017); after completing reparation, the solution will be saved in the cloud as a pattern and other machines will have access to this pattern to prevent the failure again (Sanders, Subramanian, Redlich, & Wulfsberg, 2017).

Regarding I4.0, CPS helps I4.0 achieve its goals as Sony (2018) and Alcácer and Cruz-Machado (2019) believe CPS is the main paradigm shift and the key feature of I4.0.

Combining CPS with the production process transfers current factories to I4.0 factories (Lee, Bagheri, & Kao, 2015).

As illustrated in figure 1.5, there are 5C architecture goals that can be achieved with CPS, such as Connectivity, Conversion, Cyber, Cognition, and Configuration (Lee et al., 2015). Connectivity is the first step in developing a CPS application, and it helps IIoT ensure that accurate and seamless data are obtained through sensors with proper specifications. Conversion is transforming data into meaningful information toward developing for prognostic and health monitoring, so machines become self-aware.

Lee et al. (2015) believe cyber is the center of the hub and it analyzes data received from different workstations, servers, and cloud. CPS gives a self-comparison ability to the machines to gather data from the fleets of machines and there are algorithms to rate the individual machine performance among fleet and predict the future machine behavior. Cognition is the proper presentation of information to users to generate thorough knowledge of the system toward collaborative, diagnostics, and decision-making for prioritization and optimization process. Machines become self-adaptive with the help of configuration; actually, they are equipped with supervisory control to determine actions to be taken by the machines, for example, self-configuration for resilience, self-adjustment for variations, and self-optimization for the disturbance.

Base on the previous information, implementation of CPS does not come free. In fact, there are several challenges to be overcome and higher standards to be met toward successfully implementing CPS. Gunes, Peter, Givargis, and Vahid (2014) count challenges CPS is facing as follows: Predictability, Interoperability, Security, Reliability, Dependability, and Sustainability.

Totally, CPS is the key point of the I4.0 that helps factories to be smarter and meet a higher level of manufacturing by integrating the cyber and physical world. Also, CPS gives manufacturers the potential to be faster and more flexible in order to respond to customer demands.

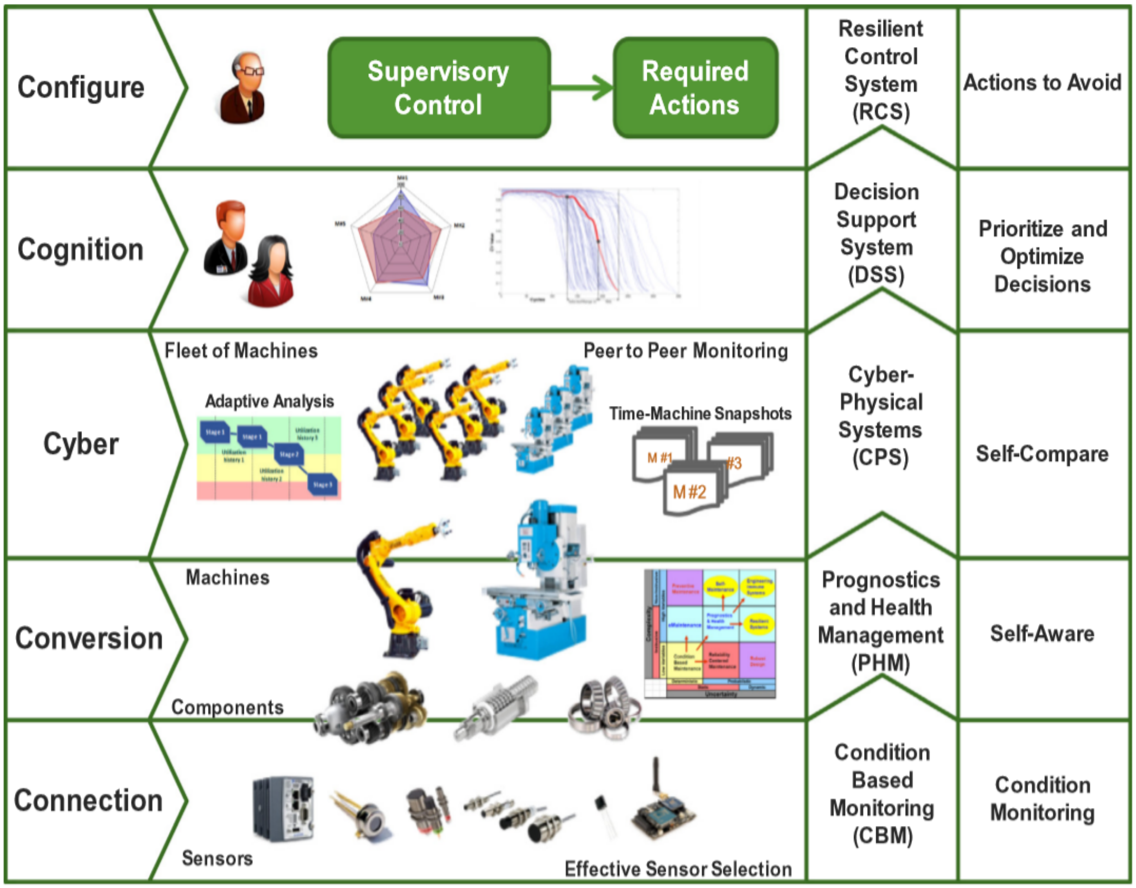

Figure 1-5 5C architecture and associated technique
Taken from Lee et al. (2015)

1.5.2 Internet of Things and Services

While recently only a limited number of devices have the ability to connect to the Internet, these days most of the devices can be connected to the Internet via IoTS that connect physical devices to the digital world. IoTS were coined for the first time in 1999 (Rose, Eldridge, & Chapin, 2015). It is a network of devices equipped with sensors, actuators, and software that have the ability to connect to each other and exchange data based on the Internet. A good example of IoT is home appliances, such as refrigerators, air conditioners, and doorbells that are able to connect to the Internet and share data with a user on a smartphone.

As illustrated in Figure 1.6, using IoT in the industry is called industrial Internet of things (IIoT). While IoT concentrates on customer usage, IIoT focuses on production processes such as manufacturing lines, logistics, and supply chains. Sensors are more precise in IIoT; therefore, the volume of data is tremendous in IIoT compared to IoT; for example, a turbine creates 500 gigabytes of data per day. IIoT contains a collection of machines equipped with sensors and actuators, and it gathers information and shares it via getaways. Gateways pass this information predominantly to the cloud.

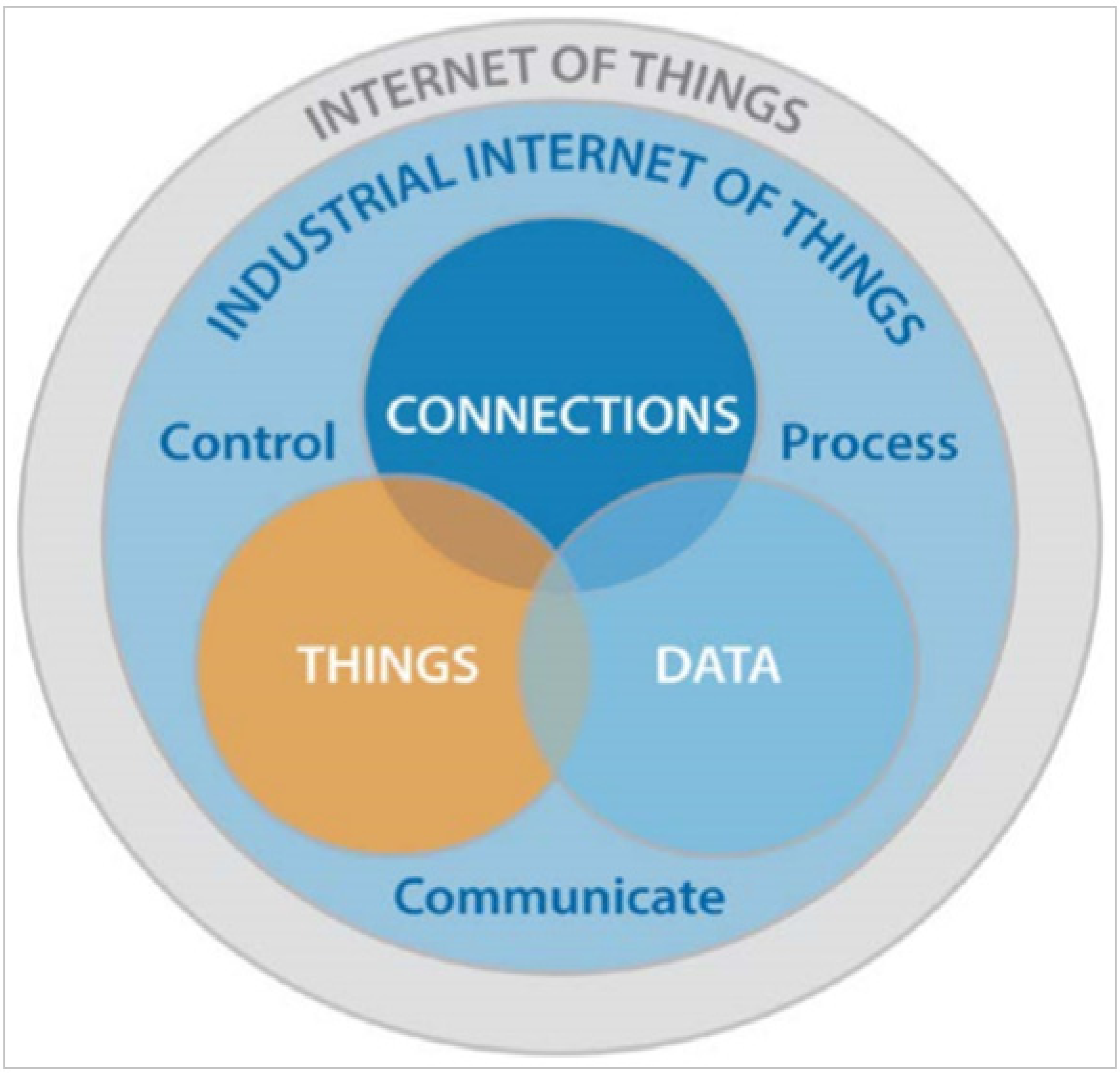

Figure 1-6 IIoT and IoT
Taken from Helmiö (2017)

Boyes, Hallaq, Cunningham, and Watson (2018) provide a definition of IIoT as follows:

> Industrial Internet of Things is a system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimize the overall production value. This value may include; improving product or service delivery, boosting productivity, reducing labor costs, reducing energy consumption, and reducing the build-to-order cycle.

The most important challenge of IIoT is cybersecurity (Mumtaz et al., 2017); also, complexity and final cost of the product, lack of standardization, and legacy-installed base are still vital challenges.

IoS is one of the main components of I4.0, which is built from combination of two concepts named Web 2.0 and Service-oriented architecture (Moon, Lee, Park, Kiritsis, & Von Cieminski, 2018). Each device that is connecting to the Internet provides a set of services bases on IoS and empowers the service provider to turn product into long-term revenue.

1.5.3 Smart Factory

The smart factory is in the heart of I4.0, and CPS, IoT, and IoS are its main components (Alcácer & Cruz-Machado, 2019). Smart factory is a kind of factory in which all tasks are done intelligently by utilizing CPS, IoT, and IoS. The aim is to increase the efficiency and reduce waste by creating connected manufacturing lines and supporting employees in making decisions with the feedback loop (Chute & French, 2019). The most important technology in a smart factory is CPS. There are physical and virtual worlds in smart factories that are intertwined completely. Each physical part of the factory has the equivalent in the virtual one and every alteration in the virtual system will be implemented in physical parts (Zhang et al., 2017). Chute and French (2019) explain the concept of smart factory as follows:

> Smart factory is the combination of cyber-physical systems and humans, connected through the Internet of things with support from the Internet of services, monitor production processes, and make decentralized decisions as part of an interdependent network. The factory management is orchestrated via smart enterprise resource planning systems and supported by human and virtual agents to develop a product that is responsive in real-time to demand, market conditions, and value chain (e.g., logistics) feedback.

In fact, a network that is built by combining IoT and IoS turns a factory into a smart factory as Zhang et al. (2017) mention that everything is intelligent in a smart factory, such as “Automated guided vehicle (AGV), warehouse, processing equipment, buffers, and monitoring devices.” Smart AGV are more intelligent than regular ones and the whole tasks and movements are done based on automatic instruction from the cloud.

In terms of the warehouse, the inventory will control things intelligently, travel time of vehicles will decrease, and the temperature and humanity of the environment will be controlled automatically. The large scale of equipment is the outshot of the smart factory, and it leads to increasing the quality of the product and total efficiency. Smart buffers will be used to adjust the speed of the WIP in the manufacturing process to prevent huge inventory in one step. Finally, the whole process from raw material to delivery, flow of information, and waste reduction will be controlled perfectly and predictably via smart logistics.

The Department of Innovative Factory Systems at the German Research Center for Artificial Intelligence introduced smart products, smart machines, smart planners, and smart operators as the four enablers of smart factory (Kolberg & Zuhlke, 2015). Vertical integration is implemented in smart factory and horizontal integration creates a connection between several smart factories toward creating end-to-end engineering over the whole value chain (Alcácer & Cruz-Machado, 2019). Figure 1.7 shows the position of the smart factory in I4.0.

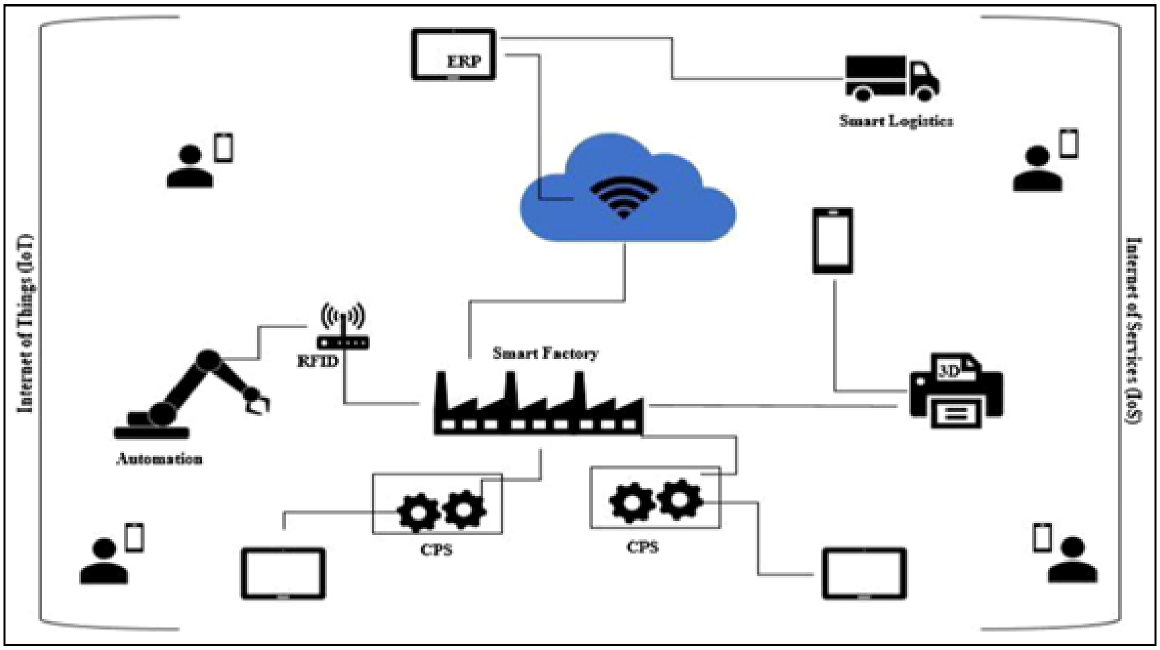

Figure 1-7 Vision of smart factory
Taken from Kamble, Gunasekaran, and Sharma (2018)

1.5.4 Big Data

During I4.0, the whole equipment and products connected to the Internet via IoT and IoS create huge amounts of data that cannot be stored and analyzed with traditional techniques. Hence Big data is a technology that deals with these extreme large data sets (Mourtzis, Vlachou, & Milas, 2016). Big data is a technique that collects, stores, and analyzes high volume of high velocity and complex data. The ability to interpret this amount of data causes IoT to be a value for manufacturers to precisely predict the future of the business.

Industrial big data are data produced by the plant and equipment of the plant and the products. It is totally different from Internet big data generated by social media and blogs. Industrial big data are connected with other platforms such as cloud service, mobile devices, and on-premises systems. Structured, semi-structured, and unstructured data are kind of data types that gathered with big data methodology (Mourtzis et al., 2016). Structured data are such data that can be easily organized and stored in the relational database, and machine language can understand it easily. Data that do not possess any pre-defined model are unstructured data. There is no precise consensus on the number of big data characteristics. Some scientists believe volume, variety, and velocity are the three main characteristics of big data (Mourtzis et al., 2016). Data that are large in volume, exhibit variety, and arriving at high velocity at the processing server. Also, some scientists believe in four more characteristics named veracity, variability, visualization, and value.

Industrial big data turns low-level data gathered from employees and equipment into vital and meaningful information that is used to make decisions in high-level sectors of the enterprise (Mourtzis et al., 2016). Via big data, enterprises utilized data that most of them even never knew existed toward creating patterns to predict the future. Big data increases customer satisfaction and efficiency, takes control of the data, transforms data to intelligent actions, and reduces costs. Also, predictive maintenance and real-time monitoring can be realized from industrial data, then the probability of occurrence of a failure is detected and maintenance can be carried out in advance. In fact, big data is the center of predictive maintenance in the I4.0 environment (Chukwuekwe et al., 2016).

1.5.5 Cloud Computing

Cloud computing is the process of having access to computers, software, and IT application directly over the Internet rather than from local physical sources, such as hard drives or onsite servers. Cloud allows to easily access any resources combined with mobile devices, personal computers, app servers, and databases anytime anywhere.

The smart factory has two sections: physical world and cloud. Cloud consists of the virtual factory and resource library. Virtual factory is connected to physical factory utilizing technologies, such as real-time simulation and servers to collect historical, customer, and machine data from the factory. The library is also a pool that acts as a source for this data (Lee et al., 2015).

Generally, four types of access are introduced to the cloud, such as public, private, hybrid, and community (Alcácer & Cruz-Machado, 2019). Public access is where cloud service is managed by vendors and access is provided for public. Private access is managed by the same organizations and provides benefit for the special organizations. Hybrid access is a combination of public and private access, and community access is provided by multi-organizations.

Three types of service model structures are identified for cloud computing, such as Infrastructure as a service, Platform as a service, and Software as service (Alcácer & Cruz-Machado, 2019), (Senyo, Addae, & Boateng, 2018), (Xu, 2012), (Assante, Castro, Hamburg, & Martin, 2016).

Xu (2012) identified two approaches toward using cloud computing in the manufacturing environment, using cloud computing applications in the manufacturing environment and using cloud as an entirely new cloud service type. The most influence of cloud computing in the manufacturing sector occurred around IT and business model to adjust manufacturing velocity base on demand and scale the flexibility of customization (Xu, 2012).

Cloud has several advantages such as streamlining operations, increasing efficiency, and reducing expense. Cost-benefit will occur due to eliminating some essential functions in traditional IT systems, speeding up the development of a new application, and ease of maintenance. Based on the data stored in the library, several algorithms are created that when something similar happens, the system will be able to predict the potential problem. For example, in case of a machine failure, the whole data related to the machine are collected by sensors and are saved on the cloud. Via analyzing this data, cloud and machine learn its behavior prior to failure; hence cloud is able to predict the next failure and activate maintenance process before occurrence. Furthermore, the machines are smart enough to share their workload with other machines in order to prevent delays and reduce costs resulting from machine failure (Helmiö, 2017).

Based on reviews, infrastructure of I4.0 is an advanced technology. The technologies mentioned above have a lower impact in an individual manner; in fact, I4.0 will succeed in maximizing technologies power, via combination and collaboration of these techniques.

I4.0 provides more flexibility for manufacturing processes while removing monotonous work and physically demanding jobs (Xu, 2012). Ease of customization is accessible in I4.0 that is vital in the current market. On one hand, the benefits of I4.0 are countless, on the other hand, organizations, especially gigantic companies face several implementation barriers toward implementing I4.0. In the next paragraphs, the candidate provides a detailed explanation of I4.0 implementation barriers, which is the most important element of the current research.

1.6 Barriers of Industry 4.0

I4.0 creates a virtual factory parallel to the physical factory to automatically control everything, and it offers huge benefits for the manufacturing sector. However, there are still hurdles to overcome toward adopting I4.0. Kamble et al. (2018) create a list of twelve reasons toward reluctancy to I4.0, such as Employment Disruptions, High Implementation Cost, Lack of knowledge in management systems, Lack of Standards and Reference Architecture, Security and Privacy Issues, etc. The authors in this research totally point out that the biggest problem is uncertainty about the benefit of high investment in digital equipment.

The majority of researchers believe that the barriers of I4.0 need more investigation (Raj, Dwivedi, Sharma, Jabbour, & Rajak, 2020). They mention that the major problems related to I4.0 are: Lack of skills, Inconvenience of employees with the new environment, Financial issues, and Lack of identified standards. Also, the authors claim that these factors influence each other and they should be considered as a whole. (Horváth & Szabó, 2019); Raj et al. (2020) concentrated on the barriers in developing and developed countries. They identified lack of information and understanding of strategic importance as the biggest issue in small and medium-sized companies in Romania.

Karadayi-Usta (2019) showed the major problem related to I4.0 implementation was Lack of education system in India, and that influence of the barriers on each other should be taken seriously. (Raj et al., 2020); Saatçioğlu, Özispa, and Kök (2019) highlighted Lack of vision as the barriers in Turkish company and believed in the importance of geographical location in this field. Stentoft, Wickstrom, Philipsen, and Haug (2021) investigated the drivers and barriers in implementing I4.0 through a questionnaire among 190 small and medium sized manufacturers in Denmark. The result was approximately the same as the aforementioned barriers, such as Lack of understanding of the vitality of I4.0 among employees and managers, Lack of knowledge among employees and customers’ employees, Lack of required project in companies, and Lack of knowledge of employee readiness. Finally, High implementation costs, known as the biggest internal challenge, and Lack of skilled workers were the biggest external challenges in implementing I4.0 (G. L. Tortorella & Fettermann, 2018). Barbier (2020) counted Overhead cost of adoption, The scale of Collins aerospace, Initial investment, Lack of digital knowledge, etc as barriers in the aerospace and defense industry in the USA.

1.7 Relationship between Lean Production and Industry 4.0

This research aims to find implementation and introduction barriers of I4.0 in the existing LP system in aerospace manufacturing sectors to help them overcome these barriers in order to start implementing or expanding it. So, as indicated in the title, the relationship between lean and I4.0 is indispensable. Understanding the result of the integration of LP and I4.0 should be taken seriously; hence the candidate has reviewed relevant literature to have a precise vision of the topic.

Sony (2018) used three kinds of integration models possible in I4.0, such as Vertical integration, Horizontal integration, and End-to-end engineering integration to align underlying principles of I4.0 with five lean principles, such as value, value stream mapping, flow, pull, and perfection. Wagner, Herrmann, and Thiede (2017) mentioned the first attempt to integrate lean and I4.0 happened in automotive companies. The authors of this paper introduce a framework for integrating lean principles and tools with the concept I4.0. They state that the cyber-physical is just-in-time to follow material process based on live data supported by I4.0. U. Dombrowski, Richter, and Krenkel (2017) and Wagner et al. (2017) proposed to use vertical integration of machine-to-machine communication instead of Kanban card in order to create a gapless information flow from supplier to customer base on big data technology. Sanders, Elangeswaran, and Wulfsberg (2016) also believe in the positive impact of I4.0 on reducing excessive time for transferring data between supplier and manufacturer. They state that IoT provides solution to the issue related to implementing JIT, such as incomplete shipment of products, wrong number of transported goods, etc.

The communication possible via IoT improves pull system, and it also lets companies track product online. The smart product allows companies to collect information from sold products as customer feedback in order to improve I4.0 components acceleration such as pull, flow, and JIT (Bauer, Brandl, Lock, & Reinhart, 2018). CPS increases the efficiency of lean principles (U. Dombrowski et al., 2017) and also improves predictive maintenance that leads to reducing machine failures and supporting continuous flow of material (Mayr et al., 2018).

I4.0 is totally on the top of the cake and LP will be more flexible, more stable, faster, and smoother after integrating with I4.0 (Rüttimann & Stöckli, 2016). I4.0 solutions can be used in the situation where lean principles do not work properly (Kolberg & Zuhlke, 2015), for example in case of failure, operator will receive an alert with details such as the error message and error location via smartwatch, which decreases the time between failure occurrence and failure notification. While in a lean environment, only some red lights notify the failure, free of aforementioned details.

All the aforementioned publications in this section believe in the positive impact of I4.0 on lean principles; in fact, the authors are on the opinion that I4.0 completes lean and optimizes its tools and principles, while there are more linkages between lean and I4.0. Some researchers introduce two more kinds of relationship between lean and I4.0, such as Lean is a basis for I4.0 and acts as enablers towards implementing I4.0, and there is a positive correlation between lean and I4.0 (Mayr et al., 2018). Actually, 2/3 of articles stated that lean acts as a prerequisite to support the successful implementation of I4.0 (U. Dombrowski et al., 2017). Companies with more than two years of experience in LP face fewer difficulties in implementing I4.0, and companies which have implement high-level LP have a better chance to implement I4.0 successfully (Guilherme Luz Tortorella & Fettermann, 2017) (Rossini, Costa, Tortorella, & Portioli-Staudacher, 2019). Also, Satoglu, Ustundag, Cevikcan, and Durmusoglu (2018) believe that LP and I4.0 are not mutually exclusive, and high performance appears after integration.

There are higher interdependencies between reducing waste and computing cloud, zero defect and big data, and LP visualization and cloud computing (U. Dombrowski et al., 2017). James and Cervantes (2019) point out that aerospace companies faced problems within implementing lean principles, and I4.0 provides the required solution to meet customer demands in flexibility, safety, and costs. They believe that integration of IoT and LP is essential in order to enjoy the benefit of I4.0 in the high-risk industries such as aerospace. Moreover, implementing I4.0 will increase efficiency and it will drop costs without reducing quality

CHAPTER 2

METHODOLOGY

It is impossible to achieve the objectives of the investigation unless it is done with a proper methodology. It should be noted that the reliability of the research achievements is strongly influenced by the reliability of the method. In this chapter, the methodology used in the thesis is discussed. The goal is to present tools and approaches used to gather data.

In total, two approaches are used by researchers to gather data: qualitative and quantitative. Qualitative study includes non-numerical data and words to describe and explain. It is helpful for deep research on the subject to build a theory regardless of the sample size. The validity of the results depends on personal involvement. Quantitative approach is used for numerical data that aims to explain and predict. It is utilized when the objectives are statistical analysis and concluding based on accurate data. Referring to the research questions, the methodology of this research is qualitative which is done via a survey.

This survey research is a descriptive qualitative study in which a large number of people are asked questions, and their responses are tabulated in an effort to identify general patterns or trends in a certain population. The goals are to provide a snapshot view of the population at a given point of time and attempt to make inferences about a larger population beyond the given time. Hence this investigation is a qualitative cross-sectional study because the data from a population will be looked at a specific time using a five-point Likert scale. The investigation makes statistical inferences utilizing accurate data to find the results. It means that many companies are asked about the same things at the same period of time. This study is descriptive, and it describes features from gathered data via the questionnaires qualitatively. The implemented methodology is briefly illustrated in figure 2.1.

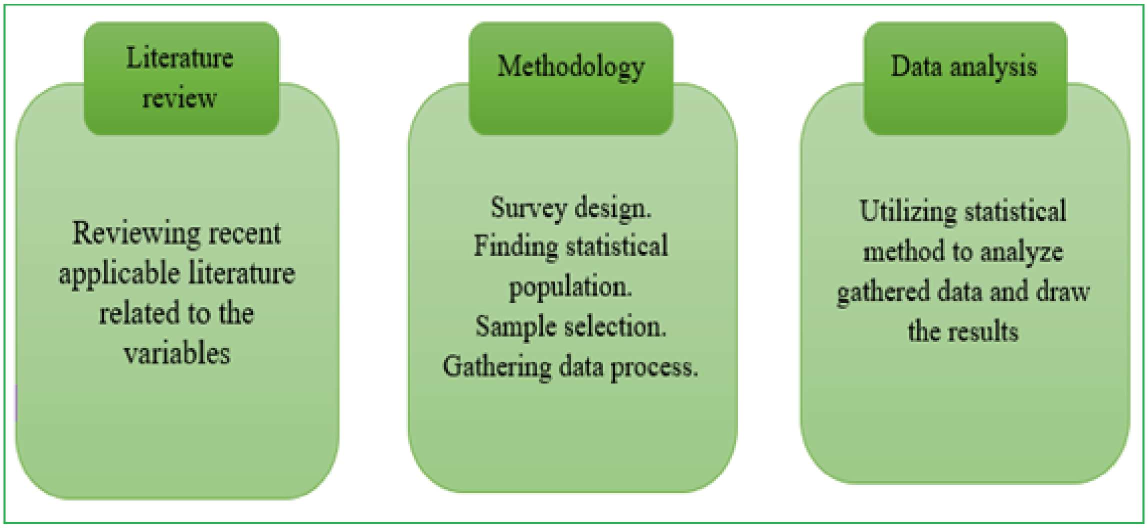

Figure 2-1 Research methodology

2.1 Literature Review

The main sources for the information about the state of the art in this research were some books and scientific articles. The books were borrowed from the university library and the supervisor. The university library database and Google scholar that are connected to some websites such as Springer, Science direct, and IEEE databases have been utilized to access the articles. The candidate searched the following keywords to find relevant literatures:

- ‘Toyota production systems’
- ‘Lean manufacturing‘
- ‘Lean production’
- ‘Lean tools’
- ‘Lean’ and ‘Aerospace manufacturing’
- ‘Lean maturity’
- ‘Lean Enterprise self-assessment tools’
- ‘Lean’ and ‘Industry 4.0’
- ‘Industry 4.0 components’

- ‘Industry 4.0 barriers’
- ‘Industry 4.0 inhibitors’

Additionally, the candidate found some master courses in Concordia University, such as INDU 6221 and INDU 6321 which were helpful in writing the literature review. The books *The machine that changed the world* (James P Womack et al., 2007) and *Lean manufacturing implementation* (Hobbs, 2003) were the infrastructure of the thesis.

The 1st to 5th sections of the literature review were devoted to Lean production, Lean principles, lean tools in aerospace, and lean maturity. In those parts, the history of lean and the main idea behind lean were discussed; five lean principles were also introduced in detail. Some popular lean tools in the aerospace industry were defined as follows. Additionally, Lean Enterprise self-assessment tools was defined to find the level of lean adoption in manufacturing companies.

The 6th section of the literature review was about I4.0. The Candidate cannot find worthy books because I4.0 is a new emerging technology; hence the whole information was gathered from articles. During this section, the history of the fourth industrial revolution and the most important factors of it were explained, such as CPS, IoTS, smart factory, etc. Barriers to adopt I4.0 practices and the relationship between lean and I4.0 were the titles of the 7th and 8th parts of the literature review.

2.2 Statement of the variables

The main aim of this section is to introduce the most important variables of the study. This study has one independent variable and two dependent variables, and the data has been obtained around them and the relationship between them has been investigated. In order to focus on the particular objective of the study, the candidate has avoided introducing several variables. As the investigation aims to find I4.0 barriers in lean aerospace manufacturing companies lean maturity is not one of the variables. The level of adopting lean practices just considered as a filter to remove non-lean companies form the main steps of the investigation because there was no list to provide lean mature companies in aerospace sector in Canada. Also, the gathered data from non-lean companies could be used to compare the level of I4.0 practices and tendency to them between lean mature and non-lean companies. The only independent variable is the degree of I4.0 adoption in lean mature aerospace companies. In Reference to the study questions, the first dependent variable is the degree of tendency to implement I4.0 among lean mature companies and the second one is the barriers of I4.0 among those companies. The mathematical relationship between these variables are in the forms of Y1=F(X), and Y2=G(X), where Y1 ‘Degree of tendency to implement I4.0 among lean mature companies’ and Y2 ‘Barriers of I4.0 among lean mature companies' are the two dependant variables and X is independent variable 'Degree of I4.0 adoption in lean mature aerospace company', F and G some function.

2.3 Statistical Population

The targeted companies were categorized based on two factors. The first factor was the type of industry. All companies that exist in the aerospace industry located in Canada were considered as targeted companies, including gigantic companies such as Airbus and Bombardier and the companies that produce parts in this sector.

Introduction and implementation barriers of I4.0 in lean mature companies had to be determined during the study, so the second factor was lean maturity of those companies. Since there was no scientific reference which sorted companies according to the level of maturity in lean practices, the candidate had to consider all aerospace manufacturing companies that exist in Canada and examine their maturity.

The managers, engineers, technicians and lean experts of the aforementioned companies are the statistical population in this research. Managers include human resource, planning and programming, quality control, support and sales, and resource planning managers. Engineers include mechanical, aerospace, industrial as well as environmental experts.

Since there is no list of aerospace manufacturing companies, the first step was finding a proper one. Therefore, the following websites have been utilized to create a proper list based on the study factors.

- https://aiac.ca/
- https://www.aeromontreal.ca/
- https://en.wikipedia.org/wiki/Main_Page
- https://ca.linkedin.com/

The above mentioned websites contain thousands of companies that called themselves aerospace manufacturing companies. Some of them did not seem to be real; for example, some companies had only one employee or some of them had nothing in common with aerospace manufacturing companies.

The companies had an account in those websites which included their field of work and services, the number of employees, etc. Their accounts were carefully reviewed to find which ones were suitable based on the research factors. Furthermore, their websites were reliable sources in this field. These websites were utilized in this process, and finally, 256 companies were chosen for the next step. Approximately one-quarter of the companies were located in Quebec so, the survey was designed in French language as well to increase the response rate.

The next step was to find the employees email addresses. Some email addresses were found on companies websites or their accounts on the websites as mentioned above. Fortunately, all companies had a LinkedIn webpage from which most email addresses were extracted. The candidate made benefit of some google extensions named ***LinkedIn email finder*** and ***Hunter*** to extract email addresses from LinkedIn pages. In total, 2584 email addresses belong the employees of 256 different companies were extracted.

2.4 Sample Selection

The sample is the subset of a population that is used to draw conclusions about the entire population, and it should be representative of the whole population. In the present study, the main tool for gathering data is an online survey and it is clearly known that online surveys have a low response rate, especially in these days, due to the high chance of being a victim of a cyberattack. The previous researches show a response rate between 10% and 20% for an online survey. As the statistical population in this study is 256 companies, the candidate expected to have 25 to 50 answers. If some companies had been removed by sampling, not enough samples would remain to gather data and draw the results. Also, candidate as a student didn't have the power to encourage companies and gather more information. Hence, the candidate ignored sampling and made effort to gather data from the whole statistical population and the respondents were considered as the sample.

2.5 Survey Design

The primary tool for the current investigation was a survey which contained four questionnaires that targeted aerospace manufacturing companies located in Canada. Since the statistical population was scattered in Canada, it was not possible to conduct a face-to-face interview and the candidate decided to conduct an online survey, hence the survey was designed in the Google Forms platform.

Respondents received emails containing some explanations about the objective of the study and a link that redirected them to the designed pages on Google Forms. The survey had three sections and four separate questionnaires that aimed to find lean maturity, the level of implementing I4.0 practices, the tendency to I4.0, and I4.0 barriers.

In the first section, some general questions were asked about the respondent and the company (See ANNEX I). The company's name was important because the candidate aims to create a list of lean mature companies in Canada that would be useful for future researchers.

In order to analyze the data, some steps have been done that is illustrated in figure 2.2. Referring to the research questions, the objectives of the investigation are to find introduction and implementation barriers in Canadian aerospace manufacturing companies, so the first step was to separate lean mature companies using LESAT questionnaire (see ANNEX I).

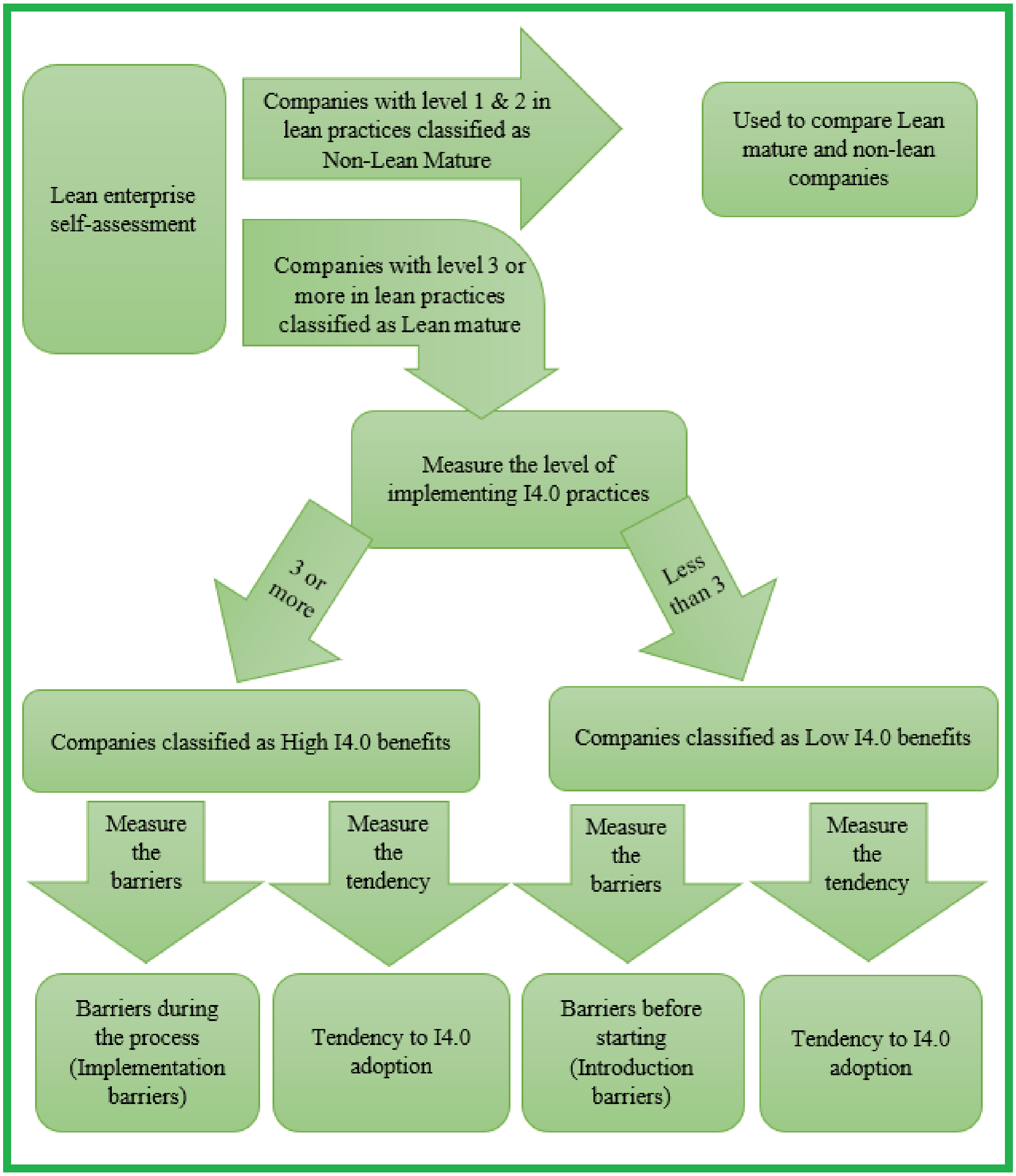

Figure 2-2 The method of analyzing the data

LESAT is a self-assessment tool that aims to find the current situation of lean, the desired situation and the gap between two situations. But in this study objective was to examine only the current situation of lean practices in participants. Also, this study has three different questionnaires containing 44 questions about I4.0, hence assessing every 54 lean items recommended in LESAT made the survey very long, and there was the possibility of the low response rate. For these reasons, LESAT tools were personalized and the questions were combined with each other, which led to 15 questions. Respondents were demanded to rate 15 statements provided via a five-point Likert scale based upon criteria from Urban (2015) and Nightingale (2001). LESAT questionnaire was analyzed using correspondence analysis via Statgraphics 18 software to determine lean maturity level. The companies that have level 3 or more in adopting lean tools were classified as lean mature others were classified as non-lean mature. Those which grouped as lean mature took on the new challenges of finding the I4.0 level, the tendency to I4.0, and I4.0 barriers; others have been removed from the main steps of the investigation and just used to compare the level of I4.0 practices and tendency to I4.0 practices between lean mature and non-lean mature companies.

Over the second step of drawing the results, companies were classified based on their level in I4.0. In this regard, participants answered 12 questions shown in ANNEX I. Respondents were asked to rate the level of implementing I4.0 practices in companies on a five-point Likert scale. These practices illustrated in table 2.1 were collected from literature reviews and designed based upon criteria from Stentoft et al. (2021). The correspondence analysis method was utilized to draw the results and find I4.0 degree. The companies that have the level 3 or more in adopting I4.0 practices were classified as High I4.0 benefits, others that have level less than 3 were classified as Low I4.0 benefits.

Referring to the first research question which aims to determine the tendency to adopt I4.0 in aerospace, a 7 questions questionnaire (on a five-point Liker scale) introduced by Stentoft et al. (2021) was conducted. The questions were looking forward to determine pressure to implement I4.0, willingness to take the risk on I4.0, and the ability to judge the value of I4.0. Furthermore, managers support and economic freedom, employees competencies, and motivation were measured via these questions. The level of inclination was separated into high I4.0 benefits and low I4.0 benefits.

Table 2.1 Industry 4.0 Practices

	Practices
1	Big Data & Analytics
2	Autonomous Robots
3	Simulation
4	Horizontal & Vertical System Integration
5	Internet of Things (including sensors)
6	Cyber-Security
7	Additive Manufacturing (e.g. 3D print)
8	Augmented Reality
9	Cloud Computing
10	Mobile Technologies
11	Artificial Intelligence
12	Radio-Frequency Identification & Real-time locating system technologies

The second and third research questions were to find barriers to implement I4.0 practices in the aerospace sector in Canada. For this purpose, a questionnaire containing 25 widespread barriers (Table 2.2) was provided and the respondents were asked to rate them on a five-point Likert scale. The candidate utilized reviewed papers, especially two previous pieces of a research done by Stentoft et al. (2021) and Majumdar, Garg, and Jain (2020) in order to create the obstacles list. Challenges that high I4.0 benefits highlighted were named implementation barriers in joining the fourth industrial revolution. Significant obstacles mentioned by low I4.0 benefits were named introduction barriers.

Table 2.2 Industry 4.0 barriers

List of barriers	
Employment disruption due to implementation of Industry 4.0	Security issues (data and information related)
Lack of knowledge about Industry 4.0	Problem of coordination and collaboration
Required continued education of employees	Seamless Integration and Compatibility Issues
Lack of trained staff	Lack of digital strategy in organization
Employee resistance to change	Inadequate maintenance support system
Lack of top management support	Lack of government support and policies for Industry 4.0
Organizational and process changes for implementing Industry 4.0	Lack of methodical approach for implementation of Industry 4.0
High implementation cost of Industry 4.0	Lack of experience in project management and budgeting in Industry 4.0
Lack of clear understanding of benefits of Industry 4.0	Lack of risk management tools for investments in Industry 4.0
Time constraint	Legal and Contractual uncertainty
Lack of database management systems	Poor research and development of Industry 4.0 adoption
IT infrastructure and Internet cover.	Fear of Failure
Lack of standard and reference architecture	

2.6 Sending Process

The questionnaires were designed in Google Forms and a link was provided that redirected the respondents to the survey pages. An email was sent along with brief information about the study purposes and the link provided by Google Forms during 1^{St} June and 31^{st} July 2021. Furthermore, some contact form provided in companies websites were filled out along with an invitation text and the survey link. Also, the survey was posted in some LinkedIn groups including Canadian Engineers and Managers in the aerospace industry. The respondents were promised that the survey objective was purely for research and academic purposes, and all individual would be kept strictly confidential.

CHAPTER 3

RESULTS

In this chapter, the results of the study are presented. The process of gathering data took around two months. The emailing process started by sending 2584 emails on 1st June, 2021. Different kinds of errors appeared during the emailing process; for instance, some email addresses were unavailable, some employees had left their jobs or were on vacation, and some people demanded to be removed from emailing list. The candidate updated the email list regularly based on the errors. In total, 269 errors appeared and 2315 emails existed in the last updated list. Reminder emails were sent each Monday for 7 more weeks. After the second week, a $5 Tim Hortons gift card was promised to the respondents to motivate them to participate. Furthermore, 127 contact forms were filled out twice along with the survey link. Additionally, the survey was posted weekly in Canadian Engineers and Managers LinkedIn groups.

The following figure also shows how statistical population went from 256 companies to 45 and how they classified into lean and non-lean. Totally, 45 participants from 41 different companies filled up the survey entirely, and the response rate was 17.5% percent. The raw data of the study presented in ANNEX II.39 of the respondents which have level 3 or more in lean tools classified as Lean mature and 6 companies that shows low degree of lean tools (Less than 3) classified as Non-lean mature.

In the next step, the degree of implementing I4.0 practices measured which 17 responses show level 3 or more that classified as high I4.0 benefits. These respondents were used to determine implementation barriers. Moreover, 22 respondents show level less than 3 in I4.0 practices that are classified as low I4.0 benefits and utilized to determine introduction barriers. The details explanation of these classification provided in section 3.1 to 3.6.

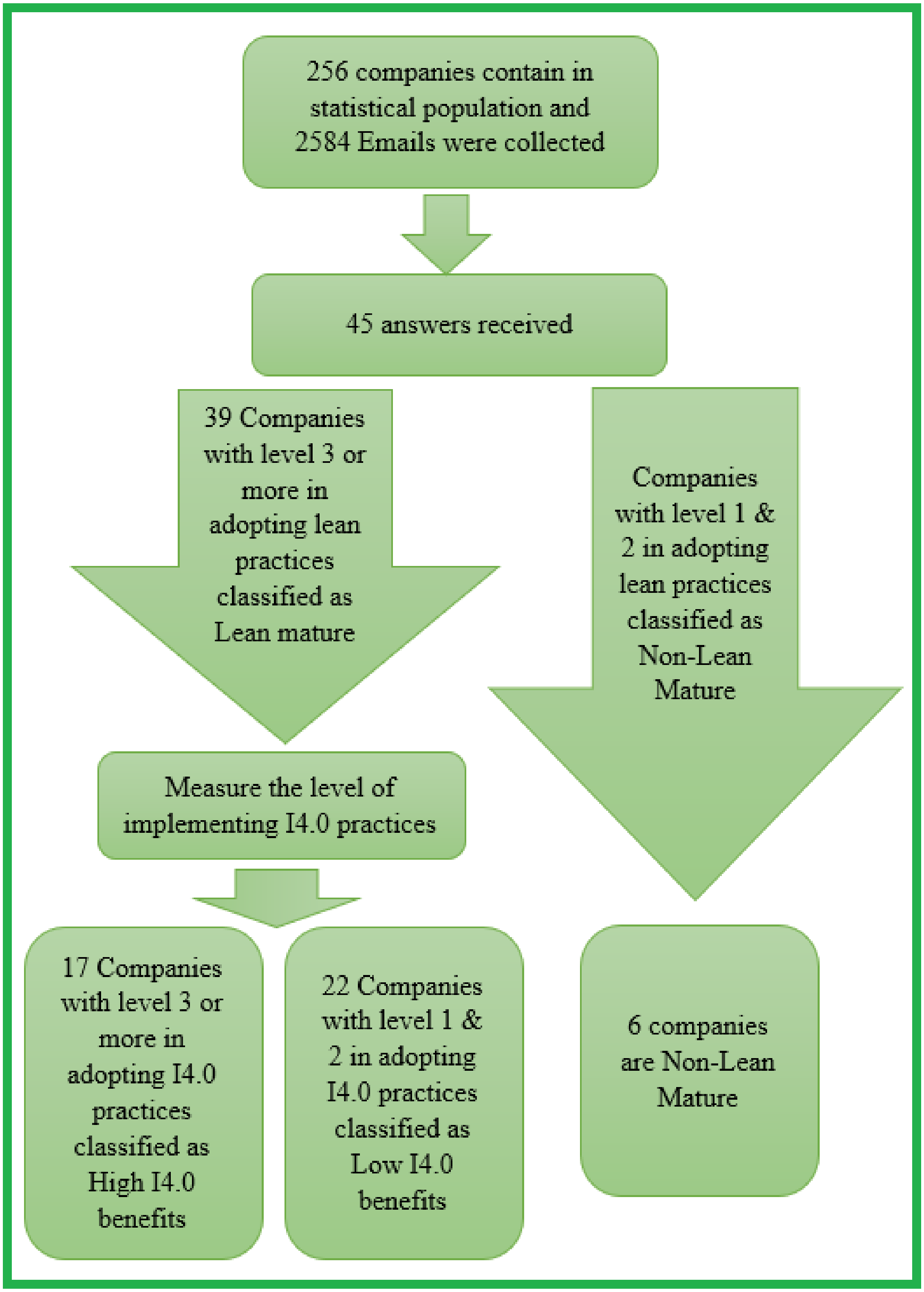

Figure 3-1 Classifying the companies to high and low I4.0 benefits

Figure 3.2 shows the number of employees in the companies. Large-size companies had the minor part in the research, and 42% of the participants were medium-size businesses. Also, the figure 3.3 shows the location of the companies. Almost the whole companies located in Quebec.

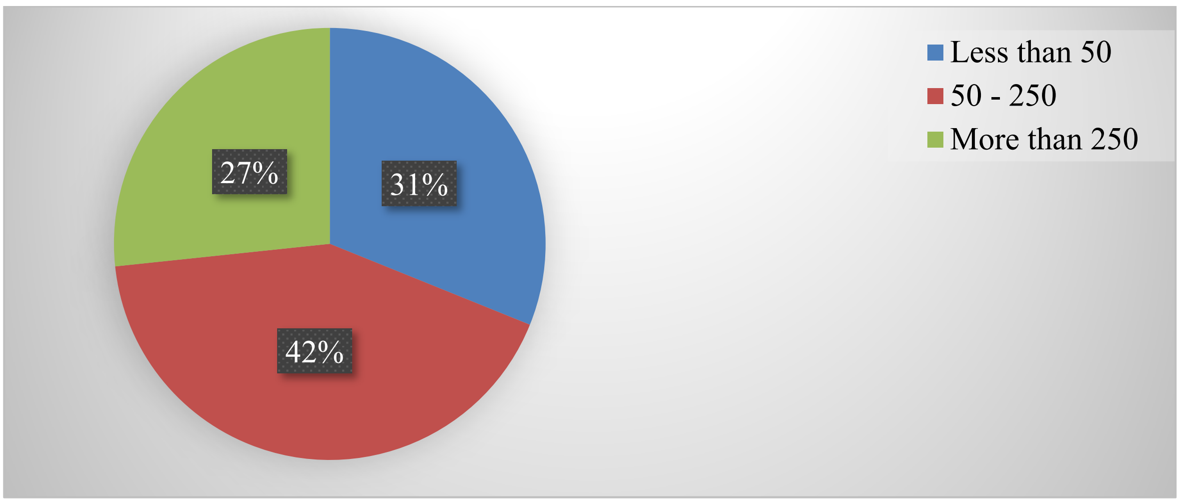

Figure 3-2 Number of employees

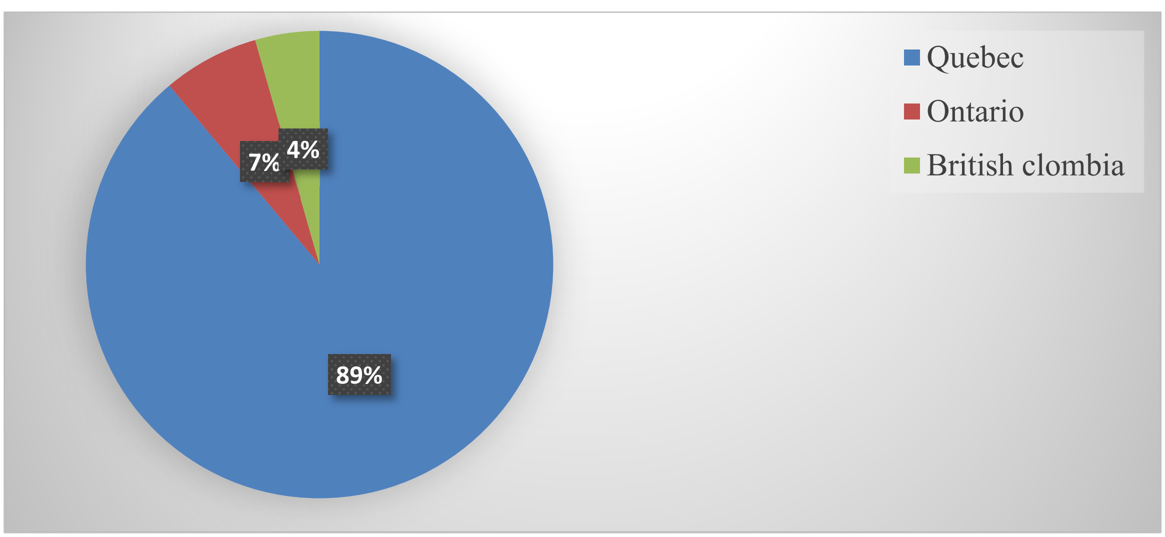

Figure 3-3 Companies location

Participants hold various positions in their own companies, the most participants were managers (31%) and technicians (24%) in different sections. The results are illustrated in figure 3.4.

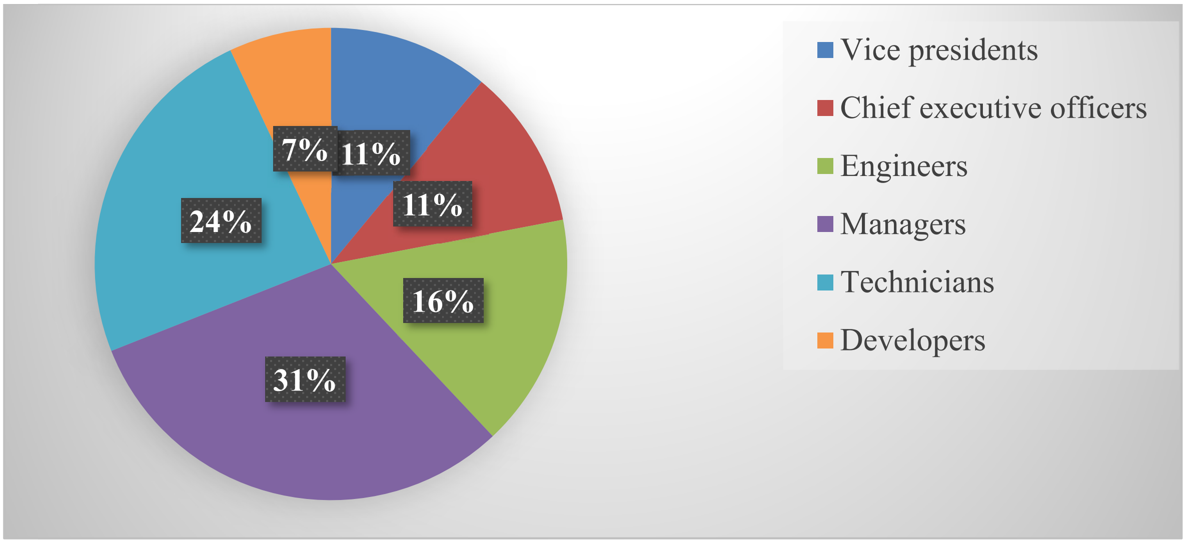

Figure 3-4 Position of participants

3.1 Lean Enterprise Self-Assessment Tools

Lean enterprise self-assessment tools technique has been used as the 4th questionnaire to find the level of lean practices. The designed questions asked to rate 15 statements based on a five-point Likert scale: Level 1=Never, Level 2=Rarely, Level 3=Occasionally, Level 4=Often, and Level 5=Nearly always. As data gathered from the Likert scale is not numerical, using mean and standard deviation for interpretation does not make sense. Gathered data from the Likert scale is qualitative and categorical data, so to find distributional properties, correspondences analysis technique is appropriate in this study.

Table 3.1 provides the row profile for LESAT results. Referring to the following chart, each row shows one company and clarifies the percentage of the responses for each level. For example, company number 1 (C1) has 0% answer for level 1, 26.7% to level 2, 20% to level 3, 46.7% to level 4, and 6.6% to level 5. In fact, the percentage of the answers to each level specifies the position of the company in a five-dimensional Euclidean space. This table provides an overall view of the answers. In order to have accurate results, the graphical presentation is essential and the correspondence map is the best choice in Statgraphic for this reason based on the current data.

Table 3.1 Lean enterprise row profile

	Level 1	Level 2	Level 3	Level 4	Level 5
C1	0.000	0.267	0.200	0.467	0.067
C2	0.000	0.000	0.067	0.533	0.400
C3R1	0.000	0.333	0.000	0.267	0.400
C4	0.000	0.000	0.000	0.133	0.867
C5	0.000	0.000	0.400	0.133	0.467
C6R1	0.000	0.000	0.267	0.600	0.133
C6R2	0.000	0.000	0.000	0.400	0.600
C7	0.000	0.000	0.067	0.067	0.867
C8	0.000	0.067	0.533	0.333	0.067
C9	0.000	0.000	0.067	0.200	0.733
C10	0.133	0.133	0.200	0.467	0.067
C11	0.000	0.133	0.267	0.467	0.133
C12	0.133	0.067	0.400	0.333	0.067
C13	0.000	0.067	0.067	0.733	0.133
C3R2	0.000	0.067	0.200	0.533	0.200
C14	0.000	0.000	0.067	0.400	0.533
C15	0.000	0.067	0.200	0.600	0.133
C3R3	0.067	0.200	0.133	0.333	0.267
C16	0.000	0.267	0.333	0.267	0.133
C17R1	0.000	0.000	0.667	0.333	0.000
C18	0.000	0.067	0.133	0.400	0.400
C19	0.000	0.000	0.000	1.000	0.000
C20	0.000	0.067	0.600	0.267	0.067
C21	0.000	0.267	0.267	0.467	0.000
C22	0.000	0.400	0.400	0.200	0.000
C23	0.200	0.267	0.200	0.333	0.000
C24	0.000	0.000	0.133	0.533	0.333
C25	0.000	0.000	0.200	0.533	0.267
C26	0.000	0.000	0.000	0.000	1.000
C27	0.000	0.067	0.133	0.533	0.267
C28	0.000	0.000	0.333	0.667	0.000
C29	0.667	0.133	0.133	0.000	0.067
C30	0.133	0.133	0.000	0.333	0.400
C31	0.000	0.067	0.067	0.533	0.333
C32	0.067	0.133	0.267	0.333	0.200
C33	0.800	0.200	0.000	0.000	0.000
C34	0.000	0.000	0.000	0.467	0.533
C35	0.000	0.200	0.267	0.467	0.067
C17R2	0.000	0.000	0.400	0.600	0.000
C36	0.000	0.533	0.333	0.133	0.000
C37	0.000	0.000	0.133	0.267	0.600
C38	0.000	0.200	0.467	0.333	0.000
C39	0.000	0.000	0.067	0.733	0.200
C40	0.000	0.067	0.400	0.333	0.200
C41	0.000	0.133	0.333	0.533	0.000

Before drawing the correspondence map, it is required to determine how many dimensions are needed to explain most of the differences amongst variables. For this reason, the Chi-square and Inertia table is provided in table 3.2. Chi-square column shows the contribution of each dimension to the chi-square statistic and inertia measures the amount of variability along a principal dimension. The chi-square and inertia are 787.069 and 1.1660. The table 3.2 shows that dimensions 1 and 2 represent 78.4892 % of the variability of the items in the questionnaire. Hence a two-dimensional correspondence map is provided as the graphical presentation in the figure 3.5.

In figure 3.5 the location of the companies in correspondence map is not clear. This figure is provided to shows the position of the companies number 29 and 33 (C29 and C33) in map. The transparent version of figure 3.5 presents in figure 3.6.

Table 3.2 Inertia and chi-Square decomposition

Dimension	Singular Value	Inertia	Chi-Square	Percentage	Cumulative Percentage	Histogram
1	0.7380	0.5447	367.6817	46.7153	46.7153	***************
2	0.6087	0.3705	250.0823	31.7739	78.4892	**********
3	0.3837	0.1472	99.3858	12.6273	91.1165	****
4	0.3218	0.1036	69.9195	8.8835	100.0000	***
TOTAL		1.1660	787.069			

In the figure 3.5 and 3.6 the x-axis corresponds to dimension 1 and the y-axis to dimension 2. Each blue vertex in these figures presents the position of the companies based on the two principal dimensions for example C30 shows the position of the company number 30.

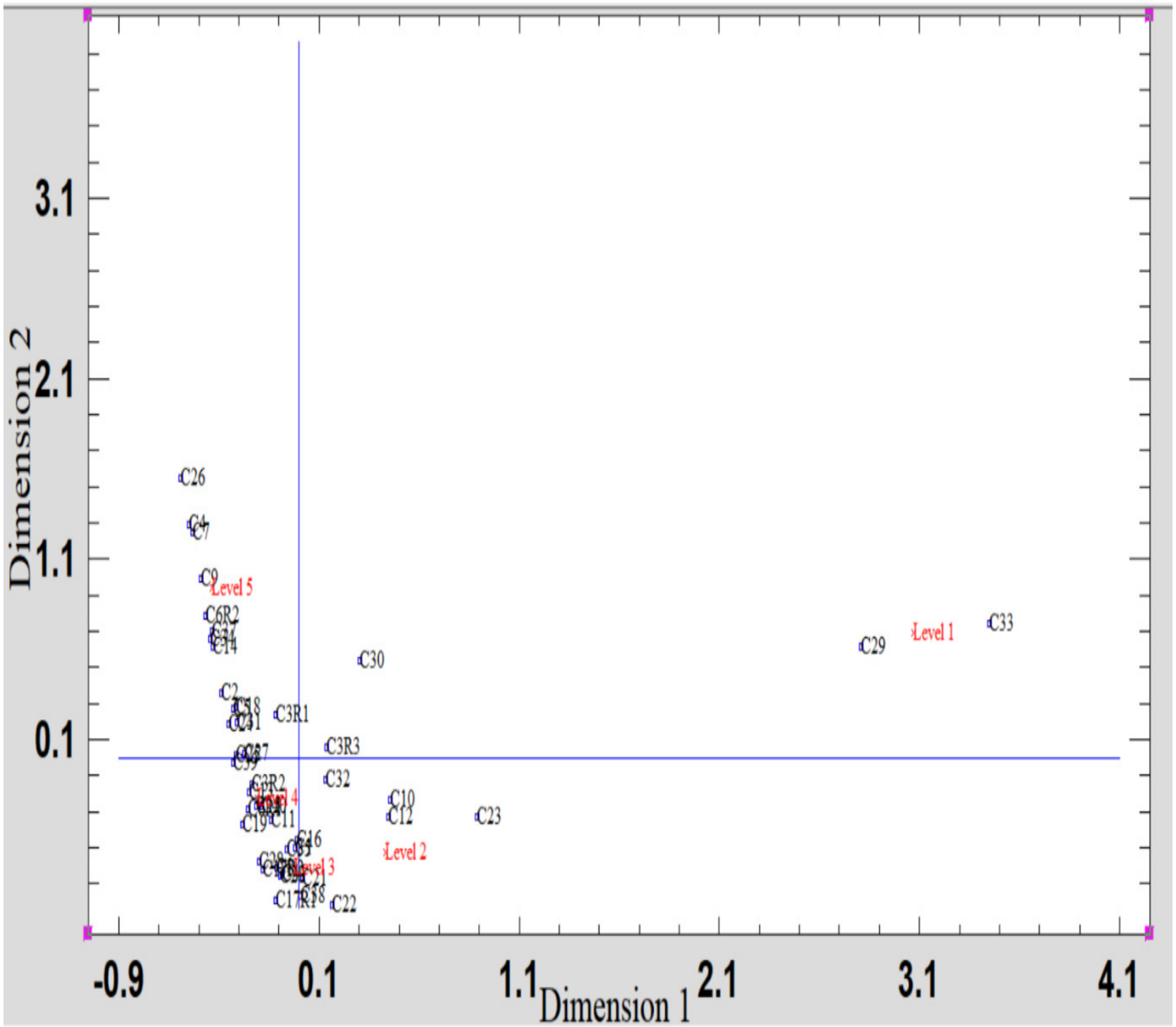

Figure 3-5 Two-dimension lean enterprise correspondence map 1

Furthermore, the map contains the vertices that show the extreme profiles related to each column. For example, level 5 vertex shows the position to which all responses are level 5. Hence the vertex (belonging to each company) that is close to level 5 shows that the company has level 5 in implementing lean tools. For example, company number 9 (C9) has level 5, company number 19 (C19) level 4, company number 21 (C21) level 3, company number 12 (C12) level 2, and company number 33 (C33) level 1.

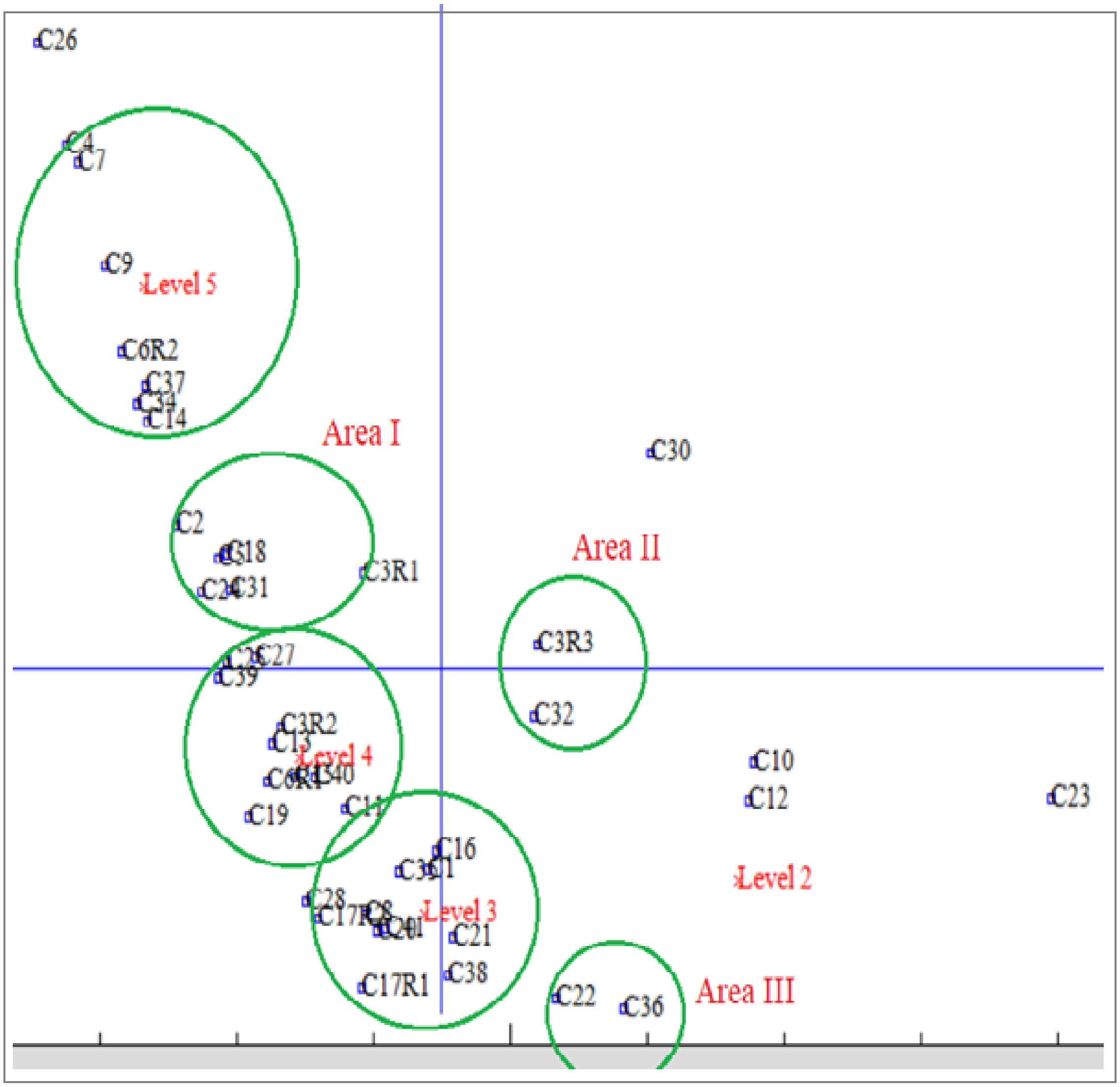

Figure 3-6 Two-dimension lean enterprise correspondence map 2

As Nightingale (2001) mentioned, companies in level 2 just have some information and informal approach of lean and it is not possible to call them lean mature companies. While, corporations with Level 3, apply lean as a systematic approach in most company sectors sustainably. Thus, the companies that show level 3 or more in the correspondence map were considered in acceptable maturity level, and they were brought to the next steps.

In reference to the correspondence map in figure 3.6, the companies that are located around levels 5, 4, 3 and area I are lean mature. But for those that are located in areas II and III, the correspondence map has no clear answer; thus, mosaic plot in figure 3.7 has been used.

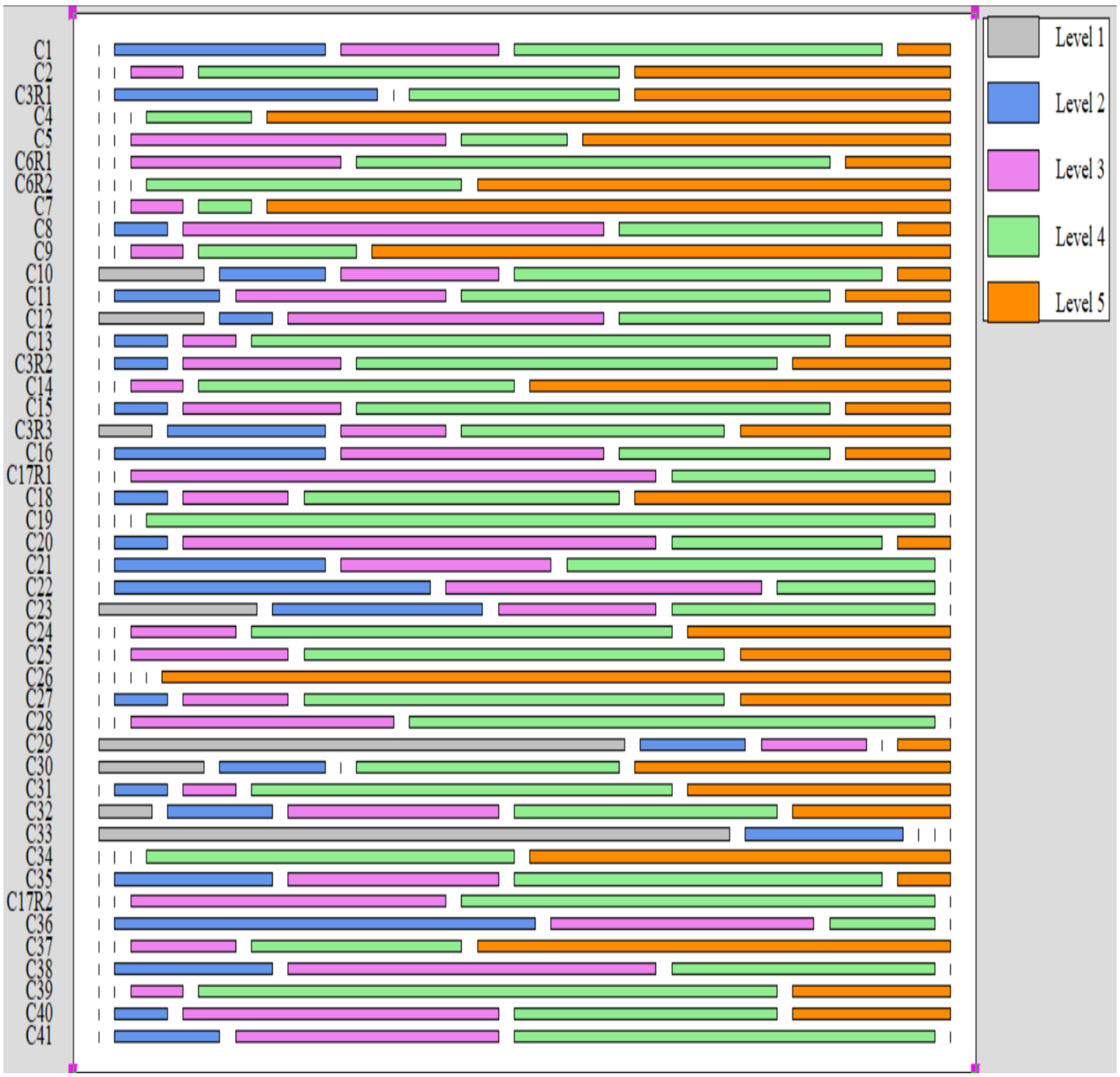

Figure 3-7 Lean enterprise mosaic plot

The mosaic plot is another nice way to look at row profiles. The mosaic plot takes every row in contingency tables and draws bars where the length of each level in row is proportional to the answers of that level. For example, company number 22 (C22) is located in area III and devoted more than 50% of the answers to levels 3 and 4 so, it can be a lean mature. The same interpretation of the mosaic plot shows that company number 32 (C32) and third response from company 3 (C3R3) are lean mature but company number (C36) is not lean mature.

The researcher has more than 1 answer for company numbers 3 (C3R1, C3R2, and C3R3), 6 (C6R1, C6R2), and 17 (C17R1, C17R2). The position of multiple answers is about the same in this correspondence map. For example, all answers for company number 3 are a bit the same, and they show the level 3 or more for their companies.

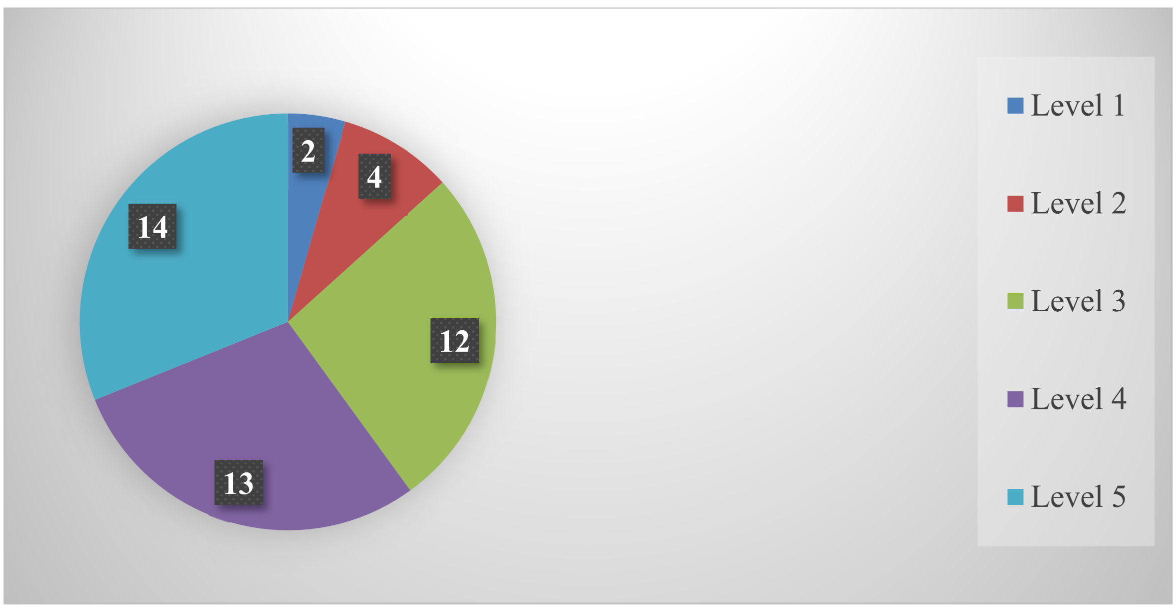

Figure 3-8 The number of companies in each level of lean maturity

Figure 3.8 shows the number of companies in each level, 14 of the companies have level 5 and 13 companies have level 4 in implementing lean practices.

Finally, figures 3.5, 3.6, and 3.7 led to the conclusion that 39 of the companies implement lean tools in acceptable level. These corporations that labeled with the symbol ✓ in table 3.3 were brought to the next steps, which are related to I4.0 practices. The other companies that labeled with the symbol × were used to compare I4.0 between lean and non-lean companies.

Table 3.3 Lean maturity

Company	Lean mature	Company	Lean mature	Company	Lean mature	Company	Lean mature	Company	Lean mature
C1	✓	C2	✓	C3R1	✓	C4	✓	C5	✓
C6R1	✓	C6R2	✓	C7	✓	C8	✓	C9	✓
C10	×	C11	✓	C12	×	C13	✓	C3R2	✓
C14	✓	C15	✓	C3R3	✓	C16	✓	C17R1	✓
C18	✓	C19	✓	C20	✓	C21	✓	C22	✓
C23	×	C24	✓	C25	✓	C26	✓	C27	✓
C28	✓	C29	×	C30	✓	C31	✓	C32	✓
C33	×	C34	✓	C35	✓	C17R2	✓	C36	×
C37	✓	C38	✓	C39	✓	C40	✓	C41	✓

3.2 The Degree of Industry 4.0 Practices

In reference to the research questions, this study aims to find introduction and implementation barriers. As mentioned before, introduction barriers are challenges that companies (Low I4.0 benefits) declare before adopting I4.0 practices. While, implementation barriers are those that companies (High I4.0 benefits) face during applying I4.0. For this reason, companies had to be separated based on their level in applying I4.0 to low I4.0 benefits and high I4.0 benefits. The analyzing method was the same as LESAT questionnaire using correspondence analysis in Statgraphic 18.

In order to interpret the gathered data, the row profiles table is provided in table 3.4. This table presents raw data and clarifies which percentage of the companies' answers belongs to each level. For example, company number 1 (C1) has 0% answers for level 1 and 2, 41.7% to level 3, 25% to level 4, and 33.3% to level 5.

The same as the previous interpretations, the row profiles table has an ambiguous view of the results so, a correspondence map is needed to obtain precise results via a graphical presentation. Again, before having the correspondence map, inertia and chi-square decomposition table says how many dimensions are needed to explain most of the differences amongst variables. The inertia and chi-square are 0.6697 and 313.404 for this questionnaire presented in table 3.5. Two first dimensions present 67.78% of the variability between items in questionnaire; thus, a two-dimension correspondence map that provided in figure 3.9.

Table 3.4 Degree of I4.0 practices row profile

Company	Level 1	Level 2	Level 3	Level 4	Level 5
C1	0.000	0.000	0.417	0.250	0.333
C2	0.083	0.083	0.417	0.250	0.167
C3R1	0.250	0.167	0.250	0.333	0.000
C4	0.000	0.250	0.167	0.333	0.250
C5	0.000	0.500	0.000	0.250	0.250
C6R1	0.250	0.083	0.417	0.250	0.000
C6R2	0.250	0.417	0.000	0.333	0.000
C7	0.167	0.167	0.250	0.083	0.333
C8	0.417	0.500	0.000	0.083	0.000
C9	0.000	0.250	0.250	0.250	0.250
C11	0.333	0.083	0.083	0.417	0.083
C13	0.333	0.083	0.083	0.250	0.250
C3R2	0.250	0.167	0.333	0.083	0.167
C14	0.500	0.083	0.000	0.250	0.167
C15	0.000	0.167	0.167	0.667	0.000
C3R3	0.417	0.417	0.167	0.000	0.000
C16	0.417	0.250	0.167	0.083	0.083
C17R1	0.250	0.583	0.167	0.000	0.000
C18	0.167	0.167	0.167	0.417	0.083
C19	0.167	0.833	0.000	0.000	0.000
C20	0.583	0.167	0.167	0.000	0.083
C21	0.167	0.583	0.083	0.167	0.000
C22	0.500	0.333	0.083	0.000	0.083
C24	0.333	0.417	0.167	0.000	0.083
C25	0.250	0.500	0.250	0.000	0.000
C26	0.000	0.667	0.333	0.000	0.000
C27	0.333	0.250	0.167	0.083	0.167
C28	0.333	0.417	0.083	0.167	0.000
C30	0.833	0.000	0.000	0.167	0.000
C31	0.333	0.333	0.083	0.167	0.083
C32	0.500	0.333	0.083	0.083	0.000
C34	0.167	0.167	0.167	0.417	0.083
C35	0.917	0.000	0.083	0.000	0.000
C17R2	0.500	0.500	0.000	0.000	0.000
C37	0.417	0.167	0.333	0.000	0.083
C38	0.083	0.250	0.417	0.167	0.083
C39	0.083	0.167	0.167	0.167	0.417
C40	0.167	0.333	0.083	0.167	0.250
C41	0.417	0.083	0.333	0.167	0.000

In reference to the I4.0 practices questionnaire in ANNEX I**,** the corporations that answered 3 to the questions, occasionally adopted I4.0 practices that would be enough to name them high I4.0 benefits. Thus, the companies with level 3 or more were grouped as high I4.0 benefits; others were low I4.0 benefits.

Table 3.5 Inertia and Chi-Square Decomposition

Dimension	Singular Value	Inertia	Chi-Square	Percentage	Cumulative Percentage	Histogram
1	0.5224	0.2729	127.6962	40.7449	40.7449	*************
2	0.4256	0.1811	84.7537	27.0429	67.7879	*********
3	0.3491	0.1219	57.0449	18.2017	85.9896	******
4	0.3063	0.0938	43.9091	14.0104	100.0000	*****
TOTAL		0.6697	313.404			

The correspondence map contains the vertices that show the extreme profiles related to each column. For example, level 5 vertex shows the position to which all responses are level 5. The blue vertices show the position of the companies based on their level in I4.0 practices for example vertex C1 shows the position of company number 1. Hence, the vertex (belonging to each company) that is close to level 5 shows that the company has level 5 in implementing lean tools.

As the companies that have level 3 and more implement I4.0 practices in high-level, the companies that are located in the big green circle around levels 3, 4, and 5 are high I4.0 benefits. Those that exist in the circles around levels 2 and 1 are low I4.0 benefits. The companies number 35 and 30 (C35and C30) that located in top left and companies number 19 and 26 (C19 and C26) that are in down left are low I4.0 benefits.

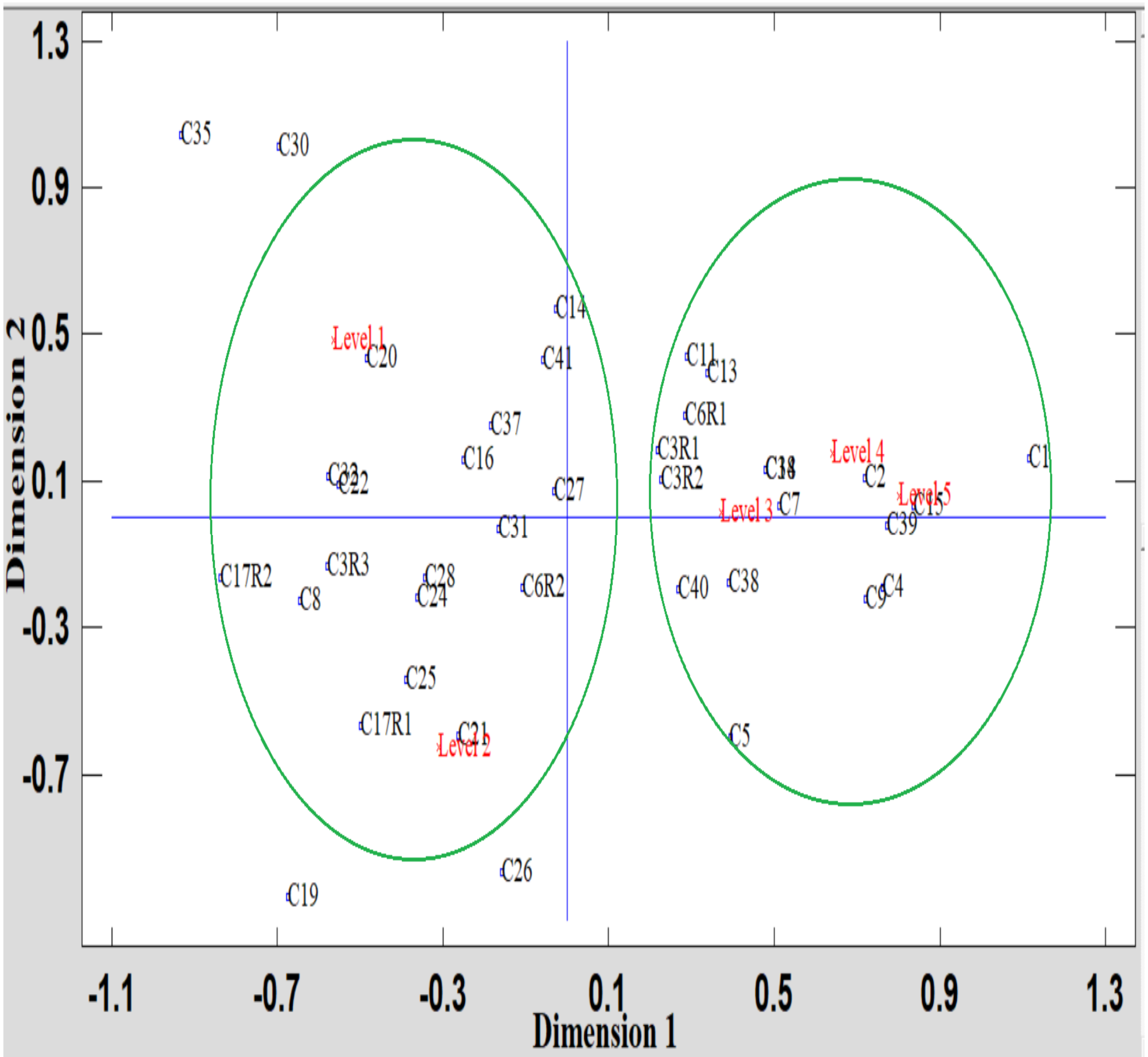

Figure 3-9 The degree of I4.0 practices correspondence map

Based on the graphical presentation in the correspondence map the companies are classified to two groups in the following table. The companies that labeled High in the following table are high I4.0 benefits, the others that labeled Low are low I4.0 benefits. Finally, 17 respondents implement I4.0 practices in advanced level and 22 are low I4.0 benefits. These two groups have been used to determine the tendency to I4.0 practices and implementation and introduction barriers.

Table 3.6 The level of adopting Industry 4.0 practices

Company	The level of I4.0 practices	Company	The level of I4.0 practices	Company	The level of I4.0 practices	Company	The level of I4.0 practices	Company	The level of I4.0 practices
C1	High	C2	High	C3R1	High	C4	High	C5	High
C6R1	High	C6R2	Low	C7	High	C8	Low	C9	High
C11	High	C13	High	C3R2	High	C14	Low	C15	High
C3R3	Low	C16	Low	C17R1	Low	C18	High	C19	Low
C20	Low	C21	Low	C22	Low	C24	Low	C25	Low
C26	Low	C27	Low	C28	Low	C30	Low	C31	Low
C32	Low	C34	High	C35	Low	C17R2	Low	C37	Low
C38	High	C39	High	C40	High	C41	Low		

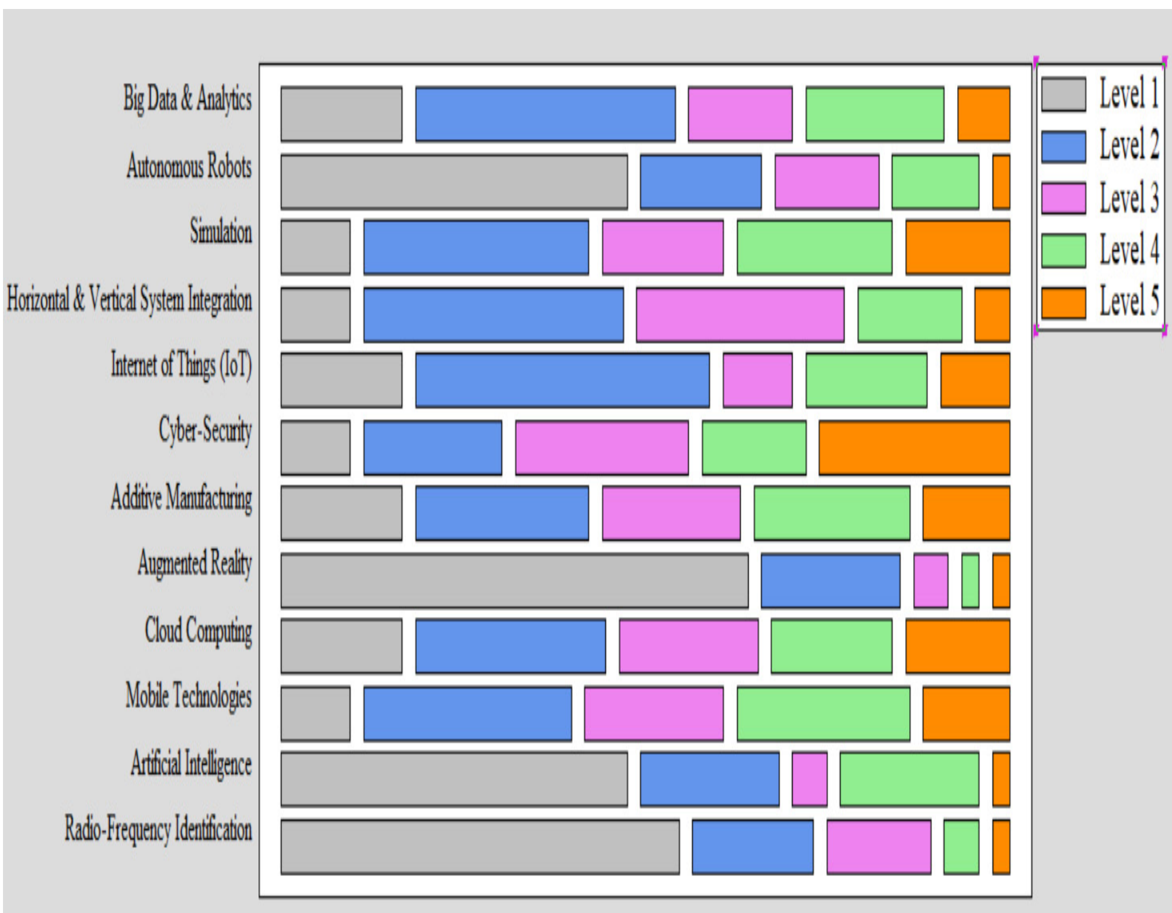

Figure 3-10 The degree of I4.0 practices mosaic plot

Gathered data from I4.0 questionnaire can be used to determine which I4.0 technology is more prevalent among lean mature aerospace manufacturing companies in Canada. For this reason, a mosaic plot in figure 3.10 is illustrated. The mosaic plot takes every row in contingency tables and draws bars where the length of each level in row is proportional to the number of answers to that level for each technology. For example, most companies devoted level 1 to augmented reality and the lowest answer to level 5 so, this practice is not popular among companies. As a result, cyber security, mobile technology, additive manufacturing, and simulation are the most popular technologies in aerospace industry.

3.3 Tendency to Industry 4.0

The first question of the research is determining the tendency to the fourth industrial revolution in the Canadian aerospace industry. The desire is to determine to what extend lean mature companies are interested in I4.0. For this reason, the second questionnaire in ANNEX I was used and the results were provided separately in two groups, based on the degree of I4.0 practices.

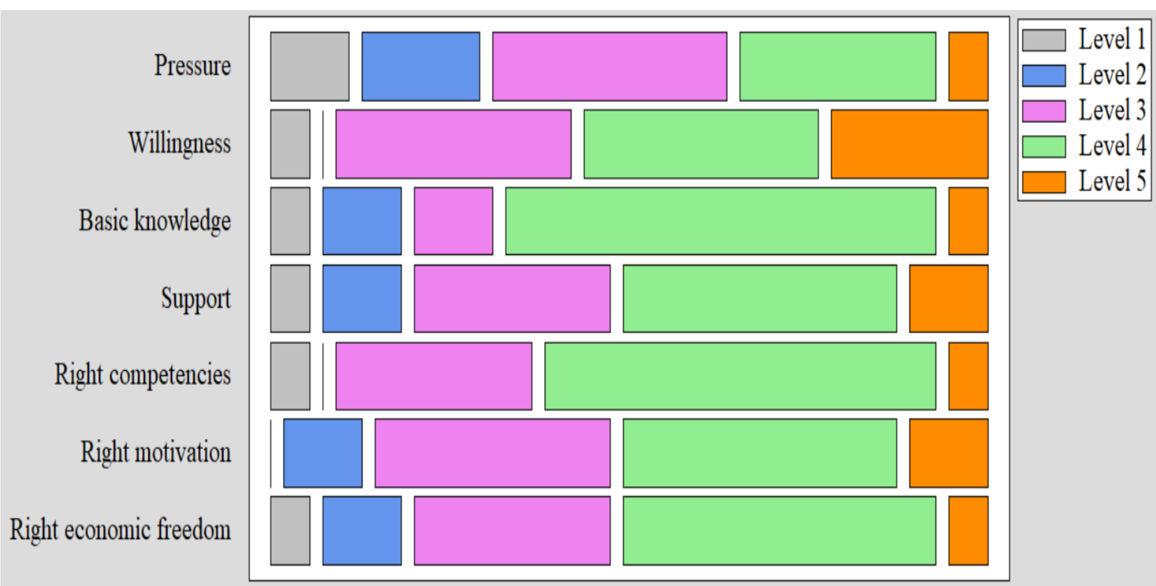

Figure 3-11 Tendency to I4.0 mosaic plot (High I4.0 benefits)

The mosaic plot has the best interpretation for this data. The same as the previous mosaic plots, the length of each level in row is proportional to the number of the answers to that level for tendency factors. Figure 3.11 and figure 3.12 clearly visualize that tendency is higher in high I4.0 benefits, compared to low I4.0 benefits in the aerospace sector because high I4.0 benefits devoted most of the answers to level 4 and 5 in all 7 factors while low I4.0 benefits devoted the most of the answers to level 1, 2, 3.

There are Willingness and right competencies among employees of high I4.0 benefits to work with and adopt I4.0 practices and there is the basic knowledge to judge the value of I4.0.

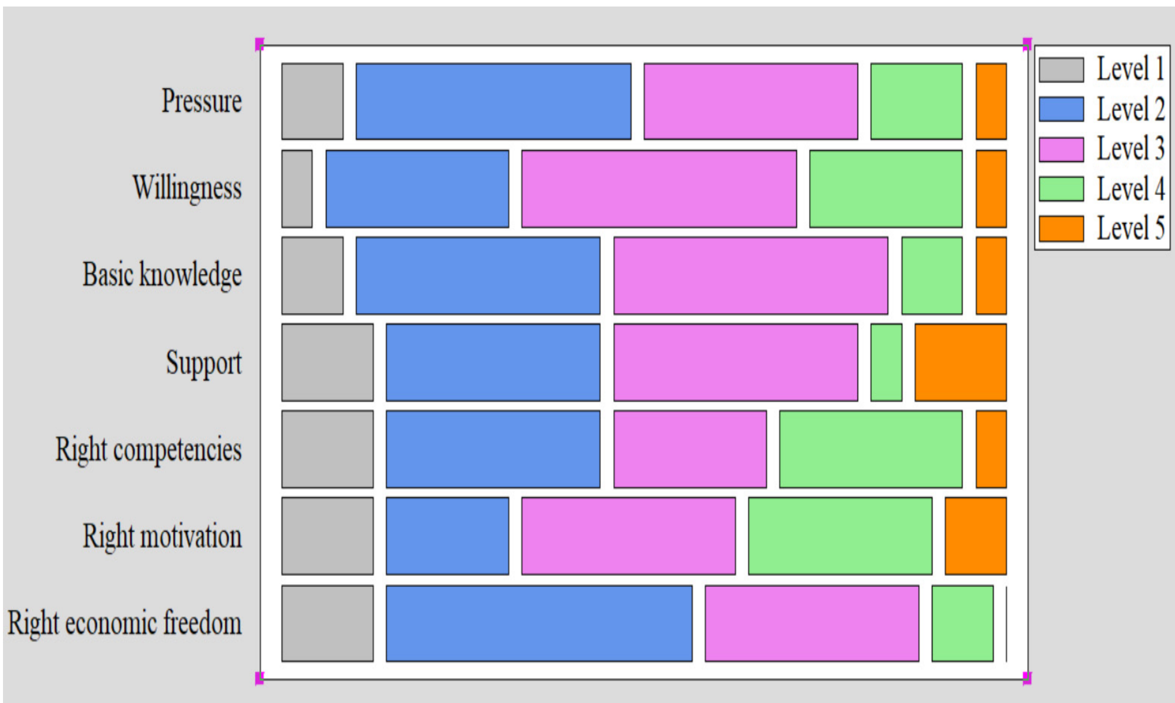

Figure 3-12 Tendency to I4.0 mosaic plot (Low I4.0 benefits)

In low I4.0 benefits, Willingness and Motivation are top-level factors. They believe there is the willingness to take risks to implement I4.0 among their managers and policymakers, also, employees have the right motivation to judge and work with I4.0.

3.4 Introduction Barriers

In reference to the second research questions, the aim was to determine the barriers preventing companies from starting I4.0 practices. For this reason, the barriers in the third questionnaire in ANNEX I that were bold with low I4.0 benefits, were considered introduction barriers.

Table 3.7 Introduction barriers row profile

Company	I4.0 barriers	Level 1	Level 2	Level 3	Level 4	Level 5
B1	Employment disruption	0.273	0.318	0.364	0.045	0.000
B2	Lack of knowledge	0.136	0.182	0.273	0.273	0.136
B3	Continued education	0.000	0.318	0.409	0.182	0.091
B4	Lack of train	0.045	0.273	0.273	0.273	0.136
B5	Employee resistance	0.045	0.273	0.318	0.318	0.045
B6	Lack of top management support	0.136	0.227	0.500	0.136	0.000
B7	Organizational and process changes	0.091	0.182	0.364	0.273	0.091
B8	High implementation costs	0.045	0.136	0.273	0.273	0.273
B9	Lack of clear understanding of benefits	0.182	0.136	0.364	0.091	0.227
B10	Time constraint	0.045	0.182	0.455	0.273	0.045
B11	Lack of database management systems	0.091	0.318	0.273	0.136	0.182
B12	Infrastructure	0.136	0.364	0.227	0.182	0.091
B13	Lack of standard and reference architecture	0.091	0.227	0.227	0.273	0.182
B14	Security issues	0.091	0.364	0.227	0.273	0.045
B15	Problem of coordination and collaboration	0.091	0.364	0.364	0.045	0.136
B16	Seamless Integration and Compatibility Issues	0.091	0.318	0.364	0.136	0.091
B17	Lack of digital strategy	0.182	0.273	0.227	0.227	0.091
B18	Inadequate maintenance	0.045	0.500	0.227	0.227	0.000
B19	Lack of government support	0.000	0.364	0.318	0.227	0.091
B20	Lack of methodical approach	0.045	0.318	0.364	0.136	0.136
B21	Lack of experience in project management	0.091	0.273	0.182	0.273	0.182
B22	Lack of risk management tools	0.091	0.227	0.273	0.182	0.227
B23	Legal and Contractual uncertainty	0.227	0.227	0.409	0.091	0.045
B24	Poor research and development	0.136	0.273	0.455	0.091	0.045
B25	Fear of Failure	0.227	0.455	0.227	0.045	0.045

In order to interpret results, correspondence analysis has been implemented the same as LESAT data. Table 3.7 has a row profile that illustrates the percentage of the responses to each level. For example, barrier number 1 (B1) devoted 27.3% of the answers to level 1, 31.8% to level 2, 36.4% to level 3, 4% to level 4, and no answer to level 5.

In order to have a better graphical presentation of the data, the mosaic plot is provided in figure 3.13. The interpretation of the mosaic plot is the same as the previous one. As visible in the following figure, respectively, “High implementation costs (B8)”, “Lack of standard and reference architecture (B13)”, “Lack of experience in project management (B21)”, “Lack of risk management tools (B22)” are labeled significant with low I4.0 benefits. These are the popular challenges companies face to start applying I4.0 practice. The aforementioned challenges were chosen because the most responses were devoted to levels 5 and 4.

Figure 3-13 Introduction barriers mosaic plot 1 for lean mature companies

Employment disruption (B1), Lack of top management support (B6), and Fear of Failure (B25) are less important barriers in low I4.0 benefits point of view because most of the answers to them were level 1, 2, and 3.

3.5 Implementation Barriers

The last question of the research was concerned with the barriers during I4.0 adoption. In order to find these challenges, the responses received from high I4.0 benefits to the third questionnaire in ANNEX I were analyzed via correspondence analysis in Statgraphic 18. The barriers which have high degree in this group are implementation barriers. Table 3.8 shows the distribution of the responses to each barrier separately.

Table 3.8 Implementation barriers row profile

Company	Barriers	Level 1	Level 2	Level 3	Level 4	Level 5
B1	Employment disruption	0.118	0.294	0.471	0.118	0.000
B2	Lack of knowledge	0.176	0.235	0.294	0.235	0.059
B3	Continued education	0.118	0.353	0.235	0.294	0.000
B4	Lack of train	0.059	0.176	0.412	0.235	0.118
B5	Employee resistance	0.353	0.235	0.235	0.176	0.000
B6	Lack of top management support	0.471	0.412	0.059	0.000	0.059
B7	Organizational and process changes	0.059	0.235	0.412	0.294	0.000
B8	High implementation costs	0.059	0.176	0.294	0.294	0.176
B9	Lack of clear understanding of benefits	0.294	0.235	0.176	0.176	0.118
B10	Time constraint	0.118	0.176	0.176	0.412	0.118
B11	Lack of database management systems	0.118	0.529	0.235	0.059	0.059
B12	Infrastructure	0.412	0.235	0.294	0.000	0.059
B13	Lack of standard and reference architecture.	0.235	0.235	0.294	0.235	0.000
B14	Security issues	0.118	0.412	0.353	0.118	0.000
B15	Problem of coordination and collaboration	0.294	0.353	0.294	0.059	0.000
B16	Seamless Integration and Compatibility Issues	0.235	0.235	0.235	0.235	0.059
B17	Lack of digital strategy	0.294	0.353	0.000	0.176	0.176
B18	Inadequate maintenance	0.294	0.412	0.118	0.176	0.000
B19	Lack of government support	0.294	0.118	0.235	0.294	0.059
B20	Lack of methodical approach	0.235	0.059	0.294	0.412	0.000
B21	Lack of experience in project management	0.235	0.059	0.412	0.294	0.000
B22	Lack of risk management tools	0.176	0.176	0.353	0.294	0.000
B23	Legal and Contractual uncertainty	0.294	0.235	0.118	0.294	0.059
B24	Poor research and development	0.235	0.235	0.412	0.118	0.000
B25	Fear of Failure	0.118	0.471	0.235	0.118	0.059

The mosaic plot in figure 3.14 has a graphical presentation for barriers. Obtained data regarding implementation barriers showed that "High implementation costs (B8)", "Time constraint (B10)", and "Lack of digital strategy (B17)" are sequentially the most common barriers in high I4.0 benefits in Canada.

Figure 3-14 Implementation barriers mosaic plot 1 for lean mature companies

Lack of top management support (B6), IT infrastructure and Internet cover (B12), and Problem of coordination and collaboration (B15) are less important challenges mentioned by high I4.0 benefits.

Although, the figures 3.13 and 3.14 clarified that low I4.0 benefits experience more challenges in adopting I4.0 practices in comparison with high I4.0 benefits but, the figures 3.15 and 3.16 present the difference between two groups in more precise manner. Figure 3.15 presents the responses received from low I4.0 benefits (Introduction barriers). The answers from high I4.0 benefits (Implementation barriers) are illustrated in figure 3.16. These plots present the whole responses that devoted to each level. In fact, the length of the row for each level is representative of the number of responses to that level. For example, in figure 3.16 fewer responses belong to levels 5 and 1 also, levels 2 and 3 have the most share.

Figure 3-15 Introduction barriers mosaic plot 2 for lean mature companies

Level 5 has a small share in both groups, but high I4.0 benefits have a smaller amount, which means high I4.0 benefits face less significant barriers. Levels 4, 3, and 2 are almost identical in two groups. The significant share for level 1 in high I4.0 benefits means that most of the barriers provided by researcher are not significant in this group. Although the borders between implementation and introduction barriers are narrow, the plots support that high I4.0 benefits have declared more minor problems in applying I4.0 practices, compared to low I4.0 benefits.

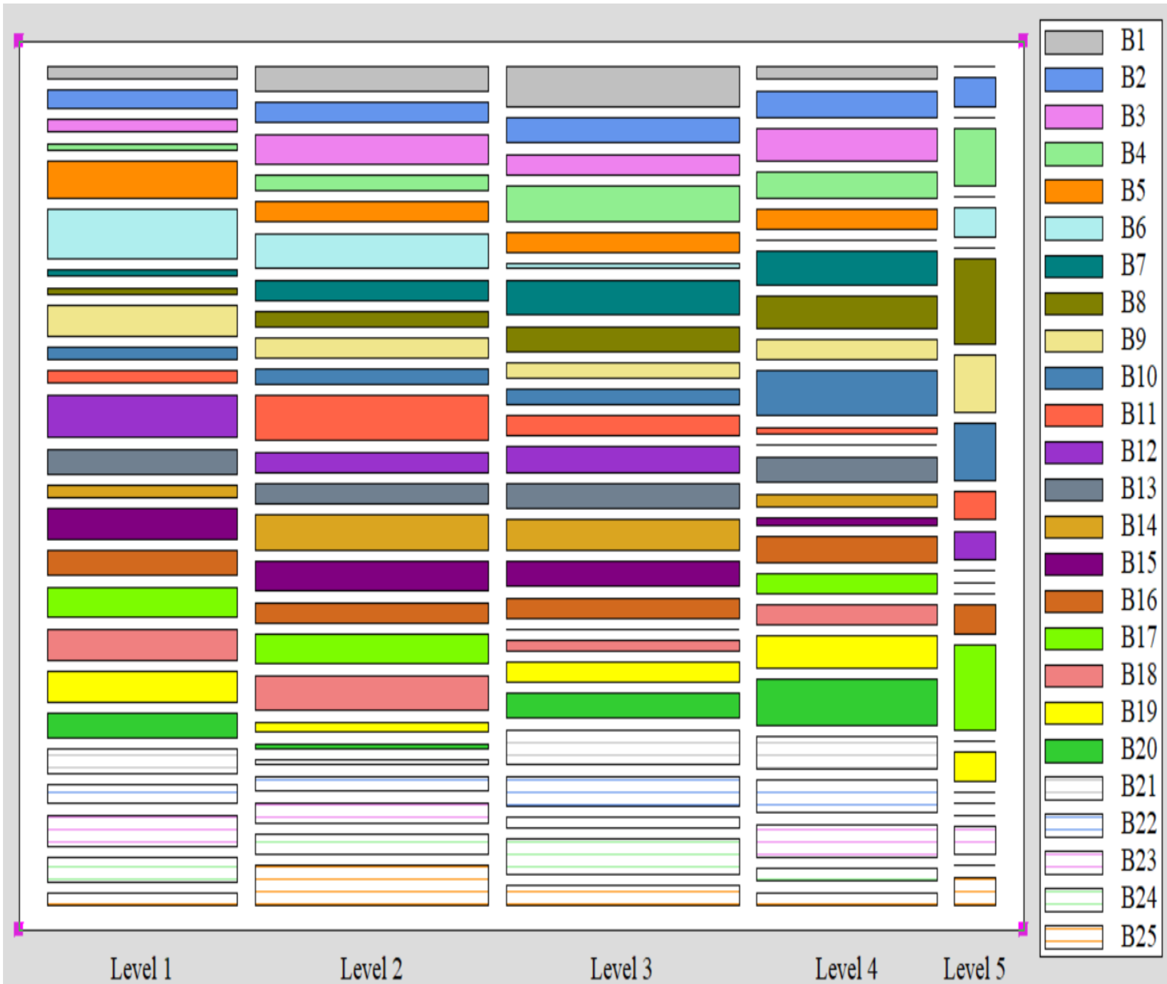

Figure 3-16 Implementation barriers mosaic plot 2 for lean mature companies

3.6 The level of Industry 4.0 and Tendency to Industry 4.0 in Non-lean companies

The third hypothesis of the study mentioned that non-lean companies are not ready for I4.0 practices. In order to examine this idea candidate used correspondence analysis to determine the level of I4.0 practices in 6 non-lean companies. As shown in Inertia and chi-Square decomposition two first dimensions present 96.3% of the variability of the items in the questionnaire. Hence a two-dimensional correspondence map is provided as the graphical presentation in figure 3.17. As shown just company numbers 12 and 33 have an acceptable level (Level 3 and more) in implementing I4.0 practices, others have a very low level.

Table 3.9 Inertia and Chi-Square Decomposition

	Singular		Chi-		Cumulative	
Dimension	Value	Inertia	Square	Percentage	Percentage	Histogram
1	0.8010	0.6416	46.1964	71.9250	71.9250	******************
2	0.4666	0.2177	15.6763	24.4070	96.3320	********
3	0.1723	0.0297	2.1385	3.3295	99.6616	*
4	0.0549	0.0030	0.2174	0.3384	100.0000	*
TOTAL		0.8921	64.228			

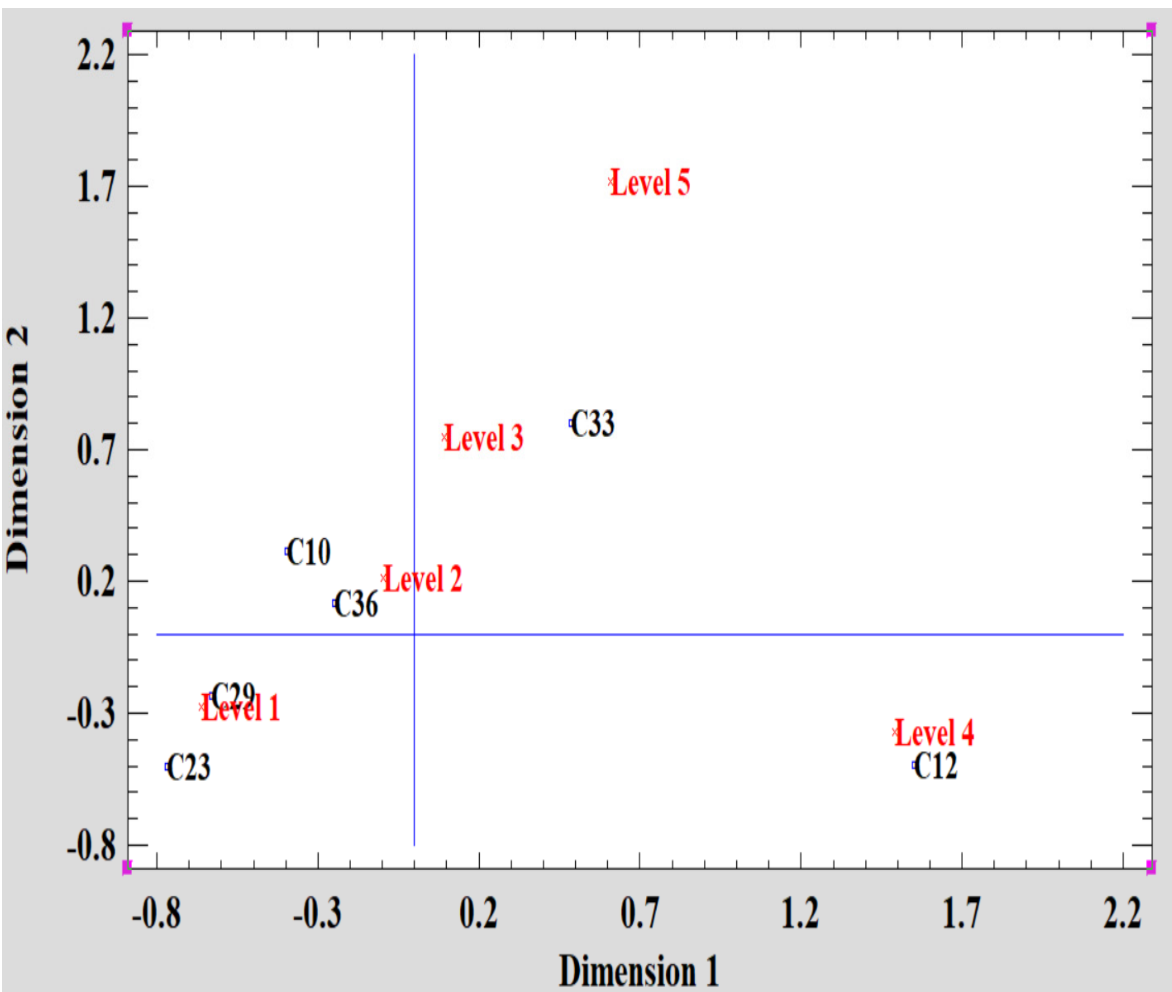

Figure 3-17 The degree of I4.0 correspondence map in Non-Lean companies

Also, based on figure 3.18, the tendency to I4.0 practices is extremely low and most of the companies devoted levels 1 and 2 to tendency factors and even there is no level 5.

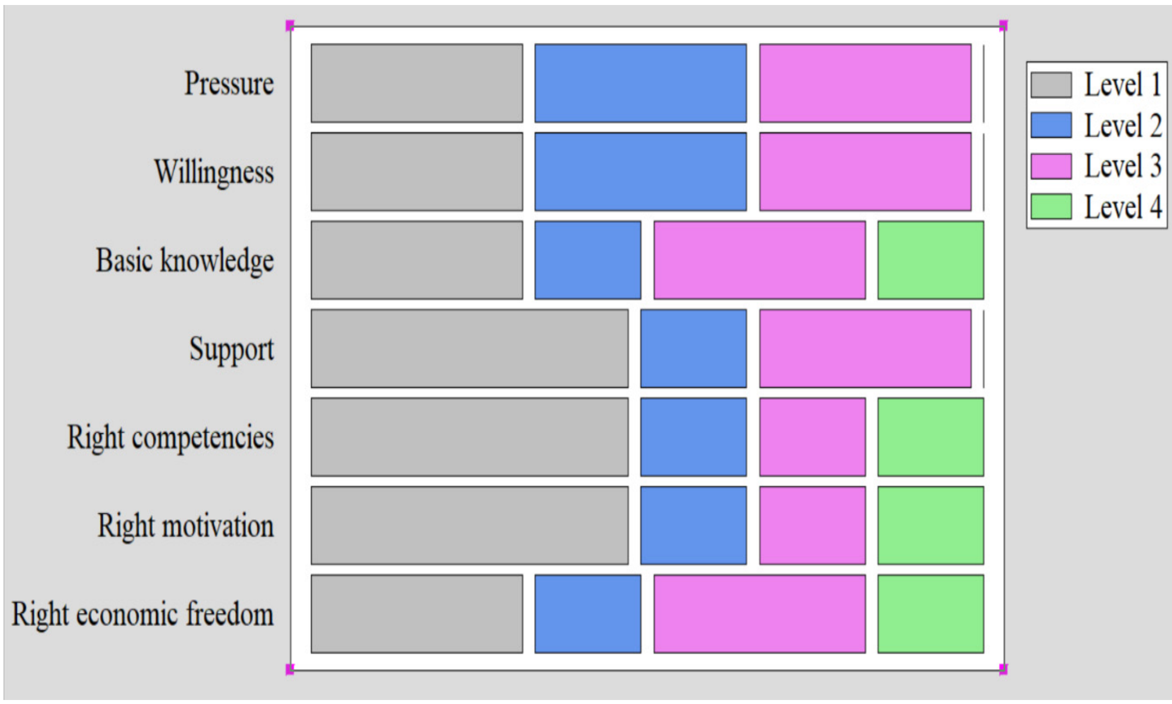

Figure 3-18 Tendency to I4.0 mosaic plot in Non-Lean companies

CHAPTER 4

DISCUSSION

In this chapter, the findings of this research are discussed. The present study has brought out new insights towards lean practices. It has also examined the tendency and the main obstacles of digital technologies adoption. 95% of the respondents asked to receive the study results. Almost all aerospace manufacturing companies (86%) implement high degree of lean practices. Advanced level in adopting lean practices was expected before initiating this study because LM is a prevalent methodology in Canada. Regarding I4.0 practices, less than half of the aerospace manufacturing companies adopt these technologies in high level. Hence this sector is in medium readiness and has a lot to do to ultimately join the fourth industrial revolution and the managers should pay more attention to the benefits of the new technologies. They can improve the productivity and efficiency of the products and achieve more flexibility by implementing the mentioned technologies.

Cyber security was the most popular I4.0 practice in the aerospace industry. Business owners understand that protecting industrial data is essential because of the increased connectivity and similar protocols in adopting new technologies. Mobile technology was another popular technology. The reason behind the popularity seems to be the number of features available via mobile technology, such as improved plant operational effectiveness, higher efficiency and productivity of staff, and improved field data collection process. Additive manufacturing was also prevalent because of the ability to produce 3D complex objects precisely.

In reference to the first research question, the tendency to I4.0 adoption is high in this sector especially in high I4.0 benefits which supports the first hypothesis of the research. There are willingness and motivation to adopt I4.0 practices and in total high I4.0 showed more tendency. The reason behind this situation comes from the power of the challenges in this way. So, there is a long way to go in this field and the overwhelming effort is crucial. Narrowing down the challenges is possible by developing an enhanced understanding of I4.0 practices. Then, transparent cost-benefit analysis and clear comprehension of benefits will convince the managers and policymakers to implement I4.0 practices.

The second research question concerned significant I4.0 barriers in low I4.0 benefits. High implementation costs, Lack of standard and reference architecture, Lack of experience in project management, and Lack of risk management tools are significant introduction barriers. Although the digitalization process received many financial resources, high implementation cost is still the most significant challenge because initiating new technologies requires a huge investment. The other barriers come from inefficient management system in these companies because they feel lack of standard and reference architecture to help managers and software developers to collaborate and communicate effectively in the implementation process. Also, they suffer from inadequate experience in project management and risk management tools.

Low I4.0 benefits considered Employment disruption, Lack of top management support, and Fear of failure as less important barriers. These companies felt that implementing new technologies does not disrupt the normal employment process and there is enough support from managers and policymakers to implement these technologies. Furthermore, they are sure about the success of implementing new technology. The obtained results in this section have a meaningful similarity to the results in the tendency section.

The last question of the research aimed to explore I4.0 barriers in high I4.0 benefits. They still have financial difficulties in adopting I4.0 practices. Another bolded barrier was inadequate digital strategy to adopt I4.0 by high I4.0 benefits. In order to justify the mentioned challenges, the candidate believes I4.0 is an emerging methodology that is growing gradually and new details are being released frequently, so even high I4.0 benefits have to make a considerable investment and time on these technologies frequently. Also, they need a new differentiating digital strategy and most of them still have problems with initiating it. Initiating a new strategy requires fundamental changes, which are costly and interrupt the routine process. As IT infrastructure is not one of the major issues, the costs are just related to the alteration in the manufacturing process. Hopefully, these companies have top management support and there is no problem in coordination and collaboration that can help them to establish the new digital strategy. In total both company groups suffer from some barriers and the number of significant introduction barriers is more than implementation barriers also, the severity of the barriers is more in low I4.0 benefits compared to high I4.0 benefits. It supports the second hypothesis of the research.

Based on the results in section 3.6 non-lean companies are not ready for I4.0 practices. The analysis shows that just two non-lean companies (33% of companies) implement I4.0 principles at an acceptable level while 43% of lean mature companies are high I4.0 benefits. Furthermore, the tendency to I4.0 practices in non-lean companies is significantly lower compared to lean mature companies that support the third hypothesis of the study.

Several researchers have used the study questionnaires before, so the questionnaires have acceptable validity by default. But some changes have been made to adjust the questions with the special needs of this study and the candidate must check the validity based on the new situation. In order to validate the questionnaires and find out whether it implies the intended purpose of the study, two Ph.D. students and an expert in question structure reviewed the questions. The first student was familiar with lean technique and had 3 years of experience as a lean expert. The second person was professional in some I4.0 principles, such as Cyber-Physical-service, IoTS, and artificial intelligence. Also, an expert in question construction was asked to review the questionnaires to find common errors, such as leading, confusing or double-barreled questions. Some changes were made according to their opinions and in the final step of validation, the questionnaires were corrected by the supervisor.

Although the validity of the questionnaires is acceptable, the validity of the research is not high. Validity of the research means the extent to which the study presents accurate results in the population under investigation. There are two reasons which reduce the validity of the research. First of all, this survey was conducted during Covid-19 pandemic that disturbs normal life and has a significant tangible influence on industries worldwide. For the time being, there is a high level of uncertainty about the economy of the country and the world. So, the respondents may have been affected by the current situation. Secondly, as mentioned in the sampling section, the candidate ignored sample selection and the respondents who filled up the survey were considered as the statistical sample. So, there is sample bias and the samples may not be a good representative of the statistical population because, there is the possibility that the respondents that answered the survey are more representative of those interested in lean and I4.0, thus the opinion of respondents less interested in lean and I4.0 may be underrepresented in the results.

The small sample size is one of the limitations of this study because the method of gathering data was an online survey and the response rate is low in this method. Also, the small sample size led to limited access to the data and the candidate as a student didn't have the option to encourage the samples and gather more data. As the survey link was posted on some LinkedIn groups, and the email addresses were extracted from LinkedIn, respondents with biases may have selected themselves into the sample. Time constraints is another limitation of this study because this is a master thesis and the candidate couldn't devote more time to gather more data. Finally, in section 3.2, two first dimensions just present 67.78% of the variability of the items in I4.0 practices questionnaire that is not enough to present most the variability between items. Most of the researchers believe the number of dimensions that present at least 70% of the differences is better to be selected. Finally, The candidate didn't ask the respondence about the barriers beyond the list of 25 provided barriers.

The key opportunity for future research is using the same formula in investigating I4.0 barriers in other sectors, such as automotive, oil, and gas because there are many similarities between these sectors. Also, in the absence of available scientific references in the literature to justify the selection of given lean practices, the results of this research could provide guidance to the future researchers about the selection of key lean practices associated with barriers to I4.0 implementation. The research results have provided the opportunity to compare the situation of the I4.0 technologies, I4.0 barriers, and the tendency to I4.0 between lean and non-lean companies. Furthermore, the same methodology could determine the enablers to adopt I4.0 practices in the aerospace industry.

The study will act as a handy tool to introduce significant barriers to adopt I4.0 practices, hence future investigators could utilize the results to help aerospace manufacturing companies to narrow down these barriers and join the fourth industrial revolution

CONCLUSION

This study was a descriptive qualitative study done by a four-questionnaire survey. The survey was sent via email and some forms in companies' websites to the statistical population (256 companies) and 45 responses were received that has the response rate of 17.5%. the study investigated I4.0 barriers and the tendency to I4.0 practices among lean mature aerospace manufacturing companies in Canada.

Almost all aerospace manufacturing companies adopt lean practices in acceptable degree. The companies classified to high I4.0 benefits and low I4.0 benefits based on their level in adopting I4.0 practices. Less than half of the statistical population are high I4.0 benefits (17 companies) and others are low I4.0 benefits (22 companies).

The tendency to I4.0 practices is high in this sector especially in high I4.0 benefits compared to Low I4.0 benefits. The challenges that low I4.0 benefits labeled as significant are introduction barriers and the obstacles that high I4.0 benefits declared significant are implementation barriers. The number and the severity of introduction barriers are more than implementation barriers.

In conclusion, the candidate believes that the main challenges in adopting I4.0 practices are uncertainty about the performance of the new technologies and lack of understanding about the benefits. Obviously, adopting new approaches requires overwhelming effort, time, and money, and it takes a good dose of courage, but it is worth considering due to massive returns. Business owners must be convinced that being current is essential in this competitive market and the future of the market belongs to high I4.0 benefits.

ANNEX I

Conference on Industrial Engineering 2020

The Relationship between Lean and Industry 4.0: Literature Review

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Abstract

Some companies adopt a new manufacturing revolution called industry 4.0 and a number of them are lean companies. Industry 4.0 helps companies be more flexible and could respond to the market change easier. Also, it increases product quality and profitability. A growing number of scientists investigated the influence of integration lean and industry 4.0 over the past years. Thus, this paper identifies major gaps for association linking lean and industry 4.0. To execute the research, 35 papers have been reviewed and a classification scheme for them was developed. In order to make the relationship between lean and industry 4.0 transparent, this paper provides a quantitative and qualitative analysis. The quantitative analysis shows in 2 figures also, the result of the qualitative analysis is presented in 3 separate sections titled as follows: 1. Lean is a basis for industry 4.0, 2. Interaction industry 4.0 and lean and, 3. Industry 4.0 completes lean.

Keywords: Industry 4.0, Lean production, Lean manufacturing, Lean management, Integration lean and industry 4.0

1. Introduction

Before 1908, the only methodology for producing cars was craft production (James P Womack et al., 2007), in this method all parts of the cars were assembled by one person. As there wasn't a defined standard, the components were not interchangeable. Henry Ford introduced mass production in 1908 by model T, it was a revolutionized methodology and vital changes have been happened in the automobile industry, since then the production speed increased dramatically. Ford succeed to increase demand through reducing the cost per car from $800 to $200, so car became affordable to common family. Ford Company had the largest share of the market in the automotive industry for around 45 years via adopting mass production until Toyota Company emerged its Toyota production systems. Taiichi ohno and Eiji Toyoda traveled to ford company to learn mass production methodology. They determined mass production is unadoptable in Japan because Toyota couldn't afford the expensive mass production facilities like in the US and Toyota could not afford to maintain high inventory. In the meanwhile, Ohno and Toyoda found out mass production is full of waste, so they utilized Ford's ideas and focused on reducing waste and low-cost automation, finally, they introduced Toyota production systems. Toyota succeeded to increase profitability through removing wastes in the production process from the customer's order and supply chain to the final delivery of the product to the customer. Toyota production systems acted as a competitive advantage in Toyota cooperation and it could become the market leader in this gigantic industry. Toyota production systems called lean by John Krafcik in his article titled Triumph of the Lean Production System in 1988.

The first industrial revolution happened in the 18th century when water power and steam power were utilized in the industrial process, it is called mechanization. The second one is identified by using electricity in the production process, this facilitates mass production in order to respond to the accelerating population growth after the world war II (Blanchet, Rinn, Von Thaden, & De Thieulloy, 2014). The third industrial revolution was automation through entrance programming and robotic arms in the mechanical process (Zhou, Liu, & Zhou).

Industry 4.0 (I4.0) is the fourth industrial revolution and was proposed for the first time at Hanover University in 2011 by the German government in cooperation with Universities and

Companies. The summary of the characteristics of the industrial revolutions is illustrated in Figure 1. There are similar methods to I4.0 in other countries for example, Industrial internet in the United States and Internet+ in China. Industrial internet and industry 4.0 have a considerable overlap but there are some changes too (Boyes et al., 2018). The main characteristics of I4.0 are connected machines, smart products and systems, and interrelated solutions (Guilherme Luz Tortorella & Fettermann, 2017). In implementing I4.0 some aspects like the computers and digital components integrate together for monitor and control physical devices (Ashton, 2009). I4.0 is a strategic plan and it aims to enhance productivity and efficiency through developing advanced production system (Frank et al., 2019). Big changes happened in consequence of implementing I4.0 in the organizations, for instance, companies become more flexible in time and space.

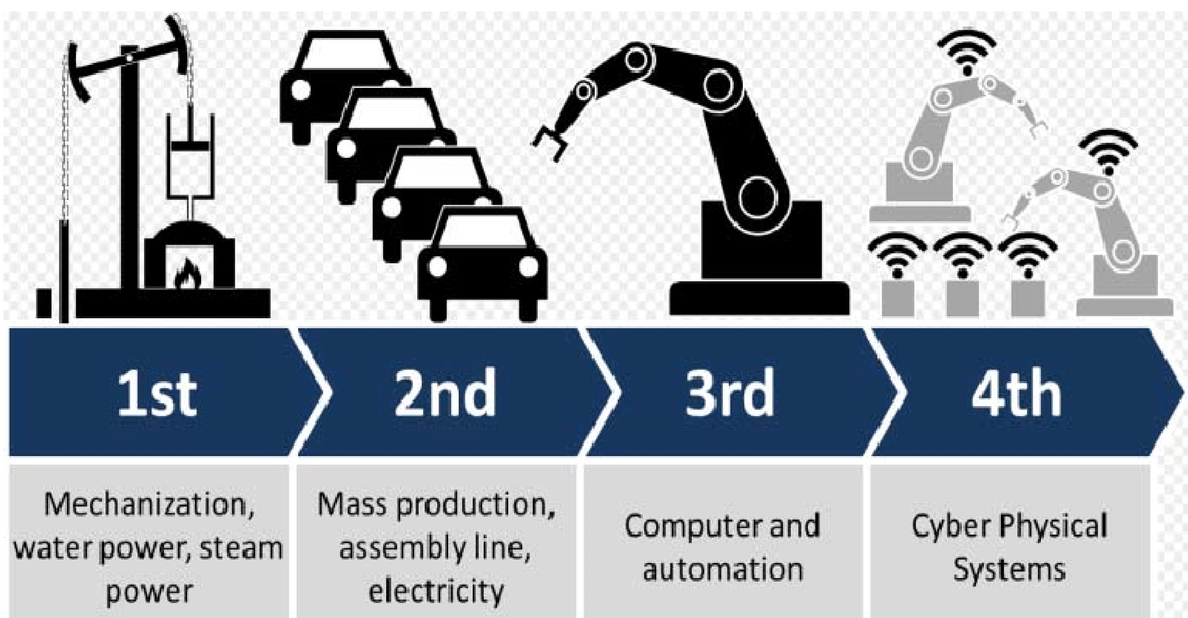

Figure-A I-1 Summary of characteristics of the industrial revolutions
Taken from Chute and French (2019)

Also, workflow is expected to become more transparent, decentralized and less hierarchical (Sanders et al., 2016). Additionally, digitalization is a risk and in some countries workers are the most defenseless group (Segal, 2018). The key objective of I4.0 is to drive manufacturing to be more effective, customer-oriented and faster. It is an enhancement in digitalization and automation manufacturing environment, moreover, it creates strong communication between products, machines and business partners through a digital value chain (Şenkayas & Gürsoy, 2018).

This paper carries out a literature review with a view to identifying the relationship between lean and I4.0 and the influence on each other. Several companies integrate lean and I4.0 to reach higher quality and reduce costs. This paper considers the influence of this integration in different industrial sections when both methods are implemented completely.

2. Literature review

2.1 Lean

Since introducing lean for the first time, scientists published a huge number of articles in this field and investigators agree on the positive impact of lean on production performance although, there was no unanimous definition of lean between them. Lean can be adopted in all sections of the company (Hines, Holwe, & Rich, 2004) and most companies prefer to start implementing lean from shop floor (Shah & Ward, 2007).

The main objective of lean is to make continuous improvement and reduce cost through eliminating wastes (non-value-added activity) and increasing process efficiency. Lean introduced several tools like 5S, Just in time, Jidoka, Heijunka, Kaizen, etc. Lean is a competitive advantage and is considered as one of the key methods in increasing profitability (Garre et al., 2017) and customer value. Lean concept is, do the most with least (Ozkeser, 2018), to achieve high performance with fewer resource.

Krijnen (2007) introduced seven original wastes of lean. They are inventory, waiting, defects, overproduction, motion, transportation, and over-processing. When Toyota production system was adopted in Europe, the workers' non-utilized talents and skills were introduced as the 8th waste of lean.

Figure-A I-2 Seven types of wastes

The raw materials and work in process that maintained, identified as the inventory. Waiting occurs when a worker can't proceed to the next task in a process, it means doing nothing or acting slowly whilst waiting for the previous step in the manufacturing line.

Also, defects happen when products deviate from what is the customer's demand. Overproduction means producing more than what's actually needed which is the worst waste. Motion happens when there is an unnecessary moving during the manufacturing process. Transportation is to transport products in order to continue manufacturing process between different sections of the factory. Finally, over-processing is each action that does not add value to the customer.

Lean companies use five general principles to remove wastes, Shah and Ward (2007) introduced these principles as follows:

"defining the value from the customer perspective, mapping the value stream process to achieve the predefined value, creating the flow along the value chain, establishing pull system and pursuing perfection..."

Also, James P Womack and Jones (1997) described the summary of these principles as follows:

“Precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let the customer pull value from the producer, and pursue perfection...”

Managers can utilize the benefits of lean by understanding lean principles completely and implementing them precisely.

Lean production contributes in improving operational performance in developed and developing countries (Shah & Ward, 2003). There are numbers of companies adopting lean production, most of them could improve their efficiency, whilst some companies failed in adopting lean successfully in consequence of misunderstanding of how lean principles work (Shah & Ward, 2007). Implementing successfully need prerequisites as Lewis (2000) mentioned context is vital in adopting lean successfully. Hence, alterations in internal and external scenarios are the most common cause in lean production failure (Rossini et al., 2019). Moreover, the characteristic of different regions and industries contribute in implementing lean (Marodin, Frank, Tortorella, & Fetterman, 2019). Different industrial sections implement lean production (Martinez-Jurado & Moyano-Fuentes, 2014) (James P. Womack & Jones, 2015). It is a complex task and companies face a huge number of barriers during the process and the brilliant result couldn’t be achieved in the first attempt (Martinez-Jurado & Moyano-Fuentes, 2014) (Scherrer-Rathje, Boyle, & Deflorin, 2009), in fact, lean production is not a one night process.

2.1 Industry 4.0

I4.0 introduces a system that makes intelligent decisions automatically based on analysis of data (Ahuett-Garza & Kurfess, 2018). It is different from current systems in which only a computer controls automated facility.

Hermann, Pentek, and Otto defined I4.0 as follows:

“Industrie 4.0 is a collective term for technologies and concepts of value chain organisation. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IOS, both internal and cross-organizational services are offered and utilized by participants of the value chain…”

I4.0 contains four key components: Cyber physical systems (CPS), Internet of things (IoT), Internet of services (IoS) and smart factory (Hermann, Pentek, & Otto, 2016). CPS elevates machines to a higher level and gives them intelligence and automation also, it is integration computations with intelligent physical processes like computers. Physical processes and computations affect each other with the feedback loop. Machines can diagnose defects by sensors and report it to the operator on the smartwatch also, activate the process for solving the problem by actuators automatically. The smart factory is in the center of I4.0 and it helps organizations to handle complexity and unexpected interrupts. IoT and IoS attempt to create a smart environment through connecting products, machines, and workers in the factory (Sanders et al., 2016). A large amount of data is gathered and shared with other devices by IoT through cloud computing and the system utilizes the collected and stored data for analyzing the process (Arcidiacono & Pieroni, 2018).

Six design principles for I4.0 are introduced that support companies to increase automation, reduce manufacturing costs and increase profitability, these principles are: interoperability, real-time capability, virtualization, modularity, decentralization, and service orientation (Hermann et al., 2016). Scurati et al. (2018) believes that the key objectives of I4.0 are expanding digitalization in manufacturing environment and increasing automation in order to create close communication between products, manufacturing environment and business partners.

3. Methodology

It is essential to do full investigation of the resources to reach the research goals. This paper concentrates on articles dealing with lean and industry 4.0 in terms of the relationship and influence on each other when two methods are implemented completely. So, candidates used the *Google Scholar search engine and ÉTS bibliothèque that were connected to databases like* Science Direct, IEEE Xplore, Emerald, and Springer *to find relevant literature.* Candidates searched the following keywords to prepare the research in *titles.*

- 'Lean' and 'Industry 4.0'
- 'Lean organization' and 'Industry 4.0'
- 'Lean production' and 'Industry 4.0'
- 'Lean manufacturing' and 'Industry 4.0'
- 'Lean six sigma' and 'Industry 4.0'
- 'Lean automation' and 'Industry 4.0'
- 'Lean management' and 'Industry 4.0'

As I4.0 is still in its infancy, the result of this process was only 35 articles published between the years 2015 and 2019. Candidates have examined each article to ensure that the content is pertinent to the perspective of the goals of current research. Finally, 22 papers have been chosen that their contribution is a relationship between lean and I4.0 and their influence on each other when the two methods are implemented completely. In terms of quantitative analysis, the following items are selected: nationality of authors, kind of paper and year published. Also, the results for qualitative analysis are presented in 3 Tables based on different opinions about the relationship between lean and I4.0.

4. Results

The target of the article is to review the literatures related to integrating lean and I4.0. In consequence, 35 papers from different sections have been reviewed and finally, the candidates have chosen 22 papers for analysis. Quantitative analysis shows scientists paid attention to this context since 2015 (1 Article) and the most articles published in 2018 (9 Articles), it shows a dramatic increase in this context over the past years. The most dominant nationality of the scientists is Germany (40%), followed by Italy and Portugal (12%). Also, 80% of the articles are published by European scientists. The articles have been selected from different kinds of paper publishing centers, 64% conference articles, and 36% journal articles. The results of the quantitative analysis are illustrated in two charts in figure 3.

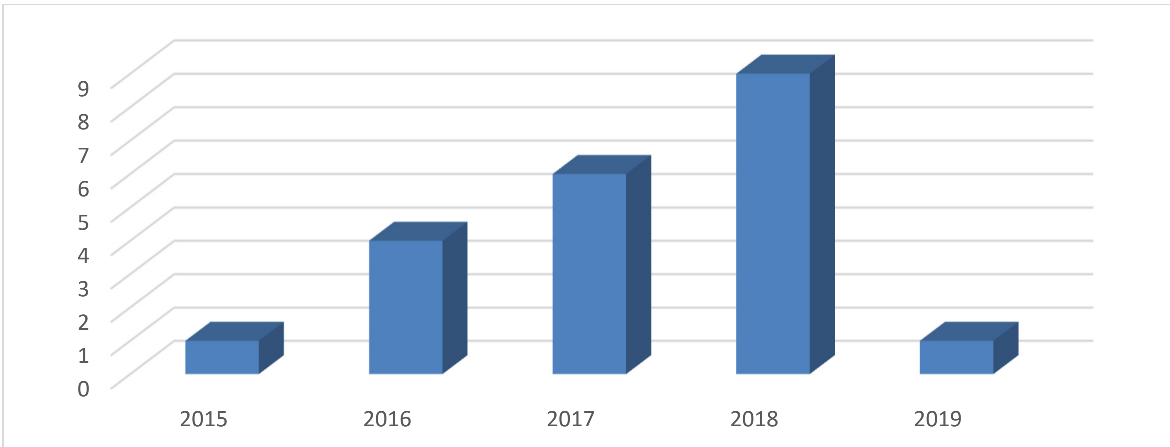

Figure-A I-3 The number of articles published each year

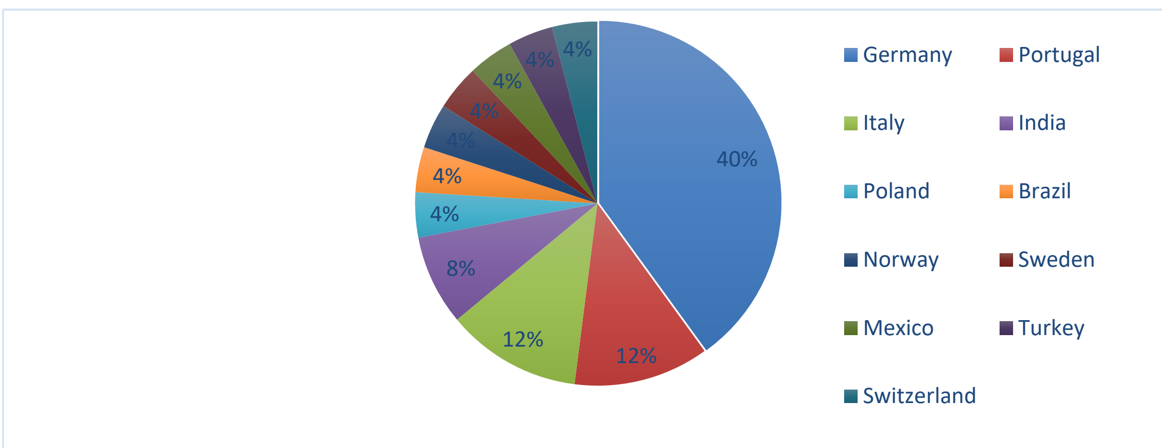

Figure-A I-4 The number of articles published in each country

The qualitative analysis illustrates that there are different ways that lean and I4.0 influence each other. The various opinions are classified into 3 separate sections:

- Lean acts as a basis for industry 4.0.
- Industry 4.0 and lean interact with each other.
- Industry 4.0 completes lean and increases lean efficiency.

4.1 Lean is a basis for industry 4.0

As it is illustrated in Table 1, 4 articles stated, lean acts as a basis for I4.0. Guilherme Luz Tortorella and Fettermann (2017) mentioned that the combination of two methods elevates the profitability and the company's background is vital for lean production, meanwhile the authors have confirmed that the companies with low experience (less than 2 years) in the lean production field have no extensive association between lean production and I4.0. Although surprisingly, the authors have founded companies poorly associate lean production, and I4.0 show a high level of performance; also, the size of the company is not vital in adopting them.

Guilherme Luz Tortorella and Fettermann (2017) and Rossini et al. (2019) concluded the chance for implementing I4.0 is higher in companies adopting lean production enormously. Leyh, Martin, and Schäffer (2017) classified 31 I4.0 models and stated, lean management and lean production are the basis for I4.0 although, it is not addressed in I4.0 models. Information and communication technology are the most important factor in the environment that the integration of lean production and I4.0 occurs. Furthermore, Rossini et al. (2019) emphasized the importance of lean production and continuous improvement in adopting new methodologies like I4.0 and Uwe Dombrowski and Richter (2018) confirmed the aforementioned statements; meanwhile, they mentioned lean acts as a basis and prerequisite for I4.0. The authors introduced lean production framework 4.0 (LPS 4.0) by the combination of LPS and I4.0.

4.2 Interaction industry 4.0 and lean

Sanders et al. (2017) believed interaction between I4.0 and lean causes synergies and helps them to adopt precisely. The current investigation found 5 papers that confirm this issue. Mayr et al. (2018) explored whether lean management and I4.0 can support each other or not. In consequence of this article, the terms Just in time 4.0 (JIT 4.0), Just in sequence 4.0 (JIS 4.0) Heijunka 4.0, etc have been introduced. The authors believed these two methods can support each other on a conceptual level and I4.0 supports lean methods in a condensed way.

The influence of I4.0 and lean manufacturing on sustainability has been explored by Varela, Araujo, Avila, Castro, and Putnik (2019) according to 252 valid answers to the survey applied in industrial companies located in Portugal and Spain. The article has had three main achievements:

- The authors emphasized, there is a correlation between I4.0 and environmental sustainability (High), social sustainability (Medium) and economic sustainability (Low).
- The correlation between I4.0 and lean manufacturing has been observed dramatically
- Len manufacturing has no influence on sustainability.

Satoglu et al. (2018) believed I4.0 and lean manufacturing are not mutually exclusive and need to be integrated also, I4.0 can solve the problems that exist in adopting lean manufacturing. The relationship between I4.0 and lean manufacturing is vital for the quality and reliability of products. Additionally, there is a high level of synergies between them. U. Dombrowski et al. (2017) concluded high dependencies between cloud computing, avoidance of waste, zero defect, and big data. The data analysis has been showed that horizontal integration doesn't have a high impact on LPS principles. The summary of the results for this section are listed in Table 2.

4.3 Industry 4.0 completes lean

The number of articles in which the authors have believed I4.0 completes lean and solves the challenges related to implementation lean is 13. The overview of the results is indicated in Table 3. Mrugalska and Wyrwicka (2017) explored the influence of smart products and machines on continuous improvement. The authors believed they decrease the time between failure occurrence and failure notification via smartwatches (Smart operation) (Mrugalska & Wyrwicka, 2017) (Kolberg & Zuhlke, 2015), meanwhile, actuators activate the process for solving the problem automatically. Also, Kolberg and Zuhlke (2015) asserted smart products make Kaizen less labour-intensive and more precise because data is gathered per product individually for value stream mapping.

Wagner et al. (2017) focused on the combination of CPS and JIT (Cyber-physical just in time) and they claimed it has a positive impact on transparency and minimizes working space. Furthermore, Sanders et al. (2016) mentioned, lean and I4.0 have a positive correlation, besides, implementation of I4.0 helps companies to overcome challenges in the way of lean. Moreover, Axelsson, Fröberg, and Eriksson (2018) believed I4.0 improves quality via reducing wastes and improving communication and coordination.

Butollo, Jürgens, and Krzywdzinski (2019) looked at the relationship between lean and I4.0 via different vision, in fact, the authors investigated the autonomy in the work process. Results showed that I4.0 provides solution for increasing demand for changing schedule and companies won't be employee-oriented also, the results clearly emphasized on the positive impact of these methods on greater task rotation and decreasing the bargaining power of the workers. Meanwhile, D'antonio and Chiabert (2018) asserted I4.0 reduces the number of employees on the shop floor because it increases the ability of the operators via physical and cognitive interaction with the machine.

One worth pursuing influence of I4.0 and lean is on the supply chain, Susana Duarte and V Cruz-Machado (2017) and Susana Duarte and Virgilio Cruz-Machado (2017) stated that I4.0 improves supply chain, makes it smart and more flexible through smart data that provides a high level of data sharing for green supply chain and lean. Totally, the authors claimed I4.0 improves the influence of lean method in supply chain.

Rüttimann and Stöckli (2016) have contrasting opinions, assumed I4.0 is on the top of the cake, makes lean faster, smoother and more accurate in manufacturing companies although, they believed lean transformation has better results in comparison with implementing I4.0 and I4.0 won't be a revolution. Jayaram (2016) focused on globalizing supply chain via creating heavy communication between companies. He claimed lean six sigma removes unnecessory process and the result of the implementing I4.0 would be faster and more efficient supply chain.

Beifert, Gerlitz, and Prause (2017) paid attention to the shortcomings in lean manufacturing in shipbuilding and the solutions that I4.0 presents. The authors have asserted lean principles are inadequate for shipbuilding because of the high market volatility and transaction costs and I4.0

provides the solutions. Powell, Romero, Gaiardelli, Cimini, and Cavalieri (2018) investigated how I4.0 supports key lean manufacturing constructs in an Italian company in the automotive sector. They have stated that I4.0 could coordinate supply chain and support Just-in-time (JIT) also, Heijunka becomes more realizable and it is optimized through big data and real-time remote visibility.

5. Discussion

The results of this article are 3 different points of view about the combination of two methods. Most of the reviewed articles have confirmed I4.0 completes lean, make lean stronger and more efficient. On the one hand, scientists acknowledge integration has positive impact on the value of the product, customer satisfaction, and competitiveness. On the other hand, they are unanimous about the way that two methods influence each other. There are several frameworks and models for integration but there are still issues that are considered as unsolved or inadequately addressed. In consequence, future researches are needed to reach a common understanding.

This literature review has two limitations: first, there is subjective bias in selection of articles and review of them. For the objectives of the paper only scientific articles have been chosen and the commercial publications have been ignored. Second, in some articles, the results have been described qualitatively. It is strict to extract the outcome of integration lean and I4.0 base of qualitative analysis.

Candidates have selected papers when lean and industry 4.0 are adopted completely, but some organizations can't implement two methods entirely because of the implementation barriers. Furthermore, in some cases, managers prefer to implement only some principles of lean and industry 4.0 due to the unsuitability of the principles in special industry. It is clear that results of *amalgamation of two methodologies* are different in this situation, it could be considered as future research. Also, the current paper has investigated pieces of literature in all types of industries and the results may be various in some special industries. This circumstance is suggested for future investigation too.

6. Conclusion

Lean could finish the dominance of mass production in the automotive section and its being spread to other industries quickly. Lean considers any activity which does not add value to the product as waste and remove them from manufacturing process to reduce the costs. I4.0 optimizes the computerization of the third industrial revolution and it makes manufacturing process smarter, more effective and productive. Most authors confirm that the integration of lean and I4.0 has positive impacts on companies though, there is no similar opinion about the way that the two approaches influence each other. In this paper the review of the literature about lean and I4.0 was presented to illustrate the whole vision of different possibilities in linking two methods.

Table-A I-1 Lean is basis for industry 4.0

Reference	Contribution	Factors	Results
(Guilherme Luz Tortorella & Fettermann, 2017)	-The influence of implementing I4.0 on lean production according to operational performance improvement and the size of the company.	-Time of implementing lean production -Frequency -Adjusted residual	-High level lean production companies have more chance in implementing I4.0 in emerging economies. -Combining lean production with I4.0 elevates the profit. -Company background is vital in adopting lean production.
(Leyh et al., 2017)	-The relationship between lean production and 31 I4.0 classified models.	-Communication between Man-Man, Machine-Man Machine-Machine	-Information and communication technology are vital factors in the integration of lean production and industry 4.0 environments. -Lean management and lean production principles are the basis for I4.0.
(Rossini et al., 2019)	-Investigation of the relationship between I4.0 and lean production in 108 lean European companies that start to adopt I4.0.	-Augment reality -Cloud computing -Integrated engineering system	-Adopting emergent methodologies are lower in companies in which lean production and continuous improvement are not established and are designed weakly. -I4.0 and lean production are correlated strongly.
(Uwe Dombrowski & Richter, 2018)	-Combining I4.0 and LPS in consequence, creates LPS 4.0.	-LPS 4.0 -Data management provision of information/data	-Lean build the biases for the adoption of I4.0. -I4.0 should be integrated with LPS to enhance LPS. -LPS is a prerequisite for I4.0.

Table-A I-2 Interaction industry 4.0 and lean

Reference	Contribution	Factors	Results
(U. Dombrowski et al., 2017)	-Different type of industry 4.0 elements have been organized to technologies, systems, and process-related characteristics.	-Cloud computing and -Big data -Horizontal and vertical Integration	-Higher dependencies between: 1. cloud computing and avoidance of waste and LPS principles. 2. Zero defect and big data.
(Mayr et al., 2018)	-How I4.0 can support lean methods.	-Just in sequence 4.0 -Heijunka 4.0, Kanban 4.0, VSM 4.0, and JIT 4.0	-LM and I4.0 support each other. -I4.0 tools can support the analyzed lean methods in a condensed way.
(Varela et al., 2019)	-The influence of I4.0 and lean manufacturing on sustainability have been measured qualitatively biased on 252 valid answer to the survey.	-Environmental, Social and Economic sustainability	-Correlation between I4.0 and environmental, social and economic sustainability. -There is no relation between lean manufacturing and sustainability.
(Satoglu et al., 2018)	-How I4.0 and automation innovative technology support implementation of LM.	-Additive manufacturing -Augmented reality -Simulation and virtualization -Overproduction and Inventory	-LM and I4.0 are not mutually exclusive and should be integrated. -The I4.0 tools can provide solution to difficulties related to lean manufacturing like mismanagement and weakly-organized manufacturing systems. -Implementing lean manufacturing and I4.0 results in saving data correctly.
(Sanders et al., 2017)	-Exploring the interaction between lean management and I4.0.	-TPM -Takt time -SMED -VSM standardization	-The most support to the lean tools has been received from real time, decentralized and interoperability. -Numerous synergies between lean management tools and I4.0 principles. -Lean management tools are the prerequisite for I4.0.

Table-A I-3 Industry 4.0 completes lean

Reference	Contribution	Factors	Results
(Mrugalska & Wyrwicka, 2017)	-Smart products and machines impact on Kaizen. -Augmented operator impact on Jidoka through recognizing the fault automatically.	-Kaizen -Kanban -Jidoka	-Pave the way of lean in terms of Kaizen. -Give better operational intelligence -Drop the time between failure notification and failure occurrence.
(Wagner et al., 2017)	-Impact CPS on JIT (Cyber physical just in time) material process.	-CPS -Big data analytic -Kanban card	-Increase transparency and stability of lean production. -Eliminate the shop floor. -Minimize the warehouse space.
(Sanders et al., 2016)	-The gap between realms of lean and I4.0. -Analysis of the barriers for lean implementation due to the lack of resources.	-Smart factory -Non-value added -Challenge to implement lean -Dimension of lean	-I4.0 makes factory lean beside being smart. -The positive correlation between lean and I4.0. -Companies could overcome challenges for lean implementation through adopting I4.0.
(Jayaram, 2016)	-Globalizing the supply chain through communication between components of an industry.	-global supply chain -Production monitoring -Industrial IoT	-Lean six sigma eliminates unnecessary process and defects. -I4.0 and IIoT make systematic management of the supply chain more efficient and faster.
(Axelsson et al., 2018)	-Outlined system of systems concept for improving productivity in road construction via lean and I4.0.	-Reference Architecture Model for Industry 4.0 (RAMI 4.0) -Hierarchical decomposition	-Improve the coordination of working machines. -Improve quality through reducing wastes and improve communication and coordination.
(Butollo et al., 2019)	-Analyzing the autonomy in the work process in organizations that apply lean and I4.0.	-Autonomy - Interdependencies -Task rotation -Employee-oriented	-Close linked value chain and industry structures are prerequisites for higher quality. -I4.0 and lean have a positive impact on greater task rotation. -New methods decrease the bargaining power of the workers.
(Susana Duarte & V Cruz-Machado, 2017)	-How I4.0 is combined with lean and green supply chain -The influence of I4.0 on lean and green supply chain.	-IoT -Smart data -Smart supplier -Smart logistics	-I4.0 makes the supply chain more flexible with more visibility. -I4.0 evolves lean and supply chain. -The supply chain has been improved by IoT. -I4.0 develops close cooperation with suppliers.
(Kolberg & Zuhlke, 2015)	-Investigation influence of I4.0 principles in lean automation.	-Kaizen -Smart operator, product, machines, and planer	-I4.0 completes and supports lean. -I4.0 improves lean production. -Lean helps I4.0 to accelerate. -Smart products make Kaizen less labor-intensive.
(Rüttimann & Stöckli, 2016)	-How lean be considered in the context of I4.0 initiative.	-Smart factory -Big data and IoT -Virtual reality	-I4.0 makes lean more stable and accurate also makes it faster and smother. -I4.0 should integrate into lean but I4.0 won't be occurred as a revolution.
(D'antonio & Chiabert, 2018)	-The influence of I4.0 in non-utilized employee's talents that is caused by the separation between the management and the process operations in lean organizations.	-Operator 4.0 -Human CPS -Intelligent personal assistants -Social networks	-Reduces the number of employees in shop-floor. -Transfers shift of human job towards the non-routine task. -Increases the ability of the operator through physical and cognitive interaction with machines.
(Susana Duarte & Virgilio Cruz-Machado, 2017)	-A conceptual model that combines I4.0 in lean and green supply chain.	-Smart logistics -Smart products -Smart supplier -Smart operator -Smart manufacturing	-I4.0 improves lean. -I4.0 makes all concept of lean and supply chain smart. -Lean supports the installation of I4.0. -The green supply chain supports the implementation of the I4.0.
(Beifert et al., 2017)	-The way that I4.0 can deal with shortcoming sin lean manufacturing of the shipbuilding sector.	-Lean modeling and lean optimization tools -Potential cybercrime	-I4.0 solves the problems related to inadequate adoption lean and accelerate engagement of shipbuilding supplier. -I4.0 is a competitive advantage for SMEs and develops them in a smart approach.
(Powell et al., 2018)	-Investigation the potential of I4.0 to support key lean manufacturing constructs in an Italian company related to the automotive section.	-Just-in-time -Heijunka -Real time -Big data	- presents an approach to coordinate supply chain and supports just-in-time. -real time remote visibility optimizes elimination of wastes from overproduction.

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ANNEX II

Survey questionnaires

Section 1. General information

Table-A II-1 General information of the participants

Email adresse:	
What is your designation?	
What company do you work for?	
How many employees work at your company (Approximate)?	
Are you interested to receive the result of the study?	

Section 2. Industry 4.0

Section 2.1. The degree of implementing Industry4.0 (Stentoft et al., 2021)

To which degree do you apply the following technologies in your company? (On a five-point Likert scale: 1=Never, 2=Rarely, 3=Occasionally, 4=Often, and 5=Nearly always)

Table-A II-2 Industry 4.0 practices questionnaire

No		Rating				
		1	2	3	4	5
1	Big Data & Analytics.					
2	Autonomous Robots.					
3	Simulation.					
4	Horizontal & Vertical System Integration.					
5	Internet of Things (IoT) (including sensors).					
6	Cyber-Security.					
7	Additive Manufacturing (e.g. 3D print).					
8	Augmented Reality.					
9	Cloud Computing.					
10	Mobile Technologies.					
11	Artificial Intelligence.					
12	Radio-Frequency Identification (RFID)					

Section 2.2. Tendency to industry 4.0 (Stentoft et al., 2021)

To which degree do you agree to the following statements? (On a five-point Likert-Scale: 1=Very low degree, 2=Low degree, 3=Moderate degree, 4=High degree, and 5=Very high degree)

Table-A II-3 Tendency factors questionnaire

No		Rating				
		1	2	3	4	5
1	There is pressure to use Industry 4.0 in our company. (e.g. from customers, suppliers, authorities etc).					
2	There is the willingness to take risks to implement Industry 4.0.					
3	There is the basic knowledge to judge the value of Industry 4.0 for our company.					
4	Top management provides enough support to employees to judge and work with Industry 4.0.					
5	There are right competencies among our employees to work with Industry 4.0.					
6	Our employees have the right motivation to judge and work with Industry 4.0.					
7	Management department provides right economic freedom to work with Industry 4.0.					

Section 2.3. The barriers of implementing Industry4.0 (Stentoft et al., 2021) and (Majumdar et al., 2020)

Rate the following barriers on five-point Likert scale (1=Not significant, 2=Somewhat significant, 3=Significant, 4=Very significant and 5=Extremely significant)

Table-A II-4 Industry 4.0 barriers questionnaire

No		Rating				
		1	2	3	4	5
1	Employment disruption due to implementation of Industry 4.0.					
2	Lack of knowledge about Industry 4.0.					
3	Requires continued education of employees.					
4	Lack of trained staff.					
5	Employee resistance to change.					
6	Lack of top management support.					
7	Organizational and process changes for implementing Industry 4.0.					
8	High implementation cost of Industry 4.0.					
9	Lack of clear understanding of benefits of Industry 4.0.					
10	Time constraint.					
11	Lack of database management systems					
12	IT infrastructure and Internet cover.					
13	Lack of standard and reference architecture.					
14	Security issues (data and information related).					
15	Problem of coordination and collaboration.					
16	Seamless Integration and Compatibility Issues.					
17	Lack of digital strategy in organization.					
18	Inadequate maintenance support system.					
19	Lack of government support and policies for Industry 4.0.					
20	Lack of methodical approach for implementation of Industry 4.0.					
21	Lack of experience in project management and budgeting in Industry 4.0.					
22	Lack of risk management tools for investments in Industry 4.0.					
23	Legal and Contractual uncertainty.					
24	Poor research and development of Industry 4.0 adoption.					
25	Fear of Failure.					

Section 3. Lean maturity (Urban, 2015) & (Nightingale, 2001)

Please rate the following statements concerning shared values within your company on five-point Likert scale, (1=Never, 2=Rarely, 3=Occasionally, 4=Often, and 5=Nearly always)

Table-A II-5 LESAT questionnaire

No	Questions	Rating				
		1	2	3	4	5
1	Our company emphasizes the development of leaders who identify with the company's vision and rules.					
2	It is obvious that top managers are often found close to the value stream, and they serve there in problem solving.					
3	We believe that decisions should be forwarded to an operational level; employees are empowered to make decisions about issues related to their work.					
4	In our company we do not accept "pretend projects" that run without a full understanding of their meanings and without the conviction that they will bring good results.					
5	It is important for our company to improve all operations systematically, and all employees continuously work on discovering and eliminating waste processes.					
6	Our company curiously search for approaches to optimize the capability and utilization of assets.					
7	Top managers establish a requirements definition process to optimize lifecycle value.					
8	It is vital in our company to utilize customer value and downstream stakeholder value into design of products and processes.					
9	Our company defines and develops a supply chain network in order to shar knowledge throughout the supplier network.					
10	Our company has a system to enhance value of delivered products and services to customers and the enterprise.					
11	Managers provide the infrastructure that common tools and systems being used across our company.					
12	In our company the financial and accounting systems been integrated with non-traditional measures of value creation.					
13	Our human resource practices are reviewed to assure intellectual capital matches process needs.					
14	In our company enabling infrastructure processes are being aligned to value stream flow.					
15	Information technology system in our company compatible with stakeholder communication and analysis needs.					

ANNEX III

Raw data

Table-A III-1 The degree of implementing Industry4.0 data

Company	Big Data & Analytics	Autonomous Robots	Simulation	Horizontal & Vertical System Integration	IoT	Cyber-Security	Additive Manufacturing	Augmented Reality	Cloud cimputing	Mobile Technologies	AI	RFID
C1	5	4	4	3	3	5	5	5	3	3	4	3
C2	3	4	5	3	3	4	5	1	2	4	3	3
C3R1	2	4	3	4	4	3	4	1	2	3	1	1
C4	4	2	5	3	5	5	2	2	4	4	4	3
C5	2	5	5	4	2	4	4	2	2	2	5	2
C6R1	4	3	3	4	2	3	3	1	3	4	1	1
C6R2	2	1	2	4	2	4	4	1	2	4	2	1
C7	5	3	3	4	2	5	2	1	5	5	1	3
C8	2	1	4	2	2	2	1	1	2	2	1	1
C9	4	3	3	2	4	3	2	2	5	5	4	5
C10	1	1	3	2	2	3	3	1	1	3	1	1
C11	4	1	2	3	4	5	4	1	4	4	1	1
C12	3	4	4	4	4	4	4	4	4	4	4	2
C13	1	1	4	5	5	5	4	3	4	2	1	1
C3R2	3	1	3	2	4	3	3	1	5	5	2	1
C14	4	1	4	5	1	1	5	1	4	2	1	1
C15	4	4	4	2	3	3	2	4	4	4	4	4
C3R3	2	1	1	3	2	2	1	1	3	2	2	1
C16	2	1	1	3	4	2	3	1	2	5	1	1
C17R1	2	2	2	2	1	3	1	1	3	2	2	2
C18	4	4	2	3	5	4	2	1	3	4	4	1
C19	2	1	2	2	2	2	2	2	2	2	1	2
C20	1	2	5	3	2	1	3	1	1	1	1	1
C21	1	1	4	3	2	4	2	2	2	2	2	2
C22	2	3	2	2	1	5	1	1	1	2	1	1
C23	1	1	2	1	1	1	1	1	1	1	1	1
C24	2	3	2	2	3	5	1	1	2	2	1	1
C25	2	2	2	1	2	3	2	1	3	3	2	1
C26	2	2	2	3	2	3	3	2	2	3	2	2
C27	2	1	5	2	2	5	4	1	3	3	1	1
C28	3	1	2	2	2	4	2	1	2	4	1	1
C29	1	1	1	1	1	3	2	1	2	1	1	1
C30	1	1	1	1	1	1	4	1	1	4	1	1
C31	1	2	2	2	1	3	4	1	5	4	1	2
C32	1	1	4	2	2	2	3	1	1	2	1	1
C33	4	3	3	3	4	5	3	2	3	4	1	2
C34	4	1	4	4	4	5	3	2	4	1	2	3
C35	1	1	1	1	1	1	3	1	1	1	1	1
C17R2	2	2	2	1	2	2	1	1	1	2	1	1
C36	3	1	2	3	3	4	2	1	1	1	1	1
C37	3	1	3	3	2	5	2	1	1	1	3	1
C38	3	3	4	2	5	2	1	3	3	3	4	2
C39	5	1	5	2	4	5	5	2	5	3	4	3
C40	3	1	2	2	2	2	5	1	5	5	4	4
C41	2	1	3	3	1	3	4	1	4	3	1	1

Table-A III-2 Tendency factors data

Company	Pressure	Willingness	Basic knowledge	Support	Right competencies	Right motivation	Right economic freedom
C1	5	5	4	5	3	4	4
C2	2	4	4	4	4	3	4
C3R1	3	4	4	4	4	4	4
C4	1	1	4	2	4	4	2
C5	4	4	4	4	3	2	4
C6R1	4	3	3	3	4	3	2
C6R2	3	3	3	3	4	3	3
C7	3	5	5	5	5	5	5
C8	5	3	3	4	4	4	4
C9	3	3	2	3	3	3	3
C10	1	2	2	2	3	1	3
C11	2	3	4	4	4	3	3
C12	3	3	4	3	4	4	4
C13	1	5	1	1	1	2	1
C3R2	3	4	4	4	4	4	3
C14	3	4	5	5	5	5	4
C15	3	3	2	2	3	3	4
C3R3	1	1	2	1	4	3	2
C16	2	3	3	3	3	4	2
C17R1	2	3	2	2	2	3	2
C18	3	3	3	4	4	4	4
C19	4	4	4	5	4	4	3
C20	3	3	4	2	2	3	1
C21	3	2	3	2	3	3	2
C22	2	2	2	3	2	2	2
C23	1	1	1	1	1	1	1
C24	2	2	1	3	2	4	3
C25	2	2	2	1	3	3	2
C26	3	3	3	3	3	4	3
C27	2	4	3	5	4	4	3
C28	2	3	2	3	3	3	3
C29	2	1	1	1	1	1	1
C30	4	3	2	2	1	1	1
C31	3	4	3	2	2	2	2
C32	1	2	1	1	1	1	1
C33	3	2	3	1	1	2	2
C34	4	5	4	3	4	5	4
C35	2	3	3	2	2	2	2
C17R2	2	2	2	2	2	2	2
C36	2	3	3	3	2	3	3
C37	3	5	3	3	4	5	3
C38	2	3	4	3	3	3	3
C39	4	4	4	3	4	4	3
C40	4	4	4	4	4	4	4
C41	4	4	2	3	1	1	2

Table-A III-3 Industry 4.0 barriers data

Company	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23	B24	B25
C1	3	4	4	5	2	2	4	4	3	4	2	1	2	2	3	3	2	2	4	3	4	4	3	4	2
C2	2	1	2	2	2	1	2	3	1	4	3	3	4	3	1	3	1	2	1	1	1	2	1	2	2
C3R1	3	3	4	3	1	1	2	4	3	4	3	2	4	3	2	2	2	2	3	4	4	4	4	3	3
C4	2	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C5	4	4	4	4	4	2	4	3	2	4	3	3	4	4	4	4	4	4	4	4	4	4	4	2	4
C6R1	3	3	3	3	4	2	3	5	4	4	2	3	3	3	2	2	2	2	4	3	3	4	2	3	2
C6R2	3	2	3	4	4	2	3	3	3	4	2	3	2	4	3	3	1	2	4	2	2	2	3	2	2
C7	4	4	4	3	2	1	3	4	1	2	2	1	2	2	2	3	2	1	3	4	3	3	4	3	3
C8	1	2	2	2	2	1	2	3	1	2	3	3	3	3	3	2	2	2	3	3	2	2	3	3	3
C9	3	3	3	4	1	3	3	3	4	4	2	2	1	2	1	2	2	1	3	2	1	1	3	3	2
C10	4	5	3	4	1	2	3	2	5	5	4	3	3	2	2	2	3	2	2	2	3	3	3	4	1
C11	2	2	2	4	3	2	3	4	3	5	3	2	3	2	3	4	5	2	1	4	3	2	1	2	2
C12	4	4	5	5	4	2	3	3	5	4	4	4	4	4	4	4	5	2	3	3	2	5	4	5	4
C13	2	2	1	5	4	5	4	5	5	5	4	3	3	1	2	5	5	4	5	4	4	3	5	2	5
C3R2	1	3	2	3	1	1	3	3	2	2	2	2	2	3	2	2	2	2	4	3	3	3	2	3	2
C14	1	2	3	2	3	1	4	3	1	2	3	2	2	1	2	2	3	3	3	1	1	2	1	1	1
C15	3	2	3	3	3	1	4	3	2	4	2	1	2	3	3	4	4	4	4	4	3	3	4	4	4
C3R3	2	5	4	4	2	3	3	3	4	4	4	2	3	4	3	4	3	4	5	5	4	5	1	2	2
C16	2	4	2	2	2	2	4	5	3	4	2	3	4	2	2	2	4	2	2	2	3	2	2	3	3
C17R1	1	2	2	2	3	3	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2
C18	3	3	2	3	3	2	3	4	4	3	2	1	3	2	1	1	1	2	3	3	3	3	1	1	2
C19	1	1	2	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
C20	3	4	3	4	5	4	4	5	5	5	5	5	5	5	5	5	5	4	2	4	5	5	3	5	5
C21	3	4	3	3	4	3	3	4	4	4	2	2	3	4	2	2	3	2	3	3	4	3	3	2	2
C22	2	3	4	4	4	3	3	2	3	3	4	4	3	2	2	3	4	3	2	3	4	4	2	3	2
C23	1	5	2	2	5	3	1	1	5	3	3	5	5	4	4	2	4	4	4	4	5	5	5	5	4
C24	3	4	4	4	4	3	3	4	5	3	5	4	4	2	3	3	3	2	3	3	3	3	3	3	2
C25	1	4	3	4	3	4	2	4	5	4	4	4	5	3	3	4	4	4	4	5	5	3	5	4	3
C26	3	3	3	3	4	4	4	4	3	3	3	4	4	4	3	3	3	3	3	3	3	3	3	3	3
C27	4	1	2	2	2	3	4	5	3	3	2	1	2	3	2	3	1	2	2	3	3	4	2	2	1
C28	2	3	2	3	3	2	4	3	3	3	3	2	4	3	3	2	2	3	3	2	4	3	4	2	3
C29	2	4	2	4	5	5	5	3	5	1	4	4	4	4	4	4	5	4	5	5	5	5	1	5	5
C30	3	5	5	5	3	3	2	3	5	3	5	3	5	3	5	5	5	3	4	3	5	5	3	3	2
C31	2	3	3	3	3	3	3	4	2	3	1	2	4	2	2	3	1	2	3	4	4	4	4	4	2
C32	2	4	3	3	2	3	5	5	3	3	1	1	2	2	5	3	2	2	2	3	2	4	1	3	2
C33	5	5	4	5	5	4	4	5	5	5	3	2	4	2	4	3	3	3	2	2	4	4	3	3	1
C34	3	5	2	3	3	2	4	5	5	3	5	5	3	3	3	4	5	3	2	3	3	3	2	3	3
C35	3	3	3	5	4	2	3	5	5	3	3	2	4	4	3	3	4	4	4	2	2	3	3	3	2
C17R2	1	1	2	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	2	2	1	1	2	1	1
C36	2	3	3	3	4	3	3	4	3	4	2	4	3	4	4	4	4	4	4	4	4	4	3	3	3
C37	3	3	4	3	3	3	3	4	3	4	3	2	1	1	1	1	2	2	5	5	5	5	1	3	1
C38	1	2	2	2	2	2	3	2	2	2	2	3	4	4	3	3	4	3	1	4	4	4	4	3	3
C39	2	1	3	1	1	1	2	2	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1	1
C40	3	1	1	2	1	1	2	2	1	3	2	1	1	2	2	1	1	1	1	1	2	2	2	1	2
C41	2	5	5	5	4	3	5	5	2	3	5	5	5	4	4	4	4	4	4	4	4	5	3	3	4

Table-A III-4 LESAT data

Company	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13	Q 14	Q 15
C1	2	2	4	4	2	3	4	4	2	3	4	5	3	4	4
C2	5	4	4	4	4	5	4	4	4	5	4	5	5	5	3
C3R1	2	5	4	2	4	5	2	5	2	4	5	2	5	5	4
C4	5	5	4	5	5	5	5	5	5	5	5	4	5	5	5
C5	5	3	5	5	5	5	3	5	5	3	3	3	4	4	3
C6R1	4	4	4	5	4	3	3	4	4	4	4	3	5	3	4
C6R2	4	4	5	5	5	5	5	5	4	4	4	4	5	5	5
C7	5	5	5	5	5	5	5	5	3	4	5	5	5	5	5
C8	4	4	4	3	2	4	3	5	3	4	3	3	3	3	3
C9	4	5	5	4	5	5	5	5	3	5	5	5	5	4	5
C10	2	4	3	4	4	4	4	5	2	4	3	1	1	3	4
C11	4	4	4	4	3	4	3	4	4	5	5	3	3	2	2
C12	4	3	4	3	2	3	3	5	4	4	3	1	1	3	4
C13	4	4	4	2	4	5	5	3	4	4	4	4	4	4	4
C3R2	5	4	4	4	5	4	3	5	3	4	4	4	2	3	4
C14	5	5	4	5	5	5	4	4	4	5	5	3	4	4	5
C15	4	4	4	5	4	4	4	5	4	4	3	3	2	3	4
C3R3	4	3	5	2	5	4	3	5	2	4	4	1	5	2	4
C16	2	2	4	5	2	4	4	3	3	3	3	2	4	3	5
C17R1	3	4	4	3	3	4	3	4	3	4	3	3	3	3	3
C18	5	5	5	4	4	4	3	5	2	4	4	3	5	4	5
C19	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
C20	2	3	4	5	3	3	3	4	3	3	3	4	4	3	3
C21	4	4	4	4	3	2	2	4	3	3	4	2	4	3	2
C22	3	4	3	3	3	3	2	4	3	2	2	2	2	2	4
C23	3	4	4	3	4	2	2	3	2	1	4	4	1	2	1
C24	5	4	4	4	5	5	4	5	5	4	3	4	3	4	4
C25	4	5	5	4	3	4	3	5	4	5	4	3	4	4	4
C26	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
C27	5	4	4	4	5	5	4	5	4	3	4	2	4	4	3
C28	4	4	3	3	4	4	4	4	4	3	3	3	4	4	4
C29	2	3	1	5	1	1	1	1	1	2	1	1	1	1	3
C30	5	4	4	5	5	4	4	5	5	2	2	5	1	4	1
C31	5	5	4	4	5	4	4	5	4	5	4	3	4	4	2
C32	3	4	5	2	3	3	4	4	2	5	4	1	4	3	5
C33	1	1	2	1	1	1	1	1	2	1	2	1	1	1	1
C34	5	5	4	4	5	5	5	5	4	4	5	4	5	4	4
C35	4	4	3	3	4	4	5	2	3	4	2	3	4	4	2
C17R2	4	4	4	3	3	4	4	3	3	4	4	4	3	3	4
C36	4	3	2	2	4	2	2	2	2	3	3	3	2	3	2
C37	5	5	5	3	5	5	5	4	5	5	4	3	4	5	4
C38	4	3	2	2	4	4	4	4	3	3	2	3	3	3	3
C39	4	4	4	4	4	4	4	5	4	5	4	4	4	3	5
C40	5	3	4	2	3	4	3	5	3	3	5	4	4	4	3
C41	4	4	4	2	3	3	3	4	4	3	3	2	4	4	4

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