Implementation of the Industry 4.0 in the aeronautical industry in Belgium. A key success factor for maintaining its global competitiveness ?

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Implementation of the Industry 4.0 in the Aeronautical industry in Belgium

A key success factor for maintaining its global competitiveness ?

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I’m grateful to my academic promoter and lectors for having trusted me with this subject. Their wise advice helped me define how to approach the problematic ; especially at the beginning, when laying the basic goal and orientation of the thesis. Each of them brought a high added-value in its dedicated field.

This report would not be comprehensive without the people that accepted to be met and sometimes interviewed. They brought their field expertise to feed the study and I’m thankful to them for taking the time and energy.

Being the concluding achievement of this two year Master in General Management, I take this thesis as an opportunity to warmly thank CMI and my manager for respectively financing it and supporting me through their understanding of logistical difficulties linked to exams and workshops imposed dates and so on.

Managing both the entry in the professional life and an executive Master is not a piece of cake and it implied some sacrifices. Fortunately, my friends and family understood these difficulties and supported me along the road. I’m very thankful to them.

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1. Introduction

This thesis aims at bringing together two significant current trends:

- The digitalization of our economical landscape, namely through Industry 4.0
- The increased competition due to the globalization of industrial trading

Put together, the question that is raised here is to determine whether the implementation of Industry 4.0 in developed countries may be a significant leverage for competing with emerging economies.

Due to the conciseness of this project, the study will be specifically focused on the aeronautical industry in Belgium. The choice of the aeronautical industry is made because it lies at the frontier between regular manufacturing and technological high-end activities.

Why this subject

The reason for me being concerned with this subject is primarily linked to the industrial globalization. Even though it's basically not a new trend (some consider globalization really started when Christopher Columbus discovered the Americas[1]), it's for me important now that the ratio of power might change and that Occident might come to lose its industrial power, with all the resulting consequences.

My technical background naturally leads me to wonder whether new technologies might be the answer for these upcoming challenges.

Methodology

To answer the question, the following methodology will be conducted:

- First, a state of the art will be reviewed, to ensure the best use of previous work related to the subject
- Industry 4.0 and the aeronautical industry will be independently presented, to get a faithful idea of both situations
- Implementation of the Industry 4.0 in the aeronautical industry in Belgium will be discussed. After theoretical applications are introduced, goal is to understand how it could practically happen, namely through case studies

[1] http://www.economist.com/blogs/freeexchange/2013/09/economic-history-1

2. Literature review

Even if no study was exactly dedicated to assessing the impact Industry 4.0 would have on the aeronautical industry in Belgium, a lot of works (most of them published by consulting firms, some by academic institutions) have addressed the digitalization and its consequences on the industrial landscape.

Main outputs of these works is that digitalization must be embraced by public authorities and industrial companies. The availability of the new digital tools must be adopted by manufacturing companies. A study focused on Germany concluded Industry 4.0 could generate 390,000 jobs (Rubmann, et al., 2015). Another study highlighted the expectations of manufacturing companies in the aerospace industry (Gilmore, Kutschera, Hauser, Geissbauer, Vesdo, & Schraud, 2016). It showed through a survey that the implementation of digital tools is expected to enable a cost reduction of 3.7% per annum and additional revenue of 2.7% per annum.

Public organisms have also conducted (and/or financed) numerous analyses focusing on the competitiveness of their industrial powers. A good synthesis of the related findings is the competitiveness analysis of EU, conducted by Ecorys and financed by the European Commission (ECORYS Nederland BV, 2009). It gives emphasis to the historical strong position of European R&D, but also to high labor and energy costs that characterize our landscape.

It has to be noted that a lot of studies on the competitiveness of the aeronautical industry in Europe also cover topics that are out of the scope of this study. For example, the exchange rate risk management, financial markets, technological spillovers of military R&D,… will not be covered by this study, while they are not to be neglected in a comprehensive analysis.

3. Contextualization

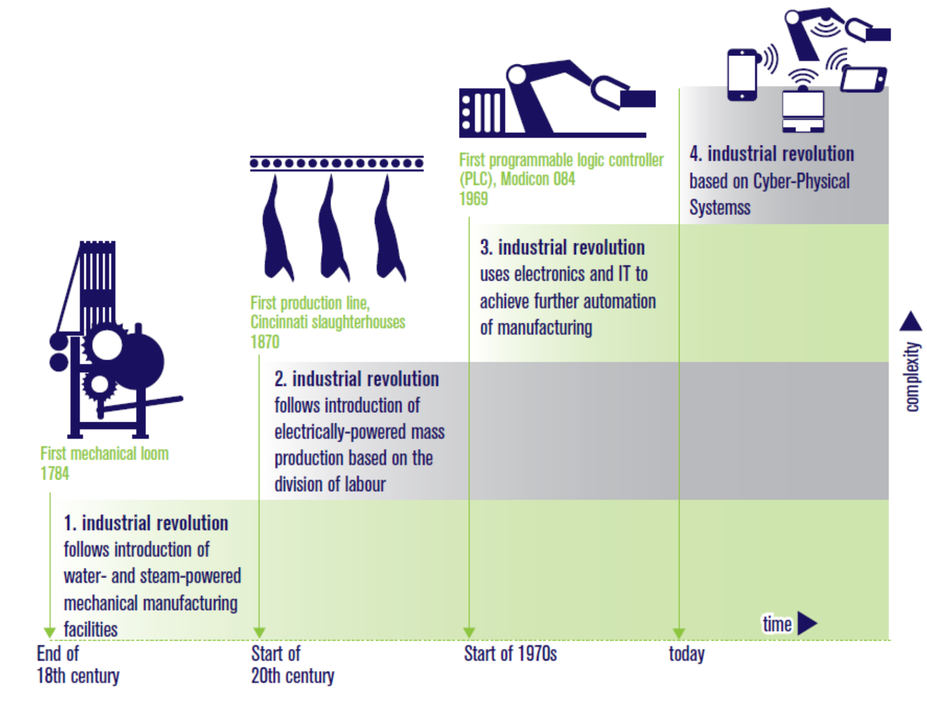
This section aims at developing the two merging fields of this project : Industry 4.0 and the aeronautical industry in Belgium.

3.1. Industry 4.0

For clarification, starting with semantic may be useful. “Industry 4.0” is the direct consequence of the German strategic initiative “Industrie 4.0”, presented by Germany Trade And Invest (GTAI) in 2011 at the Hannover Fair (Kagermann & Wahister, 2014). A series of brand names erupted worldwide afterwards : “Industrie du Futur” in France, “Factory of the Future” for the Sirris technological center in Belgium, up to “Made in China 2025”[2] in PRC.

All these brand names refer to the Fourth Industrial Revolution, following the steam power introduction (18th century), the electrification (1910s) and the first automates (1970s) (Figure 1). Whatever the name used to qualify this 4th Revolution, the driver is digitalization, through a series of more or less specific technologies.

In this study, “Industry 4.0” will be used to qualify the technological revolution described here above.



[2] http://www.scmp.com/news/china/economy/article/2089953/manufacturers-china-ill-prepared-industry-40-says-mckinsey-report

Figure 1: The Four Industrial revolutions (SAP)

3.1.1. Technological aspects

Although the specific technologies involved in Industry 4.0 are diverse depending on the source, it’s useful to briefly present some of the most important of them.

3.1.1.1. Industrial IoT

Sensors and actuators are growing in number among manufacturing facilities due to increasing qualitative constraints. Classically connected through PLCs with Profinet/Profibus networks, they are increasingly connected using wireless technologies. They form an intelligent web of objects able to communicate with each other, vertically and horizontally integrated. Beyond the machines, the products detain themselves information to be shared with the rest of the web, by the mean of labels, barcodes, RFID,…

► In his SmartFactory^{KL}, Bosch Rexroth© implemented a continuous follow up of its manufactured products through RFID[3]. [4]

3.1.1.2. Big data

Using more and more sensors and recording the measurements generate a massive amount of information. Giving value to this ocean of data can be performed using new tools including artificial intelligence and machine learning. Non expected trends can therefore be identified and related actions can be taken.

► Semiconductor manufacturer Infineon© managed to decrease the product failures using cross measurements between failure frequency and very upstream production patterns[5]. [6]

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[3] https://www.boschrexroth.com/en/xc/trends-and-topics/directions/we-are-demonstrating-the-feasibility
[4] https://www.boschrexroth.com/
[5] https://www.infineon.com/cms/en/about-infineon/part-of-your-life-part-of-tomorrow/Industry-4.0-the-change-has-begun/
[6] https://www.infineon.com/

3.1.1.3. Cloud

Cloud commonly allows the access to information from any computer (/phone/tablet/…) with internet connection. But more than sharing storage capacities, cloud can be used to share computation capacity. This cloud computing is the key for achieving huge data analytics mentioned in 3.1.1.2.

► D-Link© has saved 2M $ through the shift of its non-ERP business to the cloud. Beyond the cost reduction, it strongly enhanced its business agility[7].

[8]

3.1.1.4. Comprehensive simulation

Cloud computing is not solely dedicated to Big Data, it also has direct interests for simulation. Simulation as presented in the frame of Industry 4.0 is not limited to a single topic such as aesthetic design, heat flows, electronic connections, mechanical resistance,… Comprehensive simulations tools allow to simulate all the aspects of a new product, machine or even plant, from bottleneck analysis to people flows. Simulated "digital twins" will hence push the design to a next level, avoiding the prototyping costs and ultimately optimizing shapes, material, layout,…

► Battery OEM Banner© is currently reengineering its production facilities using digital twin software of Siemens, such as PLM® and Tecnomatix® suites[9].

[10]

3.1.1.5. 3D Printing

The optimized design of products may lead to ideal parts that are difficult to manufacture with classical methods. This issue can be solved through 3D printing. But beyond this aspect, additive manufacturing could reveal being the manufacturing key for distributed flexible manufacturing capabilities, reducing the lead time and distribution costs.

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[7] https://www.gartner.com/doc/1761616/case-studies-cloud-computing
[8] us.dlink.com/
[9] https://www.plm.automation.siemens.com/en_us/about_us/success/case_study.cfm?Component=250751&ComponentTemplate=1481
[10] https://www.bannerbatterien.com/

► The medical company ACIST© deployed a 100% 3D printing manufacturing process for prostheses. Compared to classical suppliers that are limited to standard shapes, ACIST is able to deliver a prosthesis that fit the unique patient's morphology[11].

[12]

3.1.1.6. Augmented (/Virtual) reality

Another perspective of the systematic simulation is that equipments and plants would virtually exist well before the actual physical construction. During this time, operators could already be trained thanks to virtual reality, allowing them to evolve in the virtual environment that is expected to put them in the same conditions as the definitive situation.

This training before construction is an example but many other situations can justify the use of AR training (such as geographically deported to reduce travel costs, phase 1 AR training to limit risks linked to hazardous equipments, and so on). Augmented reality (alongside with virtual reality) can generate many other opportunities : remote maintenance, immersive design, marketing, …

► EON reality© has provided Volvo with augmented reality tools for personnel training. The tool, called LKDF Interact, trains user on how to fix their diesel engine, without the need of having physical issues to troubleshoot[13].

[14]

[11] http://www.stratasys.com/resources/case-studies/medical/acist-medical-systems
[12] acist.com/
[13] https://www.eonreality.com/portfolio-items/augmented-reality-diesel-engine-training/
[14] https://www.eonreality.com/

This summary of emerging technologies does not intend to be exhaustive. The goal is to briefly introduce the opportunities that are to be considered when talking about Industry 4.0. It has been seen that most of the new digital opportunities are related and support each other, that's the reason why it is consistent to present them as a global trend rather than single technical developments.

Another important comment is to keep in mind that a sine qua non condition for the deployment of these new digital tools is the underlying **cyber security**. Huge sets of data, remote controls and generally speaking cyber physical systems come with the risk of being manipulated by non authorized people that may have fraudulent goals. As this report is written, *ransomware* attacks have shaken Europe, destroying massive sets of data and sticking planes on tarmac for days[15]. Cyber security is therefore a major challenge for ensuring a robust roll out of Industry 4.0 among companies of any type.

► Cyber threats are modeling the way hardware and software electrical grids systems are designed in the US.[16]

►Beyond classical security means (passwords, anti malware softwares, …), disruptive solutions shake the way cyber security has been addressed so far. Blockchain, for example, could open the way for peer-to-peer security to be applied in digital identity, distributed cloud services, and more [17].

[15] http://fortune.com/2017/06/28/fedex-tnt-express-ransomware-attack/
[16] http://www.securitymagazine.com/articles/85785-security-implications-of-the-electric-smart-grid
[17] http://www.huffingtonpost.com/ameer-rosic-/5-blockchain-applications_b_13279010.html

3.1.2. Global implementation throughout the world

Punctual implementations in specific companies and plants have been depicted to illustrate the technological trends in 3.1.1. But this is equally important to investigate what are the global drivers that led countries or regions to digitalize their industry.

These global drivers are typically political. Even if the root causes of Industry 4.0 are selfish needs for diminishing costs, improving market positioning and addressing markets with innovative products, political incentives are a necessary condition for winning the race toward a digitalized economy (K., Taigang, & Lifeng, 2015).

As introduced in 3.1, many declinations of the digitalized industry exist throughout the world. Made in China 2025, Alliance Industrie du Futur, Industrial Internet Consortium are typical examples of political incentives aiming at developing a suitable economical and industrial landscape for the new industrial generation. Setting up innovative clusters and start up incubators, education, eased financing and tax incentives are typically chosen ways to empower the digital revolution (Borrelli, Salvatore, & Pasini, 2017).

The German case

All kinds of solutions mixes exist, so in order to be more specific, the case of Germany is studied more in depth. Germany's plan for Industry 4.0 is called "Plattform Industrie 4.0". This platform has been set up in 2013 by the German business associations BITKOM, VDMA and ZVEI, in the frame of the German's 10 year strategic plan. It now gathers more than 300 players from 159 organizations [18].

The Plattform Industrie 4.0 is structured in 5 thematic working groups, dividing the responsibilities as presented below. The choice of such a division gives an interesting insight on the typical challenges to be faced by a Western economy going toward the digitalization (Plattform Industrie 4.0, 2017). The work is still under progress, but some outcomes are already cleared, and presented below (presentation aims at relating the working groups and the findings at most) (Plattform Industrie 4.0, 2016).

[18] http://www.plattform-i40.de/I40/Navigation/EN/ThePlatform/PlattformIndustrie40/plattform-industrie-40.html

- Reference architectures, standards and norms

Basic idea behind this work group is that a common language is necessary among digitalized companies. For improving communication and fluidity but also to ensure a good working of the innovative technologies together, through design best practices.

A “Reference Architecture Model of Industrie 4.0” (RAMI 4.0) has been published, and has ultimately been formalized thanks to its publication as a DIN specification.

- Research and innovation

Main task of this group consists in accompanying industrial companies through the conclusion of technical contract. This way, they help identify what are the technological obstacles that are met in practice. This diagnosis is fed to dedicated laboratories (Labs Network Industrie 4.0), that are themselves responsible for the innovation needed for filling the gaps.

- Security of networked systems

As securing its network is not the core business of most industrial companies, this group’s role is to help them achieving the fundamentals with the less effort and money. Compilations of best practices are available for member companies, and the group proposes supports for implementation.

- Legal framework

Significant legal challenges await for the digital revolution, such as dividing the responsibilities of an AI that has been programmed by a bunch of informaticians and built in a dedicated workshop. Crucial role of the legal group is to help meet the rapidly evolving needs of tech companies with the inertia of government’s law and juridical landscape.

- Work, education and training

This group is responsible for identifying the changing needs of the industrial market and for giving recommendation for adapting education leading to this market. Beyond that, the group aims at bringing a rational point of view on the threats and opportunities that Industry 4.0 shall have on employment.

In addition to these high level studies and recommendations, the platform has the key role of bringing the numerous stakeholders around the same table, understanding the needs of each of them and helping find common ground. This is pursued through all sorts of networking events and common projects. Eventually, the platform also provides very concrete services to companies willing to strengthen their digital presence, such as a toolbox with practical and intelligible guidelines (Anderl & Fleischer, 2015).

Even if not that tangible because high level, this is important to understand the major empowerment that can be given by professional associations and politics to single companies. As seen later in this study, the Sirris non-profit organization in Belgium assumes a role in Belgium equivalent to the Plattform Industrie 4.0 in Germany.

3.2. Aeronautical sector and focus on Belgium

3.2.1. Presentation of the sector

3.2.1.1. Market

The aeronautical manufacturers are basically providing capacity to airline companies. Hence, the target market here directly depends on the airline passengers needs. As shown in Figure 2, Revenue Passenger Kilometers (RPKs) have been steadily growing for 30 years, with a Compound Annual Growth Rate (CAGR) of 4.7 % over the last 10 years.

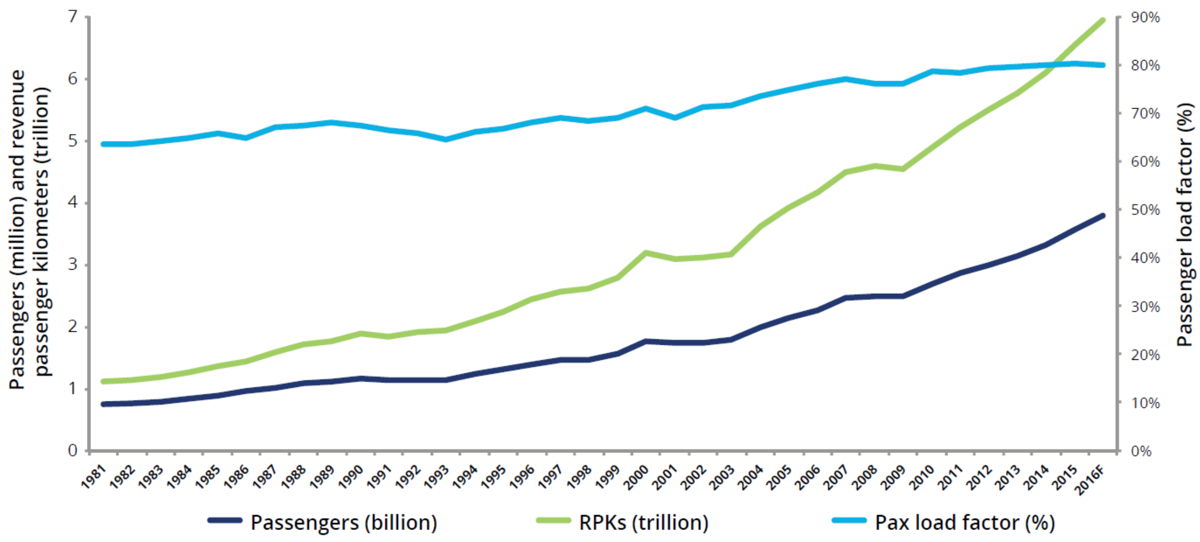

Figure 2 : Global airline traffic from 1981 to 2016E (Captain & Hussain, 2017)

The demand for passenger aircraft is expected[19] to experience a growing trend that aims at satisfying the travel demand. Figure 3 shows that besides this increase in capacity (22,730 new aircrafts), almost as many new aircrafts (16,890 units) will be built in order to replace the existing fleet. This second driver is directly linked to a need for more efficient aircrafts, counterbalancing the long term increase of fuel costs (Kharina & Rutherford, 2015), but this issue is out of the scope of this study.

[19] These figures come from Airbus and Boeing forecasts

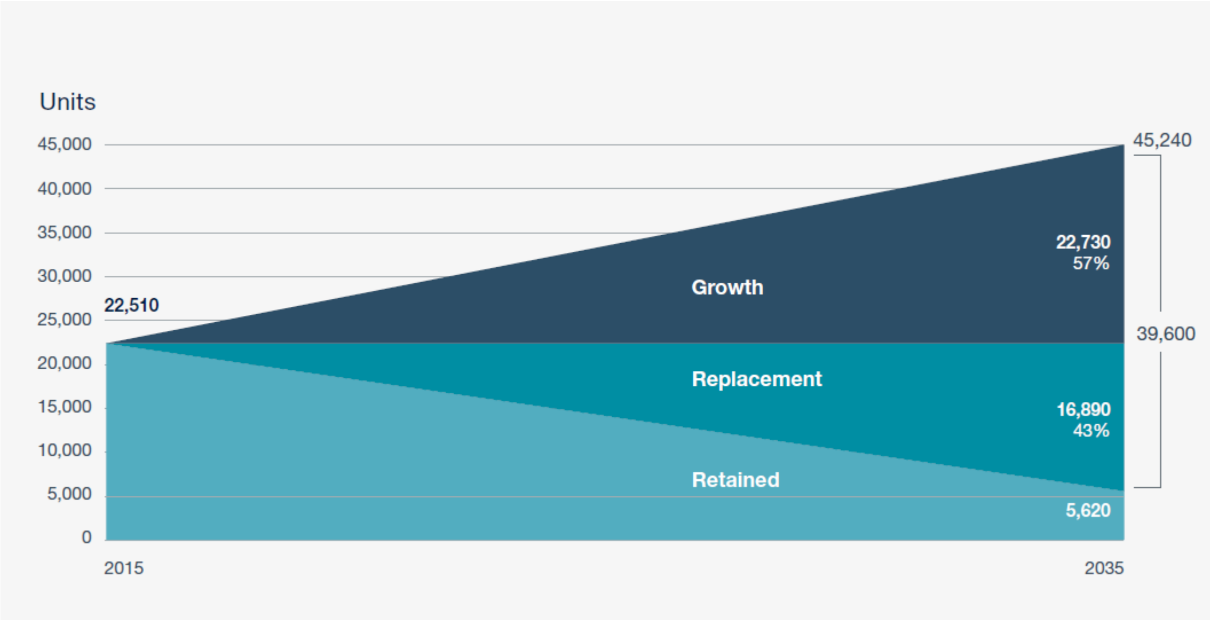

Figure 3 : Expected demand for passenger aircraft (BOEING, 2016)

3.2.1.2. Main actors

The commercial aircraft market is mainly divided among 2 actors : Boeing (US) and Airbus (EU). They share respectively 38% and 28% of the market ; the last third being shared among Embraer (BR), Bombardier (CA) and smaller players (including Chinese new entrants, see 3.2.3.3).

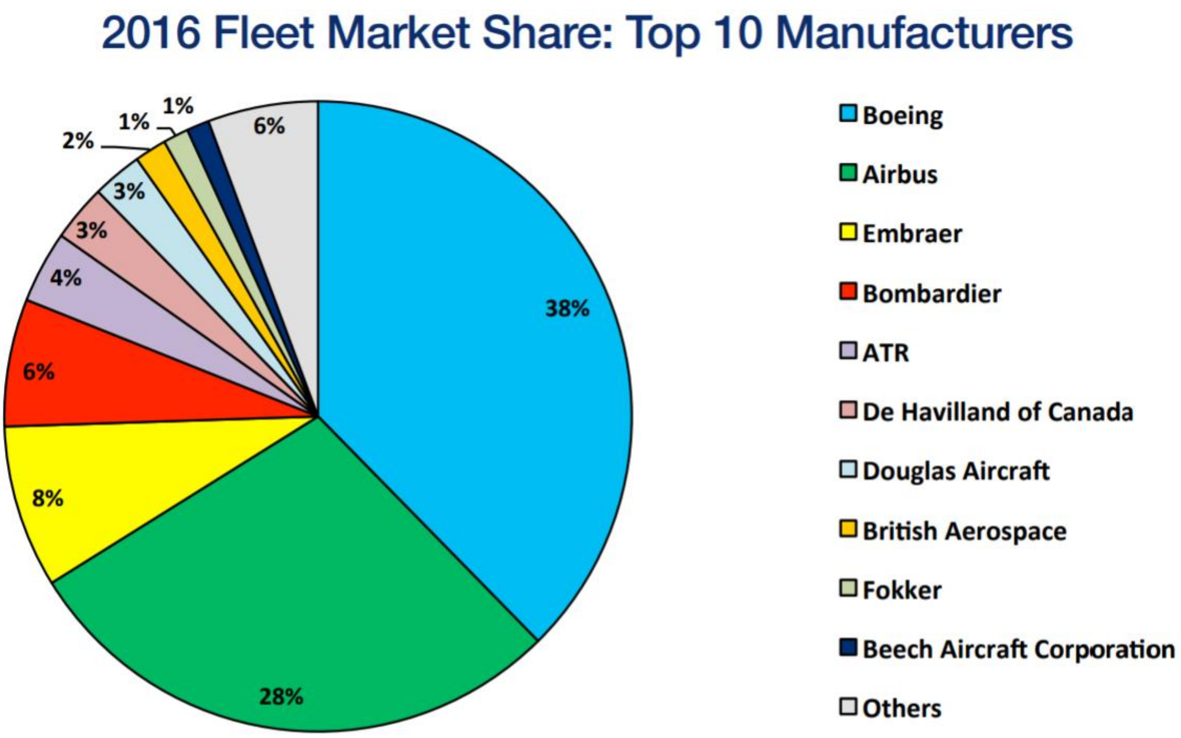

Figure 4 : 2016 Fleet Market Share (Aviation Week, 2016)

These aircraft manufacturers (Original Equipment Manufacturers - OEMs) are themselves supplied by Tier-1 and Tier-2 manufacturers. Tier-1 suppliers typically supply large critical parts, such as jet turbines and fuselage. Tier-2 suppliers provide smaller equipments, such as sensors, screens, seats,…

The top 20 commercial aerospace companies consolidated revenues of 176 b$ in 2016, with operating earnings amounting for 13.9 b$ (Captain & Hussain, 2017).

In Europe, the aeronautical industry provided 500,000 jobs in 2013, with a turnover of 140 b€[20].

[20] https://ec.europa.eu/growth/sectors/aeronautics_en

3.2.2. Situation of Belgium

Although Belgium doesn't benefit from the activity of any aeronautical OEM company on its soil, its economy is strongly linked with aeronautics through the activities of major Tier-1 and Tier-2 companies. Following figures come from statistics of Belgian Minister of Economy (SPF Economie, 2015).

From the 17.5 b€ of revenues generated by the transportation equipments industry in Belgium, only 9.3 % are consolidated by the aeronautical activities. But these activities represent 22.9 % of the value creation. This difference demonstrates the valuable expertise and input of aeronautical companies on the Belgian ground.

This expertise requires and provides jobs to approximately 7000 people in Belgium.

The aeronautical activities are not evenly distributed across Belgium. As shown in Table 1, the aeronautical activity is mainly concentrated in Wallonia (almost twice as much jobs in Wallonia than in Flanders), whereas more than twice of the Gross Domestic Product (GDP) is generated in Flanders.

Indicator	Wallonia	Flanders	Brussels	Belgium
Population [people] (2016)	3,602,216 (32%)	6,477,804 **(57%)**	1,187,890 (11%)	11,267,910
GDP [10^6 €] (2015)	88,547 (23%)	226,219 **(59%)**	68,762 (18%)	383,740
Revenues in aeronautics [10^6 €] (2012)	904 **(55%)**	634 (39%)	98 (6%)	1,636
Jobs in aeronautics [people] (2012)	4,093 **(58%)**	2,355 (33%)	633 (9%)	7,081

Table 1 : Indicators across Belgium. Data from SPF Economie, IWEPS and Belgium.be.

One of the reasons behind this uneven division is the presence of the headquarters of two major companies in Wallonia : Safran Aero Boosters© in Liege and Sonaca© in Charleroi. These companies will be presented later in this report, in the frame of dedicated case studies.

In addition to providing job, generating revenues and added-value creation, the aeronautical activity in Belgium is important because of (BON, 2017) :

- ✓ Spillovers resulting from R&D activities in aeronautics are valuable for other industries (Niosi & Majlinda, 2005). A concrete example is the development of composite materials, that is both beneficial to aircraft's fuselage and tank's turret innovation.
- ✓ Development of side activities, such as mechanical workshops and miscellaneous maintenance companies.
- ✓ The expected growth has to be seized to ensure a healthy development of Belgian economy.
- ✓ It exports more than half a billion Euros a year, contributing to keeping a positive trade balance.

3.2.3. Why a need for vigilance ?

Two illustrative reasons are here unfolded to demonstrate why Belgium (and Western Europe in general) should be vigilant about maintaining its competitive position : the rise of China's air travels and the general increase in China's capabilities. China is taken as an example of what can and do occur in Asia but more generally speaking in developing countries.

3.2.3.1. Rise of China's air travels

Liberalism and growing world's openness drive Chinese people to more air travels (Leung, Li, Hoc Nang Fong, Law, & Lo, 2013). And the strong growth of GDP (CAGR of 9.74% from 1989 to 2016[21]) make these travels more and more affordable.

As a result, significant growth of kilometers travelled by air is expected in China and other developing countries, as shown in Figure 5.

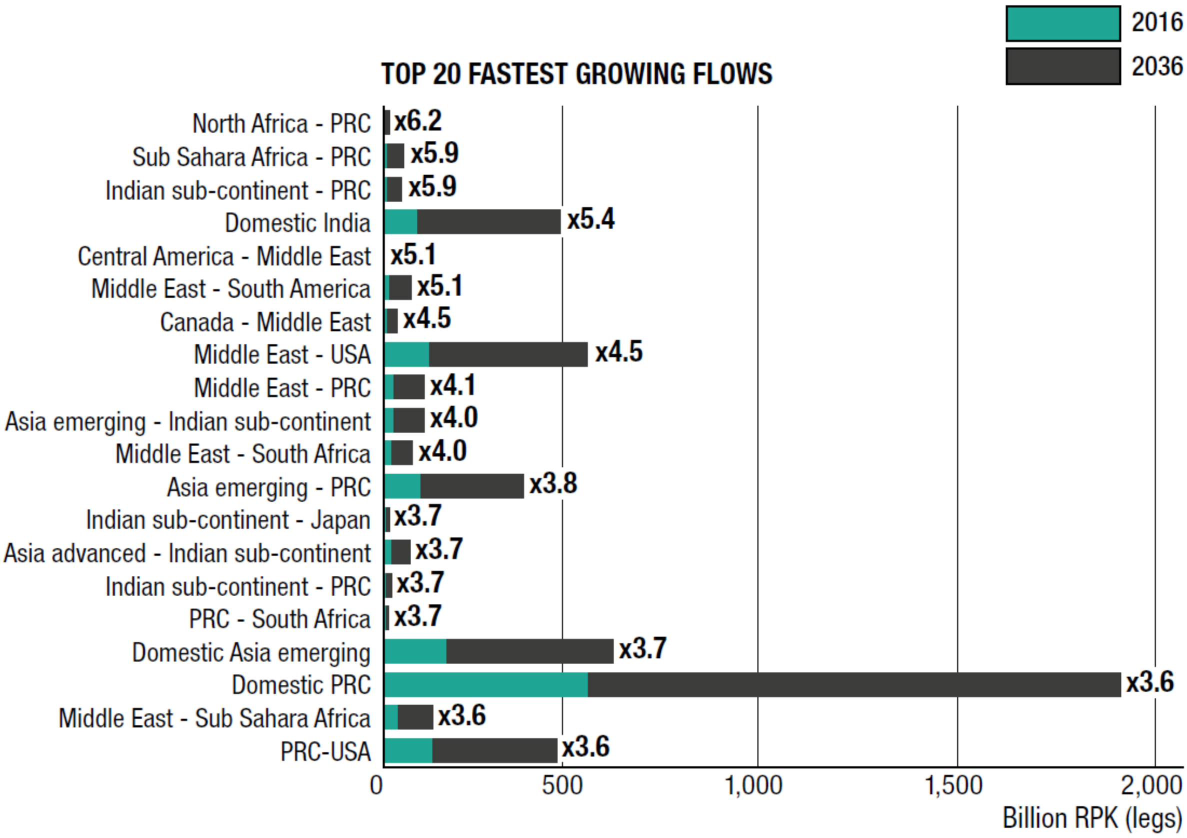

Figure 5 :Expected growths in RPK per country (Airbus, 2017)

[21] https://tradingeconomics.com/china/gdp-growth-annual

The significant emergence of Asian passengers is generating a related need in investment. These investments are intended to cover the infrastructure needs as well as the equipments needs (Clayton, 2014).

3.2.3.2. Capabilities of emerging countries

For years, companies looking for reducing their costs have found suitable opportunities with the developed countries. Benefiting from lower labor costs and available workforce, simple then more complex tasks have been progressively shifted towards emerging economies. Decrease of transportation costs, political bindings and facilitated communication drove this tendency for years, as shown in Figure 6. It has to be mentioned that besides cost reductions, outsourcing and off-shoring offer other significant advantages : for example gaining access to new capabilities and resources, sharing risks, and so on (Handfield, 2006).

Large developing economies are moving up in global manufacturing

Top 15 manufacturers by share of global nominal manufacturing gross value added

Rank	1980	1990	2000	2010
1	United States	United States	United States	United States
2	Germany	Japan	Japan	**China**
3	Japan	Germany	Germany	Japan
4	United Kingdom	Italy	**China**	Germany
5	France	United Kingdom	United Kingdom	Italy
6	Italy	France	Italy	Brazil
7	**China**	**China**	France	South Korea
8	Brazil	Brazil	South Korea	France
9	Spain	Spain	Canada	United Kingdom
10	Canada	Canada	Mexico	**India**
11	Mexico	South Korea[1]	Spain	**Russia**[2]
12	Australia	Mexico	Brazil	Mexico
13	Netherlands	Turkey	Taiwan	**Indonesia**[2]
14	Argentina	**India**	**India**	Spain
15	**India**	Taiwan	Turkey	Canada

1 South Korea ranked 25 in 1980.
2 In 2000, Indonesia ranked 20 and Russia ranked 21.

Figure 6 : Manufacturing capabilities of emerging countries (Manyika, Sinclair, & Dobbs, 2012)

By hosting more and more manufacturing activities, emerging countries are benefiting through two aspects :

- Through foreign investments and technical sharing, they learn from technological capabilities from developed countries. In the steel industry, for example, European experts are sent to train South-East Asia operators on how to master galvanizing lines.
- They receive cash to be invested in internal developments and innovation.

This is particularly true in the Chinese case because the government prevented foreign companies to establish on the Chinese ground on their own. They therefore shared R&D assets and generated domestic profits. China's capital is now massively flowing out of the country (on average 310 M USD per year since 1998[22]), namely buying tech and manufacturing companies such as the takeover of Volvo© by Geely© in 2010.

The natural consequence is the following : from a nice partner to outsource its low added value manufacturing activities to, China is becoming an aggressive and innovative competitor. Strong tech companies as Huawei© (whose 60% of revenues are generated outside China) and Lenovo© (that bought iconic IBM's PC division in 2005) embody this tendency for the electronics industry.

[22] https://tradingeconomics.com/china/capital-flows

The representation of the Global Value Chain

The Global Value Chain (GVC) is a concept that was formalized by the Duke University in 2000[23]. It basically shifts the classical view of the Value Chain to international horizons, emphasizing the importance of collaboration as well as competition among continents to explain the trends in international economy.

It is appropriate to use this concept to support the argument of the growing capabilities of emerging countries. Particularly through studies that were carried about the flourishing role of emerging economies in the worldwide landscape (Gereffi & Sturgeon, 2013).

		Industrial sector				Export	Change in percentage value 2000–11					Export value
Country	Primary products	Resource based	Low-tech	Med-tech	High-tech	Value (US$ Bil)	Primary products	Resource based	Low-tech	Med-tech	High-tech	2000–2011 Per cent increase
China	3	9	30	24	33	1898	(4)	(0)	(11)	5	10	662%
Brazil	32	37	5	19	4	256	11	10	(7)	(6)	(8)	365%
Russian Federation	45	27	2	8	1	478	(3)	8	(3)	(4)	(3)	364%
India	11	39	21	17	8	301	(3)	10	(18)	6	3	617%
Republic of Korea	3	16	9	45	27	555	0	5	(7)	11	(9)	223%
Mexico	20	8	9	38	22	350	7	3	(7)	0	(6)	111%
South Africa	29	30	5	26	3	93	13	(0)	(5)	0	(2)	254%

Figure 7: Export growth of some "emerging" countries

As can be seen on It is appropriate to use this concept to support the argument of the growing capabilities of emerging countries. Particularly through studies that were carried about the flourishing role of emerging economies in the worldwide landscape.

		Industrial sector				Export	Change in percentage value 2000–11					Export value
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South Africa	29	30	5	26	3	93	13	(0)	(5)	0	(2)	254%

Figure 7, exports volume of "developing" economies are experiencing massive growth. That confirms the evolving capabilities of emerging countries as stated above.

Beyond this observation, the GVC notices a shift in nature of exports among these countries. It shows that China and India, for example, are turning their industrial exports to more technological and value added goods and services. Others countries, as Brazil and South

[23] https://globalvaluechains.org/about-us

Africa, are doing the opposite, shifting their export volume from high tech to primary products.

According to the GVC Initiative, this trend depends on the industrial policy of the country. Regulation of trade, political stability and management of exchange trade are main tools to help its economy shift to high tech goods and services, but those considerations are out of the scope of this study (Humphrey, Sturgeon, & Gereffi, 2006).

The take-away of this GVC analysis is that some emerging countries are both strengthening their exports, and shifting their economies to higher value activities (provided they have the right industrial policy).

3.2.3.3. Impact of both trends together

The result of these two trends for the aeronautical industry in some developing countries is fast growing capabilities in manufacturing and innovation.

As a first step, China has been awarded with several production facilities, such as the A320 assembly line in Tianjin in 2008, as a Joint Venture with China Aviation Industry Corporation (AVIC)[24].

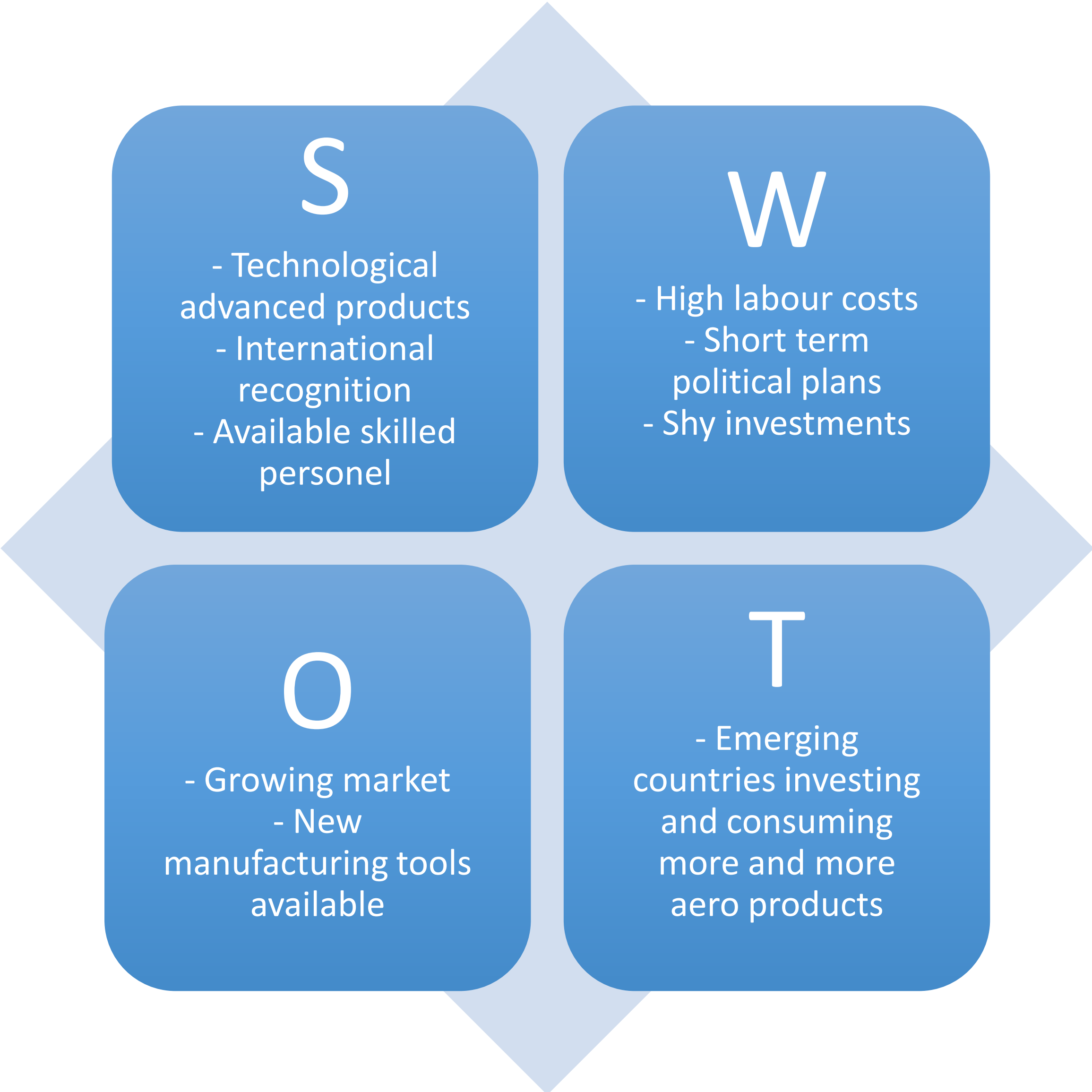
Afterwards, the national aeronautical company Commercial Aircraft Corporation of China (Comac©) collaborated with the major aircraft manufacturing companies and managed to develop the first Chinese aircraft, the Comac ARJ21. This plane was commercially introduced in 2016 under the operation of Chengdu Airlines. The next Comac aircraft is the Comac C919, presenting the same characteristics as the Boeing 737MAX and the Airbus A320neo. It did its first flight on the 5th of May 2017 and is intended to be commercially operational by 2020[25].

It has to be noted that these Chinese aircrafts still use major parts from Western manufacturers, such as the CFM LEAP© motors of the C919, that are provided by a JV between GE© and Safran©.

[24] http://www.aircraft.airbus.com/company/worldwide-presence/airbus-in-china/
[25] http://english.comac.cc/products/ca/

3.2.4. SWOT analysis

To formalize a summary of the situation of the aeronautical industry in Belgium, a SWOT analysis is presented below. Some points have been developed above, others come from studies made by public institutions assessing the situation of European and Belgian aerospace activity (ECORYS Nederland BV, 2009) (Vekeman, 2006) (SPF Economie, 2015).



4. Implementation of Industry 4.0 in the aeronautical sector

This section aims at presenting the outcome that could result from the implementation of Industry 4.0 technologies in aeronautical manufacturing companies.

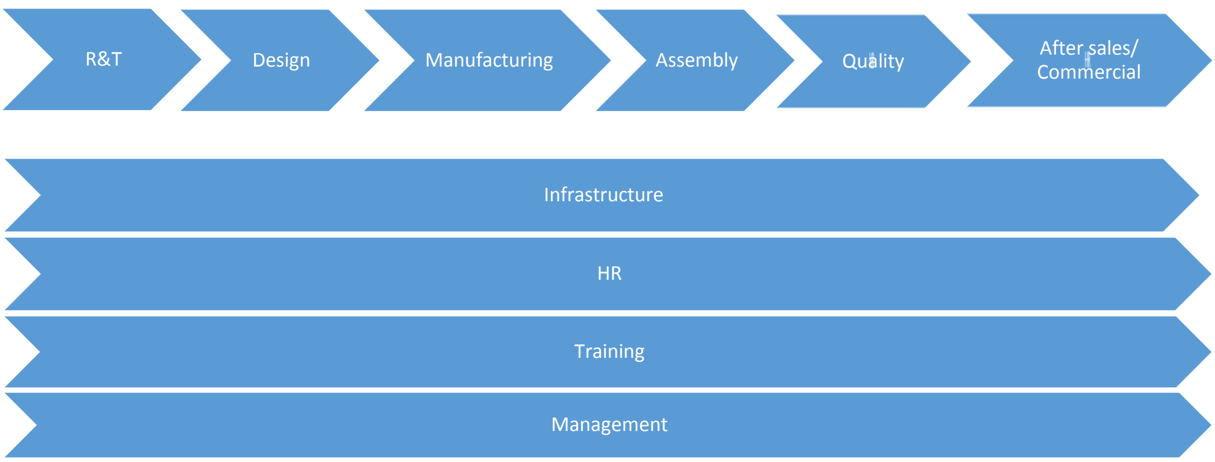
To be more specific, activities of such companies will be divided along their value chain (VC). Key activities of the VC will be presented in their classical configuration (i.e. before implementation of 4.0) and then in a 4.0 configuration. First of all, theoretical implementation will be proposed, based on state of the art technologies. Then, concrete experiences will be used from case studies from Sonaca and Safran Aero Boosters (SAB) to support this study.

Case studies rely on public information from the companies, plants personal visit from the author and interviews that are presented in the Appendices (Chapter 9) (BON, 2017) (DELAUNOY, 2017) (DELVAUX, 2017) (PRETE, 2017) (VANHEVEL, 2017).

Comparisons will be discussed to highlight the potential advantages of the 4.0.

4.1. Typical Value Chain

In order to lay down the situation of an aeronautical manufacturing company, a typical value chain is proposed here below :



4.2. Activities breakdown and study

Each activity has a significant role to play in the competitiveness of the company. As presented in 3.1.1, 4.0 technologies can leverage various types of tasks. This report will focus on the "core activities", that are the most linked to technological value creation.

4.2.1. R&T

R&T activities lie between fundamental research and projects developments. It aims at creating the appropriate technological environment for the fast and efficient resulting developments.

Basically, this activity requires most of all highly skilled workers to identify and investigate unexplored technological areas in an industrial level. They work with various calculation softwares and laboratory equipments.

R&T are no systematic activities. They don't require movements nor material or significant data flows and monitoring. As a result, the implementation of 4.0 is only indirect. It can for example be done through advanced simulation, fed by Big Data and concluded with cloud computing.

SAB case

SAB's investments are in percentage more and more dedicated to R&T. Reason is the need for having the most advanced product on the market with the shortest lead time. It allows SAB to deliver low-pressure compressors that are 15% more fuel efficient than their previous versions, which is the main reason which jet aircraft motorists give them significant orders.

These tasks are critically confidential and no detail can be given on R&T processes of SAB. At least a path of development can be discussed : in order to identify the critical needs, big data type monitoring is to be implemented throughout the manufacturing facilities. It will permit to better spot the weaknesses and how to address them.

4.2.2. Design

Design is the concrete step defining the shape, properties and functions of an equipment/machine/…

The goal is clearly defined and processes are more classical than those of R&T. These activities mainly require dedicated software.

SAB case

Design is a core activity of SAB engineers. They produce drawings of compressors parts and instructions for their manufacturing.

Engineers in SAB use FEM software for CFD, as well as design software such as CATIA© for realizing the drawings.

Drawing design software are progressively integrating FEM capabilities. This horizontal integration increases the agility of various designers and allows for a better usage of data resulting from parts shaping.

4.2.3. Manufacturing / Assembly

Manufacturing and assembly activities are definitely the most suitable for 4.0 technologies. Manufacturing typically consists in machining parts, cutting and forming elements. Assembly relates to bringing manufactured parts together. All these tasks result from a combination of human and machine operations.

SAB case

Two recent 4.0 applications are presented here, 3D printing and FMS lines.

3D printing is seen by SAB to be used in two areas.
→ The first is the production of very dedicated tools for helping the assembly activities . Typically, the assembly requires tools as guides and rules for bringing the parts together in a correct and safe way. These tools are changing as a function of the parts to be assembled, the materials, and so on. Without them, the assembly line is stuck. Originally, they are ordered to external workshops that take on average 5 days to deliver them. This delivery time requires a rigid operation plan and therefore presents some risks of bad usage of men and machines, as well as extended lead time. Thanks to 3D printing, SAB’s operators are capable of producing

the tools locally and within a very short time. The single price is still higher than the external workshops' so it's currently a combination of both solutions that is used.
→ Second is still under development. It aims at replacing some machining operations by compressor's parts additive manufacturing. Critical challenges are not to be disclosed here but the outcome can be huge (cf. 3.1.1.5).

FMS (Flexible Manufacturing System) **Lines** are a very concrete way of using integrated digital intelligence to empower both operators and classic machines.
The principle is that machines and men are better used thanks to an intelligent logistics, performed by a central AI. In a non FMS line, let's consider the piece has to go through a series of machines, each of them performing a machining and/or assembly task. From one machine to the other, an operator has to pick the piece, handle it to the next one and to enter some information in it so it can perform the following task. A lot of bad machine and human usage results from this practice. For example, the man may want to place the piece in the next machine but it may be occupied and the operator is stuck. Similarly, the machine may be waiting for a piece to machine but the operator is occupied on a totally different task. Finally, choices from operators cannot consider all the lead times of the machines in a global vision ; they are therefore not optimized. FMS lines cope with these wastes by handling autonomously the piece before the first operation to be performed, to the exit of the last. Operators simply have to enter the piece on the entry deck, to let the line handle it and to pick it up once all the operations have been carried, taking into account the numerous and complex constraints. SAB already transformed small lines into FMS, and similar works on larger lines are currently being pursued.

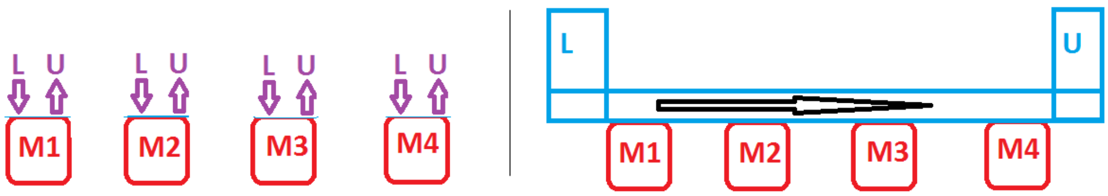


Figure 8: Non FMS and FMS lines (L and U : Loading and Unloading stations, M : Machine)

4.2.4. Quality

Tasks such as quality control and assurance are primordial for ensuring the good performance of the whole process. It helps identify flaws in the upstream activities and helps avoid claims coming from downstream activities.

Generally speaking, quality activities can be seen as various tests that are carried for a product development, certification and qualification.

Acting as a firewall, the filtration process of the potential flaws has to be conducted in a rigorous way. This rigor takes time, which is a scarce resource ; a wise compromise has therefore to be found.

SAB case

To help optimize this compromise, 4.0 technologies might offer assisted diagnostic and systematic flaw identification. Internal developments are under way to enable augmented reality. When achieved, it will allow operators to highlight the sensor (or the part on which it's installed) that gives a defined value.

4.2.5. After sales and commercial activities

This generic package contains very diverse activities depending on the company and the product. It can go around maintenance, product follow up, commercial negotiations, and so on.

SAB case

Once a compressor is delivered, it is mounted on an motor then an airplane and its life becomes way more unpredictable than when it was following rigid manufacturing processes. It can fly over oceans, deserts, or rather mountains and continental landscapes. It can perform short and long haul journeys, with more or less cabin and luggage weight. All those parameters have an impact on the maintenance frequency and the performances guaranteed by the manufacturer. Behind the uncertainties lies room for improvement, and Big Data might be the solution.

With the monitoring of all their compressors in action throughout the world, significant trends can appear in the way they behave depending on multiple parameters. These patterns can then be used to adapt and individualize the maintenance schemes for each aircraft, limiting the related costs and predicting the failures. Negotiated performance guarantees can be better oriented as well, limiting too high risks on some cases and allowing for better performance on others.

This example under development also show the complexity of the data ownership. Complex juridical discussions go around the identification of the (single) owner of the information. The main question is to entail whether the owner is the one that provides the part, the one that integrates it or the one that operates it.

5. Quantitative case study

The choice of investing in 4.0 technologies lies upon many qualitative and quantitative factors. But in order to objectify the choice, a simple tool has been set up. Its goal is to determine whether a 4.0 investment is worthwhile or not, based on the unit cost of one piece manufactured in a plant.

5.1. Presentation of the tool

5.1.1. Introduction

This tool aims at giving a clear overview of the factors that enter into account when considering a technological investment, keeping the compromise between generic application and accuracy to faithfully reproduce a practical case.

First of all, the monthly cost breakdown is developed for the situation before the investment. Then, this cost breakdown evolves and is considered after the investment. If the cost reduction is sufficient, the investment is to be done. The cost reduction has to be above zero in a invest or not situation, or above any reduction that would be offered by any alternative (such as outsourcing).

PARAMETERS				
	Productivity upgrade	Cost of 4.0 investment	Cost of 1 machine	Annual salary
	180%	€ 1.500.000,00	€ 550.000,00	€ 90.000,00
	Utilities overcost	Amortization period (years)	Amortization period (years)	
	150%	3	15	
	Maintenance overcost			Cases in blue to be completed
	100%			

BEFORE THE 4.0 INVESTMENT					
# Parts	/month		650		
Direct costs	#	unit cost		cost/part	%
material cost	650	45	€ 29.250	€ 45,00	31%
Packaging	650	€ 4,00	€ 2.600	€ 4,00	3%
Transport	650	€ 7,50	€ 4.875	€ 7,50	5%
Indirect costs	#	unit cost / month			
Men	5	€ 7.500,00	€ 37.500	€ 57,69	40%
Machines	4	€ 3.055,56	€ 12.222	€ 18,80	13%
Utilities	1	€ 800,00	€ 800	€ 1,23	1%
Maintenance	1	€ 1.500,00	€ 1.500	€ 2,31	2%
Management (OH costs)	1	€ 5.000,00	€ 5.000	€ 7,69	5%
4.0 investment amortization	0	€ 41.666,67	€ -	€ -	0%
Total costs			€ 93.747		###
Cost / part			**€ 144**		

AFTER THE 4.0 INVESTMENT					
# Parts	/month		1820		
Direct costs	#	unit cost / month		cost/part	%
material cost	1820	45	€ 81.900	€ 45,00	43%
Packaging	1820	€ 4,00	€ 7.280	€ 4,00	4%
Transport	1820	€ 7,50	€ 13.650	€ 7,50	7%
Indirect costs	#	unit cost / month			
Men	3	€ 7.500,00	€ 22.500	€ 12,36	12%
Machines	4	€ 3.055,56	€ 12.222	€ 6,72	6%
Utilities	1	€ 2.000,00	€ 2.000,00	€ 1,10	1%
Maintenance	1	€ 3.000,00	€ 3.000,00	€ 1,65	2%
Management	1	€ 5.000,00	€ 5.000,00	€ 2,75	3%
4.0 investment amortization	1	€ 41.666,67	€ 41.667	€ 22,89	22%
Total costs			€ 189.219		100%
Cost / part			**€ 104**		
Reduction			28%		
Reduction if alternative			29%		
Decision			**INVEST IN 4.0**		

Figure 9 : Presentation of the tool (details in 9.6)

5.1.2. Context

Obviously, many parameters to take into account will vary from a situation to the other. The numerical example here is an upgrade of a non automated production facility to an automated one. This case is generic but is also the reproduction of a practical case met in Belgium. The data behind this case shall remain confidential and no information on the company and the final products are to be disclosed. It can be considered the line produces aeronautical components at a significant rate, implying men and machines in the process. At the entry of the line, the raw material is coming from a local mechanical supplier. At the end of the process, the component is ready to be mounted on a large equipment.

Definition of the cost breakdown

Before and after the investment, the same costs are to be found (except obviously the amortization of the investment). They are the following :

- Material costs are the purchased raw material from an external supplier

- Packaging and transport are the protection covers, the box and the loading of the components onto trucks

- Men are the operators that operate the line. One of them is assigned at a basic assembly at the end the line, while the other(s) are operating the machines.

- Machines are typical CNC (Computer numerical control) machining, cut to lengths and deburring equipments.

- Utilities are the plant HVAC (Heating Ventilation Air Conditioning), the lighting and the compressed air and electricity for the machines.

- Maintenance is monthly average of the maintenance activity that corresponds to the replacement of numerous consumables and wear parts.

- Management (and overhead costs in general) are plant’s general expenses that are distributed on this specific production line.

5.2. Comments on the practical case study

5.2.1. Before the 4.0 investment

Major costs are men and material, respectively constituting 40 and 31 % of the total cost of 1 part. As presented in 4.2.3, men are intensively needed to handle the parts from one machine to the next and to supervise each step so the machine knows what is the status of the part and what is the job to be done. The material part is considered not to be a compressible cost, even if the purchasing department might get some discounts through negotiation.

The next greatest cost is the one the machines (13%). The purchase cost of the machines ranges from 300 k€ to 1 M€, and the lifetime period is considered to be 15 years on average. Taking a shorter amortization period would give worse results and would a few sense in this reflection as the cost of the machines would disappear for the amortized machines.

Remaining costs are various and non compressible (packaging, overhead, …). The result is a cost of 144 € for each of the 650 pieces manufactured each month.

5.2.2. After the 4.0 investment

During the 4.0 transformation, the production line keeps its number of machines identical. But there's a significant upgrade in productivity due to the better usage of men and machines. As a result, the number of pieces manufactured goes from 650 to 1820 (+180%).

Direct costs don't change after the investment. Therefore, the material cost then constitutes the major cost contributor, 43% (against 31% before).

The main impact is on the operators. There's a double action, the number of men diminish from 5 to 3 men and the cost of each men is distributed among more pieces. The diminution is related to the fact that there's a need for one operator at the loading station, one at the unloading station and still one at the end basic assembly. This entails a significant reduction, from 40% to 12% of the cost of one piece.

The investment has small impacts on the utilities and maintenance, that are significantly increased but still minor compared to the other costs.

Finally, the amortization of the 4.0 investment has to be considered. The cost of the investment (taking into account the purchase cost as well as the internal costs of supervision, erection, and so on) is roughly 1,5 M€. Considered as a risky move, the payback time had to be no longer than 3 years, hence this is the amortization period considered here.

The resulting cost per piece is 104 €, that being a reduction of 28%.

5.2.3. Critics

Once again, this very simple calculation does not intend to be accurate and is aimed at giving a first idea of the situation. Nevertheless, it’s useful to give some critics on the hypotheses taken and on the situation.

- ❖ The productivity upgrade is actually not fully due to an upgrade of the capacity of the line. The 4.0 investment has been decided when the product orders was expected to largely grow. It is assumed that the line was previously not at 100% but at roughly 90% of its maximum capacity. The indirect costs in the initial case could therefore be split among roughly 10% more pieces.

- ❖ A reduction of the material cost is under negotiation, following the increase in volume.

- ❖ In a more accurate study, the reduction of costs over the years should be actualized with the weighted average cost of capital. Hence, the positive impact would be slightly reduced.

- ❖ The shutdown period during which the 4.0 upgrade has to be installed has not be considered in the cost of the investment. Depending on the way this shutdown is handled (increase of stock to anticipate the break in production, temporary outsourcing,…), a supplementary punctual cost should be considered.

- ❖ Risks linked to the imbrications among all the initially autonomous machines are not considered. A FMS line presents the drawback of being completely stuck if one machine has an issue. On the other hand, there’s less risk that an operator does a bad operation of loading/unloading as there are fewer.

- ❖ The cost of reallocation of operators from the initial line has not been considered. In the practical case, the increase in the whole production offered alternatives that did not entail over costs. In the same idea, training of the operators for the new equipment is not considered.

5.3. Scenarios

Scenarios of alternatives and opportunities are discussed to enlighten significant factors.

5.3.1. Chinese manufacturing

In this scenario, the part would be manufactured in China and imported in the Belgian for mounting on the main aeronautical equipments.

Following hypotheses are taken :

- The biggest cost reduction expectation concerns the workforce. As can be seen in Annex 9.7, historical data consistently give a hourly rate of 6€ per hour (against 100€ per hour in Europe). Maintenance, management and operators costs are decreased taking into account this rate.

- The other decrease is the material cost. Given the fact the entering material has been partially added value by low cost workforce, a decrease of 55% of the material cost is considered.

- An additional cost to consider is the travel cost. In the initial case, a FOB (Free On Board) shipping was considered. Here the sea transport up to the European port has therefore to be considered, at the amount of 0,97€ / kg (the piece is considered to weigh 40 kg).

- Tariffs have also to be taken into account. The raw material here is identified by the goods nomenclature code 7303 00 10 10 of the TARIC database
  i.e. “Tubes and pipes of a kind used in pressure systems of ductile cast iron (also known as spheroidal graphite cast iron), with the exclusion of tubes and pipes of ductile cast iron without internal and external coating (‘bare pipes’)”
  The related rate for this kind of product entering the EU from China is 3,2 %

- Given the fact this product is in the high tech industry, it is consistent to consider that the machines are of European import, and then give the same amortization cost.

As a result, the cost per piece amounts for 102 €. Cost breakdown following above hypotheses is given on Figure 10.

The reduction compared with the initial situation is therefore 29%. At first sight, this choice might seem the most natural one, but critics have to be made to enlighten some hidden costs.

- The workforce cost is strongly decreased compared with the initial situation, finally amounting for only 7% of the total cost. The first comment is that the figures of the US Bureau of Labor Statistics are an average on the manufacturing industry. The operators needed here must possess extra skills to cope with high tech products, therefore their cost might be under evaluated. A second comment is that Chinese salaries are rising very fast[26], with the risk to rapidly become a major cost item.

- The exchange rate of the Renminbi (Chinese currency) with the Euro is also a factor to consider. Formerly pegged with the dollar, the Renminbi is now officially free to evolve following the markets. The result in ten years is that the Renminbi went from 11.12 for one Euro in 2008 to 7.92 in July 2017. This strengthening means more Euros are needed for paying local material and workforce suppliers. This trend is also to be considered as a risk for seeing the Chinese price becoming less attractive.

- On the other hand, transport and machines costs (which are respectively first and third cost factors) should be balanced. In the globally evolving economy, the manufactured components could as well be shipped to Eastern Europe or South America. The fact they are shipped from Antwerpen of Shanghai makes less sense then, but we took the defensive assumption that the component had to be delivered in Belgium. Concerning the machines cost, it will be less and less clear that European imports are needed for high tech equipments, as the education and technology standards strongly evolve in China. Once again, it was a defensive assumption.

[26] https://www.ft.com/video/566dc6b8-db59-38b9-b5ce-07205c76626c

Chinese Manufacturing - BEFORE THE 4.0 INVESTMENT								
# Parts	/month				650			
Direct costs	#	unit cost					cost/part	%
material cost	650		20	€	13.163	€	20,25	20%
Packaging	650		4	€	2.340	€	3,60	4%
Transport	650	€	46,30	€	30.095	€	46,30	45%
Indirect costs	#	unit cost / month						
Men	5	€	960,00	€	4.800	€	7,38	7%
Machines	4	€	3.055,56	€	12.222	€	18,80	18%
Utilities	1	€	800,00	€	800	€	1,23	1%
Maintenance	1	€	192,00	€	192	€	0,30	0%
Management (OH costs)	1	€	640,00	€	640	€	0,98	1%
Tariffs			3,20%	€	2.056	€	3,16	3%
Total costs				€	66.308			###
Cost / part				**€**	**102**			

Figure 10 : Cost breakdown of Chinese manufacturing

Before closing the Chinese scenario, an interesting comment is the fact that investing in the Chinese plant with the 4.0 FMS technology would not be a good economical idea. Indeed, with an European 4.0 to integrate, the surplus in equipment amortization would exceed the savings in workforce and productivity. Of course, if the workforce costs evolve (and other factors), the equation behind the choice might change.

5.3.2. Incentives fully dedicated to employment

This scenario concerns a situation in which the government would try to allocate 100% of its subsidies to strengthen the national employment. Practically speaking, it is considered the cost of 4.0 investment would increase by 500 k€ and the annual cost (wages, support and infrastructure included) of the operators would go from 90 k€ to 30 k€. This extreme situation might represent a specific program to put people at work after a massive bankruptcy for example. It is considered that this significant help for employing people has the condition that workers have to work on the assigned jobs for a determined period and cannot be fired or displaced if an investment leads the job to be redundant.

In such a scenario, the cost per piece would reach 106 € (hence 27%) (see 9.9) . From this situation, investing in the 4.0 technology would be economically neutral, and the choice would be based on all the qualitative constraints.

5.3.3. Economies of scale

In this scenario, the group has decided to realize a massive economies of scale. Practically, it decided to merge its 3 European productions centers (that were considered to present the same characteristics). Hypotheses are the results of this merge are the following :

- Production is tripled
- Economies of scale allow for an increase of the men from 5 to 12 and from the machines of 4 to 10
- Utilities grow with the production
- Management and maintenance costs are doubled
- Transport costs present a 33% increase due to the average distance surplus towards consuming facilities

As a result, the unit cost amounts for 129 € (hence a decrease of 11%) (see 9.10).

Concerning the 4.0 investment, hypotheses are taken that :

- The cost would be 2.5 M€ (66% increase)
  It represents the surplus of capacity and machine is just added features of the 4.0 initial system, but the central intelligence is common.
- The productivity upgrade would be limited to 150 %.
  This represents the fact that the more the machines, the more opportunities to use them wisely. Hence, the augmentation of machines and people limits the productivity upgrade.

With this investment, the unit cost would be 96 € (decrease of 25 % compared with the situation with the economies of scale implemented, and decrease of 33% compared with the initial situation) (see 9.10).

It seems to be the best cost efficient situation. Once again, the figures taken in the scenarios are hypothetical and one given plant producing one given product will present a different profile. Moreover, it has to be noted that making such economies of scale might come with some risks. The plant might become more rigid and procedural than a smaller one in terms of work and production organizations. Some customers need to have their products manufactured from 2 or 3 different sites to ensure the unbroken supply. Finally, internal competition among plants of one group may be beneficial as well to enhance the respective competitiveness.

6. Other factors to consider

During this study, other factors were met when considering the competitiveness of the European aeronautical industry. This is fair to mention them here to place the 4.0 implementation in its context.

- ✓ **Innovation**

  Innovation is certainly the most important leverage to empower the European actors. In the high tech industry that is aeronautics, the robustness and the performance of the products are highly valuated. Flaws are not accepted in the whole supply chain. As a result, aeronautical actors are ready to pay a premium for these qualities, getting rid of the production cost difference.

  For example, on the lifetime of an aircraft motor, the acquisition cost amounts for only 12% of the total cost, 3% being dedicated to maintenance and the remaining part to the fuel consumed. The new low pressure compressor of Safran will be dedicated to the new LEAP motor of Snecma and GE. This compressor offers a fuel efficiency 15% better than the previous version. This is therefore highly valuable and even if the production cost is higher, it will be successful thanks to its innovation.

- ✓ **Regional technical support**

  Besides innovation, local manufacturing facilities can rely on the regional technical support. Long term partnerships have led trusted relationships to tie the large manufacturers and gravitating SMEs together. These symbioses are valuable and can be a drag for an installation in an emerging country.

  However, this consideration is true in the mind of Belgian aeronautical actors but is no longer in the case of some electronics manufacturers for example. Shenzhen (south of China) has even become an heaven for electronic manufacturers such as Apple’s Iphone and Intel’s chip sets.

- ✓ **Fiscal balance**

  As seen in the case study, one of the main cost item is the workforce. This is namely due to the fiscal charges that both employers and employee have to pay. These charges fuel the social system, that is useful for active and non active people. A smart compromise has to be engineered to make the European workers interesting for the manufacturers, while fueling enough cash for government expenses. This compromise will be specifically challenging to find in the coming years, with a strong ageing of the European population. The balance could for example be eased through the optimization of the administration and the taxation of financial flows.

- ✓ **Energy policy**

  Utilities cost can be decisive in the manufacturing process. In the case study, the activity was machining, deburring and assembly, which is not energetically intensive. But other tasks such as thermal treatments and wind tunnel testing can be heavily gas and electricity consuming. Therefore, a competitive and consistent energetical offer should be available for the aeronautical actors in Europe.

- ✓ **European preference**

  Most countries of the European Union are too small to set competitive programs against the USA, Russia and/or China. A group effort has to be taken to use empower the qualities of each country and to limit its flaws. The European preference can take the simple form of the tariffs, but homogenized certifications and free flows of goods and data are critical as well. A nice example of such partnerships in Europe is embodied by the European aircraft manufacturer Airbus.

7. Conclusion and perspectives

The situation of the aeronautical industry has been depicted with a focus on Belgium and it was shown that the historical strong presence may be at risk of facing emerging competitors, namely from Asia. Losing this activity would be economically harmful because of the jobs it provides and the value it creates.

On the other hand, a panel of digital technologies constituting the famous Industry 4.0 becomes now available. Generally speaking, they can handle a variety of tasks and offer to reduce the costs, shorten the supply chain and related lead times, improve product quality and leverage innovation.

The applications of these 4.0 technologies were discussed in the aeronautical industry, taking a typical value chain to sort the types of usages. Beyond the global industry, specific applications cases (implemented, under progress and in exploratory phases) were screened in Safran Aero Boosters. It gives a concrete vision of the way Industry 4.0 is able to empower a Western manufacturing facility.

After those mainly qualitative considerations, a quantitative case study (depicting the FMS line of Safran Aero Boosters) has been carried out and a tool was implemented. This case enlightened the principal cost items at stake, showing the workforce constituted 40% of the total cost. The 4.0 investment was in this case able to reduce this percentage to 12, bringing the cost of one manufactured piece from 144 to 104€ (-28%). Besides the initial case, different scenarios (Chinese manufacturing, incentives for employment and economies of scale) were used to analyze how the cost items and subsequently how the attractiveness of a 4.0 investment evolved.

The conclusion of both the field study through interviews and the quantitative case is that Industry 4.0 is definitely a ke leverage to maintain the Belgian competitiveness in the aeronautical sector (even if not the only one). But the investment choice depends on many factors and each situation is different. Anyway, field feeling is that you don’t have to make your plant 100% 4.0 to benefit from its advantages. The recommendation would therefore be to get iteratively closer to it, already allowing for quick wins improvements.

For next steps, the tool should become more accurate and comprehensive ; it would allow for a 1st order assertion of the need for 4.0. Opening the confidential industrial data of investment studies would also give useful benchmarking on the punctual needs for 4.0.

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9. Appendices

9.1. Interview with Claudine BON, Deputy Director of SKYWIN

9.1.1. Introduction

The aerospace cluster, SKYWIN Wallonie, is a group of companies, training centers and research units engaged in a public and private partnership and building synergies around common and innovative projects. It counts more than 150 members among which more than 90 SME's.

Its objectives are to foster and promote the technological advance of Walloon Aerospace companies and to enhance their activities through:

- Public subsidies, financed by the Walloon Government
- Cross collaboration among all its members (industry and research centers)

9.1.2. Interview report

On the 12th of July 2017, I met Claudine BON, Deputy Director, and asked her the following questions. Condensed answers are stated below.

[Valentin Fontaine - Interviewer] Why is the aeronautical industry important for Wallonia, Belgium, and Europe in general ?

[Claudine BON - Interviewee] The aeronautical industry is currently one of the most performing. Furthermore, it is expected to grow for at least the next 10 years. It generates strong benefits for suppliers that are not specifically dedicated to aeronautics (general mechanical suppliers,…). It is specifically important now that older industries such as siderurgy has to be replaced because taken over by lower cost countries.

[VF] What explains the strong presence of aeronautical companies in Wallonia ?

[CB] The current situation is mostly due to historical reasons, such as as the existence of companies like "Avions Fairey" (later SONACA), SABCA, Fabrique Nationale (splitted in FN and Techspace), and the strong academic expertise. This expertise allowed more standard mechanical companies to switch towards higher value activities, defense and aerospace for the most part. The political force was strong also and was able to empower the aerospace companies with a clear view on what was the target to aim.

[VF] Should we fear a decrease in Belgium's competitiveness?

[CB] Yes, we see that new comers are shaking the aeronautical industry. For example, China and India are starting to manufacture and assemble aircraft parts. They benefit from massive low cost labor workforce. Airbus and Boeing are negotiating contract with suppliers each year, driving them to reduce their price and hence their cost if not their margin.

[VF] Does the current technological level in Wallonia correspond to 4.0 criteria ?

[CB] Definitely not, too much inertia slows down this needed shift. This inertia is mainly present in SMEs. That's one of the reason why SKYWIN strongly supports its members (SME's), it allows companies and specifically small ones to benefit from state of the art technology. But habits have to change as well.

[VF] What is the importance of the gap to be crossed to reach Industry 4.0 ?

[CB] Much efforts are being done in the right direction. The remaining gap is difficult to quantify but main point to improve is the vertical integration that is needed for an homogeneous organization of the supply chain (use of same software, for example). If the gap is significant, this is due to the very recent jump in the available digital technologies that manufacturers have to quickly adopt.

[VF] Would the implementation of Industry 4.0 help improve Belgium's competitiveness ?

[CB] Definitely. As I mentioned, OEM are each year renegotiating their contracts. They want each year a few percent price reduction and reduction in lead time, flexibility of products. These improvements are now only achievable through the adoption of all the technologies promoted in the industry 4.0.

[VF] Industry 4.0 is therefore necessary, but is it sufficient ?

[CB] No, beyond the improvements offered by the 4.0, innovation will be the key to ensure a healthy development of the aeronautical industry. We have to produce in an effective way, but we have to produce innovative products, developed by our scientists, universities and competence centers.

9.2. Interview with Jean-Marc Delaunoy, Industrial investment strategist at Safran Aero Boosters

9.2.1. Introduction

Safran Aero Boosters (SAB) is a company of the French group Safran, active in Aerospace, defense and security. SAB has 4 areas of expertise : mainly low-pressure compressors, but also lubrication, test cells and space equipment.

SAB is located in Milmort, Liege Province. It employs 1450 people and generates an annual turnover of more than 650 M€.

Focusing on low-pressure compressors, it has to be noted that SAB is the world leader, consolidating 75% of market share in the single-aisle and 50% of the twin-aisle commercial aircraft market. This position is mainly ensured through partnerships with the sister company Safran Aircraft Engines with General Electric. For 15 years, SAB's low-pressure compressors equipped the CFM56 ; new model is now equipping the LEAP motor, namely giving thrust to the Airbus A320neo, the Boeing 737MAX and the COMAC C919. Major twin-aisle segment program for which SAB is also providing its products are the Boeing 787 and the Being 777X.

9.2.2. Interview report

On the 18th of July 2017, I met Jean-Marc Delaunoy, industrial investment strategist, and asked him the following questions. Condensed answers are stated below.

[Valentin Fontaine - Interviewer] Do you see an emerging competition from developing countries ?

[Jean-Marc Delaunoy - Interviewee] The emerging competition is a reality but the threat is limited on the short term for companies such as SAB. The reason behind it is the innovation advance of SAB compared with potential emerging competitors and the strong industrial footprint.

[VF] Does this emerging competition drives SAB to improve its products and its internal processes ?

[JMD] Yes, there is need to maintain the gap with competitors. The improvements are on two sides. First is on product development through R&T, second is in production efficiency through machine and robots investments. R&T is the competitive advantage of SAB because it contributes to make its low pressure compressors more efficient. For example, the LEAP motor is 10 to 15% more fuel efficient than CFM56 (previous motor). But machines and robots investments are important as well. It can be noticed that the new digital technologies that accompany classical machines act as a leverage to make them way more efficient.

[VF] Is Industry 4.0 a consistent mean for achieving these improvements?

[JMD] Yes, it is suitable contributor to empower the capital investments. It can be noticed that the new digital technologies that accompany classical machines act as a leverage to make them way more efficient.

[VF] Is SAB working 100% 4.0 ?

[JMD] Definitely not, some machines and areas of the facility are 4.0, but not the whole plant. Our focus is always to invest where there is a decent return on investment. It is not the case for all initiatives.

[VF] What are examples of processes that just turned 4.0 ?

[JMD] FMS (Flexible Manufacturing Systems) lines are a nice example of an intelligent investment that leads to an optimized use of both workforce and machines. This optimization leads to cost reduction close to 25% (considering that there's a sufficient demand to load the production lines which is the case for our flag programs). Additive manufacturing is another example of investment that SAB is making. This is allowing more complex designs to be manufactured, but also to diminish lead times and overall cost for small series/prototypes.

[VF] What are examples of processes that will soon turn 4.0 ?

[JMD] Projects are under way about big data ,augmented reality and cobots. Big data would be achieved through the monitoring of machining equipments, recording vibrations, pressures,… in order to reduce the defect risk and to predicatively maintain the equipment. Augmented reality is already used on other Safran sites and is aimed to be applied in SAB in the frame of optimizing assembly operations, maintenance, training,… Cobots should help us in assembly operations with a positive influence on efficiency and health (reduce the burden of high loads carrying).

[VF] Are there processes that won't be turned 4.0 ? Why ?

[JMD] There are some machines that will probably not be integrated in an intelligent logistics scheme. For examples, some machining equipments work autonomously for almost the whole day before needing an operator. It makes little sense to integrate them in FMS lines.

[VF] Quantitatively, what is achievable through the implementation of 4.0 ?

[JMD] It is sensitive to give quantitative analysis but globally, technology and other productivity improvements have been able to help engine manufacturers beat inflation for the last two decades. On specific operations, though, more significant reduction can be achieved, as the FMS line discussed before.

[VF] Is it sufficient to cope with emerging competition ?

[JMD] This is a question that doesn't have a firm answer to. However, I am convinced that all the technologies that tend to reduce the economic impact of our relatively expensive work force have a significant impact on competitiveness. We working hard to achieve that goal.

[VF] What are the obstacles to the implementation of 4.0 ? How should they be overcome ?

[JMD] Main obstacle is linked to resistance to change. Whether it's be because people actually risk to change their job, rotate to other jobs within the company, or that people would simply fear to lose their job, this is the main obstacle to the implementation of 4.0. Indeed, these new technologies are efficient if used with the spirit to make production more efficient. If the workers are not on board with us and understand what they eventually will gain from it, the outcome will be disappointing and first steps towards 4.0 may be the last.

[VF] What would be your recommendation for industrials thinking about 4.0 ?

[JMD] As mentioned just before, change management is obviously a key to success. Besides I would recommend to keep the final goal of 4.0 in mind. There's no sense in digitalizing if there's no payback. Intelligent transition towards 4.0 has to be industrially meaningful, not to be a pure quest for new technology. Finally, a nice advice would be keeping his eyes open to what is done among other industries because 4.0 technologies are transversal to several different industries.

9.3. Interview with Bernard Delvaux, CEO at Sonaca

9.3.1. Introduction

Sonaca is a leading Tier-1 and Tier-2 player in worldwide aerospace. While the headquarters are located in Charleroi (BE), its subsidiaries expand through the world (Canada, Brazil, Romania, China, and recently USA with the acquisition of LMI aerospace[27]).

Sonaca's major products are aerostructures such as movable wing leading edges (for which it gathers more than 50% of market share) and wing skins. It is responsible for the development, manufacturing and assembly of the products.

9.3.2. Interview report

On the 8th of August 2017, I met Bernard Delvaux, CEO. The interview was not recorded and no report was agreed to be disclosed.

[27] http://ir.lmiaerospace.com/releasedetail.cfm?ReleaseID=1031491

9.4. Interview with Rik Vanhevel, Principal Engineer Smart and Digital Factory at Sirris

9.4.1. Introduction

Sirris is a competence center aiming at bringing together technological players and industrial companies. They offer high tech expertise to large and small businesses in Belgium.

They are a nonprofit organization of 150 experts, distributed in 8 sites in Belgium.

One of the site is the Smart and Digital Factory in Courtrai. This pilot plant is dedicated at providing companies with actual examples of 4.0 implementation. For example, cobots and assisted operating tables are installed. Operations can be tried by the visitors, such as taking parts to be assembled when the intelligent platform sheds light onto the necessary part, while numerous sensors check the operations are correctly conducted to ensure a maximally reduced risk of subsequent claims. This hands on experience allows for realizing what can be achieved in a very practical way, contrasting with all the study reports of which SMEs are quite far.

9.4.2. Interview report

On the 9th of August 2017, I met Rik Vanhevel, Principal Engineer Smart and Digital Factory, and asked him the following questions. Condensed answers are stated below.

[Valentin Fontaine - Interviewer] Do you currently see a punctual breakthrough in manufacturing technologies ?

[Rik Vanhevel - Interviewee] Numerous “4.0 technologies” are available for years. But the current breakthrough is the integration of all the equipments, people and products into a decentralized control.

[VF] What drives this technological evolution ?

[RV] It’s both a need and a new offer. New offer because of abundance of cheap sensors, computational power and systematic connection between the equipments. On the need side, there are 3 areas : quality-productivity-delivery, diversity in terms of product variance and finally totally new business models.

[VF] What are typical examples of these new technologies ?

[RV] There’s a furniture maker in Flanders that used to be a simple dealer. They were the bridge between local customer’s requests and Chinese manufacturing. Thanks to the implementation of automated lines, they’re able to manufacture in Belgium at a cost not significantly higher than the one resulting from a Chinese production, and with a highly reduced lead time. They leveraged this opportunity to launch a new business model : kitchens production would not be launched after design of the house as usual, but after the finishing of the walls. They still offer a kitchen ready with the same deadline, but avoiding the risk of difference between actual building and previous design.

[VF] Are they applicable in every industries ?

[RV] Yes definitely. It can be furniture, it can be lighting, it can be automotive… there are opportunities in diverse situations, even if some operations (whatever the industry) are more suitable than other for being digitalized.

[VF] Are they limited to some steps of the value chain ?

[RV] The most common are the manufacturing and assembly activities, but it can be applied on any steps. For example, comprehensive simulation through digital twin as a way to revolutionize the design activity, but after-sales, quality and so on are interesting fields as well.

[VF] Is the manufacturing industry under threat ?

[RV] Yes, we can see that some operations were done in Belgium before and are off-shored now. It cannot go on like that. But they can be re-shored (cf. example above).

[VF] Are 4.0 technologies useful/needed for maintaining the manufacturing activities in developed countries ?

[RV] Yes I believe so.

[VF] Are they sufficiently implemented ? What drivers should be leveraged to increase their implementation ?

[RV] Probably not. Main driver to trigger is to communicate and to prove to SMEs how these opportunities are suitable for them.

[VF] Quantitative examples of a wise 4.0 implementation ? CAPEX/OPEX analysis ?

[RV] Many analyses were carried with Sirris customers and partners (such as for a company offering deburring for trucks). But the results are internal and not to be disclosed.

[VF] Are such implementations sufficient for coping with emerging markets ? Other costs to be considered (cost of goods sold, investment, utilities, workforce, transport, risks, taxes/tariffs[, lead time], travels)

[RV] I would prefer to see the time view than the cost view. They are finally linked obviously (e.g. CAPEX is split among the number of operations it can perform in one day) but the time view is more direct. With the time view, you quickly understand where and how to make gains. QRM, for example, is a good leverage to reduce average time per operation and eventually reduce costs linked to workforce, investment and overall plant utilities.

[VF] Besides technological advances, what is needed for manufacturing activities in Belgium to maintain their competitiveness ?

[RV] Besides technology, organization and learning are critical. Organization relies on a limited inertia of operators habits, they have to be flexible and to work autonomously. Learning is namely necessary for managing the huge sets of data that will be created.

9.5. Interview with Yves Prete, CEO at Safran Aero Boosters

9.5.1. Introduction

See 9.2.1

9.5.2. Interview report

On the 10th of August 2017, I met Yves Prete, CEO at SAB, and asked him the following questions. Condensed answers are stated below.

[Valentin Fontaine - Interviewer] Is the aeronautical market important for Wallonia, Belgium and to a larger extent, Europe ?

[Yves Prete - Interviewee] Obviously yes, it provides jobs to many people, through large companies such as SABCA, SONACA and SAB, but also all the smaller actors that go around the big ones. The situation is similar for other Western countries.
This market is specifically important because of the long term expected growth, on average 4-5% a year.

[VF] What are the main factors explaining the strong aeronautical activity in Wallonia ?

[YP] The main reason is historic. Governmental helps in the 20th century drove mechanical companies to specialize in aeronautics products. For example, F-16 programs gave a lot of activity and it was a good bet.

[VF] Is there a threat for losing this activity ?

[YP] Yes there are many threats upon the aero companies. Shareholders are not tied to Western countries and can therefore delocalize if better for them. Another threat is the fact that many countries try to develop national aeronautic plans. The reasons behind are ideological because it shows the greatness of a country, economical because this is a healthy industry, and finally military because aeronautics is closely linked to defense and this is typically a national value. Belgium lacks of military programs, moreover because Belgium therefore misses the resulting spillovers.

[VF] What are the drivers to keep this activity that should be leveraged ?

[YP] Keeping the design activity in Belgium is a necessary decision. Even if savings can be done in the short term by outsourcing the design, it will be a long term huge loss. Being the designer and technology owner gives the decision power.

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[VF] Are the Western manufacturing activities necessary for SAB ?

[YP] In complex products such as the aeronautical ones, this is mandatory to keep the manufacturing activities close to the design activities. Otherwise, design engineers would lose the concrete understanding of their products and their ways of producing.

[VF] Is there a new external competition arising in SAB markets ?

[YP] Yes, Chinese actors are expected to shake the market. But not before a few years.

[VF] What is the impact that the development of Chinese aircrafts might have on SAB ?

[YP] Products of SAB are dedicated to Western and Chinese aircrafts, without making any difference. Motors for Chinese aircrafts include SAB's compressors, so orders from Comac simply mean a turnover for SAB.

[VF] Is there a technological difference among Safran's production facilities throughout the world ?

[YP] The global trend is toward automation and digitalization. At a moment in time, there are of course discrepancies but they evolve similarly. Generally speaking, the way plants and offices work throughout Safran group is standardized, for the technology, the communication, the management, and so on.

[VF] What is the level of manufacturing technology in SAB ?

[YP] Very difficult to give a label on the level. We're quickly progressing toward automation.

[VF] Are 4.0 technologies useful/needed for maintaining investments in manufacturing facilities in Belgium ?

[YP] Indispensable. The salary costs are so high that if we want to keep the tradeoff “ok let’s ousource” away, we have to invest in digital technologies.

[VF] What is the expected return of 4.0 technologies ? Achieved example ?

[YP] The expected returns are increasing the productivity, better know our products, and improving the logistical paths.

[VF] Would these be sufficient ? What would be the others factors to consider ?

[YP] The most important is to empower people through education. There’s a mismatch between the job needs and the offered skills. We need to build better formation courses and to learn people to be more flexible in the changing landscape.

9.6. Details of the investment decision tool

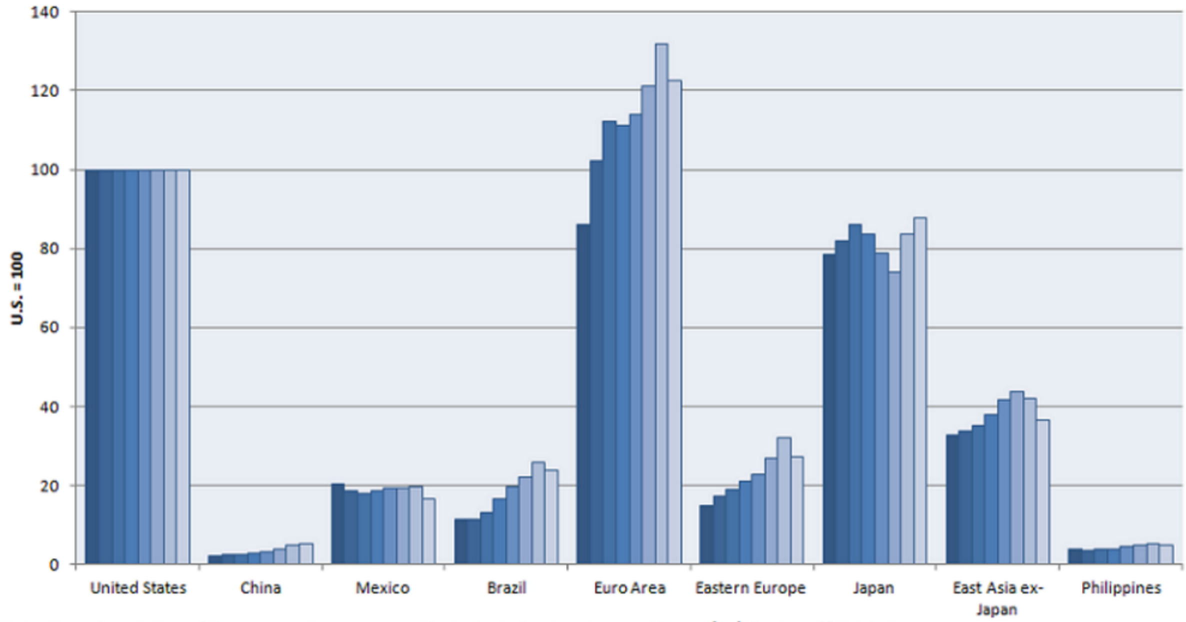
PARAMETERS	Productivity upgrade	Cost of 4.0 investment	Cost of 1 machine	Annual salary
	180%	€ 1.500.000,00	€ 550.000,00	€ 90.000,00
	Utilities overcost	Amortization period (years)	Amortization period (years)	
	150%	3	15	
	Maintenance overcost			
	100%			Cases in blue to be completed

BEFORE THE 4.0 INVESTMENT								
# Parts	/month			650				
Direct costs	#	unit cost				cost/part		%
material cost	650	45	€	29.250	€	45,00		31%
Packaging	650	€	4,00	€	2.600	€	4,00	3%
Transport	650	€	7,50	€	4.875	€	7,50	5%
Indirect costs	#	unit cost / month						
Men	5	€	7.500,00	€	37.500	€	57,69	40%
Machines	4	€	3.055,56	€	12.222	€	18,80	13%
Utilities	1	€	800,00	€	800	€	1,23	1%
Maintenance	1	€	1.500,00	€	1.500	€	2,31	2%
Management (OH costs)	1	€	5.000,00	€	5.000	€	7,69	5%
4.0 investment amortization	0	€	41.666,67	€	-	€	-	0%
Total costs				€	93.747		0%	###
Cost / part				**€**	**144**			

AFTER THE 4.0 INVESTMENT								
# Parts	/month				1820			
Direct costs	#	unit cost / month				cost/part		%
material cost	1820		45	€	81.900	€	45,00	43%
Packaging	1820	€	4,00	€	7.280	€	4,00	4%
Transport	1820	€	7,50	€	13.650	€	7,50	7%
Indirect costs	#	unit cost / month						
Men	3	€	7.500,00	€	22.500	€	12,36	12%
Machines	4	€	3.055,56	€	12.222	€	6,72	6%
Utilities	1	€	2.000,00	€	2.000,00	€	1,10	1%
Maintenance	1	€	3.000,00	€	3.000,00	€	1,65	2%
Management	1	€	5.000,00	€	5.000,00	€	2,75	3%
4.0 investment amortization	1	€	41.666,67	€	41.667	€	22,89	22%
Total costs				€	189.219			100%
Cost / part				**€**	**104**			
Reduction					28%			
Reduction if alternative					29%			
Decision				**INVEST IN 4.0**				

9.7. Manufacturing workforce cost in China

Average hourly compensation costs of manufacturing employees, selected economies and regions, 2002-2009



Note: For a description of the economic groups, see the technical notes at www.bls.gov/ilc/ichcctn.pdf, Table 2.
Source: U.S. Bureau of Labor Statistics, International Labor Comparisons.

9.8. 4.0 Investment in the Chinese plant

Chinese Manufacturing - AFTER THE 4.0 INVESTMENT								
# Parts	/month				1820			
Direct costs	#	unit cost / month					cost/part	%
material cost	1820		20	€	36.855	€	20,25	20%
Packaging	1820	€	3,60	€	6.552	€	3,60	3%
Transport	1820	€	46,30	€	84.266	€	46,30	45%
Indirect costs	#	unit cost / month						
Men	3	€	960,00	€	2.880	€	1,58	2%
Machines	4	€	3.055,56	€	12.222	€	6,72	7%
Utilities	1	€	2.000,00	€	2.000,00	€	1,10	1%
Maintenance	1	€	384,00	€	384,00	€	0,21	0%
Management	1	€	640,00	€	640,00	€	0,35	0%
4.0 investment amortization	1	€	41.666,67	€	41.667	€	22,89	22%
Total costs				€	187.466			100%
Cost / part				**€**	**103**			
Reduction					-1%			

9.9. Subsidies fully dedicated to employment

PARAMETERS	Productivity upgrade	Cost of 4.0 investment	Cost of 1 machine	Annual salary
	180%	€ 2.000.000,00	€ 550.000,00	€ 30.000,00
	Utilities overcost	Amortization period (years)	Amortization period (years)	
	150%	3	15	
	Maintenance overcost			Cases in blue to be completed
	100%			

Subsidies to employment - BEFORE THE 4.0 INVESTMENT								
# Parts	/month			650				
Direct costs	#	unit cost					cost/part	%
material cost	650		45	€	29.250	€	45,00	43%
Packaging	650	€	4,00	€	2.600	€	4,00	4%
Transport	650	€	7,50	€	4.875	€	7,50	7%
Indirect costs	#	unit cost / month						
Men	5	€	2.500,00	€	12.500	€	19,23	18%
Machines	4	€	3.055,56	€	12.222	€	18,80	18%
Utilities	1	€	800,00	€	800	€	1,23	1%
Maintenance	1	€	1.500,00	€	1.500	€	2,31	2%
Management (OH costs)	1	€	5.000,00	€	5.000	€	7,69	7%
4.0 investment amortization	0	€	55.555,56	€	-	€	-	0%
Total costs				€	68.747			###
Cost / part				**€**	**106**			

Subsidies to employment - AFTER THE 4.0 INVESTMENT								
# Parts	/month				1820			
Direct costs	#	unit cost / month					cost/part	%
material cost	1820		45	€	81.900	€	45,00	42%
Packaging	1820	€	4,00	€	7.280	€	4,00	4%
Transport	1820	€	7,50	€	13.650	€	7,50	7%
Indirect costs	#	unit cost / month						
Men	5	€	2.500,00	€	12.500	€	6,87	6%
Machines	4	€	3.055,56	€	12.222	€	6,72	6%
Utilities	1	€	2.000,00	€	2.000,00	€	1,10	1%
Maintenance	1	€	3.000,00	€	3.000,00	€	1,65	2%
Management	1	€	5.000,00	€	5.000,00	€	2,75	3%
4.0 investment amortization	1	€	55.555,56	€	55.556	€	30,53	29%
Total costs				€	193.108			100%
Cost / part				**€**	**106**			
Reduction					0%			

9.10. Economies of scale

PARAMETERS	Productivity upgrade	Cost of 4.0 investment	Cost of 1 machine	Annual salary
	150%	€ 2.500.000,00	€ 550.000,00	€ 90.000,00
	Utilities overcost	Amortization period (years)	Amortization period (years)	
	150%	3	15	
	Maintenance overcost			Cases in blue to be completed
	100%			

BEFORE THE 4.0 INVESTMENT								
# Parts	/month			1950				
Direct costs	#	unit cost				cost/part		%
material cost	1950		45	€	87.750	€	45,00	35%
Packaging	1950	€	4,00	€	7.800	€	4,00	3%
Transport	1950	€	10,00	€	19.500	€	10,00	8%
Indirect costs	#	unit cost / month						
Men	12	€	7.500,00	€	90.000	€	46,15	36%
Machines	10	€	3.055,56	€	30.556	€	15,67	12%
Utilities	1		2400	€	2.400	€	1,23	1%
Maintenance	1	€	3.000,00	€	3.000	€	1,54	1%
Management (OH costs)	1	€	10.000,00	€	10.000	€	5,13	4%
4.0 investment amortization	0	€	69.444,44	€	-	€	-	0%
Total costs				€	251.006			###
Cost / part				**€**	**129**			

AFTER THE 4.0 INVESTMENT								
# Parts	/month				4875			
Direct costs	#	unit cost / month				cost/part		%
material cost	4875		45	€	219.375	€	45,00	47%
Packaging	4875	€	4,00	€	19.500	€	4,00	4%
Transport	4875	€	10,00	€	48.750	€	10,00	10%
Indirect costs	#	unit cost / month						
Men	8	€	7.500,00	€	60.000	€	12,31	13%
Machines	10	€	3.055,56	€	30.556	€	6,27	7%
Utilities	1	€	6.000,00	€	6.000,00	€	1,23	1%
Maintenance	1	€	6.000,00	€	6.000,00	€	1,23	1%
Management	1	€	10.000,00	€	10.000,00	€	2,05	2%
4.0 investment amortization	1	€	69.444,44	€	69.444	€	14,25	15%
Total costs				€	469.625			100%
Cost / part				**€**	**96**			
Reduction					25%			

Executive summary

This Master thesis aims at bringing together two significant current trends : the emerging competition in the aeronautical industry and the digital technologies that are expanding under the name of Industry 4.0. Reasons behind the emerging competition are shown to be linked with increasing air traffic in emerging countries and the global manufacturing empowerment that results from the historical outsourcing of more and more complex activities from Western countries. The digital technologies (such as additive manufacturing, big data, cloud computing, and so on) are presented and examples of applications are given.

The question raised by the merge of the two trends is to determine whether these technologies could be a significant leverage to maintain the aeronautical activities in Belgium.

To answer this question, qualitative considerations are formulated, fed by field research and interviews with Belgian industrials. Applications that are implemented, under development and in exploratory phase are given for practical cases in Belgian plants. They shed light upon the potential behind the technologies and the challenges that are faced.

After the qualitative considerations, a quantitative case study is presented. This case is processed by a investment decision tool developed in the frame of this thesis. The tool takes parameters linked with the way the plant works, the cost of workforce and machines, then gives a 1^{st} order estimation of the reduction on the manufacturing cost per piece before and after a potential 4.0 investment. The tool is used in this thesis to depict a real case situation of a Belgian aeronautical manufacturing company. Then, the real situation evolves through 3 scenarios (Chinese manufacturing, incentives on employment and economies of scale) to show the dynamics behind the principal cost factors. It allows for a deeper understanding of the potential attractiveness of a 4.0 investment in the aeronautical industry in Belgium.