INDUSTRY 4.0 ADOPTION FOR US AEROSPACE AND DEFENSE SECTOR.

An exploratory research of the implications for companies.

Louis Barbier

International Business
Bachelor's Thesis
Supervisor: Susan Grinsted
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ABSTRACT OF
BACHELOR'S THESIS

Author: Louis Barbier
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Objectives

This study is conducted to explore the implications for companies of an Industry 4.0 adoption in the US Aerospace and Defense sector. The thesis's main objectives are to assess the current intellectual and business impact of the fourth industrial revolution on US Aerospace and Defense companies, to describe the barriers they are facing toward an efficient adoption, and to provide them recommendations to take advantage of this wave of innovation.

Summary

The literature review examined the US Aerospace and Defense sector and the Industry 4.0, then showed the way companies could adopt innovations, and finally, the opportunities opened by the fourth industrial revolution for the targeted sector. To reach the research objectives, a qualitative study based on structured interviews of professionals from three major US companies and one European leader of the market, was conducted to explore and discuss their motivations and level of recognition on Industry 4.0, the challenges that could appear toward its adoption, and finally recommendations to achieve it. Also, a framework for Industry 4.0 adoption has been made thanks to respondent's answers.

Conclusions

To conclude, even though the concept of Industry 4.0 is recognized as highly promising for US Aerospace and Defense Industry, its real impact on companies is currently still modest due to a lack of digital literacy from executives, shy financial decision making, nature itself of the business and the lack of governmental incentives. The thesis recommends the targeted sector companies to gain competitive advantage through Industry 4.0 following adoption process: the evaluation of digital maturity, pilot phase, building a strategy for the transformation, the holistic implementation, and the optimization of the change. This roadmap should be supported by the establishment of the three following pillars; a digital workforce, digital business models and strategic collaborations.

Key words: Industry 4.0, Aerospace and Defense industry, Innovation adoption, Supply Chain Management, Technology Strategy.
Language: English

Grade:

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ABSTRACT

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1 INTRODUCTION

1.1 Background

Innovation is nowadays a word used daily by all companies as a sales and marketing argument. It is thus frequent to hear that technological progress will change our lives in the coming years, and this from generation to generation. Sarcastic observers such as O'Bryan (2013) denounces this kind of sentence said by the CEOs of companies around the world. And if we were to name just one industry that embodied this rapid and exponential willingness of technological progress during the 20th century, that politically embodied or was the armed arm of international conflicts, it would be the Aerospace and Defense industry (Bilstein, 2001). The ideology of constant innovation, which fought over man's craziest dream, but also over his most destructive demons, was for a very long time carried by the United States, leaders of the air, of weapons, and then of space. However, the US Aerospace and Defense (A&D) industry is now facing challenges, and in such a tense geopolitical context, there are new opportunities to be grasped in order to consolidate its position as a global market leader, in the face of new competitors, largely supported by their respective nations (Deloitte, 2018). For once, the concept of innovation is not to be taken lightly as it will be the main vector of an evolution, if not a transformation, called by some the fourth industrial revolution; the Industry 4.0 (Aerospace Industries Association, 2019).

1.2 Research Problem

The US A&D sector has changed a lot over recent years, with the arrival of developing countries as China on the market with huge investments and an increasing geopolitical uncertainty at the global level has raised the investments in defense budgets from the majority of countries. Consequently, the demand is so huge that A&D companies sometimes can't follow up in times. The management of the supply chain of US companies will be crucial, to deal with the new entrants from emerging countries, SMEs, startups, IT companies (Deloitte, 2019). In order to outperform in this particular industry, but also highly innovative and competitive global market, the key is said to be Industry 4.0 (Lewis, 2019). The benefits of technologies as Internet of Things, Additive manufacturing, Blockchain, advanced robotics and cognitive automation, are shown to be particularly relevant adapted to A&D industry. However, a survey conducted by Deloitte (2019) to show the current state of Industry 4.0 adoption across manufacturing industries, "84% of A&D executives said they consider leveraging new digital technologies as key to market differentiation, yet only a quarter of A&D companies are currently using those tools". If lots of experts in the field affirm that Industry 4.0 is beneficial for companies, it seems that the case of its adoption in the US A&D sector, which is dominant, but more and more under the threat of new entrants, has been little addressed in academic research. The problem to be solved will be for US A&D to fill the gap between words and acts by adopting the Industry 4.0 in the most efficient way.

1.3 Research Questions

Being the initial step of a research project, the research questions are made to answer the research problem targeted and stated above. The research questions goal is to set up a scope for the subject you want to study on (Farrugia et al., 2010). The Research problem implies the following research questions:

1. How is Industry 4.0 currently impacting US Aerospace and Defense companies?
2. What are the challenges US Aerospace and Defense companies are facing toward Industry 4.0 adoption?
3. How can US Aerospace and Defense companies adopt efficiently Industry 4.0?

1.4 Research Objectives

These research objectives are based on the research problem and questions with the purpose to state what need to be achieved by the end of the research in order to

analyze the different implications US Aerospace and Defense companies can consider for adopting Industry 4.0.
These five objectives are:

1. To assess the current motivation and recognition of Industry 4.0 by US A&D professionals.
2. To assess the current level of maturity of respondent's companies toward an Industry 4.0 strategy.
3. To express the main barriers US A&D companies are facing toward an I4.0 adoption in their organization.
4. To provide recommendations for US A&D managers to take part in the fourth digital revolution.
5. To conceptualize a concrete roadmap for an efficient I4.0 adoption.

2 LITERATURE REVIEW

2.1 Introduction

Industry 4.0 is a buzzword we hear all the time without grasping its essence. This literature review reports and analyzes previous work that revolves around Industry 4.0 adoption for aerospace and defense industry companies in the United States. It will first analyze the US market, but also the underlying nature of the aerospace and defense industry to grasp what is specific to it and why technological progress such as Industry 4.0 represents an opportunity for it. It will then look at this very progress to understand its meaning and the challenges it brings. After this part more focused on the context of our research, the literature review will address the theoretical and conceptual approach to the issue of the phenomenon of adoption, and diffusion of an innovation, to finally assess a more practical side of the potential impact that Industry 4.0 technologies could have on the value chain of A&D companies.

2.2 Context

2.2.1 Defining US Aerospace & Defense Industry.

2.2.1.1 US Aerospace & Defense Industry.

As its name suggests, the Aerospace and Defense Industry (A&D) serves two markets: Aerospace which concerns the design, manufacture, sale and service of commercial aircraft (US Senate, 2005), and Defense which concerns the production and trade of weapons. Technically and industrially, both sub-industries are very close. The American A&D has been at the heart of their economic success for 100 years by moving, connecting and securing the world. It generated in 2018 sales exceeding 929 billion $ while supporting over 2.5 million US. Jobs (881 000 direct jobs and 1.67 million supply chain jobs) according to AIA, the Aerospace Industries Association (2019).

The sector can be characterized by problems of cashflow (Guenov et al., 2005), a high level of technology, a never ending need for capital, a high strategic importance for the producer country, a high involvement of government authorities in new programs, a high concentration of constructors, a high concentration of customers, and a relative disengagement of the state in recent years (Malaval, Bénaroya, Aflalo, 2014).
The A&D is driven by different demands. These are the countries willing to buy weapons, people traveling by plane for business or leisure, the trades by cargo aircrafts, and finally organization working on space conquest like the NASA. The three main type of companies that enable the sector to answer this demand are the aircraft manufacturers (Boeing), airframe and engine manufacturers (Lockheed Martin) and equipment manufacturers (Collins Aerospace).

The business model of an A&D manufacturer is based on a rather classical economic model of trading (i.e. selling production at a price higher than its costs) with the specificity of selling at a loss for the first models of product (Malaval, Bénaroya, Aflalo, 2014). For example, aircraft manufacturers would buy airframe components and engines from a supplier, then to sell an assembled product to different countries armies, flight companies. A&D companies don’t have any link with leisure flight customers, who buy a service from flight companies. The biggest challenge related to its business model is the problematic cash flow Indeed, aerospace companies require high-risk investment, development costs and long payback periods (Stice 2017). Beside the economic aspect, the aerospace and defense industry are considered crucial for many countries because it reflects the strategic success of their economic, political and social model on an international scale, but also their technological progress, implying their level of education or attractiveness. This aspect, therefore, reinforces the interdependence that exists between A&D companies and states (Hartley, 2015).

Finally, the A&D companies produce products adapted to a long-term evolution of the market, the safety and security standards because of the high lifespan of their products (aircrafts, tanks etc..). This regeneration rate is described by Guyon et al. (2019) as "the ClockSpeed" factor; the regeneration frequency (significant evolution, shortage) of a certain technology." Considering that components parts of an A&D final product might have different ClockSpeeds, Guyon et al. (2019) underline that a desynchronization of the supply chain due to the implementation of new technologies generally would more likely slow down the increase in production rates.

2.2.1.2 Structure of A&D sector.

From the point of view of the adoption of innovation in enterprises from a certain industry, it is necessary to qualify what the structure of the industry is. According to Koblen and Nizniková (2013), "the supply chain is a group of companies that provide products or services on the market contain all the phases involved directly or indirectly in meeting customer requirements." More precisely about the A&D supply chain, its organizational model is described by the European Association of Aerospace Industries (AECMA, 2002) as stratified and hierarchically organized into "tiers of suppliers" (Figure 1).

Figure 1. Typical supply chain of the aerospace industry (Niosi & Zhegu, 2005).

The Figure 1 resumes the organization of the different tiers and their respective relationships. The knowledge flows go from the bottom, suppliers specialized in production of specific processes, to the top, the OEM (Original Equipment Manufacturers) who focus on development of the final product (Boeing). The development of technologies such as those in Industry 4.0 is usually first developed by third tier companies and then gradually assimilated by the upper tiers. (Niosi & Zhegu, 2005).

To resume, the A&D industry supply chain pyramid is divided into four tiers:

- OEM: deliver the complete product with all systems and responsible for qualification and certification.
- First tier contractors: They take part in the production of complete subassemblies (engines, landing gears).
- Second tier subcontractors: They are specialized in the technical field and more precisely the production of components.
- Third tier subcontractors: They are SMEs providing simple components and manufacturing technologies. This is a very competitive market.

2.2.1.3 SWOT of the US market.

A “Strengths, Weaknesses, Opportunities, Threats” (SWOT) analysis provides information on the specificity of U.S. competitiveness in the aerospace and defense sector, as well as a brief written description of each category to explain some of the points discussed. The aim of this approach (Table 1) is to give a national graphical representation of the sector.

Strengths:

The Aerospace & Defense Industry is still at the heart of the American economy success being responsible alone for 1.8% of the country's GDP ($374 billion). In 2018, its total sales revenue exceeded $929 billion, which is an increase of 4.17% from the previous year (AIA, 2019). A&D showed a major impact on the global sector, recording a positive trade balance of $89.Billion. A rise of entrepreneurial activity in the sector is also noticeable since few years, and 2018 has seen the investment aerospace startups reaching nearly $1 billion which is a new and valuable asset for A&D (Fernholz, 2018).

Strengths	Weaknesses
• US are the primary growth driver for A&D industry. • Strong reputation of quality and industry leadership. • Emergence of entrepreneurial companies.	• Low spending in R&D efforts. • Unsatisfactory delivery schedules and cutomization for US A&D customers. • Lack of qualified workforce. • Aging infrastructure.
Opportunities	**Threats**
• Rise of military expenditures due to security threats. • Increase of US government investment in research, technology, and commercial services. • Industry 4.0 promise.	• Emergence of China and other recent entrants. • Declining production rates. • Ability to recruit and retain technical talents. • Weakness of tier 2 and 3 of supply chain. • Declining commercial aircraft backlog.

Table 1. SWOT model of the US A&D industry. (Own realization).

Weaknesses:

Talking about weaknesses, it is important to affirm that the strengths definitely outweigh them for the moment. However, a production inability to keep up with growing demand which is asking for more customization possibilities and faster delivery schedules. Also, a high dependency on exports to China is noted (AIA, 2019), which could be problematic given the growing political tensions between the two countries. Finally, several weaknesses are related to the sector's labor force, which is considered aging and less and less able to perform increasingly technical operations, beside to the sector's inability to recruit and retain new high-performing employees (AIA, 2019).

Opportunities:

Numerous opportunities are opening up for the US aerospace and defense industry, particularly in the face of growing military demand from most countries for obvious geopolitical reasons. However, this opportunity should be qualified because the US government plays a major role in this global instability, which could also lead to the consideration of possible specific export penalties for companies. Also, with the growing attractiveness of countries such as China, India and established competition from European nations, the U.S. government is seeking to strengthen the technological side of its economy by investing globally in research, technology, and business services in the sector. Finally, the promise of Industry 4.0, which has already been discussed, is being examined, despite some reluctance, with a view to possibly unlocking a competitive advantage. (AIA, 2019).

Threats:

Research and Development (R&D) US government investment has declined for the last past six decades. For AIA, this is even more exacerbated by the Budget Control Act in 2011, which “limit spending and thus lower the federal budget deficit, capped discretionary, non-military personnel related defense spending.” At the same time, rivals such as China, have increased their total R&D expenditure by 71% in 2012. The industry has difficulties in recruiting the brightest graduates from universities, as A&D is no longer considered as attractive as it used to be, which can be a concern in developing new and innovative ways of production (Sadeh, 2012). Also, Deloitte (2020) claims that the US production rates aren’t meeting the new requirements for both commercial aircraft and defense equipment, which could be a big issue to keep their leadership position in the market.

2.2.1.4 Issues of the sector on a global scale.

This section will address the challenges observed for the global A&D industry as it relates to the manufacturing activity that it embodies. Challenges related to the legislative aspects of the industry that exist will not be analyzed to remain within the scope of the study.

The global Aerospace and Defense industry is doing well, with an average annual growth of 6% according to Pipame (2018). However, it is important to note that this constant growth does not correlate with the maintenance of competitive positions, and that certain factors have completely or are about to upset the existing balances. Because of this growth, many professionals in the sector see opportunities emerging, and confidently look forward to exploiting them to assert their competitive position. This perpetual growth is due in particular to the huge investments made by emerging markets to compete with the United States and Europe on exports, but also to the uncertainty regarding the current geopolitical situation in the Middle East.

It is risky to comment on the upward trends in demand for the coming year 2020, but in view of the conflict situation between President Trump's America and Iran, and the global growing tensions between the world's major powers (USA, Russia, China, North Korea), the terrorist threat (ISIS). A growth in demand for the A&D sector could rationally be planned. However, Colbert (2017) suggests that the OEMS but also the three tiers rarely have the production capacity to catch this new demand and to perform in key contracts, which could generate a significant production disruption. There is a need to evolve or transform the global manufacturing capabilities of all the supply chain structure of the sector to achieve their economic goals and satisfy their customers. Also, to temper these estimates, the corona virus health crisis may ease or put these global tensions on hold for some time.

This transformation for many experts could go through the digitalization, also called Industry 4.0, which could help A&D companies change their business models and value chains. Integration of Industry 4.0 in the manufacturing process of these companies is seen as a priority by many consultants in the sector, but the real effects of such an adoption, the enthusiasm that it generates is still rather vague, which provokes a certain distrust for some professionals. However, EY (2020) argues that "some of the technologies that A&D players use in their manufacturing and other business processes are decades old". The implementation of some of the new technologies, or the full adoption of Industry 4.0 remains a major challenge for the global sector: for developing countries, it could enable their expected arrival in the market, but for nations like the United States, a way to maintain their hegemony in the sector in the face of increasing competition. More details on the impact of such managerial decisions will be seen later in the thesis.

Indeed, the increasing competition is without a doubt highly influenced for Wood (2019) by globalization, which, while it has helped the industry to bring down market-specific regulations and improve the supply chain, has also exploded the competition that was once reserved for a few giants in the sector (i.e. the Boeing/Airbus duopoly) but also the dependence of their success on any event which happen in the world.

Finally, the EY study reports that one of the major issues in the sector is the retention of talents. Indeed, the consulting firm has noted "losses of key personnel, coupled with an inability to train adequately other personnel, hire new personnel or transfer knowledge". With the ageing of the general skilled workforce and the explosion of competition for the latter, the A&D industry, which embodies highly skilled and technical expertise, cannot afford such shortcomings. Possible solutions through our approach will be considered later in the thesis.

2.2.2 Industry 4.0

2.2.2.1 Defining what is Industry 4.0

The human civilization is now facing what is being called the fourth industrial revolution. It is said to be the next big evolution that will revolutionize the human relationships, the way we think, but especially the way we work. Even though some professionals are reticent and have reservations about the importance of this phenomenon, it remains

that the nature of this evolution is a source of opportunities that only needs to be seized if one does not want to be left on the side of the road.
Indeed, history is filled of stories of leaders in their field that got disrupted by similar revolutions. Before, Industry 4.0, three prior industrial revolutions are noticed for generating major changes in manufacturing industry: the first characterized by mechanization through steam power, the second one by mass production through assembly lines, and the third one by automation through information technology.

The term “industrial revolution” was first brought into English language and conceptualized by Toynbee (1884) as "the substitution of competition for the medieval regulations which had previously controlled the production and distribution of wealth". His work was an attempt to describe the Industrial Revolution 1.0 which began at the end of the 18th century with the adoption of water and steam power in manufactures, which helped the productivity of commercial activities, agriculture, textile and steel industry.

The second industrial revolution is considered as the most important in our history because it is the source of the foundations that shape our society as we know it today. The development of electricity, oil, mechanical engineering, and chemistry enabled the birth of the phenomenon of globalization that regulates our economy, of the large American companies, the theorization of Taylorism and productivity gains through assembly-line work and mechanization.

Rifkin (2011) theorized the concept of the third industrial revolution in “The Third Industrial Revolution; how Lateral Power is Transforming Energy, the Economy, and the World”, which would be characterized as a new industrial and economic revolution that would differ from the traditional production sectors and would have started in the middle of the 20th century with the development of new information and communication technologies.

Finally, the term Industry 4.0 comes with a media overexposure denounced by some. Indeed, Industry 4.0 is a nebulous term that has been used a lot in the recent years and does not really explain conceptually what it is to readers and the general public. While several academic authors have obviously addressed the subject, there is still a great imbalance between popular knowledge of the term and the true understanding of what it implies. Shu et al. (2018) discussed the definition of Industry 4.0 after its introduction by Germany in 2011 during the Hannover Fair event. But to give a simple explanation, I4.0 is a branch of the manufacturing process that include new technologies such as Big Data & Analytics, Simulation of Things, devices (Cyber Physical Systems (CPS)), cloud computing, Internet of Things) and their functional aspects as services, ensuring a constant communication and relationship (Marr, 2018). Industry 4.0 roughly refers to a new generation of connected, robotized and intelligent factories (also known as Industrial Internet of Things in the US).

This generation uses progress in information technology and communication to increase the level of digitization and automation of the manufacturing process. The purpose is to transform the product design to control the entire value chain process by improving productivity and proposing higher quality, more personalized goods and services. According to Cotteleer and Snidermand (2017), the integration of digital information from many sources and locations (IoT, Robotic tools, Big Data, AI) can drive the physical act of doing business, in an ongoing cycle. (Figure 2). Inside this loop, intelligence flow and real-time information are going from digital to physical, then to digital steps of manufactuing through steps characterized by the same Deloitte report (2018):

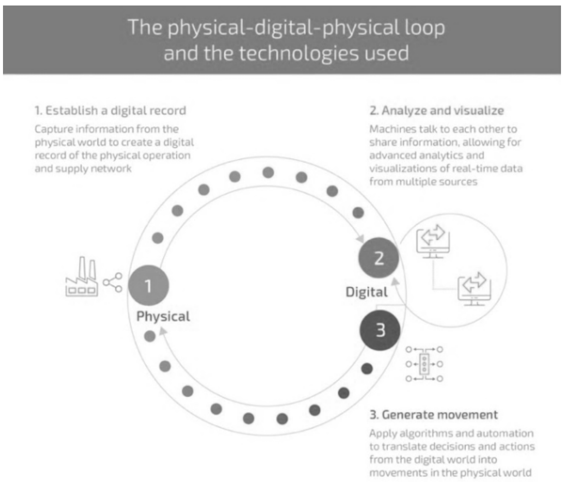

Figure 2. Toward the next Horizon of Industry 4.0 (Deloitte, 2018).

- “Physical to digital: Capture information from the physical world and create a digital record from physical data.”

- “Digital to digital: Share information and uncover meaningful insights using advanced analytics, scenario analysis and artificial intelligence.”
- “Digital to physical: Apply algorithms to translate digital-world decisions to effective data, to spur action and change in the physical world.”

These steps enable Cotteleer and Sniderman (2017) to affirm that the true essence of I4.0 is *the ability to act upon data and information that has been analyzed*.

2.2.2.2 Industry 4.0 Front end technologies

Even if traditional technologies are still massively used in manufacturing industry, the emergence Industry 4.0 came with many new technologies that will enable the evolution from factories to smart factories. André (2019) justifies the strong and organic relationships those technologies share by conceptualizing the diffusion of any winning technologies. For him, major technological disruptions are transversal, combinatory and contagious. It enables us to understand why Industry 4.0 front end technologies (see Table 2) are often graphically represented as a global ecosystem. Some of them might not be as useful as others for the scope of our subject, but it is necessary to present them all considering the correlated nature of Industry 4.0.

Front end technologies.	**Definitions**.	**Real-life current applications.**
Big Data Analytics.	According to Gartner’s definition (2001), Big Data is a “high-volume, -velocity, -variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making.” For S. Sicular (2013), the variety part refers to the possibility companies have to draw insights from a huge variety of unused but collected information while velocity is the most misunderstood characteristic (related mostly to real-time analytics even though it’s also about linking data sets from different speeds and tempos).	The Aerospace and Defense company Rolls-Royce (2015) is using Big Data intensively to create simulations of new engines at the design-stage, which enable them to analyze enormous quantities of data to decide whether or not the new model is good, and to improve its quality.
Autonomous Robots	Current robots are becoming autonomous, cooperative, flexible and communicative. I4.0 autonomous robots will	Boeing used autonomous robotics previously implemented in their Melbourne

	interact with each other and collaborate with humans under their guidance. (Michniewicz, Reinhart, 2014).	fabrication site to build the aero structure of their "Airpower Teaming System", which is an armed wingman drone (2020).
Simulation	To include those technologies in I4.0 ecosystem and to deal with their uncertainty, simulation technology is obviously highly relevant. Simulation allows experiments for the validation of products, processes or system design and configuration (Mourtzis, Doukas, Bernidaki, 2014). This system produces an imitation of an operation, thanks to the concepts of "Digital Twin", "Discrete Event", or "Predictive Analysis" to prove its validity and make a business decision.	The Aerospace company "Rolls-Royce" is currently developing digital twin technology for their airplane engine product called the Trent. They noticed a significant improvement in time of analysis and bigger capacity, making them able to replicate the whole engine. (2018).
Industrial Internet of Things	If the term "Internet of things" can be attributed to Ashton (1999), today's definition of "Industrial Internet of Things" agrees that it refers to the vast number of machines and devices – or 'things' – a business uses that are now connected to the Internet. (Slevin, 2019). IIoT collects this data, to be able to react when an event happens in the supply chain.	Northrop Grumman (2018) has incorporated the Internet of Things technology in its manufacturing process to predict when parts of an airplane should be replaced, with a successful rate of prediction of 99.3% of the time.
Cloud Computing	If companies are already using cloud-based software for their operations, the nature of Industry 4.0 requires an optimization of connectivity and control through every industrial process of the smart company. These goals can be achieved thanks to cloud computing, which is defined as the provision of infinitely scalable computing resources as a service over the internet. (Ezell, Swanson, 2017).	EaglePicher Technologies (2013), a battery designing and manufacturing leader for the A&D industry, has been using a cloud computing solution, "Plex Manufacturing Cloud", which resulted in quicker and easier processes custom orders, improved speed of and accuracy of financial tracking and a more efficient manufacturing management.
Artificial Intelligence	Artificial Intelligence which is the simulation of human intelligence process by a computer, can be applied in automation, machine learning, robotics, natural language processing which enables factories to automate complex tasks and provide	According to Deloitte (2019), AI has the potential for Aerospace and Defense to increase safety in aircrafts, be implemented in autonomous drones.
Additive Manufacturing	Additive Manufacturing is described by Scott and Harrison (2015) as an industrial process of creating an object from nothing by building it one layer at a time. The term commonly refers to 3D printing technologies.	In 2020, Hindustan Aeronautics Limited has signed a partnership with another Indian based company, Wipro 3D, which is specialized in metal 3D printing services.
Augmented Reality	Augmented reality (AR) is a technology that involves the overlay of computer graphics on the real-life operations. (Silva, Oliveira, Giraldi, 2003). This way, technicians can	Lockheed Martin (2018) noticed significant ROI and a 95% reduction in time of technical interpretation drawing and text instructions

	watch real-time data, assistance, security guidelines while performing their task.	since they started using AR in their Space Systems division.

Table 2. Industry 4.0 Front end Technologies (own realization).

2.3 Adoption of innovation in the company

2.3.1 Diffusion of Innovations

The diffusion of innovation is a theory conceptualized by Everett Rogers (1962) which aims to explain and to show why and at what rate innovation, new things, or more precisely technology spread. The concept of diffusion is defined by Rogers as "The process in which an innovation is communicated through certain channels over time among the members of a social system." This founding theory of innovation has, of course, been debated (diffusion and adoption are considered as too complicated or even impossible to quantify precisely) improved and modified by many researchers, but still 60 years later it still applies to technologies or technological ecosystems such as Industry 4.0. The concept of innovation is described by Rogers (1962) as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption." From this concept the author affirms different rates of adoption which is the speed with which an innovation is adopted, based on following criteria and attributes of innovation:

- "Relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes."
- "Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters."
- "Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use."
- "Trialability is the degree to which an innovation may be experimented with on a limited basis."
- "Observability is the degree to which the results of an innovation are visible to others."

By assessing different cases thanks to those criteria, Roger (2003) has modeled the diffusion of innovation model following a normal distribution curve (Figure 3) which referred to five different adopter categories with a frequency of distribution percentage: innovators, early adopters, early majority, late majority, laggards.

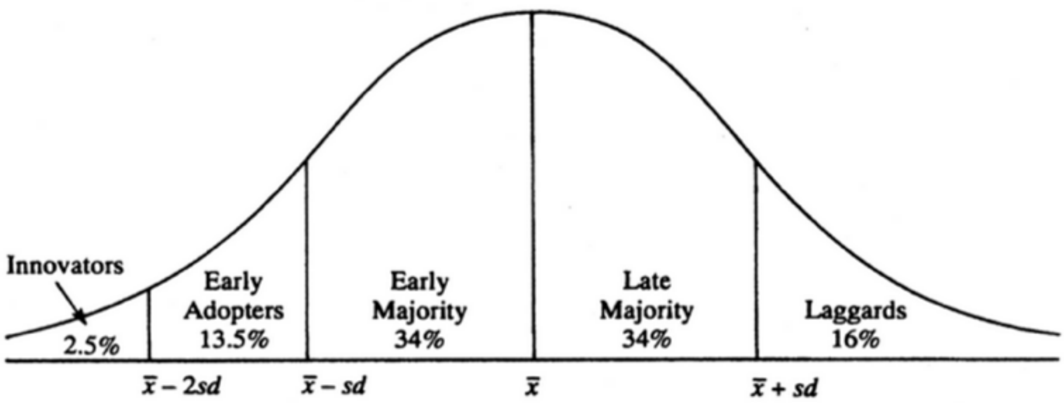

Figure 3. Adopter Categorization on the Basis of Innovativeness (Rogers, 2003, p. 281)

2.3.2 Innovation Process for Innovation Adoption

In the thesis “Industry 4.0 Adoption in the Manufacturing Process, the researchers Olsson and Xu (2018) used the model created by Roger (2003) as a reference to develop an improved version (Figure 4) using and analyzing the many criticisms and/or suggestions the author had received since 1963.

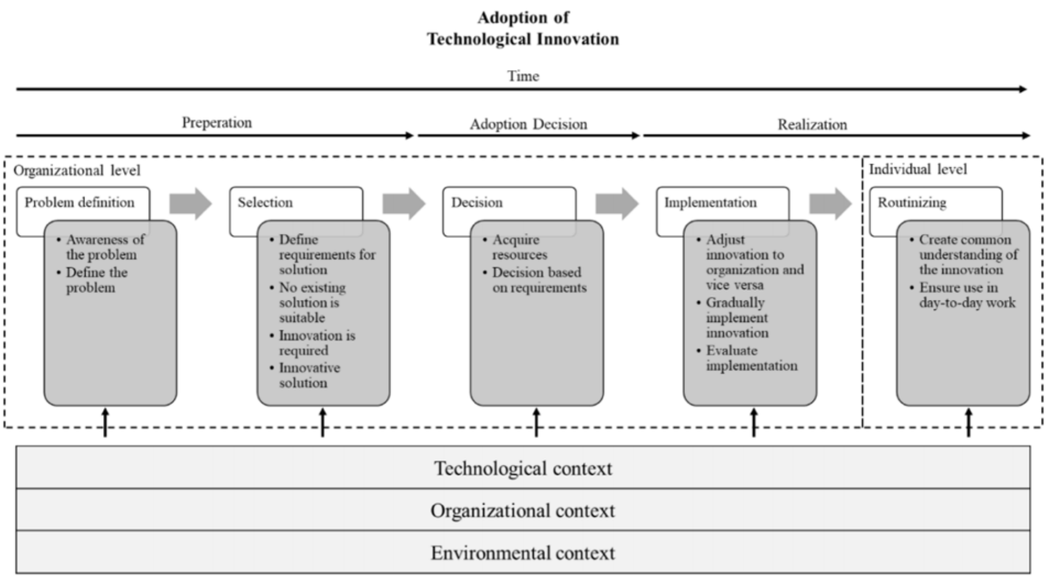

Figure 4. Model for Adoption of Technological Innovation (J. G. Olsson, X. Yuanjing, 2018)

This model (Figure 4) includes five steps (problem definition, selection, decision, implementation, routinizing) divided into three sub processes (preparation, adoption decision, realization). The authors specify that even though the whole process is designed as straight; it is possible that an innovation is rejected. In that case, the company can go back (a loop back) to the selection several times after the implementation, or/and the routinizing step to change requirements for example. They underline also that the individual has a very important role in the adoption of innovation as showed by the last step of the model, routinizing, which involves a clear understanding of the implemented technology by employees that will use it every day.

2.3.3 Maturity Model for the Adoption of Industry 4.0

Geissbauer, Vedso, Schrauf (2014) affirm that companies should start the implementation of Industry 4.0 in their processes by assessing their company's current digitality level, in order to "understand what strengths you can already build on, and which systems/processes you may need to integrate into future solutions." This assessment can be made using a maturity level tool, described by Fowler (2014) as a "tool that helps people assess the current effectiveness of a person or group and supports figuring out what capabilities they need to gain next to improve their performance." While the quality and relevance of several "Industry 4.0 maturity level" assessments is debated in previous research such as "A Critical Review of Smart Manufacturing & Industry 4.0 Maturity Models: Implications for Small and Medium-sized Enterprises (SMEs)" by Mittal et al. (2018) there is an academic gap when it comes specifically to the aerospace & defense industry.

It should thus be noted that, like many concepts, a maturity model is a simplification of what still needs to be learned, or ideally put in place, and is therefore inherently false but nonetheless useful. Also, the concentrated competitive nature of the U.S. A&D industry leaves limited room and relevance for a quantitative analysis of results based on the performance of companies that have passed the test, but instead is very useful for them as individuals.

2.4 Opportunity of Industry 4.0 for A&D industry value chain.

The US Aerospace and Defense is considered as the world leader in the three following operations: design, development & manufacturing, Maintenance, Repair & Overhaul (MRO) services, of aircrafts, space systems and defense capabilities.
This section's purpose is to identify the possible impact of Industry 4.0 adoption for the different activities implied for US A&D sector.

2.4.1 Potential impact on the Research and Development

Very often considered as the most important aspect of A&D industry, the Research and Development (R&D) is defined by the Organization for Economic Co-operation and Development (OECD as a creative work undertaken systematically to increase the stock of knowledge (including knowledge of man, culture and society) and the use of this knowledge to devise new applications. The A&D industry focuses more on industrial R&D which remains closely linked to the creation of new products and production techniques. In this sector, R&D concentrates more on tasks like the development of new aircrafts, space launchers, weapons, military technologies and related equipment, improving the manufacturing processes efficiency, extension of current knowledges on raw materials, etc.

For Naujok et al. (2016) there is no doubt that R&D activities will be the most important, leading the way in the digital transformation of the A&D sector. The decisions taken in this sector will impact on the whole value chain of companies. As we explained previously, Industry 4.0 is a major challenge for A&D but also the whole manufacturing industry and is considered as the start of the road toward innovation. Kates (2016) claims that "Whether developing new products and services to meet emerging demand or tailoring existing products to meet the specifications of customers in new markets, A&D organizations will need to push aside the status quo to grab new opportunities and drive exceptional execution."

Concretely, the adoption of Industry 4.0 for the actors of research and development departments could see the use of machine learning and AI based techniques to solve mathematical algorithms, robotics could take care of repetitive tasks in the long run, which could leave more time for engineers and scientists to take care of creative tasks, and we could see simulation and digital twin technologies completely overhauling the way engineers work, allowing them to test their work at a fraction of the cost of traditional R&D. This need to apply the benefits of Industry 4.0 to research professionals translates into the opening of innovative research places digitized by these new technologies such as the "Industry X.0 innovation center" (2019) in Germany. Following this example, one could imagine the use of such spaces within companies in the American A&D industry.

2.4.2 Potential impact on the Engineering

Aerospace Engineering, also commonly called Aerospace Design, is the part of the value chain concerned with the design, development, testing, production of A&D products, components, and related systems (PennState College of Engineering, n.d.). For this discipline, the attributes of Industry 4.0 are easier to implement because it involves systematic software activities, as opposed to research and development. The main goal of an adoption will be more focused on maximizing the quality of the tasks and reducing the time between design and manufacturing. The company DXC.technology (2019) underlines four potential opportunities in this phase: virtualization, Digital Twin, High Performance Computing, Digital life cycle.

- The "Virtualization" refers to optimization of the software and technology making people able to work in the same time on one project ignoring geospatial limitations. Designer for example thanks to Cloud Computing will draw, work, discuss on one drone project in the same time to finally come up with a quicker solution, from the best employees possible.
- The "Digital Twin", already mentioned in part 2.2.2.2, refers to the replication of an asset effect, performance, through a technical simulation, to assess physical deficiencies or ways of improvements.

- The “High Performance Computing” (HPC) opportunity means the practice of aggregating computing power in a goal of delivering much higher performance than a physical computer. It can also create and optimize theoretical and arithmetic designs. For example, HPC could analyze and decide whether on keeping actual metal used on combat ships or new lighter.
- The “Digital life cycle” refers for Robledo (2016) to a journey of innovation that seeks continuous excellence to respond with agility to possible global economic changes, business competition, new regulations, new technological disruptions to arrive to achieve for example rapid prototyping.

2.4.3 Potential impact on Manufacturing and Assembly.

The Manufacturing process is defined by the OECD (n.d) as “the physical or chemical transformation of materials or components into new products, whether the work is performed by power- driven machines or by hand, whether it is done in a factory or in the worker's home, and whether the products are sold at wholesale or retail. Included are assembly of component parts of manufactured products and recycling of waste materials. » Manufacturing activities in A&D are the most suitable for Industry 4.0.

In the A&D Manufacturing and Assembly stage, the critical priority is to meet the growing demand, by increasing throughput and improving efficiency, and to reduce useless inventories. According to Baptista et al. (2018), “digital technologies can boost A&D companies’ revenue by 5 to 15 percent and lower their costs by 4 to 10 percent”, which is far from negligible for US companies which are competing with rivals with much lower overall costs.

This improvement could be made through automated factories such as Boeing Sheffield, a smart factory test bed which showed 50 percent productivity benefit, 30 percent reduction in defects and 50 percent improved to market (University of Sheffield, 2019). Also, A&D companies to rival with low-cost workforce from China and India, could start investing in collaboration with robots, which could reduce for Knight (2014) the workers’ idle time by 85%. Moreover, it seems that such investment in Robotics require at the moment patience, considering that it took Cornell Dubilier 12 months to show ROI after hiring Baxter, a robot in charge of tedious tasks of labeling and inspections. Such an expectation for returns on investment seems difficult to envisage for companies that take 4-6 months to produce an aircraft which could disrupt the Clock Speed factor discussed previously in the short term. A possibility worth considering is the use of machine learning and cognitive sciences to help employees to, or even make decisions about supply chain configuration in case of an issue, or for productivity's sake (Simon, Huet, 2018).

2.4.4 Potential impact on Maintenance, Repair and Overhaul (MRO)

One of the main priorities of the Aerospace and Defense sector is to ensure the production of reliable, safe, and quality products, which must meet the criteria of their customers, as well as government laws and standards. The globalization of the A&D industry's production has greatly complicated this for companies, especially OEMs, who often have to deal with national requirements from different continents at the same time. It is a general truth that the A&D industry is one of the most careful when it comes to safety because its products put human lives at stake, but also geopolitical issues that cannot afford poor quality products (Tomic, Spasojevic-Brkic, Klarin, 2012). In the context of the Boeing 737 scandal (Gelles, 2019), which suffered two crashes due in particular to faulty design, quality certification and risk assessment, the quality of the product seems to be a major factor in Boeing's poor financial performance, and could contribute to building a bad reputation for the US industry.

MRO services is planned to be improved through machine learning-based predictive maintenance, a method in which the service life of important parts is predicted based on inspection or diagnosis to use the parts to the limit of their service life (Mokhatab, 2019). According to Deloitte (2017), it could increase equipment uptime by 10 to 20% while reducing overall maintenance costs by 5 to 10% and maintenance planning time by 20 to 50%. Also, another application considered is Augmented Reality supported MRO, which could be embodied by technical inspection using smart glasses, getting access to real-time data and guidelines. Boeing (2016) reported cutting production time by 25% with smart glasses. However, some argue that humans should not be put aside too much for security controls, so technology should remain the tool of man.

2.5 Conclusion and Conceptual Framework.

According to my literature review, A&D companies from the US sector enjoy a leading position and globally recognized competitiveness. However, we are now seeing a new industrial revolution, which could disrupt the entire manufacturing industry. The Industry 4.0 offers tremendous opportunities for many manufacturing industries, but with this literature review, highlights not only the infinite possibilities but also the many weaknesses of the US market, which could be exploited by the competition. The Industry 4.0 front end technologies presented are all interrelated and could spread through the global aerospace and defense value chain thus reshuffling the cards on the domination of the aerospace and defense global market.

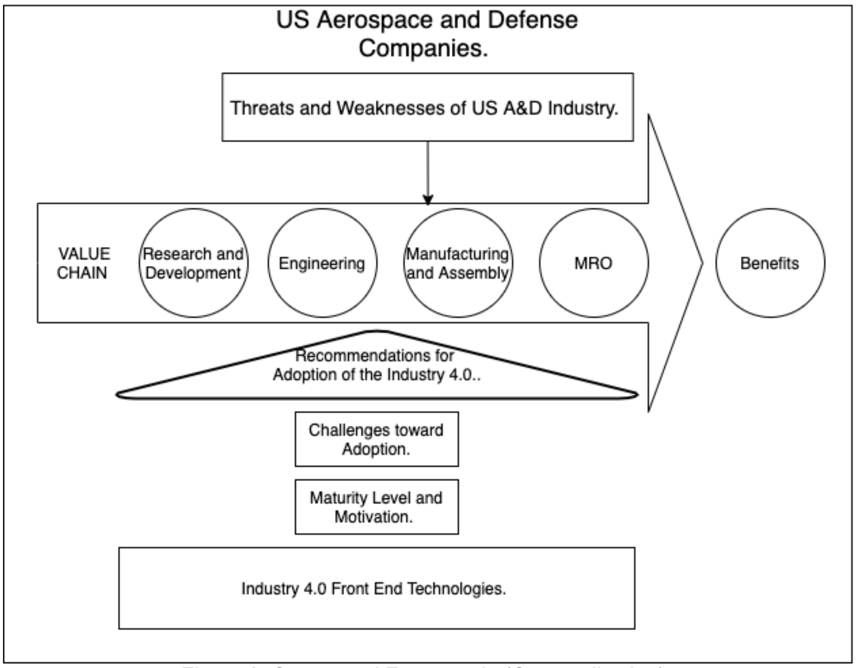

Figure 6. Conceptual Framework. (Own realization).

The challenge for U.S. companies in the sector is thus to discern the good from the bad in the full scope of the term Industry 4.0, to be among the first innovation adopter, and thus be able to meet the growing demand due to permanent geopolitical tensions, to maintain their hegemony in the face of increasingly innovative nations. These companies are known to be aware of Industry 4.0, without really putting any significant efforts to catch up this train. Numerous studies and market reports have established proposals for these players in the manufacturing industry, without ever taking a specific interest in American A&D which is a significant gap of literature.

My thesis will therefore build on these previous researches findings to analyze the current level of adoption and recognition of the potential benefits of Industry 4.0 by these businesses, the barriers encountered to their full exploitation, and finally to draw up recommendations for American companies for the adoption of this digitalization in their value chain. The conceptual framework (Figure 6) helps to summarize the knowledges gathered in the literature review and drawing relationships between them and the empirical missing data toward an efficient Industry 4.0 adoption for US A&D companies. It describes on one side the threats and weaknesses that act as a negative force on the US A&D value chain, which has been described through the potential benefits of each of its part in the literature review. On the other side, the research of the thesis will aim to see what can act as a positive force through the current impact of Industry 4.0 on the US A&D industry, the challenges toward its adoption, and recommendations based on pillars and a roadmap for companies. This will lead to benefits that won't be able to be analyzed in the thesis.

3. METHODOLOGY

With the existing gap in the literature being recognized as the process of Industry 4.0 adoption in the Aerospace and Defense companies, especially the US ones, it seems that the research should be exploratory in order to solve this gap, provide recommendations for companies, and discovering future research tasks.
The following chapter will express the methodological research approach adopted to find answers, the method of data collection, of analysis, and its limitations.

3.1 Research design

Because the thesis is exploratory, a qualitative research based on the views of experts is chosen because considered as particularly suitable and adapted to discover in depth knowledges of experiences from professionals, opinions, causalities; to answer to the questions, “How?”, “Why?” (Cooper, Schindler, 2014). In the contrary, a quantitative research aims to describe, predict, rank, measure, and is commonly explained as being “all about numbers”. For Maanen (1979), qualitative study implies “array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world.” Through this method, I will orient my interest on professionals of the industry level of recognition, motivation, but also experiences and in-depth knowledge and interpretations about their own companies to answer to my research questions. The research approach will be inductive, which mean that the research purpose is to draw concepts, and hypotheses rather than test them (Sanders et al., 2008).

A qualitative explanatory research implies enabling the research to draw from data such as particular emotions, experiences, interpretations, finding in the form of general themes, process, recommendations, concepts (Cooper, Schindler, 2014). For that process, structured interviews by emails, and semi structured interviews by phone call (see the questions Appendix 1) from professionals of the sector are chosen to collect primary data, which means that questions are prepared before the meeting or email contact (Cooper, Schindler, 2014). Focus groups wouldn’t have been possible considering the respondents localization on another continent.

The interview questions were constructed on the basis of sections referring directly to the research questions. The literature review was used to understand the mechanisms of technology adoption, but also tools such as the maturity model for this purpose. Also, the literature review eclipsed any questions regarding the potential of Industry 4.0 for their sector, allowing the interview to focus more on the actual concrete impact of this technology on the respondents. Therefore, the question concerning the recommended adoption process was very important, and its proper formulation was crucial as the promise of an answer to the last research objective rested on it alone.

3.2 Data collection.

For the primary sources, the participants from US A&D industry have been chosen through many channels such as LinkedIn, companies' websites, and social connections from February to March 2020. An interview from a European Industry professional has been collected too in order to reflect on the US companies position from a competitor's perspective. A system of formatted emails including the identity of the person contacted, their gender, and different approaches depending on their role was put in place and over 100 professionals were contacted with a disappointing interview acceptance rate. However, it is interesting to note that the response threshold was much higher and that a significant proportion of the professionals showed a definite interest in the results of the research and insisted that the research be forwarded to them when completed.

Then, more than twenty companies concerned were contacted directly by their website and media service, with a certain rate of non-response, noting however that the smallest companies were the most understanding of the research issues, but nevertheless the Bachelor level of research was apparently a hindrance to the consideration of the email response service, according to some answers. It is also important to clarify that in order to simplify the process for the respondents, a word file with the questions of the interview was sent by email, but also an online questionnaire to be able to send the link more easily, and thus avoid the loss or omission of the questionnaire in the form of a word file among the other tasks and responsibilities of the respondents. and issues related to time differences between Europe and the United States. The detail informations of participants in the primary interviews, also called "sample" are provided in table 3 below.

Respondent	**Title.**	**Company Brief Description.**	**Number of employees**
Respondent 1.	Design engineering manager.	The respondent 1 is part of one of the largest suppliers of aerospace and defense products. The company designs, manufactures and creates services systems and components for commercial, regional, business military aircrafts, helicopters and other platforms.	31 200.

Respondent 2:	Flight Mechanics Engineer.	The respondent 2 is part of an American engineering, technical products and service provider to Aerospace and Defense industry.	228.
Respondent 3:	Director Digital Factory, Manufacturing Operations.	The respondent 3 is part of an American conglomerate which employs more than 211 500 employees, and researches, develops and manufacture Aerospace products.	240 000.
Respondent 4:	Head of Supply Chain.	The respondent 4 is part of a European leader A&D manufacturer which designs, manufactures, and delivers commercial aircraft, helicopters, military transports, satellites, as well as providing data services, navigation, communications.	133 671.

Table 3. Respondent's profile.

3.3 Data Analysis.

The method of data analysis chosen for this thesis is the thematic analysis. According to Jugder (2016), it is the most commonly used method to analyze transcripts of interviews. For Braun and Clarke (2016), the function of this method is to "identify, analyze, and report patterns within the data in relation with the research questions". This method enables the researcher to identify those relationships, discuss them within existing knowledges, and challenge them. To analyze the data from the 4 respondents, the following steps have been followed: transcription, reading and familiarization, coding, searching for themes, reviewing themes, defining and naming themes, and finalizing the analysis (Braun and Clarke, 2016). The coding is made manually, based on data-derived codes than can be found at the beginning of each part of the section 4 (Findings).

3.4 Limitations of the method.

Although the qualitative method was chosen purely to serve the good of the thesis, as it was more adapted to its exploratory aspect, it revealed to be particularly complicated, long, and time-consuming to collect data from the respondents. Indeed, it seems that the nature of the subject, mixing several disciplines, provoked a certain rejection from professionals who, for the most part, did not wish to take part in the study, some of whom did not consider themselves experts enough on the subject, and others who did not want to speak on behalf of their companies. The dependency to the amount of time respondent took to answer the questionnaire delayed the planned research process too, but the unequivocal quality of the responses provided counterbalanced these difficulties.

4 FINDINGS

In this chapter, the empirical results from structured interviews of professionals of A&D industry are presented. After the interviews of experts were conducted by emails, the key results have been translated in different subchapters of this chapter. They are divided and named like the four sections that delineated the questions asked of their companies' experts: Motivation & Recognition toward Industry 4.0 adoption, Category of I4.0 adopter, Challenges toward Industry 4.0 adoption in US A&D value chain, The efficient way for US A&D to adopt Industry 4.0.

4.1 Findings - Motivation & Recognition toward Industry 4.0 adoption

Based on the data collected during the interview, the table 4 represents a summary of the mentioned current motivations and level of recognition toward an Industry 4.0 adoption among US Aerospace and Defense Industry.

Section 1: Motivation & Recognition of respondents toward Industry 4.0 adoption.			
Respondent 1	Respondent 2	Respondent 3	Respondent 4
Very little recognition of I4.0. Wireless connectivity. Sensors. Real-time data. Simulations.	Simulation / Digital thread / digital twin. Cybersecurity. Positive opinion of I4.0 as an advantage. Data connectivity / real-time data.	Data connectivity / real-time data. Digital Thread / Digital Twin. Connecting Data in a single operational intelligence platform.	Robotic Process Automation. Data connectivity / real-time data (behavioral patterns of customers). AI implementation on the medium / long term. Better control on production.

Table 4. Findings - Motivation & Recognition of respondents toward Industry 4.0 adoption.

Overall, the level of recognition toward the Industry 4.0 adoption in US A&D from experts is good. Experts have all heard of the term and recognize the value of the technologies it implies but puts into perspective the ecosystem approach involved in adopting Industry 4.0 for the time being. Indeed, Respondent 3 being heavily invested in Industry 4.0 and digitization, however, shows a moderation on the term Industry 4.0. Indeed, she starts from the premise that the term industrial revolution is itself outdated, and therefore it is futile to speak of a 4th or 5th industrial revolution. For her, we are now in the age of "Technology revolutions". The respondent 4, from the European perspective, appreciate the industry 4.0 approach in "*highly volume intensive activities to reduce the volume or repeatable low value add activities to use the resources the best possible efficiency and release the time from using hands to thinking".*

From these interviews came out a great craze for real-time data, being quoted by all the experts in different ways as data connectivity, single operational intelligence data platform, or real-time data. However, the experts all mentioned different ways of acquiring this data, which is the real challenge for them in the short-term.
Respondent 1 thinks that this can be acquired through other digital technologies such as wireless connectivity and sensors (CPS) for real-time feedback "on how our seats are working in the field". From the concurrent perspective, the Respondent 4 wants to make everything real-time by "*connecting all necessary processes seamlessly*

together and support the E2E (End to End) [supply chain] *with holistic graphical reporting backbone".* According him, this could be achieved by an extensive use of Artificial Intelligence to find behavioral pattern of customers and to enable a "real-time data" based production. This view is also shared by Respondent 4 who think AI should be taken seriously as an investment on the medium and long term. The importance attached to this concept is significant to the point that Respondent 3 characterizes it as a "*corporate asset*". Indeed, she thinks that while Aerospace and Defense industry is suffering from decades of neglect, machines are seen as corporate liability because they aren't able to adjust to shifting market conditions or external events.

Also, a major motivation for simulation technologies, (digital twin / digital thread) has been noted, being quoted by three different experts. Respondent 2 said that simulation is extremely important to his company's work to generate statistics of interest for example. Then, robotics and automation terms are mentioned three times (R1, R2, R4) as a source of motivation, whereas cybersecurity surprisingly isn't mentioned more than once.

4.1 Findings - Current level of Industry 4.0 adoption of respondents

4.1.1 Findings based on maturity model

Based on the data collected during the interview, the table 5 represents a summary of the findings on the current level of Industry 4.0 maturity of interviewed expert's companies. This assessment is based on a maturity model conceptualized by Olsson and Yuanjing (2018). (See Appendix 2).

Section 2: Current digital maturity of respondents.				
	Respondent 1.	**Respondent 2.**	**Respondent 3.**	**Respondent 4.**

Vertical integration of digital technologies.	Maturity level 2.	Maturity level 3.	Maturity level 2.	Maturity level 2.
Horizontal integration of digital technologies.	Maturity level 2.	Maturity level 2.	Maturity level 2.	Maturity level 2.
Development of products.	Maturity level 3.	Maturity level 3.	Maturity level 2.	Maturity level 3.
Manufacturing operations.	Maturity level 3.	Maturity level 1.	Maturity level 2.	Maturity level 2.
Supply chain.	Maturity level 2.	Maturity level 1.	Maturity level 2.	Maturity level 2.
Service maintenance.	Maturity level 2.	Maturity level 3.	Maturity level 2.	Maturity level 1.

Table 5. Industry 4.0 Maturity level of A&D respondents.

The majority of the interviewed companies are at Maturity level 2 for the vertical integration of digital technologies, which means to tie together all logical layers in the A&D companies from the field layer (production) to R&D, MRO, sales, marketing, in order to generate real-time data (Tronserve, 2019), and for the horizontal integration, which means the process of integrating those technologies at the same parts of the supply chain. The level 2 means that experts think their companies started the vertical and horizontal integration of digital technologies only between single departments, instead of across them, or in the whole value chain.

The majority of the interviewed companies are at Maturity level 3 for the development of products, which means it is supported by multiple digital technologies. The answers for the Manufacturing operations section are the most elusive with maturity levels going from 1 to 3. It is important to put in light that Respondent 2 are service providers, which explains the low level of maturity for manufacturing operations and supply chain parts. About the supply chain, the answers go in the direction of an approximate score of 2, as well as for service maintenance, meaning that it is only partially done with the support of Industry 4.0 digital technologies.

4.1.2 Findings – Current and planned digital strategy

Based on the data collected during the interview, the table 6 represents a summary of the findings on the current and planned digital strategy of interviewed expert's companies.

Section 2: Current and planned digital strategy of respondents.			
Respondent 1	Respondent 2	Respondent 3	Respondent 4
Not involved in digital strategy.	No new implementation expected. Development of established aspects.	Digital strategy facilitated by digital exposure of leaders. Aligned enterprise strategies around a common platform. Enabling the digital thread through true use of Internet of Things.	Current Maturity level considered insufficient. Fully automatic order execution loops from customer order to the delivery.

Table 6. Findings - Current and planned digital strategy of respondents.

Due to the nature of the hierarchical and sectoral positions occupied by respondents 1 and 2 in their respective companies, they were not able to answer about their company's digital strategy. For Respondent 3, the biggest driver of evolution for A&D companies is digital literacy increase from organizational leaders. There is indeed a need for them to be more open minded about the mutation of their own industry, and to plan actual concrete strategies (See quote below).

"I hope for strategies aligned around a common platform and enabling the digital thread through true IT/OT [Information Technology / Operation Technolog] *convergence*" (Respondent 3).

Respondent 4 accepted to answer to questions about his company's strategy and affirms that they didn't reach the relevant maturity level for an Industry 4.0 adoption. His company targets for the next few years to set up "*fully automatic order execution* *loops from the customer order to the delivery all the system connected including suppliers"*.

4.2 Challenges toward Industry 4.0 implementation for US A&D industry

Based on the data collected during the interview, the table 7 represents a summary of the findings on the respondent's views on the challenges US Aerospace and Defense companies can meet toward an Industry 4.0 adoption.

Section 3: Challenges toward Industry 4.0 adoption.				
Questions	Respondent 1	Respondent 2	Respondent 3	Respondent 4
Main barriers toward the adoption of Industry 4.0 technologies in the US A&D industry.	Overhead cost of adoption. Scale of Collins Aerospace. Initial investment.	Provide service so can't exploit production aspects of I4.0. Dependence on government guidelines and specific contracts. Corporate uncertainty.	Lack of digital knowledge. Outdated business model. Corporate level uncertainty and outdated leadership.	Limited business volume. Lack of digital knowledge. Geographical distribution of customers. Nature of the Industry.

Table 7. Findings Challenges toward Industry 4.0 adoption.

Overall, the challenges were presented in a frank and effective way, without hesitation or further questioning. Rarer for a qualitative study of this scale, the answers were equivalent but above all balanced. There are responses based on cost, the nature of the business, workforce, and mainly the lack of digital literacy or knowledge. About this one, Respondent 3 claims that it is the reason 70% of digital transformation projects fail at the corporate level. The respondents 1,2, 3 agree that the lack of technological knowledge for higher hierarchical positions, due to the correlation of age and experience, which is even more true in the American Aerospace and Defense industry, poses a real problem to a digital mutation. The respondent 3 goes even further by saying that most of the executives of the industry "have earned their stripes by making a part / pushing a part tied to manual, labor intensive cost cutting initiatives (See quote below). The Industry 4.0 adoption perspective goes at the opposite of this old school management style.

« Most corporate executives have made a career out of being tactical thinkers who made things happen over the last 30 years through brute force, threat, intimidation or a financial shell game until financial market pressures decreased" (Respondent 3).

She affirms that corporate executives from the baby boomers simply don't have the digital DNA needed to navigate into digital transformation projects, and that they tend simply to use catchy buzz words such as "agile" to pretend being innovative, without actually changing anything but a "bunch of territorial status quo (always doing what we always did). Respondent 2 can add to that the workforce generally start projects, or "pilots", at a small scale to get promotion in an easy way, without any real digital literacy. They then change department before any progress of their project in the A&D company, the latter thus being destined to fall into oblivion after 18-24 months of existence.

Also, a barrier usually raised in interviews is obviously money and costs. Respondent 1 shows that "The overhead cost to introduce new technology on a scale of which my company operates can be hard to have approved ». He then nuances his words by saying that people in the A&D industry are conscious of the benefits of Industry 4.0, but that it is very hard to justify the considerable initial investment needed due mainly to digital literacy and the issues raised by Respondent 3. This one, explains too that due to their lack of digital knowledge about Industry 4.0, corporate leaders very often hire consultants who say, "*all the words no one understands but claim digital literacy and they promise to have the solution to all your problems*". There is therefore a lack of link in A&D companies between IT, consultants, leaders, manufacturers, etc., and the IT department.

The nature of the Aerospace and Defense industry in America also plays a role in preventing its players from capturing and exploiting the benefits of the 4.0 industry. Respondent 1, 3, 4 mentioned it in different ways, Respondent 4 supports the idea that regardless of geographic location, whether in Europe or America, the nature of the

Aerospace & Defense business greatly complicates the full exploitation of a model such as Industry 4.0 because limited business volume and geographically distributed customer base of those kind of companies, with only few deliveries per customer per year. Also, he adds that for many companies, the number of repeatable volumes is too limited in many areas to fully enjoy I40. Respondent 3 also thinks that the majority of A&D business models are outdated. She says that US A&D companies are still too much in the perspective of “cost cutting or reducing heads”, and that Industry 4.0 needs a digital business model through agility and speed of connecting and consuming data. Again, Respondent 4 tempers his enthusiasm affirming that his main concern is the nature of A&D industry, where companies have generally more like one off projects with limited deliverable so manufacturing and that supply chain wise I4.0 is not bringing so much except for data analytics.

Finally, a perspective related to the national uniqueness of the US A&D industry is provided by the Respondent 2, who underlines that his company’s main barrier to Industry 4.0 adoption is its dependence on approval for specific contracts or government guidelines as a whole in order to satisfy IT requirements. Strangely enough, given the role that the state plays in the Aerospace and Defense industry, this remark was made only once.

4.3 Findings – A guideline for an efficient Industry 4.0 adoption in US A&D companies

Based on the data collected during the interview, the table 8 represents a summary of the findings on the current level of Industry 4.0 maturity of interviewed expert’s companies.

Section 4: Respondent advices for an efficient Industry 4.0 adoption in US A&D companies.				
Questions	Respondent 1	Respondent 2	Respondent 3	Respondent 4

Main resources for a relevant I4.0 adoption in an US A&D company.	Digital literacy of workforce. Interaction between interaction, design and testing teams.	No knowledge Cybersecurity for its holistic aspect.	Have a real digital literacy. Real digital leadership. Strategic Partnership.	Visual and clear business processes. Long term business models. Strategic Partnership. Visionary digital leadership.
Reasons for US A&D companies to start a digital transformation.	Need of tools with self-decision on minor adjustments. Need for speed of operations.	Speed up of daily efficiency. Spreading out to new sectors.	US A&D facing a massive disruption in data security, governance, and compliance. No influx of technology advancements for 30 years.	Silo approach inside specific activities and function in big organizations. Lack of company level vision regarding the digital transformation.
Recommended process of adoption.	Start small and build up. Trial phase, pilot. Test and adapt.	Start small and build up. Expensive transition so needs to adopt holistic approach.	-> Connect the enterprise -> Rationalize -> Stabilize -> Optimize.	->Analyze the digital maturity. ->Analyze the related process ecosystem. ->Make them support each other. ->Build a vision for the transformation.
Necessary changes for A&D companies.	Digital business model. Teach workforce. Information technology.	Not involved enough in the business decisions of company.	Digital business model. Workforce.	Move from project model thinking to product model thinking. Business model.

Table 8. Respondent advices for an efficient Industry 4.0 adoption in US A&D companies.

In order to establish and propose an industry 4.0 adoption strategy, it was important to ask respondents what they thought were the reasons why US A&D companies should start a digital transformation now. The range of reasons given by the respondents during the interviews is very wide. The first reason is the vital need to boost the productivity of companies in the A&D sector, for example in relation to the competition already mentioned in the SWOT part of the thesis. The respondent 1, 2 think that A&D need to speed up daily efficiency and allow companies to spread out into new sectors. This need to be made for Respondent 1 through wirelessly connected sensor that give real-time feedback but also the use of tools which can make minor adjustments and decisions on their own (Machine learning). From another perspective, Respondent 4 thinks that A&D companies lack a company level vision regarding the digital transformation, and a real understanding of the potential benefits explained in the literature review. He wonders also on the existence of silo approach inside specific activities or functions of these companies about the Industry 4.0 or related terms such as smart factory, industrial internet etc. Respondent 3 goes further than that by denouncing the policies and strategies pursued by US companies the A&D industry since the last 30 years. According to her, they operate in a steady state with almost no disruption, innovation, or influx of technology. She calls it the “business of usual”. But she argues that this era is now gone considering the A&D facing a strong headwind in data security, governance, and compliance. They can’t continue business as usual. She even adds that they may have already begun to render themselves as obsolete and unable to compete.

Before starting any Industry 4.0 adoption, US A&D need resources to carry out such as process. Once again, the need for digital literacy among the workforce is considered paramount by the majority of experts. Respondent 1, 3, 4 agree on the need to have a team and digital leaders, to help understand the requirements needed, and make the right changes. The Respondent 3 supports this point by stressing the need for US A&D companies to be industry experts in what good looks like for their business in order to drive change. The expansion of digital literacy among the workforce goes also through more internal interaction between the different departments such as customer interaction, design team, testing team of a A&D company according Respondent 1. Another very interesting point raised by half of the respondents (Respondent 3,4) is the need to have interesting strategic partnerships. This goes by finding key strategic partners to work with for this transformation journey. It is thus stressed that having 2.3 important partnerships with whom to walk hand in hand, experts in their field, in a technology or other, is much more efficient than hiring hundreds of consultants on short-term contracts, taking the already mentioned risk that they have no digital literacy and content themselves with buzz words, short-term plans, or others. Then, Respondent 2 who claimed not be qualified in this subject enough to answer question, proposed cybersecurity as an important asset to put in place before starting any big scale digitization scale in the company, which also drastically increases vulnerability to cyber-attacks. On his side, Respondent 4 made the point that an important resource for A&D companies was to first establish "*visual and clear business processes, longer term business models to build on".*

When the respondents were asked what their opinion would be on the process to be adopted for effective Industry 4.0 adoption, they all had a similar approach to the question, but with answers that were obviously seemingly in the process form, but different at the same time. The following graphs present the result they provided.

Figure 7. Industry 4.0 adoption recommended process by Respondent 1.

Figure 8. Industry 4.0 adoption recommended process by Respondent 2.

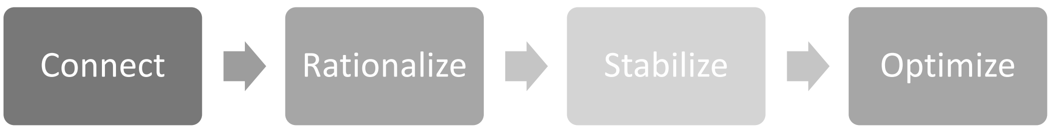

Figure 9. Industry 4.0 adoption recommended process by Respondent 3.

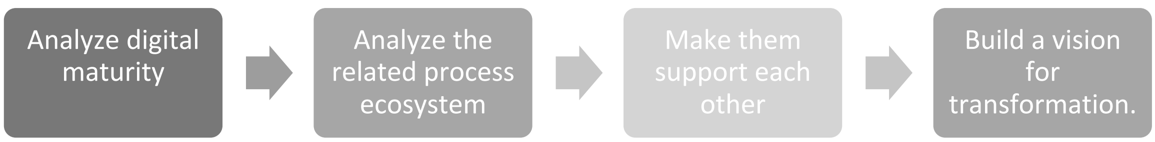

Figure 10. Industry 4.0 adoption recommended process by Respondent 4.

Finally, when asked on which pillars US A&D players could rely in order to implement this digital transformation strategy based on the 4.0 industry model, the results were rather equivalent and balanced. The first answer cited the most times (3 different respondents knowing that respondent 2 did not wish to express himself on this subject considering he wasn't involved in this aspect of his company) was the subject of the business model. Indeed, Respondent 3 and 4 had quite the same opinion on this matter, addressing a necessary shift in the business model. For the respondent 3, it was from an analog business model to a digital business model. She explained that while an analog business model is based on a manual, reactive, disconnected headcount manipulation and cost cutting measures to hit financial targets, a digital business model is a profit building model based on connectivity, real-time visibility, speed and agility to predict and adjust quickly to changing market conditions or global market/environmental events. Respondent 1 could agree with that, stating that adaptation and understanding of I4.0 front end technologies as a part of business model is a first step. Respondent 4 have a kind of similar answer explaining that A&D global industry would need to move from project model thinking to product model think to avoid process wise any one-off implementations. While project thinking focuses on the output and its timelines, product thinking is focused on the outcome. Another area who will be a driver of an efficient I4.0 adoption for A&D companies is the workforce. As the Findings proved it, the lack of digital literacy is a crucial challenge for US A&D companies. Two respondents on three mentioned it in their answers, adding to that the need of retaining talents, and attracting new ones from universities.

5 ANALYSIS

The three research (section 1.3) questions present a way to analyze the implications for US A&D companies of an Industry 4.0 adoption. The data presented in the section "Findings" will be analyzed here with the purpose of answering the research questions.

5.1 How Industry 4.0 is currently impacting US Aerospace and Defense companies?

The results reported in the "Findings" section imply that the intellectual impact of Industry 4.0 on the U.S. aerospace and defense industry is greater than the actual impact on business. Of course, the purpose of this section is not to prove the hypothesis that Industry 4.0 has an impact or not, but to understand the motivations and opinions behind this concept, at this geographical scale and sector.

5.1.1 The Intellectual Impact

The first research goal was to assess the current motivation and recognition of Industry 4.0 by US A&D which could correspond to the “intellectual impact” on those experts. It is therefore obvious that the representatives recognize the importance of a concept such as Industry 4.0, and it is surprising that they are all familiar with the term, considering that other terms such as smart manufacturing, digital factory or industrial internet are more commonly used in their geographical area. Only Respondent 3 noted a judgment on the terminology adopted and clarified that it used another term, “digital adoption.” It is interesting to note that over the course of the four interviews, the level of motivation and recognition in relation to this term definitely varied. It was also clear that despite answering questions about their motivations and visions of the effectiveness of a system such as Industry 4.0 for their industry, some respondents gave answers that went significantly against their initial statements. Also, the results show that contrary to the literature review, technologies with Industry 4.0 do not really interest the respondents, but the outputs of the industry are seen as areas of motivation, even among technical professionals and engineers. Respondents overall were not as alarmist and worried about the state of their industry, unlike respondent 3, who claimed that US A&D industry was suffering from decades of neglect.
Thus, the 4.0 industry has been perceived as very interesting for the US A&D industry especially for its generation of real-time data, which is seen as a "corporate asset" for the future. And this is very understandable because, as the literature review pointed out, US production rates aren’t meeting the new requirements for both commercial

aircraft and defense equipment, and its customers are expecting more and more business models relying on them. Real-time data is a direct answer to those issues, by enabling continuous improvements of product quality, real time production schedule, better cycle times, level of accuracy, precision, customization etc. Real-time data is also an answer for the issue raised by respondent 4 saying that his company had a too geographically distributed customer base with only a few deliveries per customer per year. Respondent 1 would like to use sensors and CPS systems to collect and sell this data; as companies like Boeing, Airbus, General Electric, Bombardier are creating new business models out of this according to Maire and Spafford (Wyman, 2017).

The analysis of the interviews also implies that simulation, digital twin and digital thread technologies were considered being of particular interest to players in the A&D industry. As pointed in the literature review, companies such as Rolls-Royce combine well those technologies by using and generating big data through sensors to create simulations of new engines, and then decide on plenty of criteria on the quality of the prototype. This example embodies the essence of the industry 4.0. Also, robotics and automation are obviously sources of motivation for experts being quoted by three of them. An important fact is that AI technology was cited as interesting by respondents from the US industry, whereas it was considered too recent to justify investment, in the minority by the respondent from Europe. This characterizes, therefore on a small scale, the differences in recognition and motivations between the two main competing industries. What emerges from the interviews is that the 4.0 industry is seen as particularly promising and innovative, but that barriers persist and make it difficult to adopt it as it should be. Cybersecurity was mentioned a little bit in many responses, as if it was obvious in the digital age in which we are engaged that it is a priority for any company, any industry. In this regard, it appears that unknowingly, the respondents' responses raised issues, questions that were answered by Industry 4.0 technologies, each of which was intertwined, improving the quality of each solution by its interdependent nature. It would appear from the intellectual motivations gathered that Industry 4.0 is indeed and should be an ecosystem governing the value chain and holistically adopted.

5.1.2 The impact on business

As was to be expected, and hence the interest of this thesis, the real impact on the respondents' companies was much more relative than the intellectual impact. The analysis of the assessment of the level of maturity of the respondents' companies (Table 5) corresponds approximately to an overall level of industry 4.0 adoption of level 2. According to the theory of diffusion of innovation (Everett Rogers, 1962) discussed in the literature review, they would correspond to the “late majority”. This category is described as a skeptical group, adopting new ideas just after the average member of a social system. As also noted in the literature review, Rogers' theories have been criticized for the difficulty of measuring innovation, and this is found here. The lack of hindsight on other industry players and their own reflection of their level of industry adoption makes it difficult to place them in an appropriate category. However, the maturity model as a tool is useful to understand the impact of Industry 4.0 at the company level, and for them to be aware of what they’ve to achieve to be more matured. For their current digital strategy, it is interesting to note that the respondents themselves are reluctant to express themselves and had additional questions, which implies that their companies did not have a really clear one, or that internal communication was not good, as pointed out the respondent 4 referring to silo effect issues. Not all of the current strategies mentioned were particularly concrete and consisted of "building on what has already been implemented", "better leadership", or justifying its absence by a "current level of maturity that is too low”.

It is important to note that the average intellectual impact and the concrete impact of Industry 4.0 on these industry players implies a lack of communication of the potential benefits of such adoption discussed in section 2.4 of the literature review.
This lack of a concrete strategy reinforces the need for research such as this one, which addresses the challenges of a digital transformation for US A&D companies but also provides keys for its implementation.

5.2 What are the challenges US Aerospace and Defense companies are facing toward Industry 4.0 adoption?

The results reported in the "Findings" section imply that the respondents were very knowledgeable and generous with information for the challenges US Aerospace and Defense companies were facing toward I4.0 adoption.
As discussed in the previous section, the level of recognition and motivation towards Industry 4.0 is high, but the potential benefits of adoption are not considered worth it, or communication about them is not strong enough at this time. Those barriers can explain this low actual adoption rate.

5.2.1 The lack of digital literacy

The respondents mainly think the main barrier facing US aerospace and defense companies is the lack of digital literacy in the workforce. Beyond the need to create a digital workforce for the routinization of activities (Figure 4) related to Industry 4.0 technologies, the real challenge is focused on corporate leadership positions. Indeed, Respondent 3 raised a very interesting point saying that the lack of digital literacy or knowledge was the reason 70% of digital transformation projects fail at the corporate level. The leadership of A&D defense companies seems to be a particularly good example of this. This could be potentially due to the growing number of retirement-eligible employees in the US industry assessed by a report from AIA Aerospace (Rentsch, 2016). A good example of this phenomenon is the company Boeing which employs 14 000 workers over age 61, and 56 percent of the company's engineers are 50 years old or older. Respondent 1 and 3 support this point saying that the baby boomer generation simply doesn't have a digital DNA, and as a result are far away from today's manufacturing sector digital knowledge standards. It seems that this generation of leaders hoping to stay relevant in this digital age use multiple dissimilation processes such as the launch of small-scale projects with no real purpose or old-school style management techniques, through brute force, threat, intimidation, labor intensive cost cutting initiatives that are the opposite of those needed to adopt Industry 4.0. Indeed, the Respondent 2 added that the most experienced professionals

launch projects called pilots, who fall into oblivion after 18-24 months of existence, with the only motivation to be able to present it and reach promotions.
At the same time, while this is a barrier to the adoption of Industry 4.0 for the time being, it is an indicator of a new generation in aerospace and defense that will make this transition. We are therefore in a pivotal period which reinforces the priority of launching major changes now, in order to unlock a considerable competitive advantage over late movers.

5.2.2 The financial decision making.

The main second challenge raised by respondents is the financial aspect of the Industry 4.0 adoption. This factor is obviously linked to the level of digital literacy of the corporate leaders of American A&D companies. Indeed, it seems that the initial investment is not judged too high for the respondents, but that they doubt that it is justified in the eyes of the hierarchy. The respondent 1 affirms that the ecosystem nature of Industry 4.0 implies an overhead cost that would be hard to be approved by his company's leaders. This lack of deep motivation is also linked to the real absence of a digital strategy within Aerospace and Defense organizations. The website Pyxl affirms that one of the main purposes of establishing a clear digital strategy is to track ROI (Return on Investment). A PWC report (2016) surveyed many manufacturing companies and assessed that most companies believe they will see a ROI on their I4.0 investment in the next two years or less while a third of them anticipates longer timescale of three or five years. In the absence of the latter, it is therefore impossible to clearly establish the possible advantages and benefits of a technology implementation, which logically provokes a spiral in which the implementation itself cannot be justified. Instead of dazzling a corporate strategy, A&D companies tend to hire many consultants for short-term projects, distilling a few buzzwords and concepts, ultimately wasting corporate funds that could have been invested in real adoption. This issue has been denounced by Pete Winiarski (2017), claiming that well established companies (such as the majority of Aerospace and Defense companies) should privilege the formation of their workforce for long term ROI instead of hiring too many consultants. The lack of a strategy therefore causes a lack of the crucial link to the full exploitation of the 4.0 industry, with communication problems between players with different interests and individual ambitions to be satisfied thanks to the digital trend. We are talking here about IT, consultants, leaders, manufacturers, who unintentionally generate the silo effect described by Respondent 4.

5.2.3 The nature of Aerospace and Defense industry

The third challenge US Aerospace and Defense companies are facing is the nature itself of their business. Indeed, when reading several consulting reports concerning the adoption of Industry 4.0 in manufacturers, the A&D industry is rarely mentioned in the first examples, for a good reason. As explained in the literature review, the business model of this industry is rather different from others manufacturing sectors. As pointed out previously and by Respondent 4, A&D companies have because limited business volume and geographically distributed customer base, adding to that the cash flow issues already addressed. Thus, it seems the number of repeatable volumes is too limited in many areas to fully enjoy I4.0 benefits. This point of view could be discussed by the potential benefits of I4.0 for A&D companies assessed in the literature review, and by the interdependence nature of the front-end technologies noted in the part 5.1. But Respondent 4 adds that A&D companies have mostly individual projects with limited deliverable, implying that supply chain wise I4.0 doesn't bring so much except for data analytics. To reinforce this point, Respondent 1,3,4 think that the majority of US A&D companies' business models are outdated. The coding shows that companies are too project thinking minded instead of being product thinking minded. This issue from these interviews reminds of the risks related to the implementation of technology for A&D pointed out by the "Clock Speed factor" in the literature review. Guyon et al. (2019) conclude that due to the high lifespan of A&D products, components parts of A&D final product have different "Clock speeds" implying that Industry 4.0 could cause a desynchronization of the whole supply chain.

5.2.4 Governmental incentive

Finally, a potential challenge was raised by only one speaker, but it was considered important to be highlighted; the dependence on approval for specific contracts or government guidelines as a whole in order to satisfy IT requirements. Indeed, the US position is not really clear regarding Industry 4.0, opposing a dilemma between overcoming the unemployment which could be caused on the short term by I4.0, and the need of becoming a leader in the global competition of industrial innovations (Popkova, Ragulina, 2018). So certainly, some incentives are made on a small scale to facilitate this digital transformation, but there is no real national investment for this issue, contrary to European countries such as Germany.

5.3 How should US Aerospace and Defense companies adopt efficiently Industry 4.0?

The results reported in the "Findings" section imply that the respondents have an established knowledge of the pillars US A&D companies need to draw on to adopt Industry 4.0 in their sector. These factors have also been targeted in the challenges section. The data collected and exposed in the Findings section will be also used with the purpose of creating an Industry 4.0 adoption process framework for US A&D companies.

5.3.1 Digital workforce

As targeted, the expansion of digital literacy among the workforce is the priority according to respondents 1,3, and 4. Workforce is the blood of a company. This is not surprising because a PWC report (2016) found through a survey that the lack of digital culture and training was the biggest challenge among two thousand companies in the world. Also, 69% of them say increasing data analytics technology and skills levels is the best road to boost global productivity. Not only will the technologies involved in Industry 4.0 cause huge changes in this workforce across all sectors, as outlined in the literature review, but this industrial revolution is a train that can only be grasped by leadership with digital literacy. While competition from Europe and China is supported by their respective governments, the U.S. Industry needs to launch incentives training programs, especially in a sector like Aerospace and Defense, which is a reflection of national good health on a global scale. As pointed out by the respondents, these changes can only be achieved through leadership, but the conclusion is that they will be replaced by a new generation with a digital DNA capable of fully exploiting the changes already made. It is on this point that the US A&D industry could act, taking advantage of this unfavorable tempo, by getting a head start on the adoption of the 4.0 industry, in order to unlock a considerable competitive advantage and by using this new-blooded workforce, completely in line with the codes of the digital factory. Respondent 1 goes further saying that US A&D companies need more internal collaboration in the organization, between departments such as customer interaction, design team, testing team.

5.3.2 Digital business model

Then, the need of endorsing digital business models has been quoted by three different respondents as an important pillar of I4.0 adoption. If the ways of expressing this change have been different, with for example a shift from analog business model to digital one the idea is the same. The considerable amounts of data collected by A&D through Industry 4.0 have to be used for this purpose, in addition of generating benefits from the value chain. Digital business models are profit building model based on externalities from Industry 4.0 front end technologies such as connectivity, real-time visibility, speed, and agility to predict and adjust quickly to market changes. Those new assets should be exploited to redefine product and services and gain add-value and competitive advantages. This what the company Thalès is doing by developing innovative new Aerospace products based on the front-end technologies presented in the literature review (Lamigeon, 2018). Those products are called minimum viable product and use I4.0 completely to make those products become a reality on the market faster, better and cheaper (Deloitte, 2018). This shift toward a digital business model is deeply linked with the digital literacy factor because it will be achieved only under the authority of management with digitization as a top priority. Respondent 4 would agree with that stating that the digital transformation can be made only with a company level vision. A possibility proposed by Respondent 2 is that the insights based on the data collected could offer main A&D companies a possibility to pivot from being only a product provider to being also a service provider.

5.3.3 Strategic collaboration

The third pillar that emerged from the interviews is the creation of strategic partnerships and more generally a stronger collaboration among the industry. According to Respondent 3,4 this goes mainly by finding strategic partners to work with this transformation journey. Collaboration's benefits are obvious and the exchange of I4.0-related skills within the US supply chain could enable the industry to achieve definitive global dominance. As previously said, Respondent 3 specified that having 2.3 important partnerships with whom to walk hand in hand, experts in their field, in a technology or other, is much more efficient than hiring hundreds of consultants on short-term contracts, taking the already mentioned risk that they have no digital literacy and content themselves with buzz words, short-term plans, or others. A suggestion based on the data collection, when many US A&D industry startups were contacted in the hope of interviews, would be to establish numerous collaborations with these small companies that specialize in the use of certain technologies such as AI, and that could greatly help the larger players in the sector at costs that are definitely lower than potential R&D investments. Also, small companies can be very often more agile and easier to adapt to larger platforms such as American A&D companies (Deloitte, 2018).

5.3.4 A roadmap of Industry 4.0 adoption for US A&D companies

Finally, the data collected on respondents' views on the process to be adopted for effective Industry 4.0 adoption in US A&D companies and the analyses made, led to the conceptualization of a roadmap below (Figure 11). This roadmap describes five practical steps for companies to lead efficiently the digital transformation.

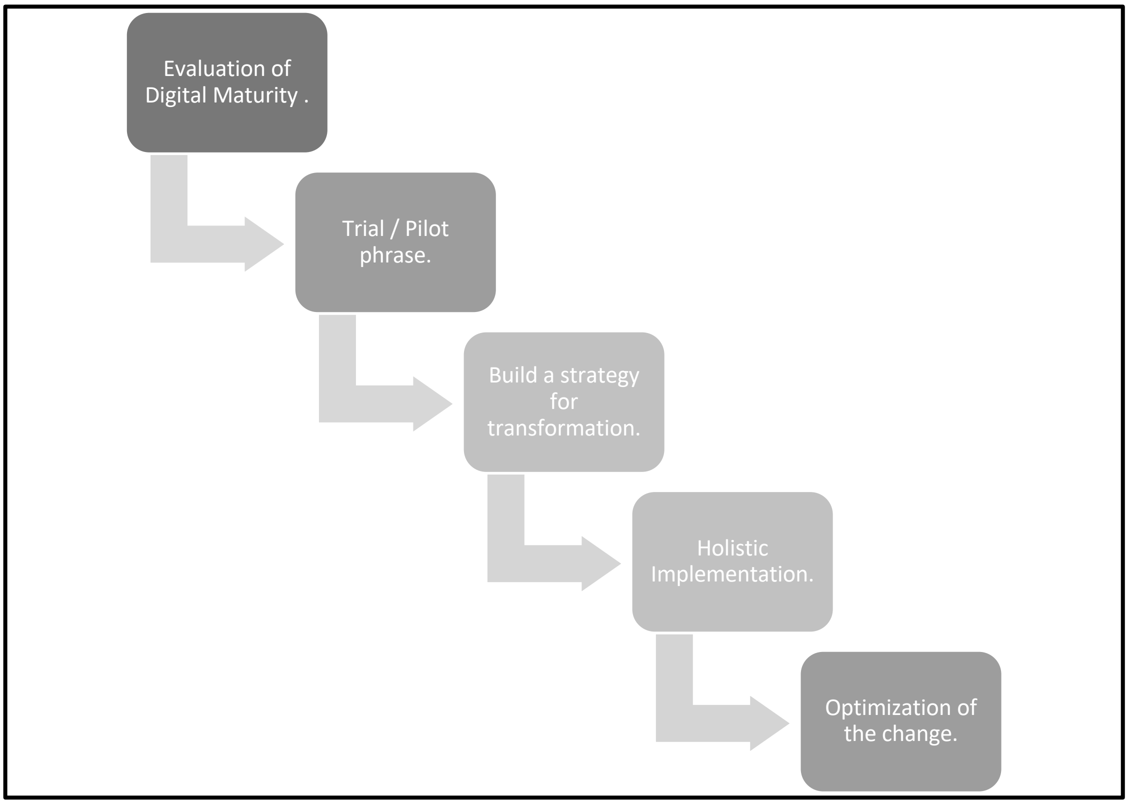

Figure 11: Industry 4.0 Adoption roadmap for US A&D companies (Louis Barbier, 2020).

As it is said in the literature review Section 2.3.3 and by the respondent 4 (Figure 10), the first of an Industry 4.0 adoption for US A&D companies shall be the assessment of their current digitality level, to understand what are their strengths they can already build on, and which systems/processes they may integrate into future solutions (Geissbauer, Vedso, Schrauf, 2014). These assessments are generally made through tools called maturity models such as the one used for the data collection of this thesis (See Appendix 2). Then, based on Respondent 1 and 2 views, companies should run trials and pilot projects. This step is considered important even if criticized by some respondents in a context or led by leaders without digital DNA. If the US aerospace and defense industry is evolving its workforce, then pilot projects will be an inevitable step. Digital A&D leaders have to prove the viability of industry 4.0 through this step and justify the initial investment needed. After the trials phase of the roadmap, A&D companies are aware of what is missing in their approach and need to adapt it to the whole organization (Figure 6). It is the construction of a global strategy for transformation. The workforce and strategic collaboration pillars are crucial to fill the potential gaps. While all these steps are equally important, the crucial step remains implementation. And the conclusions drawn in the section 4.1, the literature review, and Respondent 2 views are going in the direction of a holistic implementation, as an ecosystem. The final step toward the Industry 4.0 adoption is the optimization of the change toward the most efficient results and concrete profits, based on the answer of Respondent 4.

6 DISCUSSION

6.1 Thesis significance

The thesis aim was to provide a potential solution to the US Aerospace and Defense industry players facing the challenges ahead, particularly in terms of productivity. The task has proved to be much bolder than expected, given the immensity of the possibilities implied by a new industrial revolution. The qualitative approach, through interviews with players in this industry, proved to be particularly appropriate. Overall, all the research objectives were answered, final completion of a roadmap for industry players to adopt Industry 4.0 was particularly satisfying and rewarding. It is clear that the issues threatening the US A&D industry can apply to the entire manufacturing industry, on a global geographic scale. However, it was necessary to narrow the scope of the research, and it was not too much, because this task has already proved to be enormous. Due to the bachelor's level of research, it was disappointing not to be able to cover all the topics addressed or analyzed in the literature review, but clear boundaries had to be set, so that the areas considered essential by the respondents could be analyzed in depth. However, if it had to be done over again, the thesis could not be approached in a different way, as it faced not external challenges, but the limits embodied by its level. Areas such as cybersecurity could not be developed out of respect for the motivations given by the respondents, who only briefly touched on this subject, but also out of pragmatism to prevent diversion from the main topics.

In terms of methodology, the interviews were particularly engaging, although some yielded slightly more results than others. Once again, the data collection came up against the challenges that the thesis involved, which had to be answered by high level, high responsibility respondents, most of whom may not have had the time to give a bachelor's level researcher. It was interesting, however, to note also the proportion of industry executives, who did not respond by blaming their lack of knowledge on the subject, which could have highlighted as a lack of digital literacy reinforcing the respondents' arguments on the subject. Unfortunately, as the research was qualitative, this argument was deemed not admissible and usable. It was also surprising to really notice the mistrust of the leadership of the Aerospace and Defense Industry towards these new technologies. Indeed, the response rate increased drastically after establishing LinkedIn connections with other industry leaders. However, once the connections were made with those corporate leaders, it was surprising to note the level of responsibility that it was possible to reach nowadays thanks to the internet, having absolutely no personal connection with such a prestigious industry as Aerospace and Defense.

6.2 Learning points

The research has underlined the following methodology learning points for future qualitative research in this industry:

- The paid services of professional networking sites are incredibly useful and should be used as a basis for interview research, rather than as a fallback solution.
- As in the professional world, the importance of respect and politeness towards those tempted to reach is paramount.
- It is important to bring something to the players in the A&D industry, the benefits of the research must be mutual, and many people contacted for interviews, rejected the offer for lack of knowledge but requested that the results of the present be attached to them, once completed.

Finally, as is the case in much qualitative research, a higher number of interviews would have been desirable in order to increase the reliability of the research and the solutions provided. However, the four interviews provided a lot of data, and a higher number would have extended the research even further. The exploratory nature of the thesis raised many other critical areas that would merit further research, at the master's level for example. This topic would be particularly suitable for students with majors such as Industrial Management, Engineering Management or even Strategy.

7 CONCLUSIONS

7.1 Main findings

Due to its exploratory nature and the analyses made, the thesis provides the empirical foundations and directions for future quantitative research to increase the reliability of the arguments provided by the respondents.
The thesis has first explored the different motivations and level of recognition of an Industry 4.0 adoption for US A&D companies. It has been found that the intellectual impact was important, Industry 4.0 being widely recognized as an unlocker of productivity possibilities mainly through real time data, simulations, digital twin, sensors technologies. In the same time, the actual level of adoption of the respondent companies has been assessed through a maturity level and proved the claims made in the research problem saying that while the huge majority of corporate executive recognized new technologies as key driver of market differentiation, only a minority were actually using them. Based on this point, the different challenges US companies were meeting toward an Industry 4.0 have been discussed with their final identification being the lack of digital literacy of workforce, the poor financial decision making, the nature of the Aerospace & Defense industry itself, and the lack of governmental incentives for innovation. Just as Industry 4.0 technologies form an ecosystem, these barriers are all interrelated. In view of these challenges, recommendations were made by the respondents consisting mainly in building a digital business and transformation strategy, based on three pillars which are the formation of a digital workforce, the transition to a digital business model, and the negotiations of key strategic collaborations. On these three pillars can be built the following adoption roadmap for

US A&D companies: evaluation of digital maturity, trial or pilot phase, the building of a strategy for transformation, the holistic implementation, the optimization of the change.

7.2 Implications for International Business.

This thesis has deep implications for international business firstly through the subject of industry 4.0 and more broadly through the digitalization of manufacturing companies, which is one of the main factors transforming companies on a global scale, in particular through supply chain resonance effects, with suppliers and manufacturers being the first to be impacted. Also, the research raises an issue that is common to all businesses worldwide, which is the lack of digital literacy, but also the upcoming renewal of the ruling class, which will considerably change managerial personalities and decisions. The weak decision making, and the gulfs between the strategies, the projects implemented for personal interests, and the real assets generated is a problem common to all companies, especially large firms like the ones studied in this thesis, where it is easier to hide the real output of a decision. Finally, out of respect for the discipline of international trade, it was decided to make contact with a player from a different geographical area (Europe) from this focus, with the aim and the concern to bring a competitive and international dimension to the research.

7.3 Suggestions for Further Research.

This thesis is one of the first to address academically the adoption of the 4.0 industry, or digitalization in the broader sense of the Aerospace and Defense industry. It therefore makes sense that a great deal of additional research can be carried out, both quantitative and qualitative. Indeed, each section of this thesis, be it the current level of adoption (covered enough to be honest by consulting firms), or the challenges, the potential impact on each part of the value chain, or even the same concept applied to only one part of the supply chain (such as SMEs for example) would deserve further attention. The implementation process more precisely would deserve further research. Finally, the thesis tried to focus on the business aspect of the subject, but the obvious multidisciplinary with engineering may imply further research on the more technical side of such an adoption, on the processes of a manufacturer for example.

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APPENDICES

APPENDIX 1: Interview questions for Solution providers:
Structured.

The following questionnaire has been slightly modified according to the participants.

1 / Motivation & Recognition toward Industry 4.0 adoption.

Which elements of Industry 4.0 do you see as being of most interest to Aerospace and Defense industry either now or in the future and why?

What is your level of recognition of Industry 4.0 as a necessity to solve US A&D industry and your company challenges? As a competitive advantage on a global scale?

What are the benefits you would wish to see in an A&D company due to an Industry 4.0 adoption?

2 / Category of Innovation adopter.

How would you describe the implementation level of Industry 4.0 in the US Aerospace and Defense based on the matrix below? (Appendix 2).

Are you invested in the digitalization of your company's value chain through I4.0 diverse I4.0 front-end technologies?
In which part of your company value chain are planning an I4.0 adoption for the next 4 years?

3 / Challenges toward Industry 4.0 adoption in US A&D value chain.

What main barriers do you see toward the adoption of Industry 4.0 technologies in an A&D company currently, and do you think the arrival of a new generation of digitally trained professionals on the job market could make a difference?

What are the barriers in the different stages of Technological Innovation Adoption (see figure below) you can assess for Industry 4.0 adoption in the Aerospace & Defense Industry?

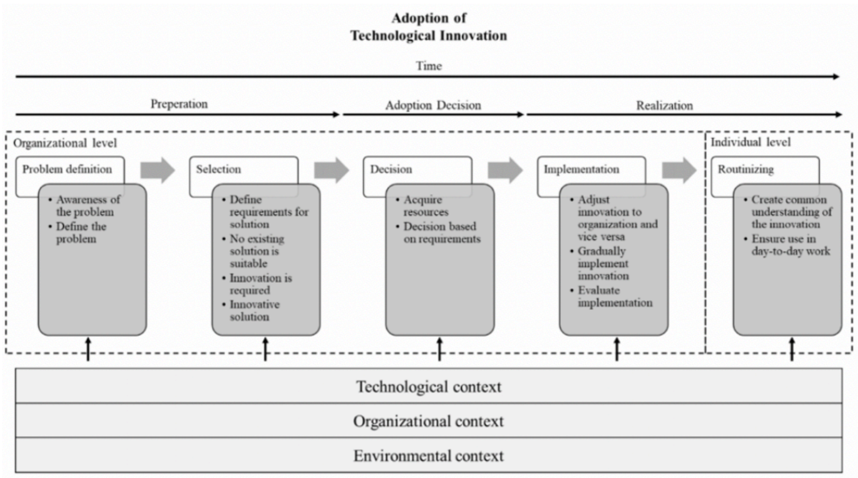

Figure 4. Model for Adoption of Technological Innovation (J. G. Olsson, X. Yuanjing, 2018)

4 / **Recommendations.**

According to you, what are the main necessary resources for a relevant I4.0 adoption in an US A&D company value chain?

Express the key areas why you think US A&D companies should focus on becoming digitally transformed enterprises?

For US aerospace & defense companies, what would be for you a good strategy to adopt Industry 4.0? Can you describe this process?

What changes are necessary for you on the business model, the organization, and the workforce level of an aerospace and defense company?

APPENDIX 2 : Maturity Model.

Dimensions	*Maturity level 1: Process of digitalization has not started yet*	*Maturity level 2: Digitalization of single departments*	*Maturity level 3: Digitalization across departments*	*Maturity level 4: Digitalization across the value chain*	*Maturity level 5: Complete digitalization*
Vertical integration of digital technologies	No vertical integration of digital technologies has been implemented yet.	Vertical integration of digital technologies between single departments.	Vertical integration of digital technologies across departments.	Complete vertical integration of digital technologies throughout the whole company and partially across the value chain.	Complete vertical integration of digital technologies throughout the whole value chain.
Horizontal integration of digital technologies	No horizontal integration of digital technologies has been implemented yet.	Horizontal integration of digital technologies between single departments.	Horizontal integration of digital technologies across departments.	Complete horizontal integration of digital technologies throughout the whole company and partially across the value chain.	Complete horizontal integration of digital technologies throughout the whole value chain.
Development of products	The development of products is not supported by digital technologies.	The development of products is supported by single digital technologies.	The development of products is supported by multiple digital technologies.	The development of products is mostly digitalized and supported by a high variety of digital technologies.	The development of products is completely digitalized and the different processes and steps are interconnected.
Manufacturing operations	The manufacturing process is not monitored or controlled by digital technologies.	The manufacturing process is partially monitored and controlled by digital technologies. As partial digitalized sub processes are implemented.	The manufacturing process is mostly monitored and controlled by digital technologies. As internal processes have been digitalized.	The manufacturing process is almost completely monitored and controlled by digital technologies and M2M communication is partially implemented.	The manufacturing process is completely monitored and controlled by digital technologies and M2M communication is fully implemented.
Supply chain	Information is not shared via digital technologies across the supply chain.	Information is partially shared via digital technologies across the supply chain.	Information is partially shared automagically via digital technologies across the supply chain.	Information is shared automagically all over the supply chain.	Information is shared in real time automagically all over the supply chain.
Service maintenance	Service maintenance is done without the support of digital technologies.	Service maintenance is partially done with the support of digital technologies.	Service maintenance is done with the support of several digital technologies.	Service maintenance is mostly done with the support of digital technologies.	Service maintenance is done with the full support of digital technologies.

Table 1 – Maturity model: Digitalization towards Industry 4.0

(Geissbauer et al., 2016; Koch et al., 2014; Leyh et al., 2016; Lichtblau et al., 2015)