Industry 4.0 in Warehouse Ergonomics: Possible Applications of Emerging Technology

A Thesis Submitted for Obtaining
the Scientific Title of PhD in Engineering
from
Politehnica University Timisoara
in the field of Engineering and Management
by

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Date of the PhD Thesis Defense: June 27, 2020

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FOREWORD

"It is not our abilities that show what we truly are. It is our choices."
J. K. Rowling, 1998.

The current doctoral study has been done at the Politehnica University Timisoara, Romania, which has provided me with the educational and organizational framework to successfully implement and publish my research activities.

The first line of thanks must go to my supervisor, Prof. Anca DRAGHICI, who has constantly challenged my thinking and provided me with an endless amount of research to delve into, while trying to refine my thinking. I would like to wish her and the faculty the utmost success in their future research and teaching.

Furthermore, I would like to thank the entire *Universitatea Politehnica Timişoara, particularly to the staff of the Faculty of Management in Production and Transportation* for the opportunity and infrastructural support to carry out the research. It has been through the countless discussions with my guiding professors and the academic employees of the university that I was able to understand the various viewpoints my work had to analyze and debate, in order to bring a fair and balanced view to the whole proceeding. They have allowed me to expand not only my scientific knowledge on the topic at hand, but also my perspective on life, and for this I shall be forever grateful.

Last, but not least I would like to thank my family who have managed to put up with the exhausting schedule I have had over the past three years, giving me the space and time necessary to work on this PhD and see it to its completion. I would not have made it this far without their constant support, encouragement, and kindness.

Timişoara, May 2020 MSc. Eng. Anca MOCAN

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Industry 4.0 in Warehouse Ergonomics: Possible Applications of Emerging Technology (Industria 4.0 pentru ergonomia depozitelor: Posibile aplicații ale tehnologiilor emergente)

PhD theses of UPT, Series 16, No. 35, Editura Politehnica, 2021, 226 pages, 68 figures, 20 tables.

ISSN:2343-7928
ISSN-L:2343-7929
ISBN:978-606-35-0377-1

Keywords: ergonomie industrială, depozite, sisteme logislice, sisteme de producție, managementul depozitelor, auditul sistemului logistic, audit ergonomic, Industria 4.0, tehnologii emergente

Abstract: Obiectivul cercetării a fost evaluarea și caracterizarea ergonomiei depozitelor și dezvoltarea unui Model de Maturitate Ergonomică cu aplicabilitate industrială, prin cercetări interdisciplinare. În acest scop, a fost dezvoltată o abordare metodologică, procedurală și organizațională pentru a completa lipsurile constatate în bibliografie și pentru a facilita îmbunătățiri și optimizări practice, în companii. Modelul propus de Maturitate Ergonomică a fost aplicat (testat și validat) în cazul unui proiect complex, în cazul căruia aspectele ergonomice au fost inițial subestimate, neglijate.

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Notations, abbreviations, acronyms

2BN	2 Bin
2BO	2 Bin Other
AES	Achieving operational excellence
AIAG	Automotive industry action group
AM	Additive manufacturing
AR	Augmented reality
ARC	Autonomous robot carriers
ASN	Advanced shipping notification
ASRS	Automated storage and retrieval systems
AVM	Avis de modification
BO	Back order
BOM	Bill of materials
BT	Bombardier Transportation
BTB	Bombardier Transportation Bruges
CPS	Cyber-Physical Systems
CR	Change request
D20	Deliver on line 20
DC	Distribution center
DN	Delivery note
DOL	Delivery online
DOM	Distributed order management
EC	European Commission
ERP	Enterprise resource planning
ETL	Extract, transform, load
EU	European Union
FOA	Form of agreement
GDP	Gross domestic product
GDPR	General Data Protection Regulation
GRLP	General Rules on Labor Protection
GPS	Global positioning system
GR	Goods receipt
HSE	Health, Safety and Environment
IM	Inventory management

IS	Information system
IoT	Internet of Things
IT	Information technology
KBE	Kanban Eigen
KBP	Kanban Paint
KBS	Kanban Stores
KBV	Kanban Vendor
KPI	Key Performance indicators
LLD	Lower limb disorders
MMH	Manual materials handling
MSD	Musculoskeletal disorders
MMOGLE	Global Materials Management Operational Guidelines/Logistical Evaluation
MOQ	Minimum order quantity
MRP	Material requirements planning
NCR	Non-conformity report
NFC	Near field communication
NGO	Non-governmental organizations
NOT	Not used
NRC	Non-recurring cost
NV	Naamloze Venootschap - Public limited company
OSHA	Occupational safety and health administration
OM	Operations and maintenance
OTD	On time delivery
OWAS	Ovako Working posture Assessment System
PCCB	Project change control boards
PI	Product introduction
PM	Post de montage
PO	Purchase order
P-O	Person- organization
PPE	Pick parts eigen
PPF	Pick parts fremd
PREQ	Purchase requisitions
QA	Quality assurance
QEC	Quick exposure check
QRC	Quick response code
REBA	Rapid entire body assessment
RFID	Radio frequency identification

RFQ	Request for quotation
RULA	Rapid upper limb assessment
SA	Société anonyme - joint stock company
SAD	Subassembly delivery online
SAS	Subassembly stores
SBB	Schweizerische Bundesbahnen
SCM	Supply Chain Management
SMB	System Manufacture Bombardier
SNCB/NMBS	Société nationale des chemins de fer belges / Nationale Maatschappij der Belgische Spoorwegen / Belgian national railway society
STC	Project specific terms and conditions
TC	Team Coordinator
TMS	Transportation management system
TO	Transport order
US	United States of America
VR	Virtual reality
WBS	Work breakdown structure
WCS	Warehouse control system
WES	Warehouse execution system
WMS	Warehouse management systems
WRMSD	Work-related musculo-skeletal diseases/disorders
WRULD	Work-related upper limb disorders
WRLLD	Work-related lower limb disorders

1. INTRODUCTION

The PhD research starting point was related to the recent development of the Industry 4.0 concept and the potential applications in the logistic system context. Both theoretical and practical perspectives have been considered for increasing warehousing speed and accuracy to cope with ever changing industry and customer requirements. During the literature review of different aspects considered relevant for the PhD research there have been discovered that ergonomic solutions for logistic operations were not considered to be the first area of interest in improving logistic systems, specifically the warehouses' workplaces and their general working conditions. Most researchers were invested in how the Industry 4.0 paradigm would apply to processes automation and robotization and not how it could be applied to the human worker's activity optimization. Thus, the topic importance and relevance cannot be ignored in research anymore.

Some arguments of introducing the Industry 4.0 paradigm in the logistics activities are provided by facts that have been provided by important international organizations:

- A Price Waterhouse Cooper (PWC) survey (2016) on Industry 4.0 implementation has shown that industrial leaders are digitizing essential functions of the enterprises, both "within their internal, vertical operations processes, as well as with their horizontal partners along the value chain. They are additionally enhancing their product portfolio with digital functionalities and introducing innovative data-based services". The study results showed an expectation of digitization expenses to increase from just 33% in 2017 to over 70% in 2020 (PWC, 2016).
- According to the World Economic Forum White Paper Digital Transformation of Industries in 2016, within SCM "key technologies will be included autonomous transport and drones, sensors for monitoring supply chains and 3D printing technology. Digitally enabled companies will incur procurement costs of 0.22% of net revenue, less than half of those of their peers (0.5%)". The value of digitization within the next decade will exceed €1333 billion (World Economic Forum, 2016).
- The supply chain will evolve and become smarter, more transparent, and more efficient because of this digital transformation and the subsequent use of intelligent cooperative systems. "There will be a particular focus in new models which will be more closely to individual customer needs, promoting a significantly increase of the decision-making quality and become more and more flexible and efficient in the near future" (Barreto et al., 2017).
- Concerning distributions centers (DC) Industry 4.0 technologies can help enable automated systems to adapt to their environment to execute tasks more efficiently in collaboration with humans. Both from the technological and organizational point of view equipment, such as low-cost sensors, computer

vision, augmented reality (AR), wearables, Internet of Things (IoT), analytics and high-performance computing can be used to enhance existing automation and remove the existing historical situation of low automation in DCs without highly standardized products. The last years trend has shown that the ways in which DC facilities are being used is changing and there is a need for smarter, more adaptable systems services (Deloitte, 2016).

- Companies are aware of this change and are proceeding to adapt their investments accordingly. Based on a recent international study of DCs, half of the surveyed IT and operations decision makers planned to move to a more modern, full-featured warehouse management system in 2015. By 2020 this number increases to 75%. 51% of those surveyed expected increased investment in real-time location systems that track inventory and assets throughout the warehouse as well as, equipping staff with technology (73%), bar code scanning (68%), tablets (66%) and Internet of Things (62%). IoT alone is predicted to connect 20 billion devices or 'things' to the existing internet infrastructure by 2020 (Zebra, 2016).

In order to reduce the productivity dips caused by poor ergonomic design of processes, that appears when ergonomics is seen as an afterthought rather than the first analysis that needs to be done, a solid ergonomic application framework is necessary to be developed. Besides the technological modifications that need to be ergonomically designed and integrated, Industry 4.0 also offers technological opportunities to support work-based learning, to reduce operators' physical loads and better monitor their health. Although robotics and human-machine interaction are disciplines with an extend literature, but the actual complexity of professional human behavior opens new ways for research that allow creating new paradigms (Munoz, 2017). The relative lack of understanding from the business world regarding emerging ergonomics developments in the research world also proves to be a fertile ground not only for improvements based on knowledge transfer, but for setting new and innovative developments.

Within the present PhD. research framework, the possibility of applying Industry 4.0 technology in the warehouse of a manufacturing facility will be analyzed. The existing market technology will be categorized, examined, and rated based on its capacity to improve the ergonomic efficiency within the warehouse, as part of the logistics system. Based on this rating and existing ergonomic framework, a model will be developed that can be used in a business environment, to track the current level of ergonomic applications, implementation practiced within the company and a development and to show the investment pathway needed to reach Industry 4.0 benchmarks.

The motivation of the research topic is determinate because ergonomics is becoming increasingly important in warehousing and logistics. Currently, due to European Union (EU) and national legislation, companies in Western Europe must reconsider their policies and focus more on individual rights, on implementing solutions of human-friendly logistics via excellent logistics ergonomics. The focus on reducing warehouse personnel turnover in to reduce the unsafe environment that workers might experience. The companies with the most stable and productive warehouse working teams are the ones with the most developed programs for safety training, ergonomics, and housekeeping.

The increased interest in ergonomics, to reduce worker turnover, is coming at a time when companies are also introducing Industry 4.0 techniques and technologies. "Scientific research will always be impeded if clear definitions are lacking and it has been shown so far that companies face difficulties when trying to develop ideas or act without understanding what to aim towards" (Hermann et al., 2015). In addition, "most companies in Germany do not have a clear understanding of what Industry 4.0 is and what it will look like" (Pascual et al., 2019; Eco – Verband der deutschen Internetwirtschaft, 2014). This creates a situation where industry experts in Germany confirm that after the implementation of Industry 4.0 in their companies, the productivity gains are up to 50%, depending on the complexity of production use cases (Bauernhansl et al., 2014), but at the same time they are not entirely sure what they are applying, and do so in a non-structured way.

This proves that the current situation requires a structured analysis to define if ergonomic applications of Industry 4.0 technologies are suited for a specific company, turning the currently practiced empiric approaches into scientific ones. Companies need to understand what Industry 4.0 benefits they can reap and how to leverage those benefits into creating a safety, more issue-free work environment for their human operators. Due to the interconnectivity of Industry 4.0 technologies, companies also need to understand the legal limit of their application and how to approach their presentation to the operators that would be in direct contact with them.

The scope of the PhD program is to develop a set of researches focus on designing a systematic and integrated approach of warehouse ergonomics condition improvement, based on the Industry 4.0 framework. Currently existing approaches of the ergonomics science has been in deep analyzed and they are the basis of the theoretical developments and experimental studies.

The general objective of the PhD research is to evaluate and characterize the relevant business research directions of warehouse ergonomics and develop an Ergonomics Maturity Model for a large-scale industry environment by using various interdisciplinary research of different management areas. For this purpose, a methodological, procedural, and organizational approach will be developed to complete existing research gaps and facilitate practical improvements and optimizations in companies, too. The proposed ***Ergonomics Maturity Model*** will be applied (tested and validated) in a use case of a low volume high complexity project in which ergonomic needs are underserved.

The operational objectives of the research approach are:

OP1. Analysis and synthesis of bibliographic references necessary to create an overview of ergonomics applications in logistics. This will provide the scientific basis for the research on ergonomics applications in a warehouse environment to present not only as a basis for the present research work, but also for further research in this area - Chapter 2;

OP2. Experimental research on the ergonomics intervention and implication in a current supply chain organization of a multinational production company (implementations of the experiments on current ergonomic issues within the manufacturing warehouse facility of the company's Belgian branch) - Chapter 3;

OP3. Experimental research on a warehouse processes improvement capability (implementation of the experiments at a Belgian manufacturing warehouse facility to identify ergonomic improvement capabilities both in the classical ergonomic approach as well as with the application of Industry 4.0 technology) - Chapter 4;

OP4. Theoretical developments and experimental research for the Ergonomics Maturity Model design and a related ergonomics maturity assessment tool (theoretical research has been accompanying by testing and validation phases within a use case of a low volume high complexity project developed in a Belgium companies and based on current legal and para-legal factors) - Chapter 5.

In order to achieve the operational objectives, the theoretical knowledge acquired from the first Industrial Engineering program at the Politehnica University Timisoara, Romania and the second program of Master of Science in Supply Chain Management at the Economics University of Vienna, Austria, as well as the practical knowledge achieved from more than five years of working experience with industrial design and warehousing solutions has been exploited and applied (Annex 7).

The overall goal and operational research targets are systematically developed and documented in the different chapters of the PhD thesis as shown in Figure 1.1.

The PhD thesis consists of 6 chapters with a total length of 184 pages (including the references list of articles, books and web pages that were used and adequately cited in the PhD. thesis text, but not the Annexes). In addition, 7 Annexes were defined to support the scientific debates and explanations with supplementary details. In totally, the PhD thesis is developed in 215 pages and consists of 20 tables, 68 figures, and 1 mathematical formula.

The way on how each operational objective has been targeted is proved by the content of each PhD thesis chapter that described the developed research activities, the results achieved together with relevant conclusions. Briefly, each chapter content is described in the following.

Chapter 1, the "INTRODUCTION", describes the problem of the research topic, the motivation, and the scientific and practical importance. Using selected examples from the literature, the challenge and the current state of research is underlined. Furthermore, the objectives of the PhD approach are briefly outlined.

Chapter 2, entitled "STATE-OF-THE-ART ON ERGONOMICS IN WAREHOUSE LOGISTICS", provides an overview of the current state of research, with bibliographic reference and focus on relevant research results. The purpose of the chapter is to give the reader an understanding of what the theoretical context is regarding supply chain management, logistics, warehousing, and ergonomics, to ease the technical understanding of the topic being discussed. Further, the chapter presents the current research into warehouse ergonomics, presenting the physical and mental strains that workers must overcome to be able to accomplish their tasks. The chapter ends with a presentation of Industry 4.0 solutions currently already being applied by the industry to monitor or improve ergonomics and how this topic can be further developed and improved upon.

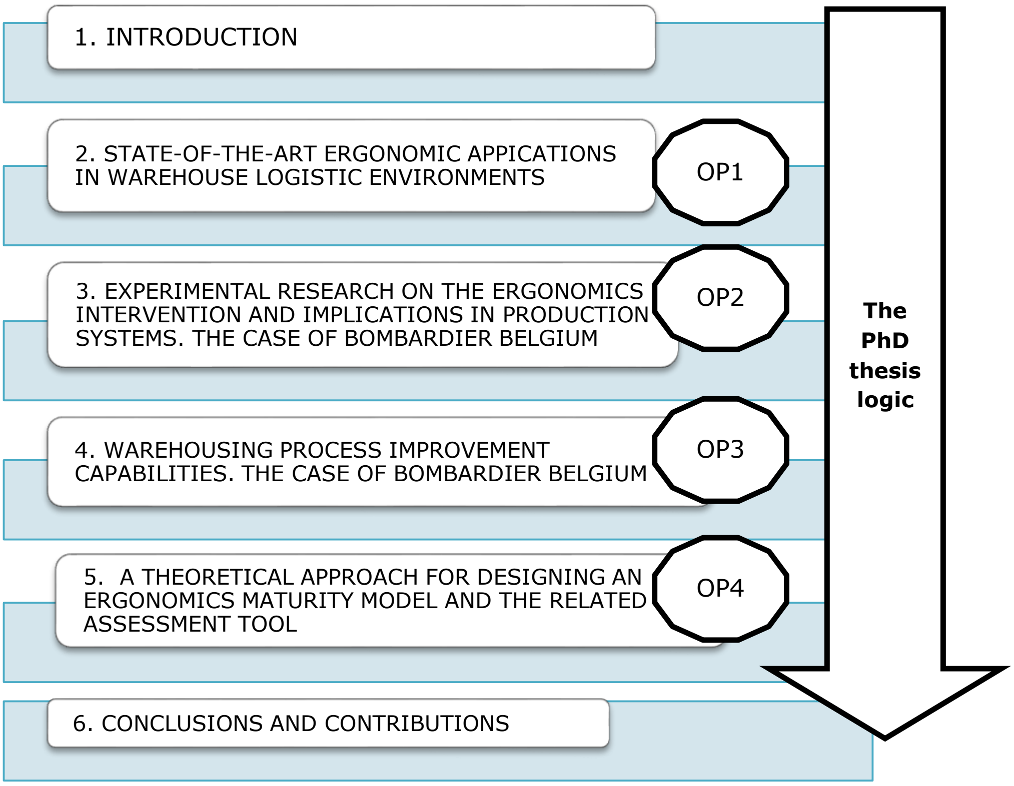

Figure 1.1. The general overview of the PhD thesis associated with the research approach (own flowchart)

Chapter 3, with the title "EXPERIMENTAL RESEARCH ON THE ERGONOMICS INTERVENTION AND IMPLICATIONS IN PRODUCTION SYSTEMS. THE CASE OF BOMBARDIER BELGIUM" examines the current ergonomic reality of a low volume high complexity manufacturing plant in Belgium. The company chosen for the experimental research (preliminary diagnosis in the real economic environment) is Bombardier Transportation Belgium NV which designs and manufactures a large variety of solutions in the field of rail transportation. The company's portfolio consists of rail vehicles, propulsion sub-systems, as well as controls units, bogies, signaling systems, and associated services for the rail transportation products such as vehicle refurbishment, modernization, and fleet maintenance. It is a representative company in the field being on the third place in the worldwide in the 2017 top 10 ranking of global Original Equipment Manufacturers (OEMs) as shown in Figure 1.2. Bombardier Transportation (BT) follows the CRRC Corporation Limited of China and Alstrom company from France, according to the SCI Verkehr[1] consulting company's study.

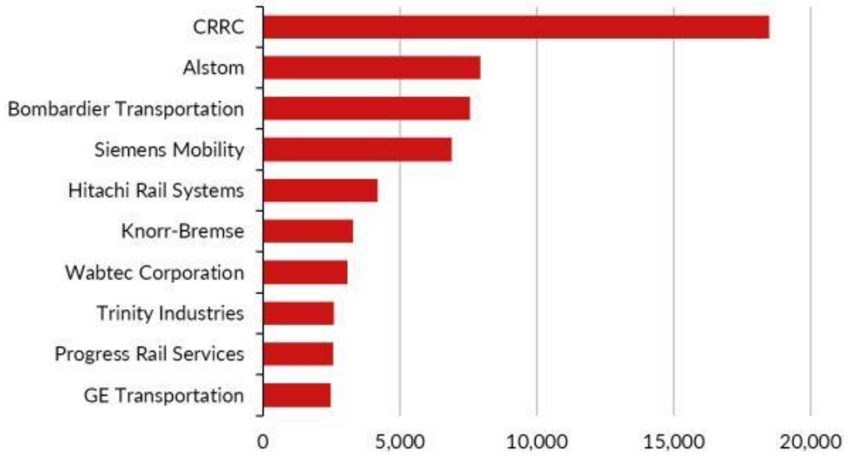

Figure 1.2. The top 10 hierarchy of the largest railway OEMs by turnover in 2017 (€m)[2]

The described research context has offered a relevant experience and results on the state of the ergonomics interventions, as well as its implications for warehouse work processes improvement. Furthermore, through the four experiments, the inbound and internal supply chain of the company is analyzed, the ergonomic aspects of the warehousing facilities are looked at and the possibility to use wearable computers in the environment is tested. The experiments fields of interest are related to the most vulnerable areas of the internal logistics system operation which were identified based on the reference review and observations in the company. Following experimental researches are described:

1. A study on the company's internal supply chain ergonomics;
2. A study on the rack's metrics;
3. The study of the cycle time Kanban bin fill-up;
4. The ergonomic assessment of the Kanban human operators.

The experiments results offer a better understanding of the challenge's manufacturing companies face when dealing with warehouse ergonomics. In addition, the studies have provided valuable knowledge about the AS-IS situation of the warehouse ergonomics and open the perspectives for improvements.

Chapter 4, entitled "WAREHOUSING PROCESS IMPROVEMENT CAPABILITIES. THE CASE OF BOMBARDIER BELGIUM", valorized the knowledge pool of research

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[1] SCI Verkehr is the most prestigious consultancy company focused on the international railway and logistics industry, https://www.sci.de/?L=1

[2] Leenen M. and Wolf A. (sept.14, 2018). SCI study forecasts upturn in global rail market, International Railway Journal. Retrieved from: https://www.railjournal.com/in_depth/sci-study-forecasts-upturn-in-global-rail-market

results build through the studies presented in the previous chapter, by analyzing the ways in which the ergonomic reality in Bombardier's warehouse can be improved. The chapter presents both traditional improvement methods based on Lean Six Sigma methodology and tools, as well as improvements that could be attributed to the implementation of automation and Industry 4.0 technologies.

First, a deep study on re-defining the workspace the analysis of the Kanban bin filling process is presented based on the Ishikawa method and 5Whys tool. These have been conducted to a detail analysis of 14 point of improvements, which are discussed following with the defined improvement impact effort matrix. The improvements are related to the following aspects:

- BT company culture;
- Project based versus process-based culture;
- Logistical MPR flow definition;
- Employee morale;
- Logistics policy;
- BT HSE strategy (0 accidents, not 0 long term problems);
- Managerial capabilities;
- Weight to lift/ergonomics policy creation;
- Workspace reorganization Kanban area;
- Workspace reorganization rack area;
- Visual management Kanban area;
- Visual management rack area;
- Time schedule for warehouse workers:
- Rethinking Kanban bin on rack logic.

Furthermore, in the chapter there are analyzed the Industry 4.0 solutions for improvement with the help of an ergonomics efficiency formula and provides advice related to the implementation of these tools in the environment case analyzed. The research conclusions focus on a comparative analysis of the improvements implementation considering the overall efficiency of automation and Industry 4.0 technology.

In Chapter 5, with the title "A THEORETICAL APPROACH FOR DESIGNING AN ERGONOMICS MATURITY MODEL AND THE RELATED ASSESSMENT TOOL", is presented a proposed theoretical model for ergonomics improvement.

In subchapter 5.1 the theoretical concept is presented following the research design approach. Ergonomic axiomatic design is discussed with regards to its utility in the current endeavor. The goal of the designed Ergonomics Maturity Model is explained as being aimed at bridging the understanding between academic and industrial experience.

In sub-chapter 5.2 the associated assessment tool is presented. The working of the tool as well as the purpose it has in guiding management professionals in their search for better ergonomic environments are discussed. The tool is filled in with the data from Bombardier's ergonomic assessment and a sample improvement process step is shown to test and validate the Ergonomics Maturity Model and the way it should be practically exploited.

In Chapter 6, CONCLUSIONS AND ORIGINAL CONTRIBUTIONS, the overall results of the research are summarized, and the core messages of the findings are presented. Reference to the previously identified gaps in the research is made together with their complete description.

Finally, the thesis ends with a list of REFERENCES which contains 404 cited titles (articles, books, and web pages) and a list of 7 Annexes including details of the different research phases and my CV with the publications list as following:

- ANNEX 1 “Attitudes about ergonomics in engineering” – Questionnaire offered to bombardier engineering
- ANNEX 2 Bombardier process flow from “Article number release” to “Delivery in production” and “Payment”
- ANNEX 3 MMOG/LE subchapter assessment and radar chart
- ANNEX 4 Optimization algorithms
- ANNEX 5 Optimization sequence and related questions
- ANNEX 6 Audit Tool (details)
- ANNEX 7 CV AND THE PUBLICATIONS LIST.

The research results we disseminated in 18 articles published in international conferences’ proceedings and journals, from which 1 in ISI journal, 6 in ISI proceedings and 7 BDI index papers. All the articles were published during the PhD program (2017 – 2020) the complete list of them being included in the Annex 7.

2. STATE-OF-THE-ART ON ERGONOMIC APPLICATIONS IN WAREHOUSE LOGISTIC ENVIRONMENTS

The general flow of the chapter is presented in Figure 2.1. In the first part of this chapter, the context in which the research takes place will be presented with the aid of current bibliographic references. This will present the theoretical definitions of supply chain management, logistics and warehouse logistics.

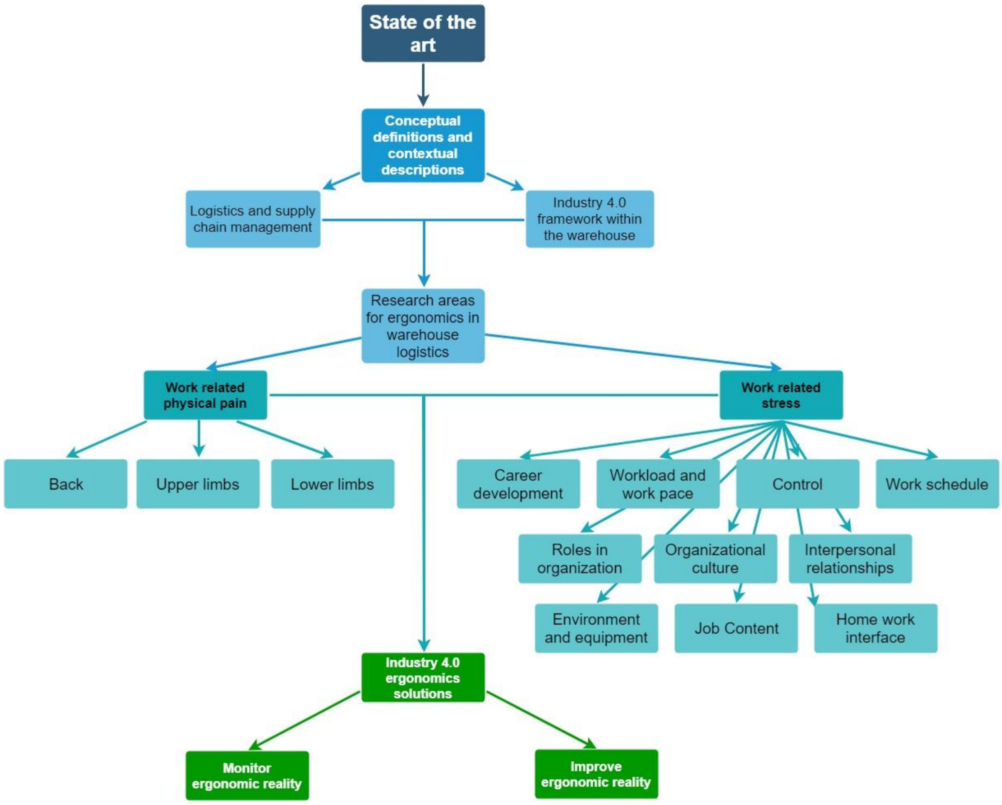


Figure 2.1. Chapter structure (conceptual map)

The chapter will continue by discussing the theoretical context of ergonomics and focus in specifically on **ergonomics in warehouse logistics**. The purpose of this approach is to better integrate and report the current research results to the existing literature in the field. The second part of the chapter will present the relevant ergonomic research within warehouse logistics, first explaining the research done on work-related physical pain, then going through the topic of work-related stress.

Finally, the chapter will end with the presentation of possible Industry 4.0 ergonomic solutions as currently existing in literature with the purpose of limiting the area of focus for further analysis.

2.1. Conceptual definitions and contextual description of this research

The purpose of this subchapter is to define the themes that will be present throughout the research and clarify its delineation. It will start with the broader definition of supply chain management, limit the scope to the logistics subtopic and then present the ergonomics research currently undergoing in the warehouse logistics niche (Figure 2.2).

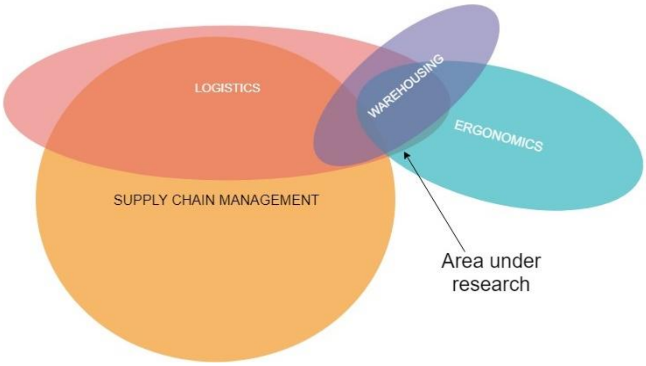


Figure 2.2. Area of interest for the PhD research

2.1.1. Logistics and supply chain management

2.1.1.1 Overview of the sciences evolution

It is a fundamentally accepted reality on Earth that not all goods are produced in the same area. Because of geographic, economic, or political reasons, each region can produce only a subset of the total amount of goods capable of being produced on earth. This leads to the need for trade between geographical regions.

Logistics and Supply Chain Management (SCM) are considered traditional sciences, as part of the general management family. Even from the historical times, trade route have been established to transport goods from one geographical area to another; principles of the materials and information flow that were created or designed to meet the customers' requirements have changed very little within the past few thousand years. Logistics capabilities were the link between winning and losing a war. From the Punic wars, to the Napoleonic wars, the American War of Independence, and even the two World Wars, have proved that the logistics system's capabilities (weakness or strength) have contributed to the changing of the course of history.

These early appearances of military supply chains have changed over time and developed in what we now come to refer to as supply chain management. Supply chain management (SCM) is a term that appeared for the first time in the 1980s, but started to gain serious traction in the 1990s, as a "hot new trend" in business and academia. It was defined as the business process integration from end-user through original suppliers that provides value added to the customer through the application (use of the created functionalities) exploitation of products, services, and information (Cooper et al., 1997). Nowadays it is defined as the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain (Christopher, 2016).

It was discussed how the purpose of SCM was to maintain the level of customer service provided while lowering the total amount of resources required to provide said service (Houlihan, 1985). While the initial literature was having a difficult time defining SCM, there is a general agreement about the components defining the science (Figure 2.3); almost all authors expect SCM to have both product as well as information flow facility structure, while also providing a work and planning structure (Cooper et al., 1997). Logistics is the component part of SCM that contains structures that facilitate flow and provide planning.

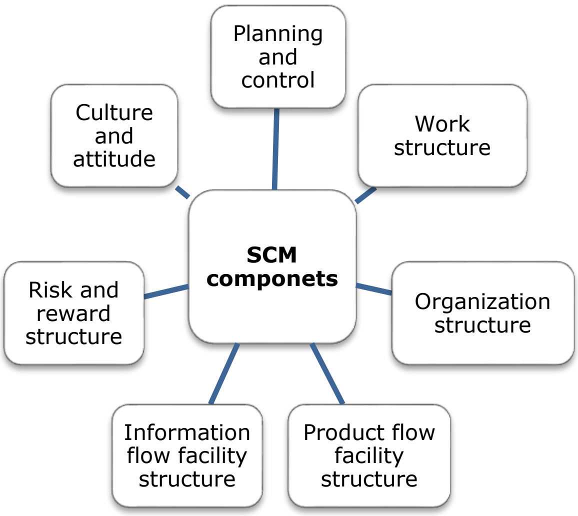


Figure 2.3. An inventory of the SCM components (results of the literature review)

2.1.1.2 What is Logistics?

According to the definitions established by the Council of SCM Professionals[3] logistics is "*the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the*

[3] https://cscmp.org/

purpose of conforming to customer requirements, including herein inbound, outbound, internal, and external movements".

The science of logistics has a planning orientation approach (frameworks) that "seeks to create a single plan for the flow of products and information throughout a business" (Christopher, 2016). This definition makes it clear that there is a difference between SCM and logistics, both in their scope as well as in their objectives. SCM is built upon an inter-company framework and seeks achieving linkage and co-ordination between the processes of other entities in the pipeline, while logistics purpose is to move and position inventory at the right time and the right place, as not doing so would decrease the inventory's value.

To satisfy the strategic benefits of logistics the five areas of work need to be closely linked together, as presented by Donald et al. (2002):

- *Order processing*: The process of collecting and transmitting customer requirements in the form of orders to the rest of the logistic network to allow order preparation, delivery, and invoicing. The biggest challenge logistically is to increase order processing accuracy;
- *Inventory*: The process of stocking items in various forms, such as raw materials, work in process or finished goods within designated areas of the supply chain to guarantee the customer on time in full deliveries. The biggest challenge of inventory is to provide the maximum level of customer satisfaction while maintaining the lowest level of inventory investment possible;
- *Transportation*: The process of geographically moving and positioning inventory within the supply chain. The challenge of transportation is to reduce total cost while increasing speed and consistency;
- *Warehousing, material handling and packaging*: The process of receiving, storing, sorting, and re-bundling materials from various facilities for meeting customer order requirements. The business challenge of warehousing is to enhance final delivery value while maintaining low stocking costs and high inventory turnovers;
- *Facility networks*: The process of designing a supply chain network that consist of warehouses, manufacturing units or plants, units as cross-dock operations, and retail stores that satisfy business and customer needs. Within this process all other processes are run. The challenge of facility networks is to determine the minimal amount of facilities needed to smoothly run logistics operations.

These five areas of work, when correctly managed, are supposed to help in the maintaining of operational objectives of logistical integration. The objectives, which are responsiveness, variance reduction, inventory reduction, shipment consolidation, quality, and life cycle support, must be simultaneously achieved. Their relative importance is based on the firm's logistical strategy and their relative importance to each area of work.

The firm's logistical strategy is supposed to be linked to its overall market strategy. The purpose of any company is to endow itself with means that create competitive advantage. The source of competitive advantage is found firstly, in the ability of the organization to differentiate itself from the competitors and secondly, to operate at a lower cost as possible. As the business competitive context continues to change this will lead to an impact on the way in which logistics and SCM are handled (Christopher, 2016).

The two things that bring about market advantage are cost and value. Each firm strives to have at least one and hopefully both markers in their overall strategy. While the existence of economies of scale can lead to a decrease in overall production costs of items, logistical processes are still relatively high and, with the advent of third-party logistics type of process externalization, even harder to control by the company itself.

While areas of improvement such as machine maintenance (Jeong and Phillips, 2001; Dekker, 1996; Cassady and Kutanoglu, 2005; Van der Duyn Schouten and Vanneste, 1995) or IT system implementation (Banker et al., 1990; Venkatraman, 1994; Kelle and Akbulut, 2005), have long been analyzed in great depth in order to optimize their costs impact on businesses, ergonomics is an area where the possibilities to both reduce cost and create value have barely scratched the surface. According to Fernandez and Goodman (1998) research, application of ergonomic approach in a workplace context has the following impacts:

- "Increasing productivity;
- Improving workers' health and safety conditions;
- Lower workers' compensation claims;
- Compliance with government regulations such as Occupational Safety and Health (OSH) standards;
- Improving job satisfaction;
- Increasing work quality and defining well-being at work;
- Lower worker turnover;
- Lower lost time at work;
- Improving workers morale;
- Decreasing the absenteeism rate".

2.1.2. Industry 4.0 framework within warehousing

Technology has disrupted SCM. The first three Industrial Revolutions have been defined by the evolution of technologies related to mechanization, electricity, and information technology. The fourth Industrial Revolution (Industry 4.0) that we are beginning to experience now has come about along with the introduction of the Internet of Things and Services into the manufacturing environment. Businesses are already starting to establish interconnected global networks of Cyber-Physical Systems (CPS) with the support of the Internet of Things (IoT) and cloud computing technologies.

Industry 4.0 creates what have been called "smart factories". These are made up of "smart machines, storage systems and production facilities that are capable of autonomously exchanging information, triggering actions and controlling each other independently" (Henning, 2013). "This capability allows improvement of business operations within, amongst others, supply chain and life cycle management, as products start becoming uniquely and continuously identifiable in time and space" (Hermann et al., 2015).

The results of a survey (PWC, 2016), on the current capabilities of companies dealing with Industry 4.0 paradigm, underlined that there was a "lack of digital skills and transformation culture" in the surveyed respondents. Thus, Industry 4.0 calls for strong data analytics capabilities, but also other technical skills, such as predictive-prescriptive analytics and forecasting, continuous automated feed-back to the organization's management and to each employee. "Only 18% of survey respondents rate the maturity of their data analytics capabilities as advanced, and more than half say that the lack of skills and competencies in their company's workforce is a key challenge to making full use of data analytics" (Botha and Theron, 2016; PWC, 2016). On a survey aimed specifically to the supply chain market, there was a clear increase of plans to invest in technology IS (information system) solutions, which include software such as warehouse management systems (WMS) and enterprise resource planning (ERP). Having moved from 49% last year to 58% this year this was the highest spending indicator for IS systems on this question over the last four years of the survey. When asked about the value of this spending the average anticipated 12-month spend prediction came to €336,664 with the median spend being €73,550. Regarding which subcategories within IS solutions would garner the most investment in the next 12 months Distributed Order Management (DOM) was at 13%, and Warehouse Execution System (WES) was at 6%. Together, WES and the closely related category of Warehouse Control System (WCS) software summed up 18% of the response. Voce picking and Transportation Management Systems (TMS) also saw slight growth in the software area, while equipment was mostly represented by mobile and wireless technologies as well as Radio Frequency Identification (RFID) gear (Peerless Research Group survey[4]). Through these survey results the tendency of managers, whether they work in supply chain or not is to invest in technology that improves data visibility and connects business processes for a quicker solution to the customer's needs.

As such the current biggest trends in supply chain concerning Industry 4.0 are (Nahata, 2017):

- *Blockchain*: "an impenetrable way to store and share transactional data, while improving credibility with fool proof transactions". Key concepts: data transfer, data security;
- *Delivery of Choice*: "the ability to choose among logistics providers". Key concepts: service flexibility, customer-oriented services;
- *Elastic Logistics*: "the flexibility to expand and shrink capabilities to align with the demands within the supply chain during a given timeframe". Key concepts: service flexibility, connected business processes, scalability;
- *Perfect Order Deliveries*: increasing "the percentage of orders delivered to the right place, with the right product, at the right time, in the right condition, in the right package, in the right quantity, with the right

[4] Retrieved from: http://www.peerlessresearch.com/

documentation, to the right customer, with the correct invoice". Key concepts: accuracy, big data, customer-oriented services;

- *Drones and Smart Glasses*: Integration of augmented reality, face recognition and hands-free route searches to make deliveries easier, personalized and error free. Key concepts: customer-oriented services, accuracy, big data;
- *Data-Driven Logistics Drive Anticipatory Logistics*: "by anticipating demand and studying the data patterns, companies can predict product demand, and thereby plan and align their operations well in advance". Key concepts: big data, accuracy, predictive analytics;
- *Building a Sustainable and Profitable Supply Chain*: "adapting best practices that are helping them reduce their carbon footprints. To achieve efficiency and reduce carbon emissions, companies will collaborate with logistics companies that offer intelligent auto-routing and smarter operations". Key concepts: big data analytics, accuracy, green logistics.

As it can be gathered from the research, big data analytics, accuracy, scalability, and customer-oriented services are the main upcoming discussion points. To satisfy an ever-diversifying customer demand companies within the logistic network need to prove their competitive advantage through the adoption of Industry 4.0 standards and practices. While the changes will be easier to implement for some companies more than others, the trend is clearly showing that the technology application is feasible, and it is happening now.

As a good example of the technological innovations in the last years, ***Amazon*** has been leading the SCM charges; Industry 4.0 developments help products fast and precisely delivery to customers, in an efficient manner. The company has set in place a series of warehouse improvements that combined has led them to be the number one online retail store in America, with over 178 billion dollars revenue in 2017. While they are not the only ones upgrading their work, they are the only ones doing it at the same time and at such a massive scale. Some of the technologies applied by Amazon so far have been:

- *Predictive analytics*: Amazon uses "a comprehensive collaborative filtering engine which analyzes what items you purchased previously, what is in your online shopping cart or on your wish list, which products you reviewed and rated, and what items you search for most, using this information to recommend additional products that other customers purchased when buying those same items" (Wills, 2018);
- *Distributed order management*: Amazon also manages to "reduce shipping costs between 10% to 40% by linking with manufacturers and tracking their inventory. Amazon uses big data systems for choosing the warehouse closest to the vendor and the customer and graph theory to help decide the best delivery schedule, route, and product groupings to further reduce shipping expenses";
- *Haptic directions*: "Amazon has patented designs for a wristband that can precisely track where warehouse employees are placing their hands and

use vibrations to nudge them in a different direction”. The concept is meant to help workers find their way through the massive warehouses and fulfil orders more quickly, by using ultrasonic tracking to identify the location of the worker’s hands (Solon, 2018);

- *Automated shelving*: Instead of “having workers go up to shelves and pick the necessary products the shelves are now automated to glide quickly across the floor while being carried by robots about the size and shape of footstools. This gives the human workers faster access to their needed product and reduces warehousing space by eliminating the need for inter-rack distance” (Knight, 2015);
- Finally, they *help other companies access their big data* by means of the Amazon Web Services. Through the provided on-line services, “companies can create scalable big data applications and secure them without using hardware or maintaining infrastructure. They therefore have access to big data applications such as clickstream analytics, data warehousing, recommendation engines, fraud detection, event-driven ETL, and IoT that are processed through cloud-based computing” (Wills, 2018). Thus, other companies may benefit from Amazon’s online services “by analyzing customer demographics, spending habits and other relevant information to more effectively cross-sell company products” in international markets, in this way ultimately reducing the cost barriers usually associated with such advanced technological and human resources investments (Schoenherr and Speier-Pero, 2015).

While there is of course a difference between the size of Amazon’s business and that of other companies, the fact that they are applying Industry 4.0 technology in their operations proves that their application is viable as a business investment. At the same time, while the trend of Industry 4.0 is presented as an advancement from a technological point of view, in both academia as well as the media, Amazon is still being questioned on the impact this is having on its employees. According to MWPVL International[5], Amazon has gone from 18 facilities in 2007 to 342 facilities in 2017[6], having 180,000 employees.

According to their statements (Reisinger, 2017) “they plan to add another 100,000 full-time, full-benefit jobs by mid-2018”. This is presented as a growth that will create many jobs in the short term. While it would not be an issue in and of itself, it does come on the heels of the company’s workers’ negative statements in recent years. They are coming forward to complain about the long working hours, low pay, bad working conditions, the physical and mental exhaustion that they have to deal with, and all this while being pressured by the company’s management to pick faster and faster each year (Semuels, 2018).

Ergonomics, in a specific sense is about designing and arranging objects so that people and things can interact more efficiently and safely, but in a general sense,

[5] http://www.mwpvl.com/

[6] Including fulfilment centres, prime hubs, and sortation centres.

concerns itself with the relationship and wellbeing of workers in their environment. Just mindlessly applying technological advancements to increase the speed of a worker's activity accomplishment, while not quantifying how this affects them on an emotional, mental, and social level is not good practice.

Industry 4.0 has a large potential for business improvement, with the area projected to grow from €420 billion in 2014 to €792 billion in global IoT spending. (Columbus, 2017). According to key findings on Industry 4.0 by McKinsey and Company companies expect Industry 4.0 to increase revenue by 23%, productivity by 26% and reduce downtime by 30-50% (Breunig et al., 2016). Furthermore, other relevant aspects about the transition from Industry 4.0 to Industry 5.0 paradigm have been the subject of the research of Paschek et al. (2019).

With such high hopes regarding its usefulness and such high investments in its application, it can be potentially dangerous to allow companies to see the Industry 4.0 paradigm as only a technological one. The role of research will be to give direction and provide methods through which companies can implement emerging technologies with a greater focus on the human element and the way technology and people interact. Because of this is it important to first understand what types of ergonomic issues people are dealing with and what emerging technologies can be used to either eliminate, reduce, or better monitor work-related ergonomic strain. The following subchapter will discuss the history of ergonomic research and afterwards focus on warehouse ergonomics topics and how these negatively affect logistic workers.

2.1.3. Preliminary conclusions and the research niche definition

The presented state-of-the-art has conducted to the definition of the ***research niche***. The focus of the PhD research is to analyze the possibility of applying Industry 4.0 automation to the warehouse environment with the result of improving ergonomic conditions for the warehouse human operators. Methods and tools, which are not related to ergonomics field, are not examined in detail, and used. While acknowledging that psychological issues, such as stress and job uncertainty, are also part of a workplace's ergonomic environment, the research focuses on physical pain and how to reduce it. In addition, the analysis is developed to provide an ergonomics design model for usage in a large-scale industrial warehousing environment.

The proposed holistic model is designed based on the extrapolated data found in the practical research done within a manufacturing facility's warehouse. While the data it is based on, is specific to the industry analyzed, the model designed is generic enough to be applied in any industrial context where ergonomics maturity needs to be analyzed. With the help of this model, the ergonomics maturity level of a company could be assessed and proposed improvement paths to reach the top maturity level could be established automatically by the audit tool that will be designed, tested and validated.

Valuable observations on this topic have been debated by (Mocan et al., 2017b). Three areas have been defined "in which ergonomic principles can be used to improve the quality of the work environment and help reduce negative incidents such as injuries" (Mocan et al., 2017b):

1. "Removing physical loads that cause error by fatigue;
2. Structured processes and training implemented to reduce the number of errors caused by lack of knowledge;
3. Leveraging emerging intelligent technologies to aid workers in recognizing mistakes".

In this context, the PhD research will focus on the second and third area of improvements.

The analysis will also look at the legal implications of using Industry 4.0 technology and the data it gathers to make management decisions about the improvement of the ergonomic environment. For the application to be feasible for application on an industrial level the legality of the visibility of the data being gathered needs to be analyzed both on a Belgian as well as on a European level. As the practical research will be done within the premises of a Belgian manufacturing facility, no other countries' legislations will be analyzed, as they are deemed not relevant to the study at hand.

2.2. Relevant ergonomics approaches in warehouse logistics research areas (the ergonomics risks)

Ergonomics in some shape or form has existed ever since the beginning of time, as Australopithecus Prometheus started making pebble tools and scoops from antelope bones and selecting the best ones for use over and over, in a clear sign that the tools that made his tasks easier were preferable. From an industrial point of view, the solidifying of ergonomics as a science came along with the creation of scientific management, at the beginning of the XIXth century.

Considering the historical perspective, the philosophical framework for the unique discipline of ergonomics (from the Greek "ergos" meaning work and "nomos" meaning natural law) has been first defined by W.B. Jastrzebowski in 1857. "Ergonomics was proposed as a scientific discipline with a very broad scope and a wide area of interests and applications, encompassing all aspects of human activity, including labor, entertainment, reasoning, and dedication" (Karwowski, 1991; Karwowski, 2005). Furthermore, the International Ergonomics Association[7] support the idea that "ergonomists contribute to the design and evaluation of tasks, jobs, products, environments, and systems to make them compatible with the needs, abilities, and limitations of people". General definition is graphical represented in Figure 2.4.

The subject of ergonomics is predominantly known in North America as "human factors", to emphasize the application of ergonomic methods to situations

[7] https://www.iea.cc/

outside of work; the terms human factors and ergonomics are essentially synonymous (ISO 63785[8]).

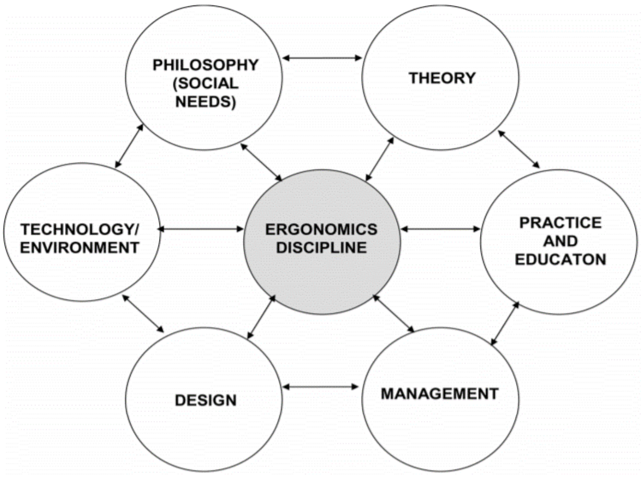


Figure 2.4. General dimensions of ergonomics discipline (Karwowski, 2005)

"Ergonomic problems at the workplace and bad work organization are part of the contributing risk factors to the abovementioned occupational safety and health problems. A number of situations within the workplace are conjectured to contribute to the increasing magnitude of musculoskeletal disorders (MSD) suffered by the workers, including postural stress from prolonged sitting, standing, or awkward position; stereotyped and repetitive tasks leading to chronic injury; peak overload injuries to the axial or peripheral skeleton; environmental factors; and psychosocial factors including psychological stresses, job dissatisfaction, and complex social issues, such as compensation laws and disability system" (Niu, 2010).

The MSD of the upper extremity have been discovered to be related to work for hundreds of years. Bernardini Ramazzini, considered the father of occupational medicine, was the first who develop a synthesis of working conditions and the associated pathology, by considering the occupational health perspective. In his 18th century book "*De morbis artificum diatribe*" he said that these diseases "*arise from three causes: first constant sitting, the perpetual motion of the hand in the same manner, and thirdly the attention and the application of the mind*" (European Foundation for the Improvement of Living and Working Conditions, 2006).

During the age of industrialization, more attention has been given to the relation between work and health. In the 1830s, in the United Kingdom there have been recorded the first epidemic of work-related MSD for the case of the civil service processes; thus, the steel nib was introduced. It was suggested that a subsequent

[8] https://www.iso.org/standard/63785.html

epidemic among telegraphists a few decades later, has led to the definition of the term "*nervous breakdown*" (Lucire, 1986).

Later in "*The Science of Labor and Its Organization*" (1919), Józefa Joteyko introduced and discussed measurements of occupational fatigue and principles in the context of the scientific management wave (Niu, 2010). Worker efficiency since then been continuously improved upon, as ergonomics has gained more traction in the past few decades. However, the growth is not increasing as fast as would be expected, considering the new ground scientific ergonomics has recently covered (Harrison, et al., 2006).

In the mid-90s a vision of the future of ergonomics was put forward by Senders and Moray (1995), when he argued that given the historical situation at the time, ergonomics was going to be looked at as a way to facilitate the improvement of the quality of life, as a partner in a multidisciplinary approach that would allow, entice and enforce behavioral change that would benefit not only businesses, but the world at large. He mentioned that "ergonomics also, needed to accept the fact that few solutions are universal, as solutions need to acknowledge the morals and the ethics of place". With the rise in globalization and digitalization, new terms such as "situation awareness, mental workload and virtual reality" started to appear in practice and in the literature, along with complexity management and cognitive systems development. In his address in 1997, Helander considered "the 90s as the decade of cognitive and organizational ergonomics". The point was raised again in 2000, saying that "the need for a broader systems perspective in addressing ergonomics challenges has not yet been found" (Moray, 2000).

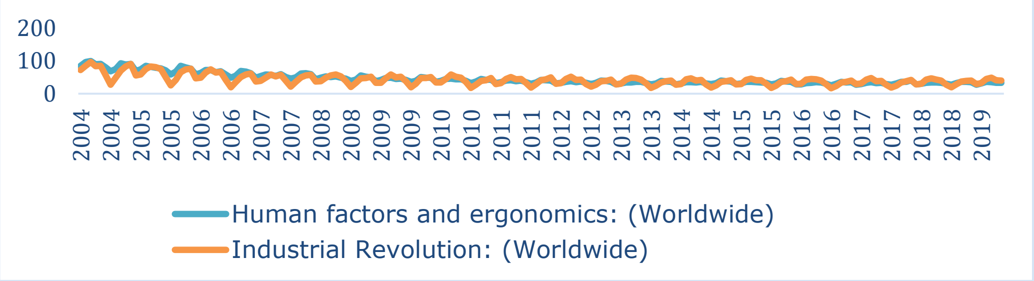


Figure 2.5. Correlation between "Ergonomics" and "Industrial revolution" (Google Trends Search)

As can be seen in Figure 2.5, there is a strong (0,83) correlation between the interest that is shown for the concept "Human Factors/Ergonomics" and the concept of "Industrial Revolution". It is also interesting to notice that even though there is a strong correlation between the two topics there is also a downward trend throughout the years, showing that less interest has been given to the topics in the past decade and a half. The trend has however stabilized after the financial crash of 2008 and exists at the same level ever since. What is interesting to see however is the spread of this interest worldwide. As shown in Figure 2.6., industrialized countries, in their majority, are more interested in "Human Factors/Ergonomics", while mostly non- or lightly- industrialized countries are interested in the new "Industrial Revolution". This spread is normal because ergonomics usually becomes enacted after the industrial revolution takes place. While the goal of ergonomics is to fix the issue before it ever occurs, it is not an easy task to achieve, leading it to mostly be a post factum implementation in the industrial ecosystem.

Figure 2.6. Geographical areas of interest for ergonomics (Google trends)

Based on a relevant literature review it has been shown that most decision support models are designed by "considering the logic of order-picking as a business process concentrated only on the short-term economic impact" (Grosse et al., 2015). Thus, "decision-making processes are ignoring the influence of the order-picking processes on the human operator" (Gajšek et al., 2017).

The question then stands, why have operational managers and engineers not kept up with the recent developments in research? The answers could lie in a lot of areas, such as ineffective terms of translating theory to practice (Brown Jr., 1991), inadequate design of training programs or even the communication style of these new discoveries not being suitable for corporate audiences (Harrison et al., 2006). Whatever the reason or combinations thereof the result is a vast difference in ergonomics application maturity levels within the same industries or between similar sized firms of different industries.

In the following we shall focus more on demonstrating the ergonomics implications in the case of the logistics systems started by analyzing the facts on the fatal and non-fatal accidents at work, Figure 2.7 (Eurostat, 2018).

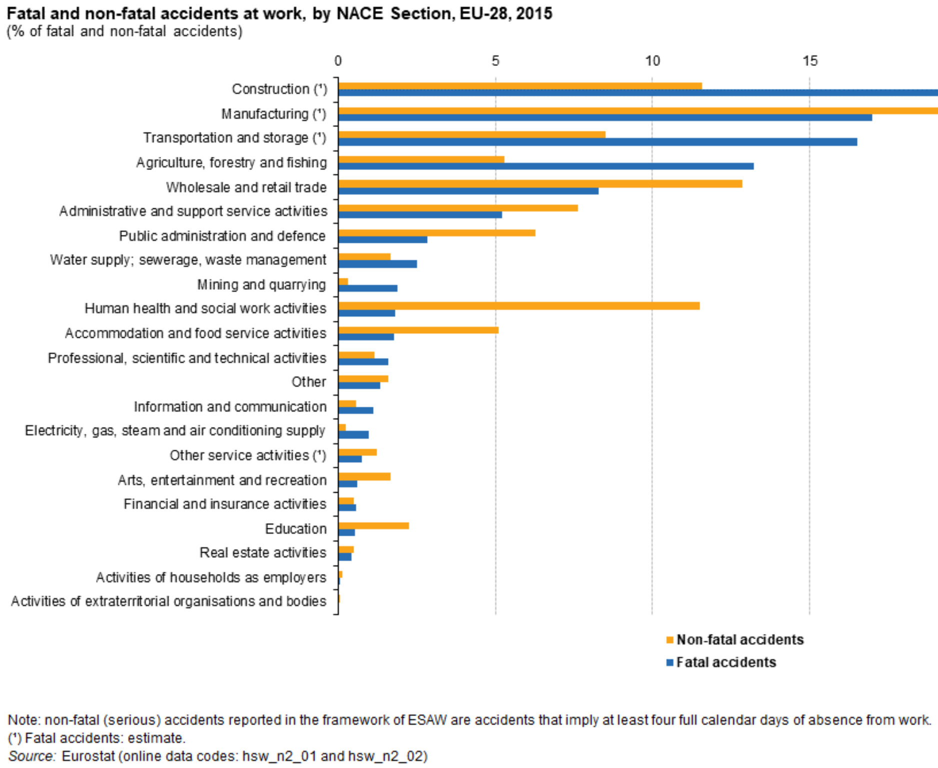


Figure 2.7. Fatal and non-fatal accidents at work by NACE section, EU-28, 2015 (% of fatal and non-fatal accidents; Eurostat (hswn201) and (hswn202), 2018)

The context of "ergonomics in the warehouse logistics is often presented by its regulatory health and safety aspect (see the statistical data of Figure 2.7), while not enough light has been shed on the competitive advantage opportunities that its applications can lead to" (Mocan and Draghici, 2019). In most of the published researches related to this field, ergonomics principles are presented at the base level, oversimplifying the information and its implementation (Mocan and Draghici, 2019; Ware and Fernandez, 2014; Stone, 2015; Knill, 2002; Mathis, 2018). The pressure felt by distribution centre managers who say that safety is the number one driving concern in recent years, most likely causes this and that solutions are needed to increase it (Stone, 2017). While also being forced to reduce costs and increase output speed, short-term vision leads them to apply superficial and non-integrated solutions to have a quick fix for the issue. This view of ergonomics and workers' safety is limiting both from an educational as well as a production perspective, as it keeps repeating the same basic information over and over, giving the reader the impression that as long as these sound bites are implemented in the overall production process nothing more needs to be done.

This is not the correct way of thinking, as ergonomics has a deeper well of solutions to offer to its users. Thankfully, this presentation of this topic has been changing in recent years along with the appearance of the Industry 4.0 mind-set. Here, ergonomic developments are seen less as being ergonomics for ergonomics' sake and more as belonging to the area of cost saving and operational streamlining facilitators. Within the logistics work areas, a large wave of technological advancements has been seen in warehousing, materials handling, and packaging. As mentioned previously, these are an integral part of the logistics process. Explaining it simply, inventory needs to be warehoused, material handling is necessary to move inventory between transportation vehicles and warehouses or within warehouses themselves and packaging helps move individual products as efficiently as possible between two places. Firms can choose between operating their own warehousing facility and outsourcing the process to a third party. Regarding to this decision, activities that commonly happen in a warehouse are sorting, sequencing, order selection, transportation consolidation, and, in some cases, product modification and assembly (Ismail, 2008). Within these processes handling or manipulation is an important activity that can be manual, fully automated, or somewhere in between.

EU-OSHA[9] and International Labor Organization (ILO) estimated that the rough annual cost related to work-related ill health and injury is costing the European Union 3.3 % of its gross domestic product (GDP), or approximately €476 billion every year. Additional arguments on these aspects have been provided by (Mocan et al., 2017b). "With an average warehouse size between 2,000 and 4,000 m^2, warehousing activities take up to between 2% and 5% of the cost of sales of a corporation meaning that improved efficiency and throughput time can lead to significant reduction of costs even in companies in which warehousing is not the core business" (Hwang and Cho, 2006).

"The increase in productivity that ergonomic system implementation can lead to will also almost automatically lead to an improvement in throughput time which in turn leads to higher returns. This is achieved by reducing the number of errors and reducing the effort put into the picking and transportation. Reduced throughput also leads to less time in the warehouse, emptier warehouses as a result, therefore the realization that the need of space is not directly proportional to the amount of items to be picked and shipped, but is a function of complexity, error and performance of the warehouse workers. It has been proven that investment in ergonomic improvements in the workplace can result on a return on investment ranging from 3:1 to 15:1" (Heller-Ono, 2014). "Previous research has demonstrated that in the case of a workstation redesign in an assembly factory, settings made by ergonomists led to an increase of over 15% of the productivity and because of the higher quantity of the work output, the productivity per worker has been increased to €2000-2500" (Hendrick, 2003).

The proof therefore exists that cost reduction in ergonomics is possible, not just by reducing the cost of injury, but also by redesigning the way in which the work

[9] https://osha.europa.eu/en/about-eu-osha/press-room/eu-osha-presents-new-figures-costs-poor-workplace-safety-and-health-world

is done. This is being taken to the next level by the implementation of Industry 4.0 solutions within the supply chain.

2.2.1. Work-related physical pain

"Within the management of the storage and movement of goods, a warehouse is a facility in the supply chain that is used to consolidate products, achieve economies of scale in manufacturing or in purchasing (Bartholdi and Hackman, 2008), or provide value added processes and shorten response time (Gong and De Koster, 2011), being one of the main areas where logistics companies can gain competitive advantage by offering their clients tailored services" (Mocan et al., 2017b). Stock management is at the core of a warehouse's activities. Within a warehouse, Manual Materials Handling (MMH) is defined as "any transporting or supporting of a load by one or more workers. It includes the following activities: lifting, holding, putting down, pushing, pulling, carrying, or moving of a load" (Council Directive 90/269/EEC).

Manual handling is developed in most of the working systems, but employees from the fields of construction, agriculture, warehouse logistics are more exposed by frequent heavy loads processes. That implies that the worker is exposed to tasks that increase his ergonomic risk factors such as lifting, twisting, lateral bending, maintenance of static postures, heavy load carrying, or a combination of these. "Manual handling can result in fatigue, and lead to injuries of the back, neck, shoulders, arms, or other body parts. There are two types of injuries that can result from manual handling namely:

- *Acute* (e.g., cuts, bruises or fractures that are caused by sudden accidents);
- *Chronic* (e.g., the damage to the musculoskeletal system of the body due to gradual and cumulative wear caused by repetitive manual handling)"[10].

These chronic injuries are called *musculoskeletal disorders* (MSD, recognized by the EU-OHS). The most common MSD are caused by inappropriate material handling and often affect the neck, upper limbs, lower limbs, or the back. The following subchapters will delve deeper into the topics discussed relating to various work-related MSD (WRMSD) in warehouse logistics.

2.2.1.1. Back pain and work-related musculo-skeletal disorders

Research related to back pain in "WRMSD focuses mostly on low back pain. Low back pain is any back pain between the ribs and top of the leg. Work-related low back pain is any back pain originating in the context of work and is clinically considered to have been probably caused, at least in part, or exacerbated by the

[10] As supported by EU-OHS publication: http://www.mtpinnacle.com/pdfs/E-fact_14_-_Hazards_and_risks_associated_with_manual_handling_in_the_workplace.pdf and (EU-OSHA, 2017b)

claimant's job. Usually the origins of low back pain are grouped under four categories" (Khalil et al., 1993):

- Discogenic/neurological, meaning that one or more intervertebral discs are the pain;
- Muscular/ligamentous, meaning that muscle sprains are the cause of the pain;
- Structural, meaning that bones and bone structure are the cause of the pain;
- Other disorders, meaning that anything from tumors to infections to genetic diseases are the cause of the pain.

"Within a warehouse environment, one of the most incorrectly done activities is the lifting and setting down of weights. Most people chose to pick up a weight by bending their back rather than squatting on their haunches" (Mocan et al., 2017b). Furthermore, "when a load is held away from the body, the stress on the lower back increases substantially. The maximum weight one can lift safely is reduced dramatically the further away from the body that the load is handled" (Figure 2.8)[11]. "Long reaches increase the risk of a lower back injury. The altered mechanics of bending at the waist as opposed to the hips causes undue strain on the muscle ligaments and vertebrae that can lead to muscle pain, herniated disks, strains on the thoracolumbar fascia or latissimus dorsi muscles or sciatica" (Mocan et al., 2017b).

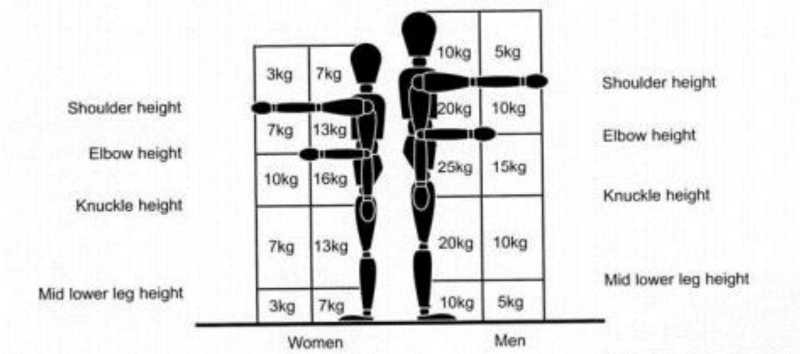


Figure 2.8 Numerical values for lifting loads
(Retrieved from: http://docplayer.net/16075167-Moving-and-handling-techniques.html)

"Work-related low back pain and injuries are some of the most common musculoskeletal disorders that manual handling causes. About a quarter of European workers consider that work-related back pain injuries affect their health, and in areas such as construction, agriculture and transportation as many as 61% of people are suffering from some form of work-related musculo-skeletal disorders with the most reported health problem reported being backache at 43%" (Mocan et al., 2017b). This was followed by muscular pains in the neck or upper limbs (42%), headache and

[11] Moving and Handling Techniques, Retrieved from: http://docplayer.net/16075167-Moving-and-handling-techniques.html

eyestrain, and overall fatigue (both 35%) and muscular pains in the hip or lower limbs (29%). According to the physical environment index, that "measures exposure to vibrations, tiring positions, lifting people, carrying heavy loads and repetitive movements, the most prevalent causes for MSD", the situation has been improving over the past 10 years in almost all countries with the exception of France and the United Kingdom (European Foundation for the Improvement of Living and Working Conditions, 2014).

Manual Materials Handling (MMH) is a hazardous activity because it affects the lower back (Troup, et al., 1988; Kumar, 1994). Studies have shown that in the case of warehouse workers, they face significant risks for lower back pain, MMH being a dominant working style (Marras et al., 1999; St-Vincent et al., 2005; Denis et al., 2006). "When the warehouse superstores subsectors are isolated from other subsectors, the proportion of injuries to the back ranges from 39% to 50% of all compensated injuries depending on the subsector, while the average proportion is 27.9% across all sectors in the province of Quebec" (St-Vincent et al., 2005).

One of the most human-work intensive activity in warehousing is palletizing and depalletizing, which is defined as the transfer and stacking of material from or onto pallets. This activity's capability to cause MSD has caused researchers to analyze the ways in which spine loading can be reduced by means of package location within the pallet, pallet distance, operator position, pallet orientation, and palletizing condition.

Because human operators must often lift with the body in extended reach positions, studies have been conducted to analyze whether the location of the object on the pallet as well as the weight of the object may determine the risk of injury to the operator. One study found that "lifting a box from low and distant locations imposes nearly twice the risk probability as lifting the same weight box from a higher and closer location, revealing that 97% of the lifts from the lower layer of the pallet resulted in spine compression values above 3400 N and would be expected to increase the risk of an occupationally related low back disorder". Increase in the weight of the box also increased spinal loading, but this impacted spinal loading greater when the position from which one lifts was taken into consideration as well. "Distant locations on a pallet required the worker to reach farther and increase the mechanical moment arm of the worker-environment system". Increasing the mechanical moment arm was equally significant between long vertical and long horizontal reach. The findings had "several implications for the design of the distribution workplace, such as how one would benefit from raising the pallets off the floor or adding handles to the boxes with the purpose of raising the height of the lift" (Marras et al., 1997). The introduction of height increasing solutions was corroborated by other research, which proved that self-levelling carousels and adjustable carts were effective in reducing the spine loads when compared to the traditional pallet-cart condition and also reduced loads (Ramsey et al., 2014).

The pallet distance from the operator is directly proportional to the torso kinematics (velocities and accelerations) and the risk low back disorder. This kinematic also increases when packages are picked up at the lower end of the pallet

(Jorgensen, et al., 2005). "Lifting from the floor was reported to produce up to twice the amount of spinal loading as lifting from a higher up location, such as elbow height. It has been shown that lifting from below the knee or from the floor magnified the negative effects of MMH on workers with low-back pain symptoms, older workers, workers with knee osteoarthritis, and workers with a high body mass index" (Ngo et al., 2017).

Gallagher and Heberger (2015) analyzed the design of operator workstations and their effect on reducing the worker injury risk. Its results clearly demonstrated that positioning the pallet at the end of a conveyor belt, results in a significant reduction in loading on the lumbar spine compared to positioning the pallet on the side of the conveyor, most likely due to the ability of using the momentum of the bag as it comes off of the conveyor "as opposed to having to forcefully redirect the bag from its course along the conveyor when the pallet is located on the side" (Gallagher and Heberger, 2015). Additionally, the study showed that controlled lower level loading has a higher impact on the pressure exerted on the spine. The way to reduce this loading was either by raising the pallet level, or by loading the pallet with the help of uncontrolled drop stacking. It was posited that lumbar compression for the drop technique were approximately 600–800 N lower than those for controlled placement at the lower levels (Gallagher and Heberger, 2015).

2.2.1.2. Upper limbs disorders generated by the manual materials handling

"Holding and carrying involve static endurance, which can be determined by the length of time a limb can maintain a certain position. The amount of muscular strength is the maximum amount of force that a muscle can exert under maximum contraction. It has been shown that isometric (or static) activities cause greater levels of exhaustion than isotonic ones, meaning that holding a weight for a period is more straining that moving it" (Salter, 1955). "Holding a weight also changes the point of gravity, thus putting a strain on posture muscles such as the trapezius and the erector spinae muscles to maintain a proper upright position" (Mocan et al., 2017b).

Work-related Upper Limb Disorders (WRULD) are related to the injuries of different body segment as the neck and the upper limb segment (shoulders, arms, forearms, wrists and hand) as a result of physical work exposure that involves application of force, either to move objects or to keep them steady. Some of WRULDs have clearly defined signs and symptoms (such as tendonitis, carpal tunnel syndrome or osteoarthritis), while others do not have a clearly defined symptom list, presenting as pain, discomfort, or numbness (Van Tulder et al., 2007). The most common WRULDs are (Petreanu and Seracin, 2018)[12]:

- "*Neck*: Tension Neck Syndrome, Cervical Spine Syndrome;

[12] Presented in the OSH WIKI. Retrieved from: https://oshwiki.eu/wiki/Risk_factors_for_musculoskeletal_disorders_development:_hand-arm_tasks,_repetitive_work

- *Shoulder*: Shoulder Tendonitis, Shoulder Bursitis, Thoracic Outlet Syndrome;
- *Elbow*: Epicondylitis, Olecranon Bursitis, Radial Tunnel Syndrome, Cubital Tunnel Syndrome;
- *Wrist/Hand*: De Quervain Disease, Synovial Cyst, Trigger Finger, Carpal Tunnel Syndrome, Guyon's Canal Syndrome, Hand-Arm Vibration Syndrome, Hypothenar Hammer Syndrome".

According to "results from the sixth European Working Conditions Survey 2015, 44.4% of workers cited problems with muscular pains in the shoulders, neck, and/or upper limbs, thus making WRULDs the most common form of occupational disease in Europe". The "carpal tunnel syndrome studies have found prevalence rates of 7% to 14,5%". According to Eurostat data, "upper limb disorders are more self-reported than lower limb disorders" and these seem to affect women more than men. While men report problems more often, "women reported upper limb disorders as the most serious work-related health problem" (Eurostat, 2018)[13]. The main WRULD factors are (Arezes, & Carvalho, 2014):

- "Force application resulting in heavy mechanical loads on the neck, shoulders, and upper limbs;
- Working in awkward positions- muscles must contract, and greater mechanical loads are placed on the body;
- Repetitive movements, especially if they involve the same joints and muscle groups, and if there is an interaction between forceful activities and repetitive movements;
- Prolonged work without the opportunity to rest and recover from the load;
- Local compression of tools and surfaces;
- Hand/arm vibration, causing numbness, tingling or loss of sensation, and requiring greater force when gripping".

These work-related musculo-skeletal disorders (WRULD) factors are exacerbated by work environment such as poor workspace layout, or poor lighting practices, individual factors such as the physical capability of the worker, or level of experience and organizational and psychosocial factors such as lack of control over the performed tasks, or time pressure. Within the European context there are a series of main directives related at preventing WRULDs, namely 89/391/EEC[14], "which covers the measures to encourage improvements in the safety and health of workers, 90/270/EEC[15], which, covers the minimum health and safety requirements for work

[13] Eurostat (2018). Statistics Explained, Accidents at work statistics. Retrieved from: https://enuveprod-universitatpolit.netdna-ssl.com/php_prevencionintegral/sites/default/files/noticia/45658/field_adjuntos/11539.pdf

[14] Retrieved from: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31989L0391

[15] Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31990L0270

with display screen equipment and 90/269/EEC[16], which covers the identification and prevention of manual handling risks".

Within a warehouse environment, the activity that causes the highest incidence of WRULD is order picking, due to the "manual carrying and lifting of bulky and/or heavy items. Order picking is the process of retrieving items from their storage locations in a warehouse to fulfil customers' orders", it is the most labor-intensive, and
time-consuming activity in warehousing, accounting for more than 50% of warehouse operating costs (Grosse et al., 2015; Gajšek et al., 2017; Tompkins et al., 2010).

The way in which WRULDs are assessed is by using the Rapid Upper Limb Assessment (RULA) methodology. This is an assessment that is used to analyze the ergonomic risk that workers face in relation to upper extremity musculoskeletal disorder (Middlesworth, 2007). "A single page worksheet is used to evaluate required body posture, force, and repetition. Based on the evaluations of the movements, scores are entered for each body region in section A for the arm and wrist, and section B for the neck and trunk. After the data for each region is collected and scored then the tables on the form are then used to compile the risk factor variables, generating a score that represents the level of MSD risk", which ranges from negligible to very high (Middlesworth, 2007).

The findings of a WRMSD study presented by Basahel (2015) "showed that the heart rate was significantly changed from rest level during performing both lifting and pulling products tasks. On the other hand, the pulling task showed a greater total wrist and arm score than the lifting task; that may be due to the range of heavy loads in the pulling task. In the pulling task, the wrist pain score (4,78) was the highest among other body regions. Following the wrist pain score was the prevalence of lower arm disorders (4,16). According to the total score of the RULA method, the lifting product task was a greater ergonomic hazard than the pulling products task in term of MSDs as well as being more physically demanding, since the score of the lifting task (5,76) was significantly greater than the score of the pulling task (4,88)" (Basahel, 2015). This type of pain can lead to severe productivity loss, as one study found that 56% of analyzed workers reported a productivity loss associated with pain intensity, pain interference with work and fear avoidance (Martimo et al., 2009).

2.2.1.3. Lower limb disorders during the manual materials handling

The lower extremity skeletal system is made of the pelvic girdle segments, thigh, lower leg, foot and the joints, cartilages tendons and muscles that connect the regions with each other. The largest articulations in the area are the hip, knee, and ankle, other articulations including that between the tibia and fibula, the tarsals, the tarso-metatarsal regions, the metatarsals, the metatarso-phalangeal segments, and the phalanges (Gray, 2015). The most common risk factors associated with the work-

[16] Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31990L0269

related lower limb disorders (WRLLD) are the repetitive kneeling or squatting, fixed postures, or frequent jumping from a height.

The biggest issue related to the study of lower limb disorders is the underestimation of the problem. At the European level, "a data trends analysis on muscular pains of the lower limbs is not possible because the indicators were introduced only in the 2000 and there is no universally recognized list of occupational musculoskeletal diseases. Some national data can provide more extensive information on lower limb disorders, distinguishing by body part affected" (EU-OSHA, 2010).

Local statistics show that there are significant gender differences between the type of WRLLD women and men must work through. "Women are significantly exposed to prolonged standing and walking, reporting more problems in hips, legs, and feet, while men are more affected by knee problems. Prolonged standing and walking is a notable risk factor in the "traditional" sectors such as agriculture and construction, but also greatly affects workers in service professions, above all in hospitality and retail, a fact that is, as mentioned before, barely reflected in monitoring and recognition of lower-limb disorders" (EU-OSHA, 2010).

Even in smaller scale studies, "the course of lower limb pain is studied less frequently than back and upper limb pain. In a study population of 139 patients with hip complaints, 24% reported recovery after three months, increasing to 37% after 12 months. A study of 251 patients done in relation to knee pain resulted in 25% of respondents reporting recovery after three months, increasing to 44% after 12 months" (EU-OSHA, 2007a).

The same lack of interest issue appears when analyzing the risk assessment models and tools that can be used for lower extremity regions. There is no WRLLD specific assessments and the tools that can be used are intended to be used for whole body use. Within the logistics systems, the lack of information is even more jarring. From statistics data available there could be known that back and lower limb disorders can occur in the case of truck drivers and warehouse employees, among others such as parcel handlers, or operators of cranes and other large vehicles (Pope et al., 1991). But overall, there seems to be very little warehouse specific literature in relation to WRLLD.

The few papers found are not warehouse industry specific, related to issues such as activities involving pulling and pushing. "The amount of force that can be exerted by your limbs depends on body posture and the direction of force. For example, when standing, one can exert more force when pulling backwards than when pushing forwards. Pushing is preferable to pulling for several reasons such as the awkward positioning of the arm stretched behind the body during pulling while facing in the direction of the walk that places the shoulder joint in a posture that can increase pain and possible injuries. Similarly, pulling while walking backwards can lead to accidents very easily as there is no line of view to see the travel path" (Cheung et al., 2007; Mocan et al., 2017b). "Further, research demonstrates that people can usually exert higher push forces than pull forces. In some situations, pulling may be the only viable means of movement, but such situations should be avoided wherever possible, and minimized when pulling is necessary. It has been shown (Hoozemans et al., 2002) that pushing and pulling lead to an increase in shoulder aches on a dose response relation and that sometimes lower back issues can also occur" (Mocan et al., 2017b).

2.2.1.4. Prevention of work-related MSD

As already presented in the previous chapters, the health of a workplace environment is directly affected by (Shain and Kramer, 2004):

- Things that employees bring with them to the workplace: personal experiences, health practices, genetic makeup, and attitudes;
- What the workplace does to and for employees once they are there: the steps that an organization takes in creating it work culture and climate (the physical and psychosocial organization of work).

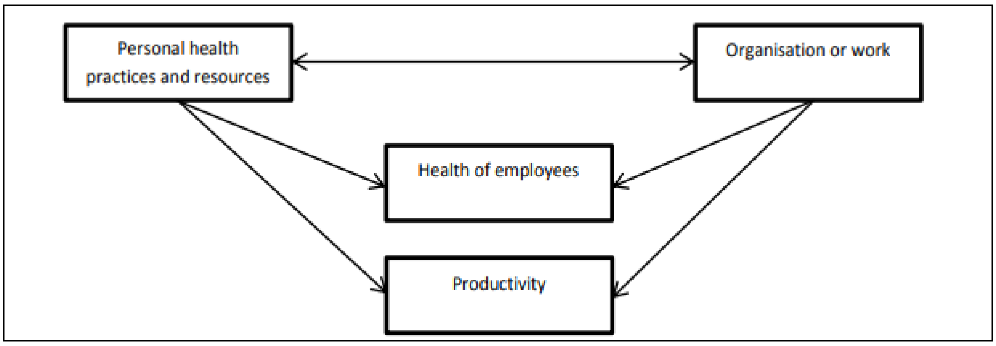


Figure 2.9. Interrelation of health and productivity

To remove or diminish the effects of WRMSD at work a series of preventive strategies can be applied. Prevention is characterized by consider three different levels:

- *Primary prevention*, in which the efforts are focused on discouraging people from using unhealthy behavior, thus applied prior to the onset of diseases. Within an organization it includes risk assessment of processes and ergonomic trainings;
- *Secondary prevention*, in which the efforts are focused in stopping the development of a disease and treating it before irreversible pathological changes take place. In a work context it involves the identification and health monitoring of workers at risks;
- *Tertiary prevention*, in which the efforts are focused on applying all available measures to reduce impairment or disability and to promote adjustments to irremediable conditions. Within a work environment this implies return-to-work actions.

While companies are working mostly in applying primary and secondary prevention within their local policies, the international administrative organizations develop legislative contexts for the application of tertiary prevention. The EU-OSH Agency (2007b) even recommends employers to act "to protect workers from the risks of manual handling" by managing risk assessment activities as well as setting up prevention campaigns. Their recommended prevention measures included are (EU-OSH, 2007b):

- "Designing and organizing tasks to avoid manual handling completely, or at least restrict it";
- "Using automation and lifting equipment";
- "Organizing manual handling tasks in a safe way, with loads split into smaller ones, and proper rest periods provided";
- "Providing information and training to workers on tasks, and the use of equipment and correct handling techniques"[17].

The current methods of treating WRULD currently imply active symptom surveillance, which can lead to early assessment and treatment. To assess the workplace risk education and involvement of workers and line managers is needed to create a collaborative and non-adversarial approach. External help should also be used to ergonomically assess the jobs being done and re-engineer the working stations to avoid unsafe repetition, force and prolonged abnormal postures (Helliwell, 1999) Treatment and recovery for chronic work illness often prove to be unsatisfactory with the final result in that case being permanent disability and loss of employment. According to the present literature study on effectiveness of work-related intervention and workers rehabilitation, we conclude that it is scarce.

The impact of training advice and working techniques for lifting equipment in a way that prevents back pain is not yet clear. Currently, due to the prevalence of back pain and its resulting economic consequences, "employers must ensure that workers receive proper training and information on how to handle loads correctly" (Martimo et al., 2008), with the help of specific techniques that have been presented by government agencies to reduce the load on the back. "Minimum health and safety requirements for the manual handling of loads where there is a risk particularly of back injury to workers" (Council Directive 90/269/EEC[18] of 29 May 1990; Martimo et al., 2008).

The study of Martimo et al. (2008), found that training did not lead to a positive outcome concerning diminishing the risk of back pain. With a sample size of just over 2500 people the resulting confidence intervals show that the possibility of the review being too small to detect differences in incidence cannot be excluded. However, almost all studies analyzed showed almost non-significant differences between training and not training. It could be that the reason "for the lack of an effect was because the intervention was not appropriate", but the studies were classified based on the learners' participation and studies that involved more intense training methods did not show outcomes that are more positive (Martimo et al., 2008). The review did not show significant capability of prevention of back pain related to workers being trained and advised by health professional on the correct lifting and handling procedures (Martimo et al., 2008). Given this situation, it could be posited that

[17] As mention in the EU-OSHA document: http://www.mtpinnacle.com/pdfs/E-fact_14_-_Hazards_and_risks_associated_with_manual_handling_in_the_workplace.pdf

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31990L0269.

perhaps current training techniques are not the way in which to reduce the incidence back pain. Either new training techniques must be developed, or tools must be used to help practitioners reduce the number of tasks that could cause back pain injuries in the first place.

It has been shown that direct observation methods (e. g., Ovako Working posture Assessment System, OWAS) is, are not replicable in dynamic work conditions and are subject to intra- and inter-observer variability (Burdorf et al., 1992; Basahel, 2015). Colombini (1998) edited a consensus document in association with the International Ergonomics Association technical group for work-related musculoskeletal disorders, which included checklists and models that describe and evaluate each of the principle risk factors. In this paper, he defined the generally accepted requirements such as tasks, cycles, and technical actions. Even though the authors provided an exposure assessment method that takes awkward positions and repeatability frequency the authors also acknowledged the difficulties involved in validating methods where many interactions occur. The need for standardization of assessment methods and methodologies is still present in today's environment for complex ergonomic activities.

As with most chronic diseases, MSDs have both occupational as well as non-occupational risk factors. As the body does not stop being in use once office hours are over, physical stresses to musculoskeletal tissues continue. In addition to occupational demands, other daily life aspects (e.g., physical activity, sports, housework) could generate physical stresses to the musculoskeletal system (Punnett and Wegman, 2004).

Within a warehouse environment, one of the most important factors that influences the pervasiveness of risk factors is the relation between stock volume and available storage space. "An imbalance between the amount of stock and the available storage space has three general types of consequences: the increase of risk factors related to the development of musculoskeletal disorders caused by increased MMH operations, an increased risks of accidents, such as falls or loss of balance and impacts on productivity and quality of service due to issues such as stock loss or time wasted that ultimately lead to customer dissatisfaction" (Denis et al., 2006).

2.2.2. Work-related stress

According to Council Directive 89/391/EEC[19] work-related stress is considered part of the legal domain of occupational safety and health within the European Union. According to the EU-OSHA (2002), "work-related stress could be defined as a pattern of emotional, cognitive, behavioral, and physiological reactions to adverse and harmful aspects of work content, work organization and the working environment. It is a state characterized by high levels of agitation and distress and often feelings of not coping". Work-related stress is experienced "when the demands of the work environment exceed the workers" ability to cope with (or control) them (EU-OSHA, 2014).

[19] Retrieved from: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31989L0391

According to the EU Labor Force Survey between the years of 1999 and 2007 approximately "28 % of respondents, roughly corresponding to approximately 55.6 million European workers, have reported that their mental well-being had been impacted by exposure to psychosocial risks" (EU-OSHA, 2014), with the most commonly selected risk factor being too much work and too little time to do it in. In addition, the EU-OSHA have underlined that "the cost to Europe of work-related depression was approximately €617 billion annually, made up of costs to employers resulting from absenteeism and presentism (€272 billion), loss of productivity (€242 billion), health care costs of €63 billion and social welfare costs in the form of disability benefit payments (€39 billion)". This is a topic that managers are aware of, with 79% of them reporting high concerned level of workplace stress. Also, managers considered the main reasons for work-related stress to be "time pressure, difficult customers and poor communication between management and employees" (EU-OSHA, 2014, completed by the OSH Wiki article: "Psychosocial risks and workers health"[20]).

A 2015 study from Harvard and Stanford University business schools found that job-related stress problems have a monetary impact on the US economy of approximately €170 billion a year in health care costs and contributed to almost 120.000 deaths a year. By looking at more than 200 other studies the researchers have found that job insecurity increased the odds of reporting poor health by 50% and long work hours increased mortality by almost 20%.

While they have been shown to be ripe in environments that pervade the physically unsafe work environment (Phipps, 2012) warehouse jobs are not exempt from work-related mental health issues either. In some trucking companies 200 to 300% employee turnover is the norm (Keller and Ozment, 1999), while retention rates for the warehousing industry range from 80% to 25%. The cost of replacing an employee in this sector is estimated to be of thousands of dollars (Gooley 2001; Mullins, 2007). While not all departures are directly related to mental health, it is widely acknowledged that big warehousing companies are not highly receptive to employee mental distress. Research related to this topic shows both workers and team leaders presenting with different stress symptoms such as work overinvestment, passive behavior, and a reduction in self-esteem (St-Vincent et al., 2006). Besides the pure link with mental stress, the primary or basic needs of safety, resting and food motivates employees. (Thomas, 2005), reminding that work-related stress can be the cause of workers' health problems.

Amazon workers, for example, are facing increased risk of "mental and physical illness", due to their exhausting (11 miles of walking per shift) and demanding (one order picked every 33 second) jobs (Jivanda, 2013). Other companies such as Blue Apron had warehouses ripe with violence.

Estimates of employee turnover within the warehousing industry range from 25 to 75% per year, with costs of replacement ranging in the thousands of euros (Gooley, 2001; McElroy et al., 1993). In the current economic environment where

[20] Retrieved from: https://oshwiki.eu/wiki/Psychosocial_risks_and_workers_health.

warehouse workers are being pushed to fulfil delivery quotas daily, a lot of unethical and unsustainable work practices in warehousing environments have come out into the public view with the help of investigative journalism reports. A possible taxonomy of psychosocial risks could include:

- Job content
- Work overload and work pace
- Control
- Work schedule
- Environment and equipment
- Roles in organization
- Organizational culture and function
- Interpersonal relationships at work
- Career development
- Home-Work interface

The following paragraphs will dive deeper into the ways in which warehouse workers are impacted by these stress factors and the issues that the pervasiveness of the risks is causing.

2.2.2.1 Job content

Job content depends on job characteristics that can lead to poor mental health for workers, such as the limited variety, fragmented and/or meaningless work, short work cycles, and low use of employees' skills. As research has shown, "job security turned out to be one of the most important factors for recruiting and retaining warehouse employees, whereas monetary incentives have little or nothing to do with warehouse employee turnover". The warehouse size was "directly related to the employee turnover due to the lack of personal attention paid to individual employees. This may have had the adverse impact on their retention" (Min, 2007).

Warehouse workers are asked to do repetitive and monotonous jobs by the very design of their work (McClelland, 2012). The purpose of a warehouse is to stock items. These items are delivered to the warehouse via another type of transportation. The job of a warehouse worker involves removing the items from the transportation means they arrived at and storing them at a predefined location. After a specific amount of storage time (dependent on the type of material being stored and the type of warehouse being used), the items must be shipped to another location. Depending on the type of warehouse orders are either large quantities of a limited number of products, such as in the automotive business (Bartholdi and Hackman, 2008), or small batch wide range orders for the warehouses delivering directly to consumers. To achieve this the items, must be picked up from their previous designated storage location, bundled up, packaged, and shipped out. Between these steps in the process various number of required scans must be done to alert the warehouse IT system of the location of the goods at any given moment. These scans can happen automatically on location or must be performed manually by operators. These repetitive motions not only cause physical pain and injury - women in the United States for example are absent from work for due to repetitive motion injuries twice as often as men (Messing, 2000)- but also lead to psychosomatic and musculoskeletal complaints and absenteeism (Houtman et al., 1994). Underuse of skills is also an issue to be mentioned, as a study using data from employees of Oregon manufacturing and warehouse firms showed. Overeducated workers are less satisfied with their job and more likely to resign than workers of an adequate education are (Hersch, 1991; Acosta-Ballesteros et al., 2018; Baran, 2018).

Monotonous job content is also what can lead to metal retirement. "Employees who are mentally retired are disconnected from their work and from the organization. Compared to others, they invest less in their work, their employability and development, and they have gradually lost their connections with their job, their colleagues, and the organization" (Huijs et al., 2019). Given the aging population that has led to the implementation of a higher retirement age throughout many countries, it is important to find ways in which to keep workers engaged with the work that they are doing for as long as possible.

2.2.2.2. Work overload and workplace

Workload can be defined as the amount of work that needs to be completed by an employee at a given time. The over or under loading of an employee is a psychosocial risk factors, together with time pressure (or the speed in which the tasks assigned must be completed). Mental workload can be described as the relationship between the cognitive resources that are necessary to fulfil a specific task and the operator's cognitive resources that are available (Wickens, 2008).

Mental and physical load can be expressed with the same components, namely stress, represented by "task demands and strain, represented by the impact on the human" (Young et al., 2015). This similarity is used even in the international standard on mental workload (ISO 10075[21]). Demands "can have multiple facets, such as time pressure or task complexity and they can be overcome with different support", such as team members or resources available to the worker (Young et al., 2015).

Workload problems receive a lot of attention, as research has proven that both overload and underload can be problematic (Frankenhaeuser and Johansson, 1976; Frankenhaeuser and Gardell, 1976; Lundberg and Forsman, 1979; Aldrich et al., 1989, Bommer and Fendley, 2018). Another stress factor described by studies has been the difference between quantitative and qualitative workload (French and Caplan, 1972, Malhotra and Chadha, 2012; Bowling et al., 2015). Quantitative workload refers to the amount of work that must be done while qualitative workload refers to the difficulty of that work. These two factors are independent of one another.

One of the reasons studying mental workload is necessary is to establish the relationship this has with operator performance (and subsequent errors coming from suboptimal workload conditions). Suboptimal workload in this case "can mean either overload or underload (Brookhuis and De Waard 2000). Overload occurs, when the operator is faced with more stimuli than they can handle" (Young et al., 2014), and this is common occurrence for warehouse workers to have 12-hour shifts. During the

[21] https://www.iso.org/standard/66900.html

end of the year holiday season warehouse managers often, apply mandatory 12-hour shifts or mandatory overtime to be able to cope with the influx of orders that must be processed. This causes work overload, as most of the time the same number of people are expected to handle a higher amount of orders. In some cases, like Walmart, store shelves are not being replenished at the needed rate because of chronic understaffing utilized as a cost saving mechanism. As Sanford C. Bernstein analyst explained in an interview there are only so many ways to cut costs before the decisions become detrimental to the work process (confirmed by the researches of (Tuttle, 2016; Dudley, 2013; Ghosh, 2018)).

The high picking targets that must be achieved by workers cause work-related pain and strain, such as carpal tunnel or Work-Related Lower Limb Disorders (WRLLD). In retail warehouses such as those of Amazon or Walmart workers are expected to pick upwards of 1000 packages per day (McClelland, 2012). In some locations, workers are not even paid per hour, but per amount of packages moved, meaning that in order to receive a proper pay check at the end of the day the pressure to load/unload trucks coming into the warehouse is high (Jamieson, 2011). This pressure is increased even more by the fact that in companies' search for more efficiency they end up being "*monitored and supervised by robots*". The system goes so far as to track "time off task". If workers break from scanning packages for too long, the system automatically generates warnings which can eventually lead to the employee being be fired (Lecher, 2019).

2.2.2.3 Control

Job control implies the degree of involvement an employee in the decision-making making process, relative to her/his job role. Within warehouses, mainly in the retail areas, the control of the pickers is slowly being relinquished to automated processed.

Some researches underlined that job demands are significantly directly related to emotional exhaustion and depersonalization and in addition to this, as self-efficacy beliefs concerning coping with aggressive behavior diminished so did personal accomplishment feelings (De Jonge et al., 2000; Brouwers and Tomic, 2016).

The job strain model developed by Robert Karasek (1979) has been used countless times ever since its inception. According to his model, the combination of high psychological demands and low control over work can turn into both a risk factor for cardiovascular diseases (Belkic et al., 2004), as well as for the elevation of the arterial blood pressure (Landsbergis et al., 2013; Babu et al., 2014).

This means that in an industry where job control is constantly diminished by the implementation of automated alternatives, workers will find it increasingly harder to get involved in their work or exhibit any decision-making initiative. This increases the level of stress that the workers are under and creates a vicious cycle regarding worker turnover and employee retention. Without increase of job control warehouse workers will not have any internal motivation for the job that they are doing and will rely exclusively on external, mostly financial compensation for their loyalty, which, in an industry that is focused on cost cutting through any means necessary, will not be a long term solution.

2.2.2.4 Work schedule

Work schedule can be defined as the amount of time a person has to work during a day and the placement of these hours during the day.

Within the warehousing industry, work working schedules imply long shifts and few breaks with badge in and badge out times. The metrics being used to calculate the work schedule and attendance caused some workers a "*state of constant anxiety that we could be fired at any moment for not meeting metrics*" (Ghosh, 2018).

Long weekly work hours and overtime have been associated with shorter sleep duration or sleep disturbances in several studies (Sasaki et al., 1999). Shift work (any work schedule not scheduled between 7 AM and 6 PM) in and of itself is detrimental to healthy sleep patterns (Drake et al., 2004).

Within Europe, a national study done in the Netherlands shows that in the transport and communication sector 21% of work time was covered via shifts, with, 37% was evening or night shift work and 41% was weekend work. According to the 5th European Working Conditions Survey, a large part of the workers in the research sample recognized that they work outside the normal work schedule of 8 hours/day during daytime, during weekdays. The survey shows that "around 17% of employees do shift work, while 21% work on call and on call work is carried out mainly in the transport sector (30%), followed by construction (27%) and public administration and defense (24%)" (European Foundation for the Improvement of Living and Working Conditions, 2014)[22].

2.2.2.5 Environment and equipment

Work environment and equipment problems could occur because of inadequate equipment availability, suitability or maintenance and poor conditions such as lack of space, poor lighting, and excessive noise. These improper conditions can lead to both physical as well as mental health impairments (Warr, 1992). In the last years, because of high degrees of temperature generated by the climate change, companies decide to support their employees by providing water and flexible work schedule some time. For example, Amazon has assured paramedics in ambulances outside their warehouses, ready to act in the case of dehydrated or heat stress affected employees.

Some former employees of the retail giant have come forward to say that the isolation and constant surveillance that they had experienced in the Amazon warehouses led to a toxic work environment that they claim was worse than being homeless (Gracely, 2014). Besides the equipment that should be used to make someone's job more efficient there is equipment that is used to track and monitor a worker's actions. In a piece of investigative reporting, Amazon pickers described how

[22] Retrieved from: https://www.eurofound.europa.eu/

the company equips them with handheld scanners that is used both to scan the scan the items they retrieve as well as monitors time between scans. "Pickers must hit a certain number of scans per hour and if they start missing their targets, a manager will show up to see what they are doing" (Ghosh, 2018). The same report mentioned how the working conditions caused one worker to have an "asthma attack during his night shift"[23] which led to his hospitalization. The most shocking of all claims are that the toilers are few and far between, causing workers to have to pee in bottles. "*As for bathrooms being a short distance from anyone in the fulfilment centre, that's just not true. There aren't enough of them, and they are always a good distance from you*" (McClelland, 2012).

2.2.2.6 The employees' role in organization

The effect of role clarity on its performance consequences can be explained by two cognitive theories, namely:

- Expectancy theory of motivation (the likelihood that focusing their effort on a specific service dimension will increase the level of performance on that dimension) and
- Attribution theory (the belief that employees do not only want to maximize their rewards but also attain cognitive knowledge about the process of the environment).

Role clarity therefore aids in the creation of the desired work focus and offers the clarity necessary to master one's job. Job clarity therefore leads to job satisfaction, organizational commitment, and increased job performance (Mukherjee and Malhotra, 2005). The lack of role clarity or ambiguity has been shown to lead to a three times higher absence risk (Väänänen et al., 2004). In addition to clarity, aspects such as role overload or responsibility can negatively impact individual health.

Ambiguity role happens when an employee has insufficient information about their work role. As defined by Warshaw (1979) it happens when, "the individual just doesn't know how he or she fits into the organization and is unsure of any rewards no matter how well he or she may perform". Role ambiguity is manifested at moments of change in the organization, such as restructuring or streamlining of human resource (Ivancevich and Matteson, 1980). This can lead to confusion about objectives, expectations, and generally about the responsibilities of the job. Early studies have shown that (Kahn, 1973) workers who dealt with role ambiguity were at a higher risk of experiencing work-related tension, lower levels of self-confidence and lower levels of job satisfaction.

In the case of warehouse workers, results reveal similar psychosocial stressors. While culture can provide a small differentiation between the ways in which role stress is perceived (Hoppe, et al., 2010), it was clear that role ambiguity compromised mental health by increasing sleep disturbances, job dissatisfaction and

[23] Retrieved from: https://www.businessinsider.in/peeing-in-trash-cans-constant-surveillance-and-asthma-attacks-on-the-job-amazon-workers-tell-us-their-warehouse-horror-stories/articleshow/64015295.cms.

desire to leave the company. On the other side role clarity increased job satisfaction (Autry and Daugherty, 2003; Tucker et al., 2018).

2.2.2.7 The organizational culture and functions

The organizational culture is related to the management styles and leadership that can cause negative consequences for employees (Ližbetinová et al., 2016). Studies in the literature have recognized that employees are socializing in the organizational environment context, using a set of three forces: (1) the hierarchical communication channels (with their managers or leaders); (2) in inter-group and inter-departmental communication channels (with other employee); (3) adapting themselves to the organizational specifics (e. g., policies, structures, procedures, methods and tools implemented for collaboration, co-operation and communication).

Person-organization fit refers to the match between the needs and preferences of the employee with the ones of the company they work in; it can be split into two categories: needs-supplies and demands-abilities (Caplan, 1987; Kristof 1996). The needs-supplies perspective considers person-organization fit to occur only when the organization, manage to satisfy individual's needs, desires, or preferences, (focus on the individual occupational needs). "The demands-abilities perspective looks at person-organization fit from the perspective of the individual's ability required to meet organizational demands, therefore the organization's happiness with the hire" (Autry and Daugherty, 2003).

It has been shown that "individuals make job choices based on perceived organizational fit with the company's personality, as they want to feel that they are becoming part of a group" (Cable and Judge 1994; Autry and Daugherty, 2003). While this is true for office workers, "warehouse employees may be more interested in immediate rewards", such as salary and benefits, rather than considering how well they will fit in an organizational culture (Autry and Daugherty, 2003). The lack of capability could lead to the increase level of occupational stress. As managers are responsible for passing on the culture and function of a company to their workers their behavior has been shown to have a major impact on the emotional well-being of workers (Landy, 1992; Corey and Wolf, 1992).

Furthermore, organizational culture and functions are sources of job satisfaction. If a warehouse employee is satisfied with their job they will put more effort into improving themselves and the work environment around them (Locke, 1969; Petty, 1984), whereas if they are dissatisfied they intent to behave in an unproductive manner (having tardiness, workday skipping, complete quitting) (Mobley, 1977; Mobley et al., 1978). Sometime, within some retail warehouses, workers feel as they are terrorized by their team leaders (McClelland, 2012).

Research shows "that employees who have realistic expectations about their company are more likely to be satisfied" (Autry and Daugherty, 2003), therefore the best way to maximize benefits for companies is to increase the hiring and retaining of "employees with expectations that can be met by the company". As this is a hard thing to assess before the hiring (Schein, 1991), managers should want to invest in improving the human resource practices of the company "to ensure that the best-matched employees are identified" (Autry and Daugherty, 2003).

Besides the pre-hiring screening, which should focus on person-organization fit warehouse management should also analyze the "candidates' compatibility with the leadership style of the supervisory staff and the cultural characteristics of the company" (Autry and Daugherty, 2003). To do these, human resources personnel should spend time to better understand the supervisors' leadership style and the work environment culture. While this kind of activity leads to a desired high fit, it is true that the current shortage of warehouse workers has left many positions unfilled and thus put more pressure on managers to hire workers who do not possess optimal levels of person-organization fit. In this case, the solution relates to creating a person-organization fit post hiring, by implementing long-term solutions such as mentorship or "big brother" socialization programs to guide new hires about existing company norms on the one hand and to listen to their perceptions of incompatibility or dissatisfaction on the other. The purpose is "to encourage active solicitation of employee ideas and opinions, increasing the sense of employee empowerment as well as creating a source of information for managers to improve working conditions in a timely manner" (Autry and Daugherty, 2003).

2.2.2.8 Interpersonal relationships

They are related to social or physical isolation, lack of support from peers and superiors, interpersonal conflict, or sexual harassment. Bad or negative interpersonal relationships could generate unsatisfaction at work, anxiety, and stress; positive interpersonal relationships and a good climate of work relation in the organization could positively affect work productivity and employees' morale. "Social context such as colleagues and the atmosphere at work can be one big engagement factor. Colleagues give the employee good resource of knowledge and emotional support. This can decrease work-related stress, which is one big factor in employee engagement" (Bakker and Leiter, 2010).

Within the fast-paced environment of retail warehousing, a lot of stress is caused by the lack of inter-personal relationship that are allowed, for the sake of efficiency (McClelland, 2012).

Violence in the workplace is another factor that causes psychological damage (Leather et al., 1999). Across the EU "3 million workers had reported being subjected to sexual harassment, 6 million to physical violence, and 12 million to intimidation and psychological violence" (Milczarek, 2010), leading to the publication of the "guidance on the prevention of violence at work" (Wynne et al., 1997). Women have been shown to be at a higher risk than men of being sexually harassed or assaulted at work. With some reports indicating that that 90% of women face sexual harassment in the workplace and, over 11,000 people filling complaints about sexual harassment with the Equal Employment Opportunity Commission (2011), thus it is clear that the problem is pervasive. Sexual harassment has severe consequences for both victims and employers, creating problems of absenteeism, low productivity, and increased turnover (Equal Employment Opportunity Commission, 2011; WWJ, 2012). With already existing pay gaps between men and women in the warehousing industry it is sometimes hard for women who rely on their salary in these sectors to come forward about their harassment for fear of losing their jobs. This creates a toxic environment for many women's mental health and forces them to prioritize their job to their wellbeing (Telegraph Report, 2018).

2.2.2.9 Career development

Career development risks are related to career stagnation, poor pay, job insecurity, and uncertainty.

The lack of career development capabilities could turn into a source of stress determined by its relationship with the competency's development. Job insecurity and status incongruity (over or under promotion, career stagnation or career ceiling) have been shown to be both sources of stress as well as having a direct impact on physical health (Margolis et al., 1974). These stressors primarily apply to older employees, who have reached their career ceiling and place a high value on stability and do not want to experience the erosion of status related to retirement. Job insecurity and redundancy related stress is even increased when the companies in which people work expect commitment (Porter et al., 1974). Poor pay, or poor payment schedule (payment/piece instead of payment/hour) is a stress source that causes negative effects in the rate of working (Kasl, 1992). Due to the routine of the job and getting used to the demands that it has on workers, "more experienced warehouse workers are less inclined to give up on their current jobs than less experienced warehouse workers" (Min, 2007). Status incongruity linked either to promotional lag or social class of the worker while growing up has been shown to cause psychiatric illness, mental health issues and put a person at a higher risk of coronary heart disease (Shekelle et al., 1969; Arthur and Gunderson, 1965).

2.2.2.10 Homework interface

Home-work interface is related to the demand conflicts between work like and home life, such as the stress and conflicts relating to dual careers or low support at home. While it does not only relate to domestic life or family life, most research has focused on the relationship between work and spouses or leisure time use (Cooper, 1981; Gardell, 1973). Another strong focus was put on women workers, especially when the family unit has young children and a way to resolve work life-family life conflicts must enhance. While most studies presented the combination of "thrusting male-caring female" dynamic. In more recent years more emphasis has been put on the dual career couple. The combination lends itself to the dissolution of traditional role expectations as both partners can express negative feelings as threat and/or anxiety. The "wasted leisure time syndrome" (Gardell, 1973) describes the frustration people with full time jobs feel when coming back home from work and not finding the time to do more than non-involving light leisure activities. Lundahl (1971) observed that workers with very high level of fatigue in their jobs are demonstrating less involvement in their social lives. Many studies have shown that this lack of capability to engage in more demanding leisure activities caused a negative psychological effect on the average worker (Kornhauser, 1965; Gardell, 1973; Cox and Howarth, 1990). The general realization was that "the unsatisfactory mental health of working people consists in no small measure of their dwarfed desires and deadened initiative, reduction of their goals and restriction of their efforts to a point where life is relatively empty and only half meaningful".

"Unpredictable scheduling practices lead to a worker's inability to plan any other aspects of life - which ranges from everything from childcare to attending school or taking a second job - which end up leading to overall negative effects on family life and their children's outcomes". "While employers' use of unpredictable schedules or just-in-time schedules is seen to boost profits by cutting labor costs, taking a more holistic view reveals these practices can cause harmful ripple effects for firms, families, and the economy". Local optimization, as is practiced in this case, does overall more harm than good. Irregular "schedules transfer the risk of doing business to workers and can harm a company's productivity as well" (Boushey and Ansel, 2016).

Already from research from previous decades it was shown that while "almost 73% of rotating shift workers were satisfied with their work-life balance the least satisfied were those with split or irregular shifts (about 65% were satisfied), on call or casual (62%), or with other shifts (63%)" (Golden, 2015; Williams, 2008). In other words, the people with the least say in what their schedules were going to be. "For families with children where both spouses worked full time shift work could exacerbate the balance needed to raise children in a good environment". The survey "shows that about 75% of full-time day workers whose spouse also worked full time were satisfied with their work life balance. When their spouse worked part time or was not in the labor force, about 77% were satisfied. While the proportion of full-time workers unhappy with their work-life balance varied, the main reasons for dissatisfaction were similar and were related to similar work-life balance issues. The main reasons for full time worker dissatisfaction were not enough time for family and too much time spent on the job". Not enough time for other activities was also a main trigger point. "Shift workers were slightly more likely than their day worker counterparts to worry about not spending enough time with family or friends (56% vs. 51%). Those working irregular schedules seemed the most affected by role overload and would sacrifice sleeping time to try to maintain enough family time" (Williams, 2008). "They would also feel constantly stressed trying to accomplish more than they could handle" (Williams, 2008). In other cases, workers do not have enough breaks during the day to allow them to talk to their family. This affects single mothers most of all.

In the past decades, the standard industry practice to increase workplace productivity has been the lean production standard work. On the one hand work has become faster and more efficient, but on the other hand more stressful for the workers. It has been shown in the past that issues such as job tension and fatigue were significantly greater in lean production environments than in traditional companies (Lewchuk and Robertson, 1996; Lewchuk and Robertson, 1997). Standardized work also increased the level of stress that workers felt (Parker et al., 1998). While the mental toll was mostly left invisible, the incident rate has clearly increased (Mirer, 1989; Fucini and Fucini, 1990) while the reporting of illness has decreased a result of managerial pressures to work under pain (Parker and Slaughter, 1994; Berggren et al., 1991).

While the problems of these cases cannot be unidirectional linked to lean and might be a compound issue of managerial decisions that have as a result cost cutting, they ultimately lead to understaffing and overtime work. It is clear from the studies presented thus far that on the one had warehouse specific injuries are wide in scope and high in quantity, and on the other that the management of most warehouses didn’t understand the impact of illness related costs on their bottom lines.

Within the emergence of the Industry 4.0 industrialization model, there is a clear opportunity to use emerging technologies not only in monitoring the wellbeing of our workers, but also in supporting them do their jobs in a more ergonomic fashion. The following subchapter will present the ways in which the Industry 4.0 emerging solutions can be integrated into daily worker life, the theoretical and practical challenges and opportunities these implementations raise and the ways in which management can assess which tools would best suit their working environment.

2.3. Ergonomics solutions in the Industry 4.0 context

By 2025, 10% of people are expected to be wearing clothes connected to the internet and the first implantable mobile phone is expected to be sold (Hutt, 2016). As the Industry 4.0 paradigm shifts forward, it will bring along with it a supply chain “disruption with long-term gains in efficiency and productivity”. This will cause “transportation and communication costs to drop, logistics and global supply chains to become more effective, and will ultimately diminish the cost of trade which will open new markets and drive economic growth” (Schwab, 2016). At the same time, there is a chance that the increase in automation will cause unrest in the labor markets. In the march towards lower costs it is unclear if the automation will substitute labor across all the economy and create an even larger inequality gap or if automation will increase the possibility for a removing low pay low reward jobs and change the employment landscape for everyone (Schwab, 2016). With the help of the Internet of Things, cyber-physical systems communicate and co-operate with each other and with humans in real-time, with the goal of personalizing mass production.

As manufacturers focus on the impact these new technologies will have on the production it is also important to assess the areas of impact that ergonomics will have from these new technologies. In Figure 2.9 the two big branches of Industry 4.0 ergonomics solutions are presented.

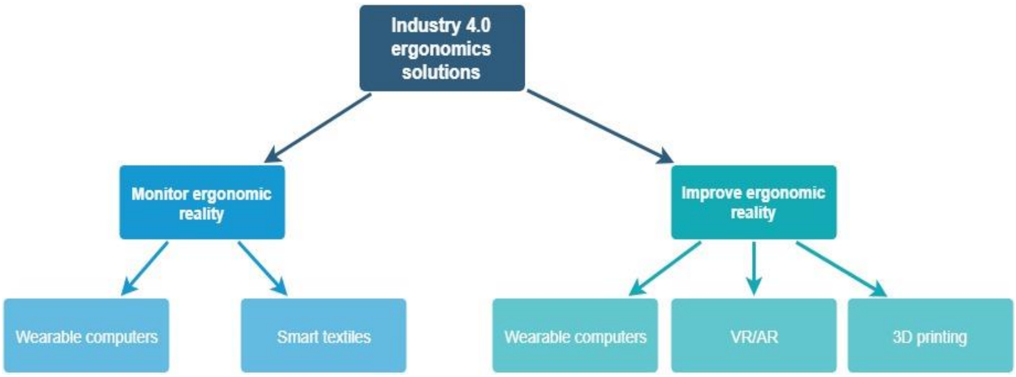


Figure 2.10. Industry 4.0 ergonomics solutions

Industry 4.0 will offer ergonomists both the possibility to reduce workload strain, both physically and mentally as well as the possibility to better monitor workers' biological reactions to assigned tasks. This would allow them to act preventively and step in before it is too late. The following paragraphs will discuss the two branches and the technologies already being used within them, while focusing particularly on Wearable Computers and Smart textiles. This decision is related to the fact that these technologies have the human at their core, while virtual reality/augment reality (VR/AR) and 3D printing, even though supporting the work that a warehouse worker would do on a daily basis, and exist independently of the person using them. They are modern solutions for training workers regarding the products that they are handling.

2.3.1. Monitor ergonomic reality

2.3.1.1. Wearable computers

The research presented in this subchapter was developed from December 2016 to June 2017 and the results have been disseminated though two articles*: *(Mocan et al., 2017a; Mocan et al., 2017b).

With the decreasing size and increasing power of most of the components of a modern computer, it was only a matter of time until computers that could be worn on the body began appearing (Bass, 1995). The social implications of a given technology are not always clear during the technology's introduction and it takes even more time for scientists to start analyzing the effects said technology has on the world around (Pool, 1977). While still in its infancy, wearable computing is graining steady ground both in the private as well as corporate life. Although its advances are still slow, wearable computing has the potential to have one of the biggest efficiencies improving impacts to date in society. Research is currently focused on using wearable computers to get this kind of technology in places where it previously was not available before, due to space or activity restrictions, such as for medical monitoring

(Martin et al., 2000), or mechanical inspection (Sunkpho et al., 1998; Ockerman and Pritchett, 1998).

A wearable computer implies a computer that can be worn or transported and on top of this, a wearable computer is a computer that is controlled by the user and has operational and interactional consistency (Mann, 1998). They should be designed in such a way that the user sees them as part of themselves. As such, for differentiating wearable technology from those being or considering portable, three criteria can be proposed" (Knight, 2002; Knight et al., 2002; Knight et al., 2006):

- "The device is attached to the body and does not require muscular effort to remain in contact with the body (i.e. you do not have to hold it);
- The device remains attached to the body during the body's orientation or activity (i.e. you do not have to take it off to perform a task specific action)"[24];
- "The device does not have to be detached to be interacted with (i.e. the first two criteria are not violated when the device is in use)"[25].

Given the above-mentioned criteria, one can separate between three different types of wearable computers that can assist with warehouse operations, as following:

- Head mounted computers (eyeglass-like);
- Arm mounted computers (watch-like);
- Hand molded computers (glove-like).

While the usage of head mounted and arm molded computers are mostly used to improve the ergonomic reality by removing the need for old versions of handheld tools, the arm mounted computers can be most easily used for worker monitoring. Within a logistical environment the number of steps being taken, the paths being followed and the amount of effort needed to move packages are pieces of information that can give insight into the efficiency of the tasks laid out to the workers and their reaction to it.

It has been shown that wearable devices and smartwatches were accurate for tracking step counts (with smartphones being more accurate than wearable devices) (Case et al., 2015). With the addition of GPS tracking capabilities this opens the possibility to assess worker spaghetti charts in real time, measuring the difference between a computationally devised optimal walking path and a the one most preferred by the worker. This can also support in facility reorganization, by providing the data regarding most frequent path combination.

While research has shown that the difference between medical grade devices and those available in retail is still to be properly bridged, the capabilities and accuracy of these devices are increasing from one release to another (Rosenberger et al., 2016). For example, some (Haghi et al., 2017) have mentioned that the improved quality of the sensors in newer releases is capable of better tracking movement. The combination of sensors, such as the primary 3-axis accelerometers with secondary

[24] As mention also in: https://cmst.be/publi/doctv.pdf
[25] Supported by the research retrieved from: http://oa.upm.es/43010/1/JORGE_CANCELA_GONZALEZ.pdf

sensors such as magnetometers, and gyroscopes can compensate for the lack of accuracy obtained in data for motion tracking. While the tracking motion is reliable with the help of wearable computers the researchers suggested that smart textiles would be preferable for heartrate monitoring as the measurements would be more precise.

Research into the capabilities of wearable hand mounted computers to convey more information regarding worker mental workload is already underway, with mixed results related to the current technology (Barber et al., 2017; Schmalfuß et al., 2018). While the capability to assess long term changes in biological output based on mental workload modification might be possible, the research does not show confidence in their capabilities to measure it short term.

2.3.1.2. Smart textiles

The "field of ergonomics can be split into two major areas: the conduction of basic ergonomic research that improves the body of ergonomic knowledge, and the assistance in product development and design (1995). To conduct ergonomic research, a lot of emphasis is put on finding models of interaction between humans and their respectively analyzed work environments. These models involve an ergonomics expert that analyzes the current work environment and acts as a change agent, by modelling the perceived actions of the subject and analyzing their impact. The problem with this approach is that the perceived actions and the actions actually done are never 1:1. Monitoring sensors are often uncomfortable and movement restraining, causing the analyzed person to change their movements in order to be able to accommodate the new machinery. This leads to wrong assumptions and measurements and reduces the added benefit that an ergonomics assessment can bring. Participatory ergonomics seeks to reduce this misinterpretation. It is a branch of ergonomics that emphasizes employees' self-potential for conducting ergonomic improvements at work, specifying that end-users should be actively involved in planning and implementing ergonomics solutions (Motamedzade et al., 2003). The challenge in this case is to create an environment that is auspicious both to scientific enquiry as well as worker input. One of the ways in which both can be accommodated is with the help of wearable technologies" (Mocan et al, 2017a).

"Wearable technology is a term that refers to clothing or accessories that are created or enhanced using embedded electronics (King, 2011), while others posit that it can be used to aid their users by monitoring information about the user themselves or the surroundings they interact with on a regular basis (Svanberg, 2013). While currently the general market for wearable technologies is small, due to the high cost of manufacturing on the one hand and the sense of intrusion of privacy on the other, innovations in the mobile and electronic healthcare area are already providing doctors and patients with expanded capabilities of physiological monitoring. Smart sensors are being used for perioperative monitoring and rehabilitation medicine allowing physicians to monitor patients in home and in community settings, which lead to a better understanding of the impact clinical interventions have on the level of mobility and the quality of life of the patient (Appelboom et al., 2014). The creation of effective and unobtrusive wearable devices is one of the basic applications of pervasive computing, and that this creation can be used to improve the quality of ergonomic research by providing both the means of seamless user analysis as well as the solution to specific ergonomic issues that arise in warehouse logistics" (Sanchez et al., 2016; Mocan et al, 2017a).

"It is important to first make the distinction within wearable technologies between wearable computers and smart textiles. Wearable computers imply electronics that are housed within a fashion accessory and which allow the consumer to carry out their tasks without being obstructed. Smart textiles are products where using either the physical properties of the material, or electronics woven into the fabric can measure and/or react to stimuli from the user or environment (Hertleer et al., 2012). They have a smaller range than wearable computers but allow the comfortable wearing of sensors for longer periods of time, making long term monitoring studies easier to do. This paper will further present the benefits of smart textiles in ergonomics research and work design applications" (Mocan et al, 2017a).

"Smart textiles are defined as textile products such as fibers and filaments, yarns together with woven, knitted, or non-woven structures, which can interact with the environment/user. Smart textiles are divided into three subgroups" (Stoppa et al., 2014; Mocan et al, 2017a):

- *"Passive smart textiles*: only able to sense the environment/user, based on sensors";
- *"Active smart textiles*: reactive sensing to stimuli from the environment, integrating an actuator function and a sensing device";
- *"Very smart textiles*: able to sense, react and adapt their behavior to the given circumstances".

"Passive smart textiles can help researchers via fabric sensors which can offer access to information such as body temperature (Sibinski et al., 2010), heart rate (Coosemans et al., 2006), movement and muscle tension (Meyer et al., 2006; Meyer et al., 2010; Bonato, 2005), amongst others. At the same time carbon electrodes integrated into fabrics allow for the reading of environmental features such as moisture, salinity, and contaminants" (Zadeh, 2006; Mocan et al, 2017a).

"Ergonomics analysis often relies on models of human movement. The human modelling tool used when showing and visually evaluating results makes a difference, in that there's a bias that leads to a more thorough analysis of *human looking* models and their postures than that of manikins or enhanced stick figures (Lämkull et al., 2006). The issue with this is the fact that the more humanoid a model looks like the more time and effort must be spent to add the extra layers of information and design. It's also safe to say that regardless of the amount of time spent improving the model, by its very definition a model is a representation of a human and not an actual human, thus there is a compromise being made between the number of characteristics a human model retains and which information is eliminated in the process of digitalization and abstraction of the real life information" (Mocan et al, 2017a).

"Due to the cost efficiency of smart textiles in contrast with the combination of motion capture suits and cameras, analysis on actual humans during the work that they do in their actual working environments becomes a possibility, especially given that traditional warehouse logistics work involves a wide range of movements and positions that would be difficult to catch on a static camera" (Mocan et al, 2017a). Furthermore, due to the influence of the Hawthorne effect, the knowingly observed subject behaves differently under scrutiny (McCambridge et al., 2014). "As represented in Figure. 2.11. textiles can gather information remotely and repeatedly over the course of a study, therefore creating an environment where the information can be extracted easily while limiting any possible observational biases would decrease the quality of the raw data thus leading to a better understanding of the underlining issues" (Mocan et al, 2017a).

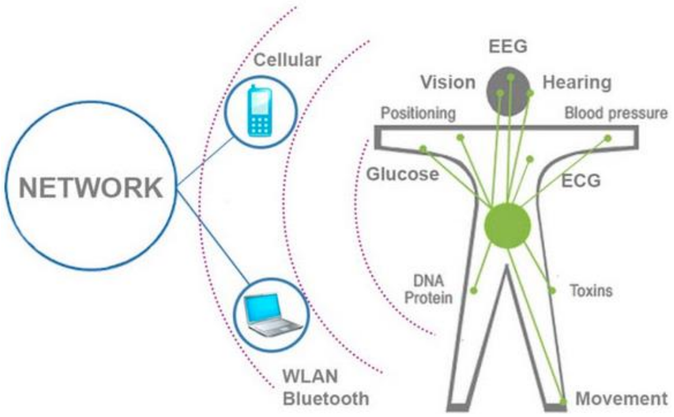


Figure 2.11. Remotely collecting user data (Gorgutsa et al., 2014)

"As a second step, after a baseline has been established, the possibility of using active smart textiles comes into play. These react to stimuli from the environment, by integrating both actuators and sensors. These textile products can react automatically to the stimuli they receive, by becoming, among other things thermo-regulated or water resistant. At this point the same type of analyzes can be done as for the baseline, but with modified parameters allowing to see how the change in environment impacts the workers and what kind of changes can improve or worsen the working situation" (Mocan et al, 2017a).

"The third and final step would be to implement a study with the worker wearing very smart textiles, where the textiles can react in a personalized way with the wearer, adapting themselves based on previous experience and learning to react better to the wearer's movements so that they lessen ergonomic strain whenever possible. Depending on the type of material used and the strength of the fabric, the possibility of a movement training harness arises, which would teach the wearer how to do correctly do their daily movements and offer support when the movement done is straining. By changing the fabric of the textile to a material that offers more support, one can effectively create an exoskeleton that could take on part of the physical strain, removing it from the wearer.

An experimental analysis should therefore have a minimum of four settings: normal textiles; baseline/passive smart textiles; activated smart textiles; activated very smart textiles" (Mocan et al, 2017a).

"These settings would allow the researcher to gain a deeper knowledge into the means through which ergonomic improvements can be brought to the analyzed workspace" (Mocan et al, 2017a).

"New fibres and textile materials are being discovered and improved upon every day, making intelligent clothing not only a possible future for ergonomics research, but a plausible one, where intelligent clothing can be worn like ordinary clothes and ensure that the wearer is protected from strain and discomfort when working. Wearable technologies could make ergonomics analysis more reliable and easier to undertake" (Mocan et al, 2017a). This can only be done accurately by customizing the smart clothing to the applicant's body shape and data that needs to be gathered (Chen et al., 2016). The information being gathered is only as good as the information that can be transmitted to a processing centre, meaning that interconnectivity of smart clothing is paramount to its successful use.

"Whether it's the use of smart textiles to perform a long term analysis of the day to day work of a warehouse employee or to actually offer them a tool through which their job becomes easier, there is clear merit in the analysis of the applicability of emerging technologies in aiding participatory ergonomics. More analysis is needed into the applicability of smart textiles in a warehouse environment particularly the type and amount of sensors necessary to collect relevant and qualitative data while not constraining the wearer by creating an environment where their moves would not be natural. Similar attention should be paid to the interaction between the electro-magnetic fields created by wearing electrically charged clothing and the human body. Previous studies have shown that there can be serious health consequences because of electromagnetic interference within the human body, so the development of smart textiles should not be prioritized at the expense of human health" (Mocan et al, 2017a).

2.3.2. Improve ergonomic reality

2.3.2.1. Wearable computers

The research presented in this subchapter has been developed between March 2017 and September 2017 and the results were disseminated through the article: (Mocan and Draghici, 2018a).

Due to the ubiquitous use of barcoding for product identification, the current process of warehouse item scanning involves some type of handheld barcode scanner, which, as ca be seen in Figure 2.12 is composed of a scanner window, a trigger switch and a cable interface port. This can be held in a gun like manner, i.e. the scanner is held with the dominant hand, gripped between the index finger and thumb, with the index finger on the trigger switch and the middle, ring and pinkie finger around the base of the grip, between the trigger switch and the cable interface port.

Given the fact that the human arm has a tremor even in a static position that influences accuracy in a negative, depending on the width and breadth of the scanner window the time it takes to find the accurate position for proper scanning is not optimal. The rapid and repetitive pressing of the trigger switch can also lead to loss of pressure sensitivity in the index finger. With the introduction of tablet like scanners or tablet integrated scanners the holding position has changed towards a cell phone like manner, with the palm turned upwards, the wrist flexed laterally to allow the scanner window proper access. Depending on the weight of the scanner and the positioning of the keyboard/buttons on its surface prolonged use of this position can induce muscle fatigue (Shim, 2012) or even enlarges the median nerve, causing pain in the thumb and decreasing hand functions (İnal et al., 2015; Patel et al., 2012).

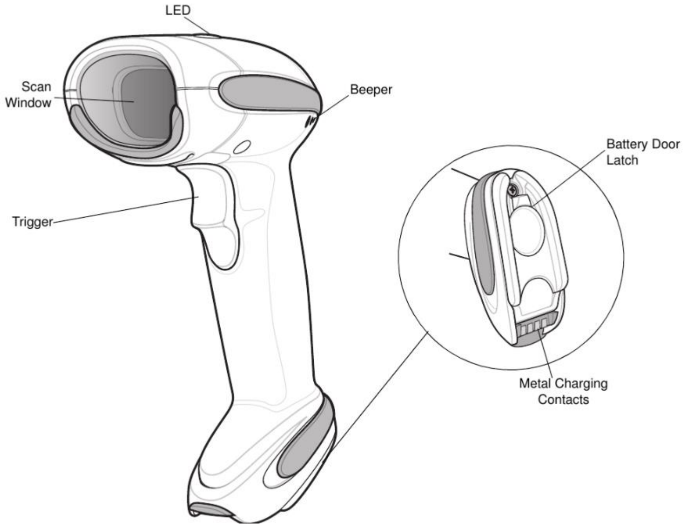


Figure 2.12 Standard components of a handheld scanner[26]

Ever since the 1960s barcodes have been used to scan products. They are standardized, readable from almost any angle and at a wide range of distances, cheap to produce and easy to print (Seideman, 1993; Global Market Insights Inc., 2016). In warehouse management, barcodes have been used for everything from goods storage to re-parcellation to movements inside as well as outside the storage facility.

While easiness of reading and processing barcodes has been an issue that has been solved in the retail business, the standard countertop laser scanner being equipped with mirrors that can obtain signals from multiple angles, it is a fact that handheld laser scanners are less powerful and less accurate than the countertop ones. They are not capable of gathering multiple signals and the necessity of operating smaller optical devices leads to worse readings or longer reading times (Wittman, 2004). Due to this, there is a clear need to analyze different scanning solutions that might limit the amount of time spent per scanning either via integrating the scanning within the already necessary manipulation movements, improving the scanning

[26] As seen in: https://fccid.io/UZ7DS6878/User-Manual/User-Manual-I-1246139

technology or both. Wearing technology instead of holding has the advantage of freeing up hands for this function (Bhutani and Bhardwaj, 2018).

Head mounted scanners provide the operator freedom to move their arms unimpeded to perform the task the way they usually do, thus causing the slightest amount of inconvenience. When designing a head mounted scanning system, one needs to take into consideration the location of the scanner and how this will be activated during regular operations. Because of this point of attention, scanners attached to eyeglasses can directly take advantage of the line of sight and of the natural tendency to look at what we are manipulating. Therefore, this limits the need to create a special "to scan" movement as the scanning takes place as soon as your line of sight aims towards the package if continuous scanning is applied. When designing such scanners as presented in Figure 2.13, the mass, the bulk, the heat dissipation, and optical performance (Spitzer et al., 1997) of the equipment must be taken into consideration. Loading of the ear and nose should be tolerable for several hours. Scanning should be easy to stop when encountering another person, in order not to cause visual inconveniences (Mocan and Draghici, 2018).

Figure 2.13 Eyeglass mounted scanner[27]
Arm mounted scanners [28]

Figure 2.14 Arm-molded scanner[29]

Arm mounted scanners take advantage of the hand placement during manipulation movements. It eliminates the need for a grip of the scanner, as it is attached to the wrist, and in some cases can extend to the finger, like in the case of Figure 2.14. For visual scanning, the device places the scanner on the front facing side of the intermediary phalange of the index finger and the trigger button on the side of the index, for easy push access from the thumb. This offers more movement control, as the scanning happens both at a closer distance and that the user's fingertips (Mocan and Draghici, 2018).

The biggest downside to the optical scanning is the need to press a trigger button and the instability of the finger scanner on the finger during strenuous manipulation. This can be fixed by the usage of radio-frequency identification (RFID) technologies (Nambiar, 2009). These were first used in the 1940s as a method to identify allied airplanes, but have current frequent applications in transportation, services, supply chain and manufacturing. During recent years, an interest in RFID technology has arisen with the goal of increasing readers' mobility as something

[27] As designed by : https://www.google.com/glass/start/

[28] As seen on: http://www.tuvie.com/wt4000-wearable-computer-for-workers/

[29] As designed by: https://m.iotone.com/hardware/proglove-mark/h5903

transparent for users, and their combined integration into wireless communications systems (Muguira et al., 2009). Passive RFID tags are small electronic components with an integrated circuit and a small antenna usually sealed in one small package. The tags do not need a battery; the reader via electromagnetic induction energizes them during access (Schmidt et al., 2000). In addition, "each tag contains a numeric code that uniquely identifies the object and can be queried by a wireless reader" (Want, 2006). While the price of this technology is slightly higher than barcodes, the ability to scan an item without having as specific target the tag itself, can lead to easier storage solutions and less manipulation of a package to be processed.

If the RFID reader can be placed within the wristband while also being screened from accidentally scanning nearby items, it would lead to reducing the amount of movement necessary and thus creating an uninhibited work experience for the operator.

The arm-molded scanner takes the wristband scanner concept and integrates the industry mandated hand protection that workers always must wear during their operation. As can be seen from Figure 2.14, it leads to less slippage of the finger-mounted grip as this feature is fully incorporated into the glove itself, minimizing unwanted movements. The implementation of a glove-mounted scanner is in RFID glove has been extensively researched (Merz et al., 2000; Muguira et al., 2009; Lee et al., 2010). While the proprietary version is still currently used exclusively for optical barcode and QR scanning (based on Quick Response Code), prototypes are already being developed to include shock resistant and water-resistant RFID capabilities. This would lead the operator to not have to rely on any extra movement to scan the item, as it would be automatically scanned upon touching it.

Wearable computers are an easy way to reduce unnecessary movement that can cause strain or injury. While there may currently be a barrier related to the cost of equipping workers with such tools, during the next few years, as technology advances, the costs will decrease, as it has already been shown for other technologies (Bureau of Labor Statistics, 2015). These mean that the incentive to use this equipment must be clearly stated and disseminated within the business decision-making community to ensure the quickest possible adoption of the ideas within the non-academic environment. Currently the cost of applying smart technologies to existing jobs is most related to cost efficient, improvement means that does not require the restructuring that automated scanning lines and robotization would imply.

Certain warehouses are already starting to use Google Glasses' functionalities to replace handheld scanners as they have been proven to reduce the time needed to pick out an item and pack it for shipping by 25%. The possibility of eliminating the scanning work by equipping cameras with RFID means to record images related to the identities and locations of all RFID-tagged objects within that image. This can lead to workplace reorganization where customer value added operations are being applied in the place of essential, but repetitive and non-value adding tasks such as scanning (Whelan, 2015).

Besides the reduction of ergonomic strain alongside reduction of throughput times the application of wearable computers has the advantage of creating an innovation mind-set within the organization where the objective of doing more efficient work in a healthier way can be easily understood by the workers as they are directly involved in the usage of the new technology. As of now, the topic offers fertile ground for more investigation.

2.3.2.2. Virtual reality, augment reality and 3D printing

With the creation of virtual reality (VR) in the second half of the 20th century and its increased availability in consumer markets at the beginning of the 21st the manufacturing industry's interest has been raised regarding virtual training for manual assembly tasks. Virtual environments have the capability to deliver cost-efficient, safe, and potentially effective training. Their unique selling point is that they can allow full operator training prior to them starting at their assigned workstation in an environment that would almost fully resemble their actual work one. This leads to the possibility for an accelerated end-to-end manufacturing process and a directly proportional efficiency increase. Studies have shown the benefits of VR applications and serious games in training and education both towards the general public (Merchant et al, 2014; Girard et al, 2013) as well as specifically in an industry and warehouse environment (Murcia-Lopez and Steed, 2018; Zawadzki et al., 2018). In the case of a forklift training application, the researchers have found that the virtual course was more time efficient than the traditional one and, enthusiastically perceived by users from the target group. In the case of bimanual assembly tasks, the virtual training was proven to be promising and validated the effectiveness of virtual training in these conditions.

Besides the training capability of the VR/AR technologies, 3D printing brings about a new change in the way in which supply chains operate (Attaran, 2017a). From the first prohibitively expensive 3-D printing device, created in 1984 by Charles W. Hull, the variety of additive manufacturing printers on the market has led to a drop-in hardware cost (Attaran, 2017b). Thanks to this, the way in which current supply chains operate is on the brink of being disrupted. Firstly, the technology has the potential to support reshoring and local sourcing, as well as lead to a decentralizing of the means of production (Mohr et al., 2015).

The increase in low volume high variability demands from customers can also be satisfied with the help of the Rapid Prototyping capabilities that Additive Manufacturing (AM) is creating. It is recognized that Rapid Prototyping provides manufacturing cost and time reductions, by allowing a more in-depth product analysis from the early innovation stages, by by-passing the costly one-off traditional manufacturing. Additionally, AM is also faster compared to traditional manufacturing, as shown in the analysis done by Siemens, and briefly presented in Figure 2.15.

Figure 2.15 Cost and time of Additive Manufacturing (Siemens, 2017).

Besides the possibility for prototype manufacturing, additive manufacturing (AM) can be used in component manufacturing for pieces that require low quantities or parts with low tolerance limits. Considering that "20% of the 3D printing market is made up of component part production for the aerospace and automotive industries" (Attaran, 2017a)[30] it is clear to see that the technology is not a long shot, but something that is already being applied in this day. Even if the pieces manufactured with the help of "AM won't replace existing conventional subtractive production methods", they are expected to be applied successfully in a series of niche areas (King, 2012; Royte, 2013; Sasson and Johnson, 2016; Attaran, 2017a).

Given the information presented thus far a gap in the research has been found regarding the usage of wearable computers in factory warehouse logistics. While the technology is being used for retail warehouses, where the products picked are varied and in low volume, industry warehouses, where variability is lower and volume higher, do not seem to be given the same level of attention. There is also no literature regarding the theoretical model to be used in applying Industry 4.0 solutions. Currently managers are inundated with new technology without having a proper guideline as to how all of this should be best applied. Given the high cost of the technology a trial and error way of working is not sustainable and even counter-productive, as reluctance to invest in machines that do not prove useless might decrease over time.

The following chapters will start to discuss this analysis by presenting the observations and experiments done in the warehouse of a manufacturing facility.

[30] Retrieved from: https://file.scirp.org/Html/1-9201960_75953.htm

3. EXPERIMENTAL RESEARCH ON THE ERGONOMICS INTERVENTION AND IMPLICATIONS IN PRODUCTION SYSTEMS. THE CASE OF BOMBARDIER BELGIUM

The third chapter of the thesis will show the measurements of the ergonomic reality of the warehouse workers in a manufacturing plant. The goal of the chapter is to understand what the state of warehouse ergonomics is in this case study factory with the purpose of further analyzing the results and proposing possible punctual as well as generalized improvement possibilities. The research has been developed during a six-month period from July 2018 until December 2018. Measurements were made in the first four months of the period and they are presented in depth in Chapter 3.

The content of this chapter will be separated into four different parts, as shown in Figure 3.1.

Firstly, part 3.1 will focus on a brief presentation of Bombardier Transportation (BT) intentional to be able to place the work being done in a global context and understand the specific challenges that the railway industry is currently facing. Then, part 3.2 will present the national presence and history of BT Belgium, to allow the understanding of the company's history in the region and the legacy tools and processes that caused the situation as was currently audited. The first two parts will contain information to briefly describe the general context of the research. In contrast to these, the following two parts will present the audit that has been done. Part 3.3 describes the specific project during which the measurements were done. The first subchapter describes the ergonomics implications and implementations that exists within the engineering department and the perception of engineering's implication in ergonomics design. The second subchapter describes the company's internal supply chain structure, the hardware and software used, and the process flows within the warehouse. It afterwards delves into the measurements done within the Kanban process regarding the time and effort workers must put into executing their tasks.

Part 3.4 picks up where 3.3 leaves off and provides a series of solutions to improve the current work processes. These solutions are split into two lines of thinking: (1) a classical process improvement (using Root Cause Analysis and continuous improvement) and (2) an advanced approach using the perspective of Automation and Industry 4.0 based improvement capabilities.

The chapter ends with a series of conclusions and recommendations based on the audit research done and introduces the topics of Chapter 4, where an in-depth improvement analysis based on the presented measurements will be presented.

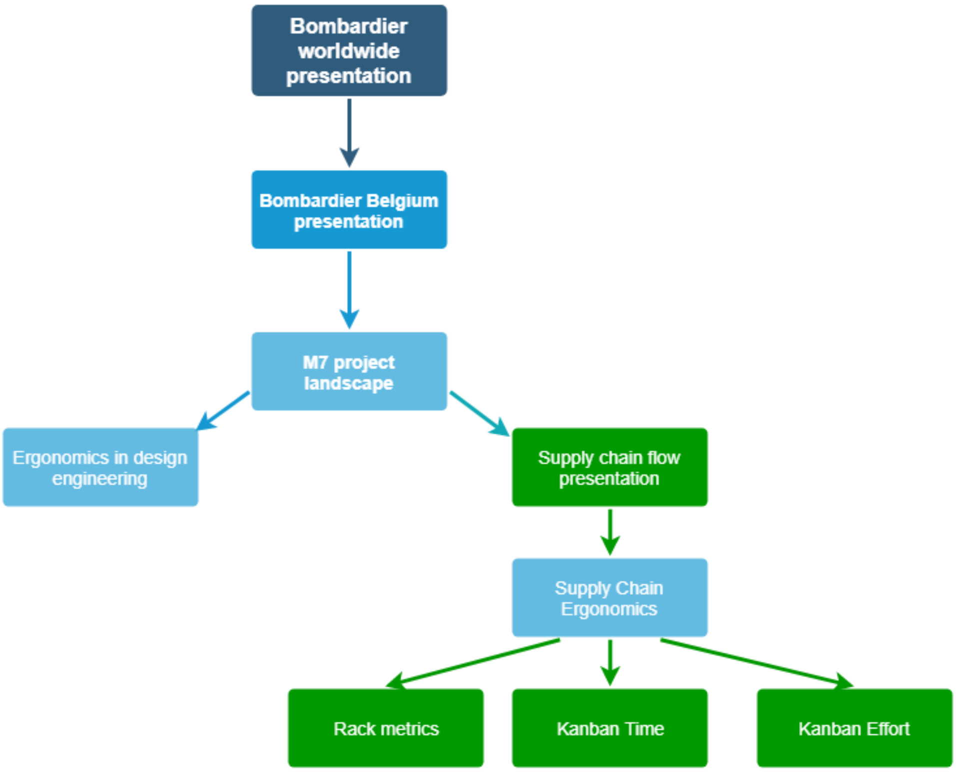


Figure 3.1. Chapter structure (the conceptual map)

3.1. Bombardier worldwide presence

According to the Association of the European Rail Industry, UNIFE[31], "the rail supply industry in 2019 accounts for nearly half of the world market for rail products and a market share of 84% in Europe. Thus, the industry accounts for nearly a quarter of the overall rail sector in the EU, which, including the workforce of the rail operators and infrastructure managers, which employs approximately 400,000 people". "Rail manufacturers were earlier connected primarily to domestic markets, but since the 1990s, mergers and restructuring in Europe led to three dominant global manufacturers: Bombardier Transportation (BT), Alstom and Siemens. In 2009 BT was accounted as the leading rail equipment manufacturer"[32], as can be seen from the data presented in Figure 3.2 (Renner and Gardner, 2010).

[31] The European Rail Industry Association Pocket Guide, 2019. Retrieved at: http://www.unife.org/component/attachments/attachments.html?id=501

[32] Retrieved from: https://docplayer.net/45954571-Master-s-thesis-continuous-improvements-during-project-based-production-a-case-study-executed-at-bombardier-transportation.html

The European governments have made a lot of investments on rail and transit and the region's modal split, where 16% of passengers travel by bus and rail (European Commission, Statistical Pocketbook 2016). "European rail car manufacturers will have contracts for the next years. In 2004, Europe had a fleet of about 25,000 light rail vehicles and 21,500 subway cars". The European Rail Research Advisory Council (ERRAC, 2009) estimated that around 15,000 vehicles will be needed for both replacement and development in the 2010-2030 period, resulting in a turnover of €22,5 billion. Companies that produce heavy and light rail systems are going to have an intensive production activity in the upcoming years. A major actor in this industry is Bombardier (BT).

BT is a global aerospace and transportation company present in more than 60 countries, with 76 production and engineering sites among them. BT is world leading manufacturer for planes and trains production, with 69,500 employees and a €14,4 billion revenue. It was founded in 1942, in Quebec by Joseph-Armand BT as L'Auto-Neige BT Limitée ("Bombardier Snow Car Limited") as a snowmobile production company, later branching out in aerospace design and rail transportation solutions. BT's market share is shown in Figure 3.2.

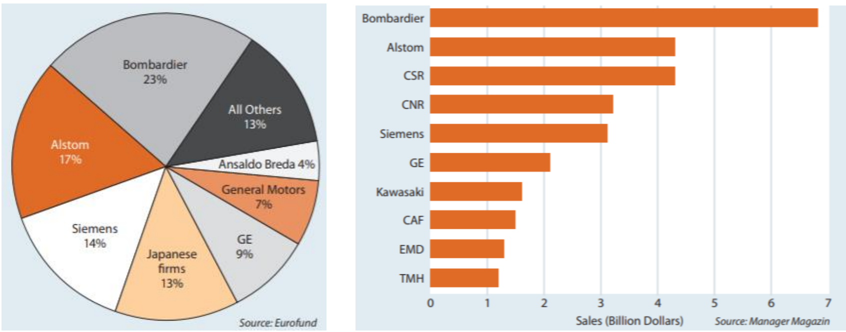


Figure 3.2. BT's market share (Renner and Gardner, 2010)

"Bombardier Aerospace designs, manufactures, and supports innovative aviation products for the business, commercial, specialized, and amphibious aircraft markets. The division covers many aircraft solutions such as:

- Business aircraft - Learjet, Challenger and Global aircraft families;
- Commercial aircraft - new C Series program, CRJ Series and Q Series aircraft families,
- Aerostructures and Engineering Services - aircraft structures, component repair and other services (as seen in Figure 3.3)"[33];
- Specialized aircraft solutions - BT aircraft modified for special missions;
- Aircraft services and training - aircraft parts, maintenance, comprehensive training, technical support and publications, and online services.

[33] Retrieved from: https://www.bombardier.com/en/about-us.html

Figure 3.3. Bombardier aerospace production line

Bombardier Transportation can produce all types of rail solutions, ranging from complete trains, metros and trams to sub-systems, maintenance services, system integration and signaling. In the period of the research analysis, Laurent Troger is the president and chief operating officer of BT, leading a company of approximately 30,000 employees and 60 manufacturing locations around the world. Some of the division's focus areas are[34]:

- "Rail vehicles - automated people movers, monorails, light rail vehicles, advanced rapid transit, metros, commuter/regional trains, intercity/high-speed trains, and locomotives (as seen in Figure 3.4);
- Propulsion and controls - complete product portfolio for applications ranging from trolley buses to freight locomotives;
- Bogies - product portfolio for the entire range of rail vehicles;
- Services - fleet maintenance, operations, and maintenance (OandM), vehicle refurbishment and modernization, and material management;
- Transportation systems - customized *design-build-operate-maintain* transportation system solutions;
- Rail control solutions - advanced signaling solutions for mass transit and mainline systems".

Figure 3.4. Bombardier transportation Belgium production site

[34] According to the public data retrieved from: https://www.bombardier.com/en/about-us.html

3.2. Bombardier Belgian presence

Started from 2011, the factory unit in Belgium was part of Bombardier Transportation as Bombardier Transportation S.A. (BTB).

BTB's factory currently focuses on two main projects, the M7 double deck passenger train for the Belgian SNCB-NMBS and the Twindexx double deck restaurant car for the Swiss Rail Company SBB. As a result of an internal realignment within BT, and a planned downsizing of 7,500 jobs all over Europe, a phased downsizing of the Belgian premises took place between 2016 and 2019. The factory, that in the 1970s was a workplace for 3,000 people, has gradually decreased its capacity on a yearly basis. Currently around 300 people still work in the factory, both white and blue collars working only on final assembly and testing. Activities such as painting, car body and machining have been moved to BT's site in Crespin, north of France. The knowledge of the social plan guided management to a Just in Time logistical strategy, where activities could continue with a limited number of workers.

Design engineering activities were active on the site up until December 2018, having afterwards also, been moved to the site in Crespin. A restricted amount of testing and methods engineers remain on the location to monitor the ongoing production.

The SBB Twindexx double deck restaurant car is a transfer from another BT location and does not act as a mass production area. The total number of train cars to be built was limited to 20 and the production does not move in a standard production line, but rather all the assembly happens in one spot, with the train remaining fixed to the ground and the workers moving around it.

In contrast to this, at the beginning, the M7 project was a Belgium started and based project, over which BTB had full control, from the design stage to final testing and delivering. The production line was designed in a sequence of mounting stations ending in a testing rig, where static tests would be performed until the train car would be deemed safe to leave the factory premises. The activities on the production line and the testing area were supported by the warehouse with the pieces necessary for the assembly.

The following subchapter will explain the M7 project landscape in more depth and delve into the analysis done in the process.

3.3. M7 project landscape – the research context

The purpose of this subchapter is to place the M7 project in the global context of BTB's work. Afterwards, the subchapter will describe the audits done in the engineering and supply chain departments. "Bombardier Transportation - Alstom consortium, signed a framework contract to supply up to 1.362 M7 double deck cars to the Belgian National Railways (SNCB-NMBS). The total order is valued at €3, 3 billion. BT's part is worth around €2, 1 billion while Alstom's share is worth €1, 2 billion.

BT's site in Belgium, will provide 65 multifunctional steering cars and 290 trailer cars, while Alstom will build 90 motorized cab cars in its site in France. These new trains will increase the overall capacity on SNCB-NMBS' network by adding an additional 145,000 seats. The trains will be able to run at speeds of up to 200km/h and will operate on all Belgian mainlines, cross border with the Netherlands and Luxembourg, including on some high-speed lines, and will replace the old M6 trains which can be seen in Figure 3.5. The goal of the new interior and improved passenger information system is to provide travelers with more comfort and better access to facilities for wheelchair users and bike commuters"[35].

Figure 3.5. Bombardier M6 project

Figure 3.6. Consortium scope of supply

The trains are split into four (4) cars categories, as can be seen in Figure 3.6:
BDx – second-class trailer car including driver's facilities– manufactured by BT;
AB – first- and second-class trailer car – manufactured by BT;
B car –second-class trailer car – manufactured by BT;
Bmx – second -lass motorized car including driver's facilities – manufactured by AT.

The M7 Project will consist of several batches with a mandatory first one of 445 cars and an option of 917 for both BT and Alstom planned with first deliveries in April 2017 for the AB-B-BDx cars and June 1st, 2017 for the BMx. The split of the Car Type orders can be seen in Table 3.1.

Table 3.1. Scope of supply batches [pcs]

Car Type	Firm Batch	Optional Batches	Total Quantity
BDx	65	215	280
AB	145	256	401
B	145	239	384
Bmx	90	207	297
Global	445	917	1,362

[35] Public information retrieved from: https://www.railwaynews.net/bombardier-alstom-consortium-to-supply-double-deck-cars-to-sncb.html

Due to delay in the Tender specifications from the customer, the serial deliveries were delayed and started in January 2018 for the AB-B-BDx cars and in April 2019 for the Bmx. As of the writing of this thesis the final delivery date of the order with the optional batches included is planned for 2028 with a total project duration of 168 months or 14 years (Firm batch + optional batches). The takt time was scheduled at a nominal production of 17 cars/month and a maximum production of 20 cars/month.

The following subchapter will describe the ergonomic knowledge of the BT design engineers responsible for creating system and subsystem designs for mechanical and electromechanical applications. The analysis also investigates the way in which they are guided by management in their design decisions.

3.3.1. Ergonomics in design engineering

The research presented in this subchapter was developed between May 2018 and August 2018 and the results have been disseminated through the articles (Mocan and Draghici, 2018a; Mocan and Draghici, 2018b; Mocan and Draghici, 2018c). Preliminary research ideas have been identified by (Mocan and Draghici, 2016).

"Engineering is the design under constraints of cost, reliability, safety, environmental impact, ease of use, available human and material resources, manufacturability, government regulations, laws, and politics" (Wulf, 1998; Salvendy, 2012). As in any scientific discipline, during the process of engineering design planning, the goals and objectives of the to-be-designed system are identified. Upon finding out what these objectives are, performance specifications are defined, to understand the constraints under which the system will operate (Salvendy, 2012). Design implies creating a structure that will systematically solve issues that might organically appear. The main concern in system design is that, while alternative design concepts are identified and tested, ergonomics related aspects are not considered to be critical inputs to be taken into consideration. Most of the time ergonomics is pushed further down the design line, into the evaluation stage and result in actions dubbed as *too little, too late* (Salvendy, 2012). What this means is that the design of the system is already too advanced to make meaningful changes, or the alteration made are too small to make any impact.

One of the reasons why this behavior exists in its current state is the lack of ergonomics-based engineering courses or study directions offered by technical universities.

"Ergonomics has a vast field of activities in varying disciplines that cover a wide range of topics such as workstation design, product design, occupational health and safety, material handling, interface design, work/rest schedules, aesthetics and environmental ergonomics, to name a few" (Naeini et al., 2013). As it can be clearly seen from its scope, the topic covers human behavior in any work condition. Because of this, engineers tasked with creating human work structures and models should be aware of the discipline that defines this. Human error has long been identified as a contributing factor to incident causation therefore for every workstation "design and installation of a product line which are related to engineering activities, anthropometric data among workers should be available" (Naeini et al., 2013). Human-machine interaction models should be applied, and performance information should be studied. Parts of the scope of ergonomics have appropriate applications in engineering environments (Naeini et al., 2013). This line of thought, however, is not seen mirrored in the academic training programs currently existing on the market. There are 189 undergraduate and graduate programs now that offer ergonomics-based trainings and specialization, out of which approximately 70 are of a technical nature. These programs also have a decidedly North American availability, the European market showing availabilities mostly in Sweden and the United Kingdom (Agarwal, 2015).

This leads to an overwhelming majority of European engineers that have little to no experience ergonomic design, designing machines that are suboptimal that do not fully respond to human needs. To stop this behavior, ergonomic aspects must be discussed in depth already on a design planning phase and followed through in the entire production process (Skepper et al., 2000). This can only be done if design engineers are ergonomically literate and consider it their responsibility to apply ergonomic principles to their design[36]. This, however, proves to be an issue, as it was shows that engineers do not consider the ergonomics and work environment aspects of a project because they are not aware of their impact on another employees' work environment (Broberg, 1997; Broberg, 2007). Even more drastically, it has been shown that engineers have an active resistance to integrating ergonomics into the design discussion, as the topic was not sufficiently covered during their school training which led to the thinking that this was not part of their responsibilities (Wulff et al., 1999). Ergonomics needs to start being applied from the moment the product gets designed. With regards to the design capabilities in BT itself, it is worth noting that Belgians are some of the tallest people in the world (NCD Risk Factor Collaboration, 2016). With an average size of 1706 mm, internationally standardized public transportation design might have adverse effects on the local population's health, as it proves inappropriate for Belgian proportions (Motmans and Ceriez, 2005). Given the trends of the last 100 years, where Belgium went from being the 31st to the 21st tallest nation, as well as global height increase trends from the last couple of centuries, it is reasonable to assume that this average will also get bigger over the years. This means that Belgian trains should be suited for use by Belgian passengers. The fact that the three busiest train stations in the country, with an average of 60,000 passengers/day, are all within Brussels shows that there already is a strong influx of people that chose public transportation to private cars. However, the Belgian railway system suffers from a very strong image problem. According to consumer satisfaction surveys, one of the top ten issues that discourage people from taking the train is comfort and lack of space. Research supports these claims, showing that the

[36] ISO 6385 "Ergonomic principles in the design of work systems", Retrieved from: https://www.iso.org/standard/63785.html

internal environment, the safety, and security of the transportation means as well as the social interaction capabilities are all points of interest to a possible transportation system user (Millar et al., 1972). As group of research shows, Belgians spend an average of 50 min in traffic every workday for one way, the most in all of Europe (Verhetsel et al., 2009). Given this, combined with the fact that more than 25% of the population is not satisfied with public transportation options, a deeper analysis into the need for improved public transportation is warranted.

As ergonomics proves to be a direct factor considered by people when choosing train transportation, this subchapter will present the level of ergonomic application within engineering schools and involvement that results from current level of ergonomic studies. Furthermore, the subchapter strives to understand the company's general design policies and its managerial involvement in the product design process.

The research questions the study started from was: What is the level of ergonomic design application in manufacturing facilities? This topic was broad enough to be branched out in two influence areas: (1) the engineers and (2) the managers. Were the engineers sufficiently trained and willing to apply ergonomic design to their day to day work, but met resistance from managers? Was management actively trying to encourage ergonomic application in the work design, but was hindered by the engineers' lack of knowledge? Or was it some sort of a combination of the two? Figure 3.7 shows the mapping of the data to be collected and the interaction between the topics.

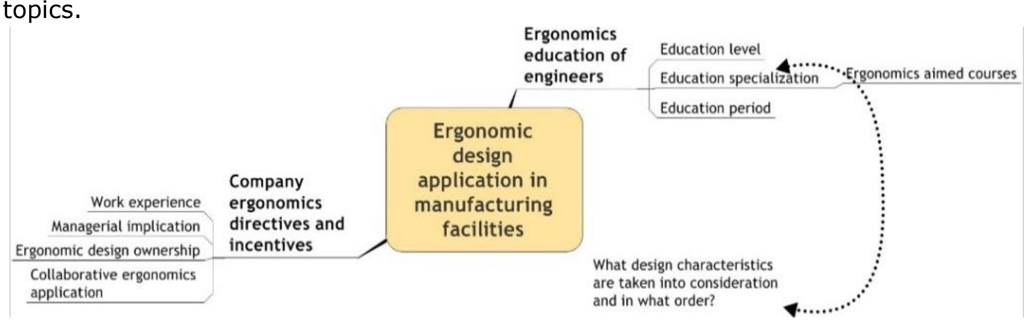


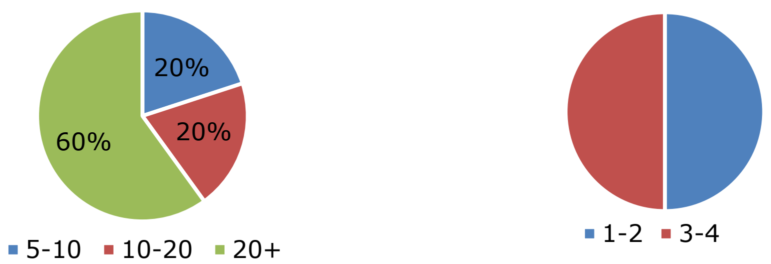
Figure 3.7. Mapping the data to be collected

The following section will describe in detail the methods used to gather this information, the resulting findings and the discussions that arise from them. A qualitative, non-random sampling questionnaire was deemed the best approach for this research, due to its capacity to provide empirical data in a fast manner, which was deemed necessary due to the reorganization process that was scheduled in the researched company by the end of the year.

BT's management was asked to approve the study and the questionnaire distribution to the engineering department, to organize a round of general discussions to present the work and its purpose and its subsequent questionnaire. Only 50% of the persons of the targeted engineer group agreed to be involved in the study and completed the questionnaire (the response rate is 0.5). The statistical data process have been done using Excel software.

The ten-part questionnaire was developed with the purpose of understanding the two influence areas determined beforehand to have an influence and impact on ergonomic decisions, particularly regarding product design in the machine production industry (Annex 1). The questionnaire was therefore split into two parts, each targeting one of the different branches. The first four questions are aimed to understand the general background of the respondents (sample demography, Figure 3.8 and Figure 3.9), namely what type of engineering background they have, what academic level they have reached, how many years they have been employed since finishing their education and how vast their work experience has been (i.e. with how many companies have they worked). The following question aims to find out, based on the respondents' best recollection, how many hours of ergonomic training their educational background provided to be able to assess their pre-existing knowledge of the topic at hand. The following set of five questions are meant to understand the respondent's relation to ergonomic design: (a) Do they consider themselves responsible for it? (b) Have they been encouraged to use it, and if yes, how and by whom? The final question asks the respondents to list the factors that they consider the most important to be considered when designing or redesigning a product to gouge the existence of underlining uniformity in execution.

One of the first findings of the questionnaire that should impact the further analysis, is the general profile of the engineers working on the site targeted by the study. The majority have been working for a long period of time - 60% of respondents have been in the workforce for more than 20 years and for a limited number of firms- half have worked with maximum four firms, while the other half with maximum two. This leads to a situation in which, while well experienced in their field over a long period of time, the engineers have not seen different ways of working. They have therefore a significant knowledge specifically related to their current employer, but little in relation to overall industry standard.



a.

b.

Figure 3.8. a. Years of employment / b. Number of companies worked for

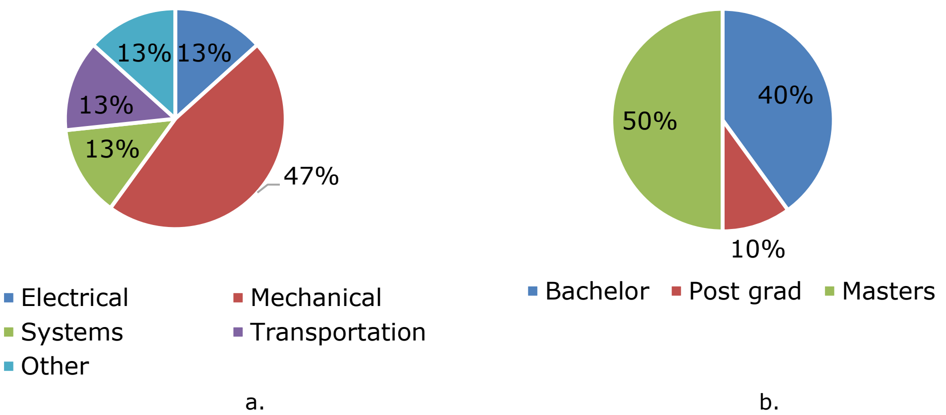
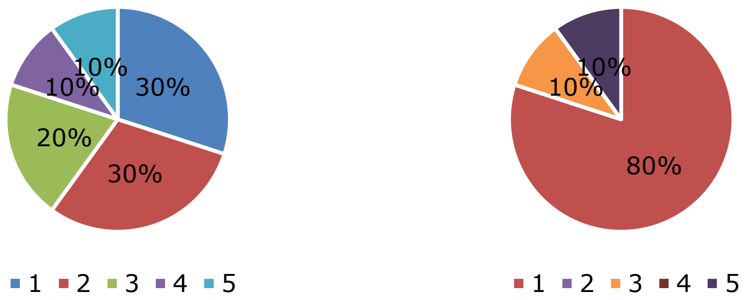


Figure 3.9. a. Engineering specialization / b. Level of education

As was expected in the targeted production environment of the company, Figure 3.9a shows that most of the responding engineers were specialized in the mechanical engineering field. The interesting finding was that almost half (40%) had a double specialization. Another point of interest that proves hard to analyze, is the self-reported level of education. This is related to Belgium's previous educational system, where a "Masters" implied the specialization period of the Bachelor, and not, as it is currently implied, a separate stage of studies. Because of this the data cannot be meaningfully used for further analysis and correlation and requires further interviews with the respondents to understand the meaning of the words used.

The analysis of fifth question, where the respondents were asked how many hours of ergonomics or ergonomic design they had done during their studies, led to a shocking conclusion. Except for one engineer, who majored in industrial design and reported around one hour per week of ergonomic topics throughout his entire studies, all others replied that they had done zero hours. While there is a possibility that other tangential topics were covered during the studies, the respondents were not considering those topics to be like their understanding of ergonomics.

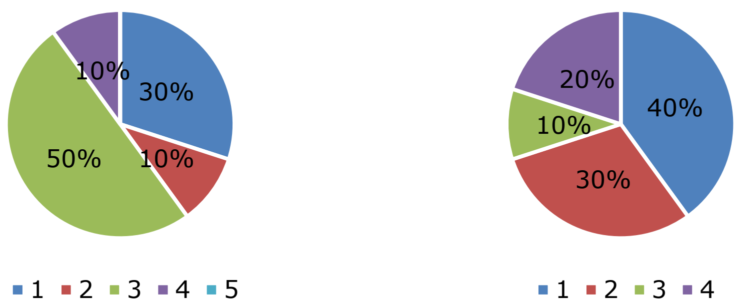
Starting from the sixth question onwards the questionnaire focused on understanding the relationship between engineering and ergonomics by utilizing rating scale answers. As can be seen in Figure 3.10, even though the engineers were tasked with designing new products for upcoming projects, more than 60% of them considered strongly that ergonomic design was not their responsibility. That, coupled with the 80% of them that have acknowledged that they have not received any sort of ergonomic training after university, leads to an environment where employees do not think of ergonomics as a design constraint to be considered. This corroborates other studies (Verhetsel et al., 2009; Broberg, 1997; Broberg, 2007) that also showed engineers having poor knowledge of how to apply ergonomics principles in their day to day work. The discussion here should be expanded in the future to analyze what kind of training the other 20% have received, both in content, level of detail as well as in style and overall duration.



a. b.

Figure 3.10. a. Ergonomics responsibility / b. Post university ergonomics training

Questions eight and nine showed that the situation was not improved by managerial involvement (see results in Figure 3.11). Within the analyzed group, participants have not often participated in a cross functional design team with 30% of them never having even done so. Furthermore, 40% of respondents have never been encouraged by a manager to take more of an interest in ergonomics. This issue has been found throughout other companies (Dul and Neumann, 2009), not just in a machine production environment, but also in other areas, such as medical design. This is related to the fact that managers relate ergonomics to comfort (Zare et al., 2016), which always takes back seat to functionality and price. They do not take into consideration the defects reduction and quality improvement in the production process that a good ergonomic design can lead to, along with the cost saving that this implies. It has been shown that improvement in ergonomics design can lead to higher efficiency, lower misuse of products and productivity increases. All this translates to customers that are willing to return for more products from the same manufacturer (Hendrick, 1996).



a. b.

Figure 3.11. a. Participation in cross functional design teams / b. Managerial encouragement to apply ergonomics

The final question, as previously mentioned, was to request that the respondents list the factors that they consider the most important to be considered when designing or redesigning a product (Figure 3.12). This was done to find out if their engineering education or subsequent company policy had incentivized them to prioritize a set of design policies above others.

Final product cost	5	6	6	5	2	7	3	7	5
Design time	1	2	7	6	3	9	9	6	4
Final product integration	8	7	1	2	1	5	1	1	1
Aesthetics	3	8	9	4	7	2	6	3	9
Usability	7	1	4	3	6	1	2	2	3
Ease of maintenance	9	5	2	8	5	6	5	5	7
Modularity	2	4	5	7	4	4	7	9	6
Ease of production	6	3	3	1	8	3	4	4	2
Ease of transportation	4	9	8	9	9	8	8	8	8

Figure 3.12. Representative subset of design factor rankings

The answers to the question provided the best cue that a companywide design policy either did not exist or was not actively implemented in the studied company. The variability of answers is very visible, as each engineer set a different ranking in place. This made a de facto design trend very difficult to set almost all agree that ease of transportation is one of the lowest priorities to set in a design process, while final product integration seems to be the overall highest-ranking aspect. In the middle of the scale people most often set ease of maintenance.

Based on the answers received in the survey the answer to the question within the studied environment is that ergonomic design application is almost non-existent.

Through the answers in the questionnaire it was clear that the engineers did not start off with a clear understanding of what ergonomics is and how it is integral to their product design. This was caused by a clear lack of ergonomic training during their university years. This state carried on in their work environment, as little to no additional training was provided into the topic by the companies worked at. There seemed to be was no perceivable overarching companywide ergonomics policy. If one existed, then the engineers were clearly not aware of it. There was also no incentive structure in place to help guide engineers to a more ergonomic design alternative. Discussions before and after the interview have shown that the company cared most about production cost and timing. It has been shown by other researchers that bad ergonomics design leads to poor assembly (Falck et al., 2010), which increases costs and production time. It is therefore in the interest of managers looking to decrease costs to invest in ergonomics trainings for their engineering department. This was not the case in the studied environment, as managers did not seem to provide any support structure to guide engineers in the right direction.

To change this type of situation in a significant way a three-direction change must happen. On a country level a change in education policy must be proposed, by describing the benefit of adding ergonomics studies to the curriculum in engineering schools. This will prepare engineers with basic ergonomics knowledge and how to apply it to their work environment. Upon this knowledge, a second step would be company specific ergonomic training for engineers, which can help them understand the companies' ergonomics requirements and application scheme. This, however, means that managers and decision makers also need to understand how ergonomic applications benefit the bottom line of the company. That implies ergonomic training for managers and the presence of a trained ergonomist within a decision-making structure of a company.

Either one of these points applied singularly will get drowned out by the "business as usual" way of working. Which is why all three must be applied simultaneously for sustainable change to happen. While the educational change in policy is out of the scope of this thesis, there is a high possibility of improving ergonomic perception within companies with the help of the proper tools. This will be further discussed in the next chapter where such a tool is presented.

3.3.2. Experimental research at Bombardier's supply chain

This subchapter focuses on auditing the existing warehouse activities, the Kanban specific flow and ergonomics of the worker's weekly Kanban fulfilling activities. As explained in the Annex 2 BT process flow from "Article number release" to "Delivery in production" and "Payment", the logistical activities that are being analyzed are in the Activity #35 to #50 range.

The manufacturing of a train implies the seamless integration of thousands of parts and components from mechanical, electronic, and electro-mechanical suppliers. Because of this level of complexity, the supply chain of a train manufacturer (such as BT or Siemens) is organized in a pyramidal structure in which the manufacturer is supplied by large system and subsystem assemblers, which in turn are supplied by parts and component suppliers. The train manufacturer carries out the final assembly and manages the entire project. The system or sub system suppliers are large companies with specific technological specialization that can also be production and design partners throughout multiple projects. The parts and components suppliers are mid and small sized firms that produce low complexity high volume pieces either directly for the train manufacturer or for the system suppliers. Most of the time, the suppliers, specifically the tier ones, deliver exclusively to the railway industry, creating a partnership that spans multiple projects and a closed ecosystem, as represented in Figure 3.13. While this situation can be both beneficial as well as detrimental, the one sure thing is that the relationships formed between the involved parties are a critical factor for the projects' success (Esposito and Passaro, 2009).

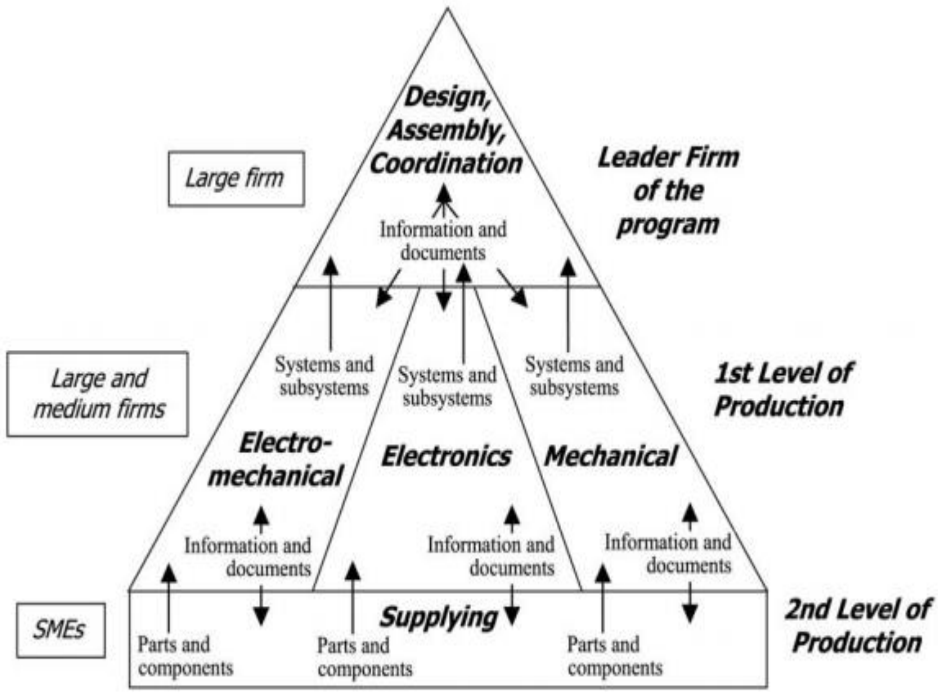


Figure 3.13. Railway supply chain ecosystem (Esposito and Passaro, 2009)

To understand the physical and information flow of goods in the warehouse the company's warehouse training manual was consulted, and the warehouse workers were interviewed during their tasks to better understand the process.

The supply chain setup of the company is not very developed in comparison to that of the automotive industry. A first analysis of the overall logistic capabilities of the company were done with the help of a "Global Materials Management Operational Guidelines/Logistical Evaluation, MMOG/LE assessment tool"[37]. MMOG/LE is an Automotive industry action group (AIAG[38]) standard self-assessment and continuous improvement tool for the supply chain management processes of a company. It is the global standard for "industry best practices and is intended to establish a common definition of materials practices to facilitate effective communication between trading partners. The tool is made to be used by both supplier and customer throughout the entire product life cycle" and in this case was used to audit the existing BT structures and understand the current supply chain maturity level and capability for change (Butner, 2010).

[37] MMOG/LE, Global Materials Management Operations Guidelines. Retrieved from: https://www.aiag.org/supply-chain-management/materials-management/global-materials-management-operations-guidelines

[38] Automotive Industry Action Group, https://www.aiag.org/

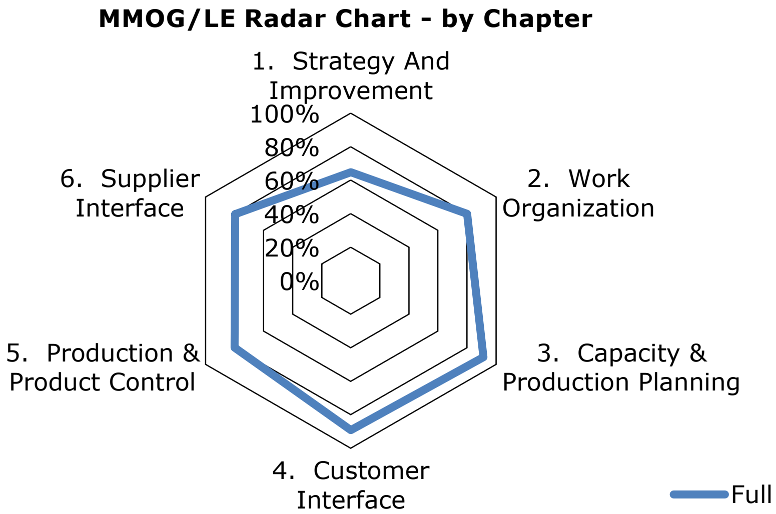


Figure 3.14. Bombardier MMOG/LE Radar Chart

The assessment, as can be seen in Figure 3.14, shows that the company is not a strong achiever of supply chain strategy and logistical process improvement capabilities. The overall hovering on the 80% boundary line would make it an unacceptable supplier for the automotive industry for example, where a general score of 85% is considered borderline acceptable. The assessment (which can be fully seen in Annex 3) shows a lack of structured processes that can result in bad long-term consequences for the company. These consequences are already felt in the company at a worldwide level, as between 2015 and 2018 around 14.500 positions were cut around the world in the aerospace and railway divisions, 500 of those in BTB. The company is downsizing in an unhealthy way and the vicious circle it creates on an operational level can be felt locally, as the following paragraphs will prove (Reynolds, 2018).

The company's global Enterprise resource planning (ERP) system is SAP, having made the switch from the proprietary System Manufacture Bombardier (SMB) at the beginning of the 2010s. In SAP, as used in Belgium, the management of the storage of goods is shared between the Inventory management flow (IM), which defines the value and quantity of goods and the warehouse management flow (WM) which defines the physical location of each goods quantity.

As presented in Figure 3.15, within the global factory network the Belgium factory is codified as BE01. Articles that are stored in the physical warehouse have storage location code BP01.

The warehouse is split into different warehouse types:

- Warehouse type 001: big pieces: pieces with a location A ...;
- Warehouse type 002: small pieces: pieces with a location X ... / L ... / ...;
- Warehouse type 003: paint: pieces with a location V ...;
- Warehouse type 004: free to grab stock with a location G ...;

- Warehouse type 005: manual Kanban: pieces with a location K ... (not Kardex);
- Warehouse type AW1: Kardex pieces (K0001N-K0002N-K0003N);

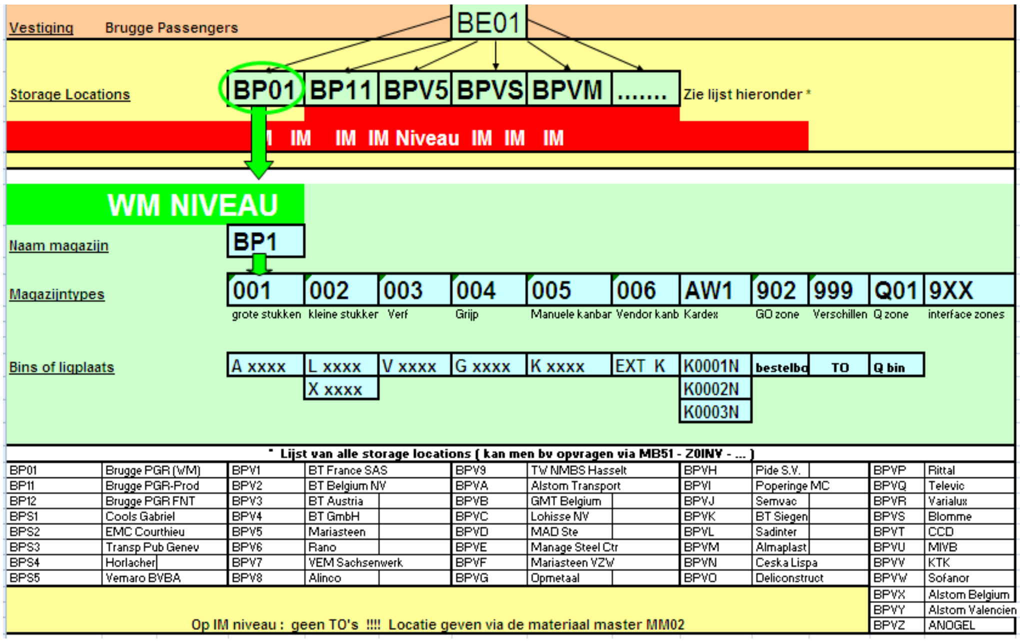


Figure 3.15. Warehouse coding structure

On an SAP level the warehouse management is split into the following areas:

- Goods reception area: 902.
- Quality area: Q01
- Dispatch area: 916;
- Production: 914.

The company has the informational infrastructure possibility to use a variety of logistical flows. Not all of them are actively used however, as each individual factory has certain particularities that exclude some flows. The flows currently used within the Belgian factory are highlighted in the list below:

- PPF: piece manufactured externally, to be received and brought into production based on the picking list;
- PPE: piece manufactured in house, but that still must be received and brought into production based on the picking list;
- SAS: piece manufactured internally, received in the warehouse via production order, brought into production based on the picking list;
- DOL: piece manufactured externally, to be delivered directly in production;
- SAD: subassembly that is manufactured in house and remains on the production line;

- KBS: Kanban piece that is stored in the warehouse;
- KBE: pieces that come from the machining department directly in Kanban racks;
- KBV: Vendor Kanban;
- KBP: Paint articles in Kanban;
- NOT: Not yet assigned logistics flow;
- 2BN: Kanban system managed by external suppliers with consignment stock pieces that do not show up in the overall company stock.

3.3.2.1. The study on Bombardier internal supply chain ergonomics

The current analysis looks at the Kanban activities that take place both with internal company management (mainly coded as KBV, KBS) as well as the Vendor Managed Inventory solution (coded 2BN and 2BO).

BAKPM351

Figure 3.16. Example Kanban rack label

Figure 3.16 shows the standard coding of a Kanban rack, showing the warehouse location, rack, and level. This information is theoretically stored for each Kanban item in SAP transaction MMBE. This is not always the case, as the articles that are not ordered with an article number (see the details in Annex 2) do not have any stock visible in the system and therefore cannot be assigned a storage location.

The standard Kanban racks used in the production and warehouse areas are presented in Table 3.2. All three types are used within the production area, without clear view as to when one is preferred over another. There were no rules found as to how the loading process is supposed to take place, if there are any restrictions on the bin-rack combination or how much weight can be held on each individual rack level. As the production expanded from one line to two lines, the amount of racks existing on stock was not enough to supply the needed amount of new storage locations created. The stock has been completed with new rack types purchased from a different supplier. They are out of scope for the current analysis as they will be put into use after the data gathering project is over.

Table 3.2. Types of racks

Size	Measurements [mm]	Height of racks	Picture
Jumbo G	Length 2230 Width 1000 Height 2040	1: 19 2: 50 3: 80 4: 141 5: 153 6: 165	
Mini G	Length 1455 Width 700 Height 2200	1: 13 2: 40 3: 68 4: 95 5: 122 6: 150	
Mini K	Length 780 Width 700 Height 2200	1: 15 2: 43 3: 79 4: 141 5: 153 6: 165	

Internal Kanban racks are placed at locations defined by Methods engineers. For each PM (post de montage - mounting station) the following safety restrictions are defined for the workers to take into consideration:

- When placing racks at ground level, position the rear side where possible with the driving area of the fork-lift trucks. This makes it easier to supply;
- When placing racks on a platform: place the back of the rack parallel to the edge of the platform and place at least 80 cm from the edge of the platform;
- Place shelves so that the bins slide down to the pick-up side of the workshop;
- Apply adhesive strips for the labels;
- The labels in the adhesive strips provide front and rear racks according to standard.

As can be noticed, the safety restrictions do not take into consideration the ergonomic ease of use of the racks and the bins placed on them but focus mostly on their installation and their marking. Table 3.3 contains a description of the three existing types of bins used within the production area. The size of the bins is determined by the Material Requirements Planner (MRP) controller based on the engineering calculation of object dimension, weight and the MRP determined fixed delivery lot size. In areas with welding processes the "S" bin is not allowed as it is made from plastic and the presence of the piece can be a fire hazard.

Table 3.3. Bin types

Size	**Measurements**	**Picture**
S	Length: 245mm Width: 150mm Height: 130mm Weight: 290gr	
M	Length: 340mm Width: 220mm Height: 200mm Weight:520gr	
N	Length: 500mm Width: 320mm Height: 200mm Weight: 4110gr	

Figure 3.17 is a drawing of the location marking for empty Kanban bins. All Kanban bins should be placed in that area so that they can be subsequently removed by the warehouse responsible.

Figure 3.17. Location marking for empty bins

Official instructions to fill-up Kanban bins in their respective racks are as follows:

- Provide a zone for empty bins or if the number of bins is limited and the space next to the rack is missing to create a zone, space may be provided in the rack with the indication "empty bins";
- Arrange articles side pick-side workshop in an alphanumeric manner;
- If possible, leave room for one bin per beam. If, because of a change, pieces are added, an extra rack placement can be prevented;

- Check the general condition of the racks (cleanliness, standard labels, etc.). Follow-up via checklist and action list;
- The total weight of the Kanban container may not exceed 20 kg;
- Determine the location of the Kanban racks on the PM stand in consultation with the Logistics Technician and Layout Responsible;
- After stabilization of the chain check if the possibility exists to limit the number of racks provided. At this moment you can also adjust the letter designation of the rack if necessary, as at the start of a project we let all indicators end at A;
- Stock size KBS: several racks for PMs are assembled in one central location in the workshop. To receive the place for this one must agree with the Method and the Logistics Technician;
- Stock size KBP: are delivered from the paint warehouse to the fireproof safes only to the legally specified daily quantities;
- Only one label may be placed on the tray. Remove old labels or cover them with the new label;
- Always use clean and undamaged containers.

While the general information of the official instructions provides useful input on how to handle Kanban bins, there is no managerial follow up noticed during the auditing and data gathering session on whether the recommendations are followed. A lack of preparation time before the start-up of the M7 project had led to inaccuracies in the system. In that situation, the rules were generally disregarded in favor of keeping production constantly supplied with material, regardless of the way this was done. This will be further touched upon in the following paragraphs.

To understand what measures are being kept track of, Table 3.4.

Presents the KPIs that are tracked on a daily and weekly basis on the warehouse shop floor. The separation of "input", "process" and "output" KPIs was done by the author, as there was no company mandated separation between them, and no analysis as to whether more output KPIs were required to properly analyze the daily warehouse work or not. As can be noticed, there is no ergonomic specific KPI that is being tracked. The three KPIs that are health and safety related are "First aid", "Risk points" and "Status 5B warehouse".

First aid, while required both companies wide as well as nationally within Belgium, does not provide any information on what the accident root cause was and led to no action plan on how the company was planning to not encounter the same issue again.

Risk points, a KPI resulting from possible risk situations encountered by workers during their jobs and reported to their supervisors, did not offer a systematic review of company risks and took an average of three weeks from encountering the risk to fixing the risk for all.

Status of 5S warehouse is not considered a priority. The lack of preparation time during the M7 start-up phase led to a backlog of articles delivered on site for safety stock that were never organized according to the agreed warehouse flow.

Another observed aspect was related to the fact that there are no training KPIs available. After a worker's basic job training is completed there is no training path available to improve their skills. During a cost cutting campaign in 2015 the training costs were reduced, limiting people to on the job spot training received from more experienced workers who remained in the company. This has led to job stagnation and boredom in the case of most employees.

Table 3.4. Warehouse KPI plan

		Input	**Process**	**Output**
Customers	Non-Quality cost			Articles without stock movement
		New bins	# warehouse caused NCRs	
			Wrong Storage location	
		Blocked stock in the 914 area (production)	# of items without storage location in SAP	
		Inclusion in Waive/Not Waive	Stock counting	
	OTD	TOs to complete	Kanban Green or Red accuracy	Time to solve a backorder
Employees	Safety		First aid	
		Risk points		
		Status 5S warehouse		
	Missed workdays	Days lost - input on the work capacity		
Financial	Wrap rate	Workload		
		Resource Manager Warehouse and QC		
	Direct hours versus budget	Follow up of direct hours in warehouse (budget)		Follow up of direct hours in warehouse (actual)

The ergonomics analysis of the Kanban process in the warehouse and production was split into three different areas, based on the observations done during the data gathering phase:

1. The metrics of the racks;
2. The cycle time for bin filling;
3. The ergonomic assessment of bin fillers.

These areas were chosen due to the large amount of internal customer complaints and the risk that they were posing to the health and security of workers. In the first step, the process was analyzed, and the issues identified. In the final part of the research, solutions are proposed to improve the situation, both with the usage of Lean Six Sigma tools and methodologies as well as with the use of Automation and Industry 4.0 tool acquisition (as will be depicted later in chapter 4.2 and 4.3).

3.3.2.3. The study of the rack's metrics

The research for this subchapter was developed between July 2018 and December 2018 and the results were disseminated through the article: (Mocan, and Draghici, 2019b).

"The current Kanban process within the company is split between internal and external Kanban. As it is not the standard understood definition, internal Kanban in this analysis is defined as Kanban activities that must be done internally within BT (for example, filling the bins, scanning the bins, management of internal deliveries). External Kanban refers to activities fully outsourced to the supplier in which BT does not activate at all. The analysis was done on the internal Kanban racks and procedures, with the aim to understand whether the current processes respect ergonomic norms and regulations" (Mocan, and Draghici, 2019b).

"There is a grouping of racks in each PM location. One rack per PM was sampled and all full bins in that rack were weighed. Full bin was defined as bins where no parts were removed. As the running system was Kanban, where (minimum) two bins existed per rack for the same article number, the second (filled) bin was measured as it was maximally full. The measurement of the weight was done with a handheld Samsonite Digital Luggage Scale Torch Black with a maximum analyzable weight of 40 kg and a sensitivity of 10 g. The bins were hooked to the scale and left to hang until the digital scale confirmed the final weight via a beep sound" (Mocan, and Draghici, 2019b).

Figure 3.18. Samsonite scale used for measurement

Table 3.5. Range of weight and height per rack level (Mocan, and Draghici, 2019b)

Rack level	Maximum [g]	Minimum [g]	Average [g]	Rack height average [mm]			Ergonomically theoretically recommended maximum [g]	
				Jumbo G	Mini G	Mini K	Men	Women
ALL	28870	270	6066,73				25000	
1	22050	740	5354,46	190	130	120	10000	7000
2	7040	570	1998	500	400	430	20000	13000
3	18610	950	7639,33	800	680	790	25000	16000
4	15100	500	3464,53	1110	950	1410	20000	13000
5	28870	270	7304	1400	1220	1530	10000	7000
6	7530	500	3393,33	1700	1500	1650	10000	7000

"The weight of the filled bins measured between 270 g and 28.870 g overall, with the weight of the bin itself included in the measurement. The weight per each rack level along with the ergonomically recommended maximum weight per related height is presented in Table 3.5. Even though only one rack was chosen for measurement per PM, in one case a rack that was not selected for the random check was noticed to have what seemed to be a heavy bin on the uppermost level. Upon trying to measure it, the bin proved very difficult to lift by the observers and caused the scale to make cracking noises as it lifted the items. The full weight was not measurable by the scale, but it was ultimately not taken into consideration in the analysis as it did not satisfy the self-imposed selection procedure" (Mocan, and Draghici, 2019b).

The Belgian law does not specify the maximum legally allowed weight (Codex VIII-3 "Manueel hanteren van lasten", 1990, specifies only that the weight cannot be too heavy - only specified limit is at 25 kg for the KB CAO Bouwbedrijf, meaning construction companies). "The European theoretical limit (EN 1005-2, 2003) is 25 kg. "The theoretical limit implies that the conditions for lifting are ideal (the weight is kept close to the body, at hip height, with a good grip and without the turning of the back). If these conditions are not met the weight capable of being lifted decreases. The ISO 11228-1 related to the manual lifting of weights mentions 25 kg as the maximum weight capable of being lifted by the overall work population but depending on the count of manipulations per minute this value decreases. With a frequency of 5 times/min maximum weight becomes 20 kg (Pinder and Boocock, 2014). The internal BT specifications limit the maximum amount of weight to be lifted to 20 kg in total, the internal guidelines not considering any height differentiation, which, as Table 3.6 shows, is clearly significant" (Mocan, and Draghici, 2019b).

Table 3.6. Average Belgian height [mm] (Mocan, and Draghici, 2019b)

Height	**P5**	**average**	**P95**
Shoulder height	1259	1394	1529
Elbow height	992	1094	1196
Knee height	403	446	489
Buttocks-Knee Length	554	607	660

"A first point of attention is related to the fact that there is no separation in the internal BTB norm between the maximum liftable weight by men and women. Regardless of this point, this maximum defined weight of 20 kg has been anyway surpassed by the two different bins found in the racks. In addition to this, as mentioned above and visualized in Figure 3.19 the maximum liftable weight varies depending on the distance the weight is kept from the body and the height that the weight is placed on. Given this information, the situation in the racks are not only stacked properly for women workers in 17% of the cases and for men in 70% of the cases. There is also a wide and lower skewed distribution of the weight per rack, the smallest weight being 270 g" (Mocan, and Draghici, 2019b).

"A first point that must be immediately improved is the maximum weight policy. Firstly, the national legislation needs to be obeyed, therefore a direct and immediate reduction of the lot size of bins which exceed the legal limit should be done. The bins found to already have overstepped the legal limit need to be removed from the racks and split into smaller lots" (Mocan, and Draghici, 2019b).

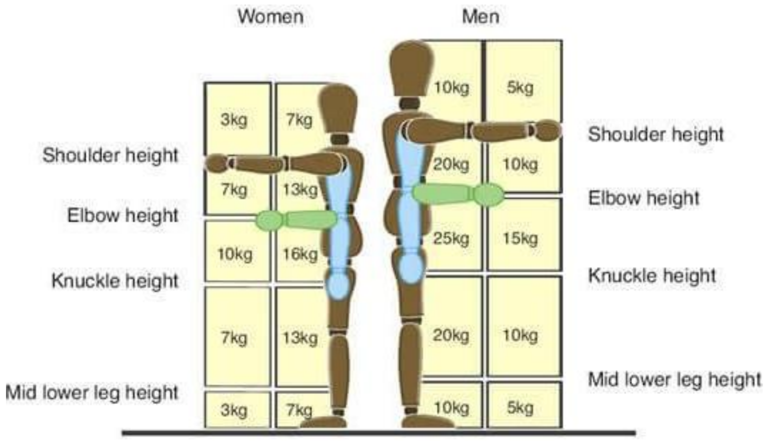


Figure 3.19. Lifting and lowering guidelines (UK manual handling regulations 112)

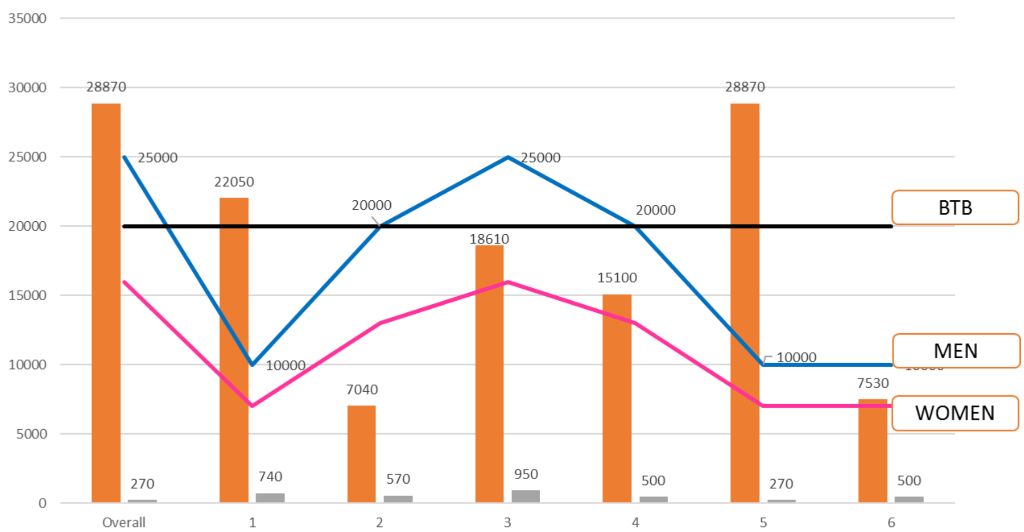
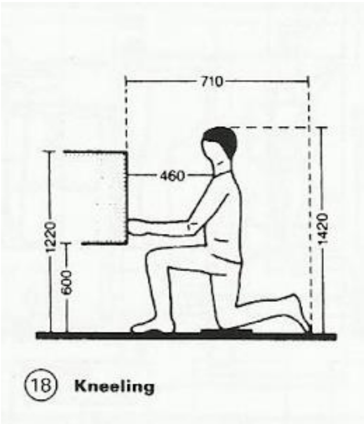


Figure 3.20. Weight of the racks and legal limits (Mocan, and Draghici, 2019b)

"As with the measurements of the weight of the bins, the measurements regarding the width between the racks was done on the internal Kanban racks. The reasons the width between the racks was chosen for analysis is because the proper handling of bins implies crouching in front of the racks to correctly remove or replace them. This cannot be done if the space between the racks is insufficient, therefore an analysis is needed to understand what the AS-IS situation holds" (Mocan, and Draghici, 2019b).

"One random gangway was chosen for each PM where a gangway existed. The distance was measured between the two most outward points of the rack (not the rack ledge itself, but the outward bending sticker ledge with a standard issue tape measure. The measurements can be seen in Table 3.7. The first observation to come out of the analysis was that there were no procedures or guidelines specifying the width of space necessary between two racks for proper kneeling/crouching capabilities. As presented in Figure 3.21, the distance necessary for crouching or kneeling is, on average, 700 mm" (Mocan, and Draghici, 2019b).



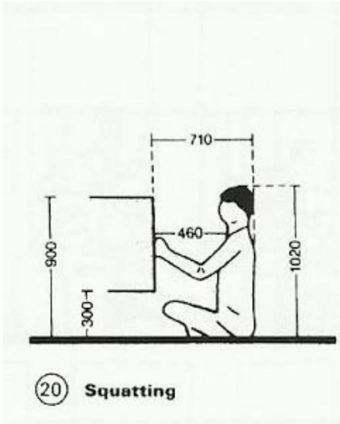


Figure 3.21. Distances defining the space needed for kneeling or squatting (Neufert et al., 2012)

"If only this distance is to be taken into consideration, the width of the racks proves to be satisfactory. However, the main purpose of the logistics worker is to stack the filled bins on the rack and remove the empty ones. Therefore, one must take into consideration the length of the bins being placed. This means that the minimum distance needed to place/remove something from the rack is the usual kneeling distance plus the length of the largest bin that is set in the rack. As presented in Table 3.7, the length of the biggest bin is 500 mm. As there is no rack in which the *N* size bin is systematically forbidden to be placed the minimum width between two racks must be 1020 mm" (Mocan, and Draghici, 2019b).

Table 3.7. Width of inter-rack gangways and dimensions of Kanban bins [mm] (Mocan, and Draghici, 2019b)

Measurement	Width
1	920
2	820
3	860
4	910
5	1040
6	830
7	1010

	Height	Width	Length	Knee width	Minimum width
S	130	150	245	700	850
M	200	220	340	700	920
N	200	320	500	700	1020

"If the minimum width is thusly measured the racks are therefore shown to be inadequate more than 85% of the time. This implies that none of the workers can follow standard ergonomic recommendations when filling in or removing the bins. They must approach the bin from the side, increasing the chance of torsional injuries of the lumbar spine that occur with load application accompanied by axial rotation. In these, damage occurs in both the annulus of the disc and the neural arch possibly causing traumatic arthritis and enabling the development of torsional deformities and subsequent neural compromise" (Mocan, and Draghici, 2019b).

"Furthermore, the labelling of the racks proved to be a difficult to follow system. Bins were grouped in a specific PM based on Methods engineering designated needs. The article numbers related to the pieces stored in the bins were stacked in racks based on the last digit. For example, rack A, side A contained all articles ending with a ***1***, rack A side B contained all articles ending with a ***2*** etc. While this did ensure that workers would be looking in the same general area for a bin to pick, the exact location would not be easily retrievable. Because of this, workers would lose time trying to find the correct item to pick. As there was no designated line picker who could, eventually, learn to navigate the racks sooner, most of the workers would lose their way quickly, or pick a wrong article. This led to small, but consistent daily delays and mistakes in the process" (Mocan, and Draghici, 2019b).

3.3.2.4. The experimental study on cycle time Kanban bin filling

Along with the analysis of the ergonomics of Kanban bin filling, the duration of the process was also measured, to understand if there is an improvement possibility in overall lead-time from reception in the factory to delivery in production. In Figure 3.22 the subprocess of Kanban bin filling is clarified.

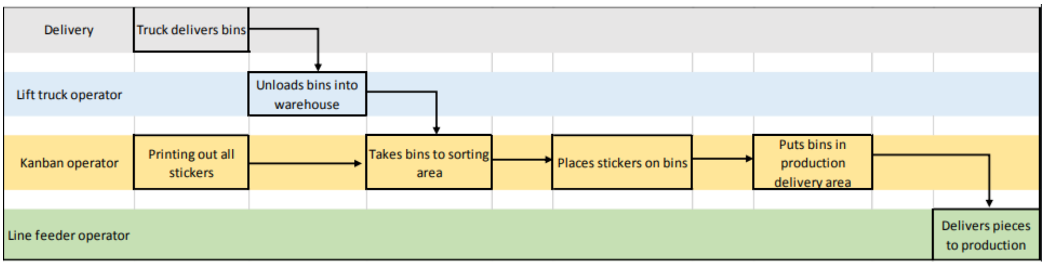


Figure 3.22. Kanban bin filling subprocess

The delivery of the bins happens once per week from the main Kanban supplier. The bins are unloaded into the warehouse by a lift truck operator. In the meantime, once a week the stickers of the bins that are in Backorder get printed and placed in the Kanban sorting area. Kanban operator then takes the bins to the sorting area and one by one places stickers on the bins. He then places the bins in the Delivery to production area. Later, when a critical mass of Kanban has formed the pieces get delivered to production. This is done by the line feeder operator or by the Kanban operator, depending on how the schedule is set.

The time spent between "Taking Bins to sorting area" and "Places sticker on bins" can be filled with various movements related to physical and system item identification, such as: "Searching through stickers"; "Searching SAP"; "Searching Excel file with modifications not yet applied in SAP"; "Double checking lists if article isn't found" etc. If the item is not found in the ERP system the bin gets stacked into a "rack of unknown items", where it will be analyzed later before being sent out to production. The measurement of lead-time was done between the steps: "Taking bins to sorting area"->"Places stickers on bins" and "Placing sticker on bins" -> "Puts bins in production delivery area".

Table 3.8. Cycle time Kanban bin sorting

Assessor	Measurement #	a. Bin filled->sticker on bin (s)	b. Sticker on bin-> bin on pallet(s)
1	1	48,71	3,22
1	2	102,69	11,73
1	3	56,29	3,76
1	4	106,28	14,18
1	5	38,13	3,65
1	6	76,82	6,47
1	7	59,75	9,57
1	8	51,88	6,25
1	9	54,39	6,22
1	10	130,67	5,79
2	11	47,13	3,19
2	12	55,79	4,73

2	13	60,47	16,63
2	14	36,41	3,96
2	15	77,89	5,20
2	16	60,08	8,63
2	17	51,68	6,65
2	18	54,84	5,77
2	19	130,57	5,30
1	20	47,44	6,50
1	21	16,88	19,35
1	22	16,39	16,78
1	23	30,80	11,64
2	24	48,14	6,86
2	25	17,06	17,40
2	26	18,04	16,47
2	27	30,41	11,98

Parts of the measurements can be seen in Table 3.8. From a first glance the first part of the process takes longer than the second. As presented in Figure 3.23, phase (a) has a mean of 58 s and a deviation of 30 s. Phase (b) has a mean of 8 s and a deviation of 5 s. Because of the lack of clarity in the process and working area, during the steps where more information is needed the pace ended up being slower. This difference of ranges is also visualized in Figure 3.24.

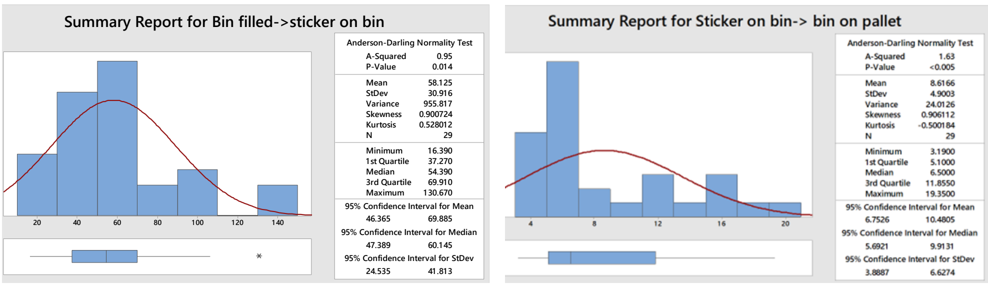


Figure 3.23. Basic statistics of bin filling time

If there is an issue in the process all communication happens between the warehouse worker and the Team Coordinator (TC). The TC is tasked with supporting the worker on all issues. Since some solution (modifying MRP settings, negotiation with suppliers, changing deliveries from Schedule line based to bin based) are outside of his area of knowledge, the backlog of not treated articles grows, or judgement calls are made by the TC without having the full view on all the impacts this causes in production. The following paragraphs will discuss some of the most common issues found during the auditing session and provides possible Automation and Industry 4.0 solutions. These solutions will be financially and ergonomically quantified in the next subchapter and recommendations for future investments will be made based on the results.

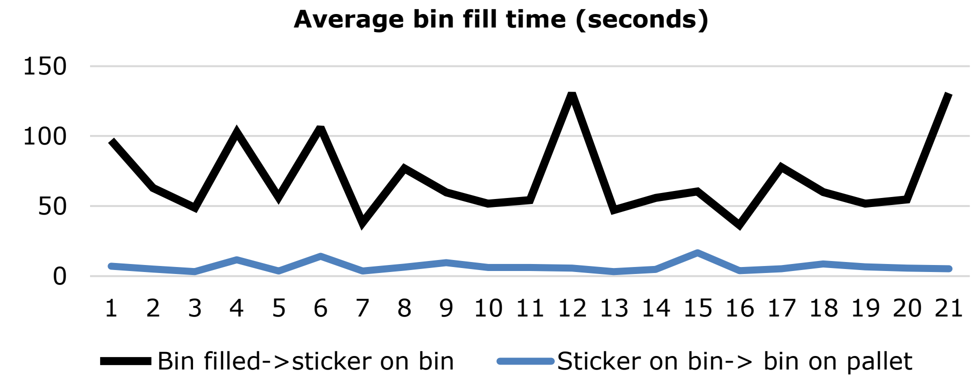


Figure 3.24. Visualization of bin filling time

3.3.2.5. The ergonomic assessment of Kanban human operators

"Over the past twenty years the assessment of musculoskeletal disorders has become an increasingly high priority for many organizations, fact which has led to the development of a wide range of ergonomic assessment techniques. Each of these techniques have advantages and disadvantages, but they are all used by practitioners in the workplace to identify where changes are necessary" (Mocan, and Draghici, 2019b). The methods for assessing exposure to risk can be divided into three categories, namely self-report, direct measurement, and observational methods.

The "***Quick Exposure Check (QEC)*** was developed in 1999 (Li and Buckle, 1999) to enable ergonomics practitioners to assess the exposure of workers to work-related musculoskeletal risk factors. The main using aspect of the method is that it is using a tool designed for and by practitioners, and as it assesses the exposure to risk instead of the risk itself, it does not have to wait for changes in the prevalence of WMSDs to become evident before suggesting solutions to the current ergonomic capability of the working environment. In layman's terms, it combines the self-report and the observational method" (Mocan, and Draghici, 2019b).

"Since the time of introduction of QEC, studies showed its value for postural assessments of jobs in several occupational settings, including construction (Rwamamara, 2007; Kim et al., 2011), supermarket workers (Coyle, 2005) and food producing companies (Mehrparvar et al., 2011), clothing manufacturing (Erdinc and Vayvay, 2008), assembly (Kim et al., 2004), firefighters and emergency medical technicians (Gentzler and Stader, 2010), sawmill and hospital (Janowitz et al., 2006)" (Mocan, and Draghici, 2019b).

"Since its launch, feedback from both researchers and practitioners identified that several improvements to QEC would be advantageous (David et al., 2003). Further development work on the QEC has been carried out to improve its usability, its scoring method, and its reliability. Some researchers have shown that it can be used interchangeably with other methods such as the Rapid Entire Body Assessment tool (REBA) (Motamedzade et al., 2011), like the Rapid Upper Limb Assessment (RULA). Others have found limitations of the method when analyzing jobs with wide range of motions (Sukadarin et al., 2013) or when using it for industries where the forces exerted were not properly represented in the questionnaire (Rwamamara, 2007)" (Mocan, and Draghici, 2019b).

"One of the limitations of QEC is related to the worker focused questionnaire. The assessment is structured into two parts: the practitioner and the worker, thus providing a fuller understanding of working practices information gathered from the field. The worker part of the assessment however is highly subjective, as the worker is asked to give his opinion on the weight he handles, the visual demands of the task, the stress level the task brings him etc. As the values gathered during the worker part of the interview further influence the overall values of risk computed by the assessor, there can be situations where the same working environment and the same job lead to two different evaluations, based on the workers perception. It therefore is hard to make recommendations about work improvements, as the findings could end being contradictory" (Mocan, and Draghici, 2019b).

"Given the high time and money costs of carrying out an ergonomic assessment there is an unspoken need to gather as much data as possible within the allotted timeframe, to best analyze the assessed condition. One of the possibilities for gathering extra information that would not hinder the execution of the task would be the usage of wearable technologies. The goal of this experiment is to understand if it's possible to combine all three observational methods, by adding to the self-report and observational method already existing in the standard QEC questionnaire, the direct measurement of ergonomic data via the application of a wearable computer" (Mocan, and Draghici, 2019b).

Barfield and Caudell (2001) defined a wearable computer as a: "fully functional, self-powered, self-contained computer that is worn on the body … [and] provides access to information, and interaction with information, anywhere and at any time". The market for fitness trackers and other wearables is growing according to International Data Corporation, (IDC, 2018) [39] mentioning that the "worldwide wearables market is forecast to ship 124.9 million units by the end of 2018, up 8.2 % from the prior year. Smartwatches will gain an increasing amount of market share over the course of the forecast, accounting for 44.6 % of all wearables shipped by the end of 2022".

The concept of utilizing direct data gathering tools to facilitate ergonomic measurement has been suggested in previous research as a feasible improvement solution (Plantard et al., 2017). The equipment used was not however body adjacent and relied on motion capturing systems to collect user data, which was subject to a lot of interference and would not be easily applicable in a production context. Other

[39] New Wearables Forecast from IDC Shows Smartwatches Continuing Their Ascendance While Wristbands Face Flat Growth IDC (2018, June 18). Retrieved from https://www.idc.com/getdoc.jsp?containerId=prUS44000018

research however uses full body Motion Capture Systems (MoCap). This system is in constant contact with the body and allows detailed data capture which does not sacrifice on quality of data gathered to the benefit of the quantity (Battini et al., 2014). While the system works in a research environment, it is not clear whether it would withstand a production one, where constant wear and tear would damage the sensors. This is the reason why equipment which is already designed for frequent utilization during exercise would be more recommendable as a measurement system. This is the reason why for the purposes of this study the fitness tracker Fitbit™ was utilized.

The aim of the study presented in this subchapter is "to analyze Fitbit™ gathered quantitative data (Figure 3.25) and how it can be used to complement QEC assessment values and give researchers more insight into individual ergonomic challenges of a specific job" (Mocan, and Draghici, 2019b).

Figure 3.25. Fitbit™ device for gathered quantitative data

"The analysis presented in this subchapter was performed in the Kanban bin sorting area of a manufacturing facility's warehouse in Belgium. The QEC assessment was applied to the two workers assigned to the bin management and was made during the final three steps of the *Kanban operator* process flow as presented in the previous subchapter in Picture 3.22. The job consisted of lifting bins from the unloading area pallets, placing the bins on a service table where they were manually labelled and then placing the bins on a separate delivery area pallet" (Mocan, and Draghici, 2019b).

"The process of bin sorting was considered for analysis as it was noticed during the tour in production and warehouse that the triage of the Kanban pieces was a source of disruption within the logistical flow. This was caused by, among others, missing or incorrect information in the company's ERP, missing or incorrect labels on the packages sent, and lack of process flow. This was considered to therefore be an area ripe with improvement possibilities" (Mocan, and Draghici, 2019b).

"The bin sorting activity was observed from the moment the bins are taken from their drop off location until they are set on the pallet for distribution in production. The assessment and measurements were done by two independent assessors for the full duration of a task cycle of 45 min, on sequential days, one per operator. There were two main operators tasked with completing this task on a regular basis (main and backup) as characterized in Table 3.9. Operators which did not have to do the task more than twice per month were not taken into consideration for the assessment. The bins being lifted had a range of weight from 28.870 g to 270 g with an overall average of 6.066 g" (Mocan, and Draghici, 2019b).

Table 3.9. Characteristics of workers (Mocan, and Draghici, 2019b)

Worker	**1**	**2**
Weight [kg]	79	82
Height [cm]	186	172
Age [years]	48	30

"In parallel to the QEC assessment, the workers were fitted with a Fitbit Ionic™ device on their non-dominant wrist (left hand). The Fitbit device had not been worn by any other user during the duration of the experiment. The number of steps registered on the Fitbit device because of bringing the device to the warehouse was written down and subtracted from the final count at the end of each session of the experiment. The device was used to track steps taken, kilocalories burned, and heart rate in order to assess the correlation between the answers on the worker assessment and their actual physical response to the activity being performed" (Mocan, and Draghici, 2019b) with the help of the following integrated sensors:

- 3-axis accelerometer;
- 3-axis gyroscope;
- Optical heart rate monitor;
- Altimeter;
- Ambient light sensor;
- Vibration motor;
- Global Positioning System (GPS);
- Near-field communication (NFC).

"The two assessors did not have any variation in the assessment values. These values can be seen in Table 3.10 and Figure 3.26. The criteria show average risk level scores in all assessed categories, with a medium-high impact on the shoulder area. This was in line with the lifting activity from and to ground level. The personal impact of the work being done did not strongly influence the overall score, as the operators attested to being able to follow the production schedule and not feeling particularly stressed or pressured by the job they were doing" (Mocan, and Draghici, 2019b).

Table 3.10. QEC analysis score per operator (Mocan, and Draghici, 2019b)

Operator	Assessor	Back	Shoulder	Hand	Neck
1	1	34	30	30	16
1	2	34	30	30	16
2	1	41	41	33	16
2	2	41	41	33	16

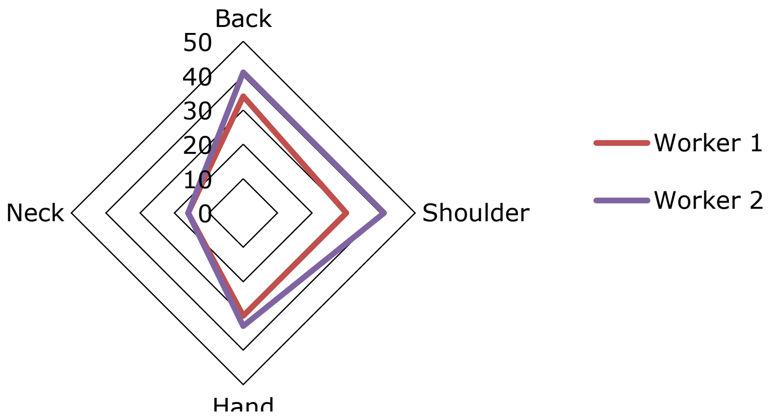


Figure 3.26. QEC graphical assessment per operator

"The second part of the experiment was related to the interpretation of the records about the heartbeat, calories consumption and the step measurements recorder by the Fitbit™. First results are presented in Table 3.11 and Figure 3.27 showing that worker 1 consumed approximately 40 kcal within the 45 min observation interval, in line with the Rest Metabolic Rate consumption of a man with his physical characteristics" (Mocan, and Draghici, 2019b).

Table 3.11. Heartbeat, kilocalories, and step counter- Worker 1 (Mocan, and Draghici, 2019b)

Measurement day	Time start	Time finish	Heartbeat [bpm]	Energy consumption [Kcal/min]	Steps [no.]
30-10-2018	8:15	8:20	77	3.2	133
31-10-2018	8:20	8:25	80	4.4	257
31-10-2018	8:25	8:30	85	3.7	160
31-10-2018	8:30	8:35	92	4.3	296
31-10-2018	8:35	8:40	92	4.3	206
31-10-2018	8:40	8:45	96	4.5	210
31-10-2018	8:45	8:50	103	5.3	239
31-10-2018	8:50	8:55	107	6.0	324
31-10-2018	8:55	9:00	99	3.4	117

"His heart rate never increased over 107 bpm, equivalent to a light intensity exercise. The activity executed does not therefore show to cause any increased stress on the worker and is in line with the QEC questionnaire answers. The number of steps taken is slightly higher than for worker 2 (1942 vs. 1844), as caused by the lack of preparation of the workspace before the beginning of the task. This topic and its influence on the measurements is further discussed in the following paragraph" (Mocan, and Draghici, 2019b).

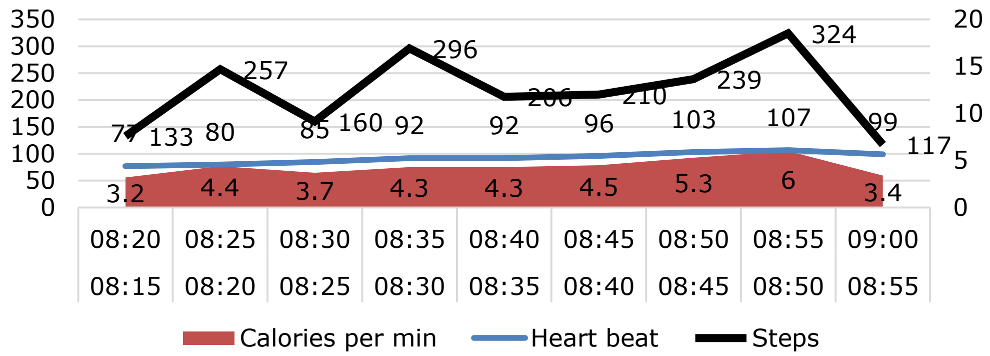


Figure 3.27. Graphical visualization of kilocalories burned, heartbeat and steps taken worker 1 (Mocan, and Draghici, 2019b)

"As presented in Table 3.11 and Figure 3.27, worker 2 energy consumption was of approximately 51 kcal within the 45 min observation interval, also in line with the Rest Metabolic Rate consumption of a man with his physical characteristics. His heart rate never increased over 120 bpm, equivalent to a light to moderate effort" (Mocan, and Draghici, 2019b).

Table 3.12. Heartbeat, kilocalories, and step counter- Worker 2 (Mocan, and Draghici, 2019b)

Measurement day	**Time start**	**Time finish**	**Heartbeat [bpm]**	**Energy consumption [Kcal/min]**	**Steps [no.]**
31-10-2018	8:35	8:40	93	4.0	190
31-10-2018	8:40	8:45	108	5.6	190
31-10-2018	8:45	8:50	114	6.0	200
31-10-2018	8:50	8:55	116	6.2	209
31-10-2018	8:55	9:00	119	6.3	198
31-10-2018	9:00	9:05	120	6.3	232
31-10-2018	9:05	9:10	109	5.3	239
31-10-2018	9:10	9:15	110	5.6	240
31-10-2018	9:15	9:20	107	5.3	146

"The activity executed does not, therefore show to cause any increased stress on the worker and is in line with the QEC questionnaire answers. The amounts of steps taken is also reduced, due to a better workspace organization at the task's beginning than in the case of worker 1" (Mocan, and Draghici, 2019b).

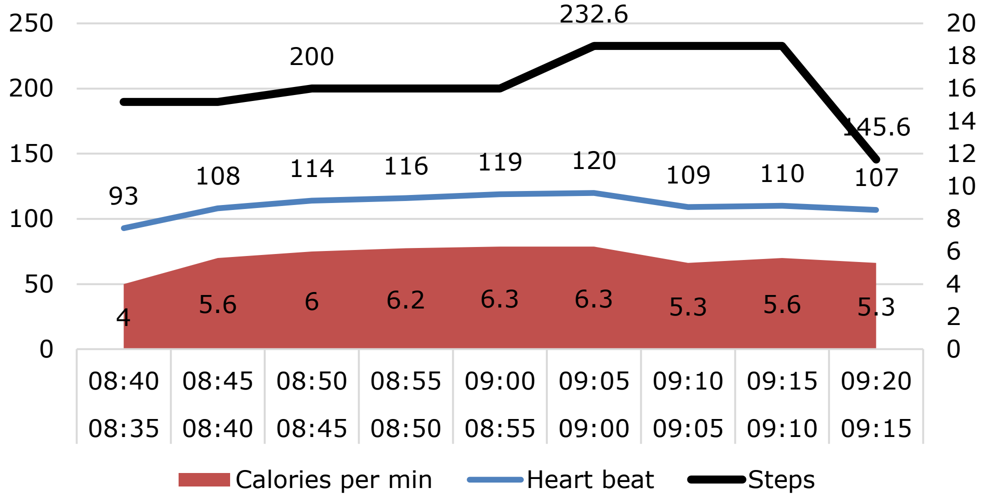


Figure 3.28. Graphical visualization of kilocalories burned, heartbeat and steps taken worker 2 (Mocan, and Draghici, 2019b)

"The tracker did not impede the execution of the work tasks. At the end of the monitoring session both workers confirmed that they did not notice tracker and they would have no problems wearing it on a day to day basis" (Mocan, and Draghici, 2019b).

An extra advantage of wearing a Fitbit while performing activities is the real-life tracking of movement and biological data. As can be seen in Figure 3.29, the GPS enabled tracking created a within 1 m reliable Spaghetti chart of the movements the worker was doing during a 30 min session of rearranging bins. When superimposed with the working area layouts it was possible to observe that the worker was not always staying within the floor marked area where walking was supposed to be safely done. While the work floor plans of the company are confidential and can't be shared in the thesis, the green highlighted area on the figure helps show where the worker was on the safety path and from which point on, he left it. While it is allowed for workers to walk outside of the marked floor path for various jobs if there is a floor path between two places it should always be taken. This opens the possibility to track the level of safety rules adherence within the company.

Further information could be gathered from the "Pace" measurement (Figure 3.29). The quick sequence of high peaks and lows along with the 19'45" average pace implies a repetitive "start and stop" type of slow movement. If trained within the meaning of the graphs an ergonomist can assess general job required movement and effort without having to go into production and audit the information in person.

"Wearing a Fitbit™ during work activities can provide complementary information for an ergonomics assessor, which cannot be ascertained from the standard QEC questionnaire" (Mocan, and Draghici, 2019b).

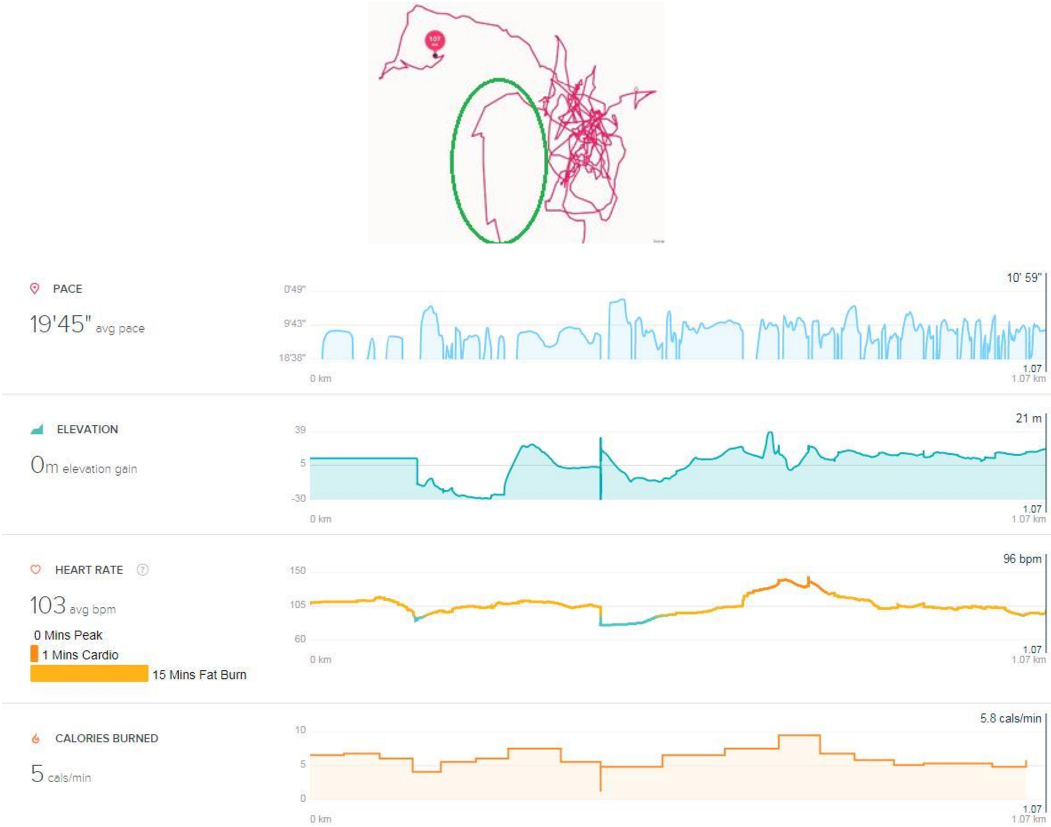


Figure 3.29. Real time Fitbit tracking

"In this case, the number of steps taken during the task far exceeded the expected result. During the 45 min of observed activity, the mail actions were related to workspace clean-up, resorting articles that were wrongly delivered in the Kanban area and clarification of the recommended storage location for articles not known by the worker. Interspaced with these actions some bins were processed and set on the *delivery to production* pallet, but this was not the main activity done within the timespan. Due to this, what the assessors were expecting to see as 25-30 steps per bin processed varied between 30 and 300. It was also noticed that the task duration did not lead to worker exhaustion or lead to any spikes in heart rate. This means that while ergonomic improvements should be implemented to reduce the QEC discovered risks, the task itself is not causing undue cardiac stress" (Mocan, and Draghici, 2019b). On top of that the burden of time spent visually assessing spaghetti charts is no longer needed, saving the company the cost of an onsite assessor, and offering a clear view of work inefficiencies or disobedience of safety rules.

"Further analysis and comparison should be done in different phases as describe in the following (Mocan, and Draghici, 2019b):

- This assessment was done during pre-series production, a specific phase of industrialization where the production pace is significantly slower than what it is expected to be in series production, therefore the values of the assessment as well as the aggravating factors could differ during full production pace;

- The ergonomic assessment has been done before any ergonomic best practice training took place. It would be useful to repeat the assessment after the training to assess if the risks would be diminished;
- Regarding the workplace itself, there was no observable tools in place or ergonomic strategy defined by the workplace supervisor that the operator was aware of or that they were told to use. The assessment should be repeated after the implementation of an ergonomics improvement plan and a better process training".

Table 3.13. Advantages and limitations of tracking (Liu et al., 2018)

Device type	Advantages	Limitation
Vision-based 9 Camera, e.g. Kinect and web camera)	Precise capture of human behavior	Vulnerable to bad lighting conditions
Sensor-based (On-body sensors, e.g. accelerometer and gyroscope)	Wide popularity of smart devices	Intrusive to wear sensors
RF-based RF transceivers, e.g. Wi-Fi router and RFID	Don does not need to wear sensors (non-intrusive)	Vulnerable to environmental changes

"Wearable technologies such as Fitbit™ can seamlessly be integrated into more classic ergonomic assessments to provide additional information about a worker's physical state during their work activities. The tracker does not impede the work being done and the quantitative data gathered with it can be used to complement the assessments done in classical ergonomic evaluations, therefore limitations such as presented in Table 3.13 are no longer a hindrance to those being examined. As the data can easily be mass downloaded, trends in worker wellbeing and activity can be analyzed more easily and without assigned professional assessors. As these devices become more common in the industry the capability of tracking employee exhaustion and monitoring possible health issues will become more common as well" (Mocan, and Draghici, 2019b).

3.4. Conclusions

As demonstrated up until now, the ergonomic of the Kanban warehouse leave much to be desired. The company does not invest in improving ergonomic reality of its workers and has serious gaps in the process that impedes it from achieving a good ergonomic status. In the following subchapter solutions will be presented that could improve the company's ergonomic efficiency and reduce the load on its workers, while maintaining at least the same level of service.

4. WAREHOUSING PROCESS IMPROVEMENT CAPABILITIES. THE CASE OF BOMBARDIER BELGIUM

As result of the measurements done within the first four months of the study and presented in Chapter 3, the last two study months were dedicated to the analysis of the improvement capabilities of the case study warehouse situation. The goal of the chapter is to present a series of possible comparable improvement strategies that the company could choose from to improve their warehouse ergonomics quality. The chapter is split into two parts, as presented in Figure 4.1. The first details the traditional improvement methods immediately applicable with the help of short implementation cycles and no financial investment in new tools or machines. The second part details the automation and industry 4.0 possible solutions available for the case study warehouse and grades them based on a self-developed ergonomic efficiency formula.

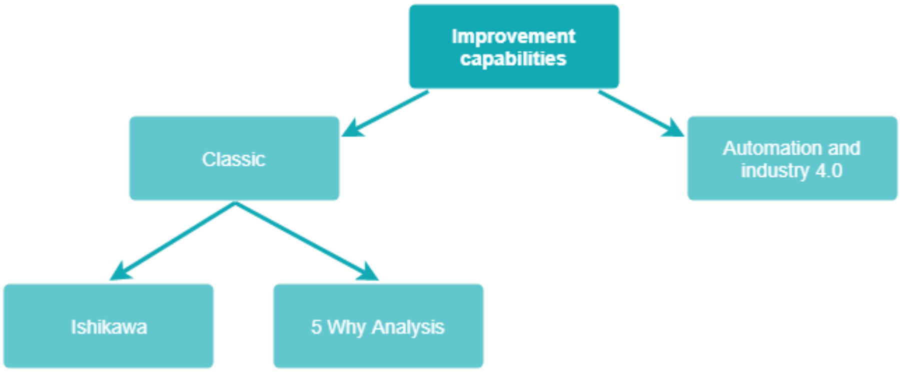


Figure 4.1 Chapter structure (the conceptual map)

The chapter ends with a summary of the analysis results and a series of conclusions resulting therefrom. As specified in the introduction, "an analysis will be made as to whether the issue could be solved with at least one type of solution, be that classical or by using Industry 4.0 technologies" (Mocan and Draghici, 2019). Furthermore, the identified solution will be graded "based on three areas of importance, namely investment amount, ergonomic efficiency, and ease of use. These aspects will be graded on a scale of 1 to 5 with 1 being least desirable and 5 being most desirable, based on which would maximize the efficiency equation (4.1)

$$E = \frac{I*p1+Ee*p2+Te*p3}{p1+p2+p3} \tag{4.1}$$

Where E is the overall efficiency;

- I – investment;
- Ee - ergonomic efficiency;
- Te - training effort;
- p1, p2, p3 - weight given to each factor" (Mocan et al., 2017b).

"The example grading explanation (Table 4.1) shows that the best possible grade that an equipment can get is 15 if all the weights in the (4.1) formula are equal to 1. Furthermore, the investment refers exclusively to the monetary investment in the purchasing of the equipment and not subsequent training costs. The ergonomic efficiency refers to the capacity of the equipment to reduce strain on the human body that would otherwise be caused by the manual manipulation that the equipment is replacing. The ease of use refers to the amount of time the average worker needs to spend in training to be able to use the equipment in the correct way, as specified by its producer" (Mocan et al., 2019a).

"Due to the current financial situation of the Bombardier Belgium entity, the factors will be weighed to increase the importance of the financial investment by a factor of 3, and the training effort by a factor of 2. This decision was taken due to the nature of the business. Cash flow problems often arise in the economic reality of the company due to the nature of the product they make and because of this a quick return on investment and freeing up personnel from training as soon as possible are more incentivized than ergonomic efficiency. Furthermore, the investment values and training effort mentioned in Table 4.1 also reflect the current financial reality of the company. The investment bracket and total cost will be calculated relative to Bombardier Belgium's warehouse needs" (Mocan et al., 2019a).

Table 4.1. Grading explanation (Mocan et al., 2019a)

Grade	**Investment [€]**	**Ergonomic efficiency**	**Training effort**
1	5.000-10.000	Minimal manipulation strain reduction	1-week training
2	1.000-5.000		1-3 days training
3	500-1.000	Average manipulation strain reduction	1-day training
4	300-500		1/2-day training
5	<300	Complete manipulation strain reduction	< 1/2-day training

Before proposing a solution to a given problem, the normal process is to understand its root cause(s), to avoid taking actions only on the symptoms and to treat the origin. To do so, two deigned tools were used for this:

- The Ishikawa - allows the user to sort the perceptible causes of a problem by numerous categories (usually given for the industry, but that can be changed for any process);
- The 5 Whys - helps understanding the root cause of a given problem by asking oneself at least five times the question "why?" (the number of occurrences is not an absolute rule and must be adapted to each situation).

Combined, these tools are a powerful way of targeting what must be done toward a given problematic situation (improving, creating, changing, …).

4.1. Ishikawa and 5 Why analysis

The research for this subchapter was developed between October 2018 and March 2019 and the results have been disseminated through the articles: (Mocan and Draghici, 2019a; (Cirjaliu, et al., 2019).

The research was separated into two directions: (1) related exclusively to the workspace redefinition issue, where the racks were shown to be in breach or Belgian legislation regarding workspace health and ergonomics; (2) related to the working process of the Kanban sorting station. The existing process is not working properly and needs to be rethought to bring the error rate down and the processing time up. Furthermore, to keep in line with the already defined Bombardier way of working, the Ishikawa diagram was standardized with the following standard causes: Human, Machine, Measurement, Methods, Environment, Materials.

4.1.1 The workspace redefinition

The details of the proposed study approach are summarized by the Ishikawa diagram presented in Figure 4.2. Additional explanations to the workspace definition are given in the following.

HUMAN

1. No one ever complained about the ergonomic issues:
    - They do not know there is a problem: the workers in BT have probably been working all their career in the same conditions and do not know adopting bad habits can lead to severe body issues;
    - There is no or few ergonomic trainings: few ergonomic trainings in BT happen rarely and without a follow-up. Nothing is made for the employees to get used to working properly, the trainings are more about passing information than adopting the good practices;
    - There is no ergonomic culture: even though BT is very keen on avoiding immediate accidents, there is no long-term-avoiding-accident culture within the company;
    - More important to do things fast than healthily: with all the projects going on and the delays occurring, it is more efficient to focus on what must be done for the clients than on what must be done for the collaborators;
    - Too many delays → Project > Process: BT has grown around a lot of project happening at the same time. Each project was the reason to create a new way of working to solve the new issues.
2. No discipline about the Kanban process:
    - No Kanban process (see Ishikawa diagram and analysis b.)

MACHINES

3. No tools used:
    - They think they do not need any: as they have always worked this way, they do not think it is necessary to change their way of doing things with the existing tools to help them.

MEASUREMENTS

4. Weight of the bins height not submitted to ergonomic rules:
    - Only one overall weight rule is defined for any item to be carried and placed at any weight (max 20 kg): this rule is the only BT standard concerning racks, and it is not respected;
    - HSE, who is aware of the ergonomic aspects of weightlifting is not directly responsible for creating rules: HSE should be the only responsible for creating, applying, entertaining, and sharing ergonomic rules and make sure they are applied;
    - TCs, who are not trained in ergonomics awareness are responsible for workplace safety: the person responsible for the well-being of the workers does not know what he should be careful to;
    - BT Belgium policy to have the local coordinator responsible for all the aspects of the work: once again, the HSE department should be responsible of the overview of the ergonomic policy and the respect of it.
5. No KPIs on Kanban usage:
    - Kanban flow decided by size and volume of pieces to be delivered, not by frequency of usage: whether a piece should be a Kanban or not should be done on the use of this piece, not his physical dimensions;
    - There is no decisional flowchart to help the responsible chose the correct logistical flow: BT has not decided of a systematic way to decide in which type of flow each article should belong to;
    - Decisions based on experience and not on standards and best practices: one person is/was in charge for this decision, and BT trusts this person: no process is defined, only the experience is considered. When the one person who knows will leave, BT will have a lot of issues to get a new person trained to do the exact same thing as the one before him did.

MATERIALS

6. Racks not adapted:
    - Same as 4.
7. Stickers sometimes handwritten:
    - Information in SAP not always updated: sometimes, SAP does not contain the correct information, which forces the workers to handwrite the stickers;
    - Articles delivered as specials: when an article is delivered as a P article, the reception can be done but the stock is not updated accordingly;

- Engineering change → not releasing new articles on time: when we have an engineering change and need the pieces swiftly, we can order an article as a special to get it in time, but then the stock does not include them;
- Not enough engineers anymore: the number of engineers is not great enough to get everything done in time according to BT's needs.

ENVIRONMENT

8. Production area not big enough to follow ergonomic recommendations:
    - Kanban percentage of articles higher than on any other project: with all the Kanban pieces received every day, storing them accordingly to ergonomic rules (provided they exist) is almost impossible. This causes the handling of the pieces to be chaotic;
    - Decreasing human resources in the warehouse: as they knew fewer people would be in the warehouse because of the social plan, BT decided Kanban would be the better flow to choose, as the supplier must take care of it.
9. No available place to store empty bins:
    - Place available but not defined: BT has not defined an allocated place to store them;
    - No responsible.
10. Not enough space between the racks to handle pieces/bins properly:
    - Same as 8.

METHODS

11. Ergonomic rules not applied by BT's methods:
    - No ergonomic rules clearly defined: as said before, there is no clear rules to be followed regarding ergonomics:
    - No ergonomic strategy from HSE department: currently, HSE is not in charge of the ergonomic follow up but should be:
    - HSE strategy based on existing dangers and not on potential ones as mention previously, BT focuses on avoiding immediate dangers, not on long-term ones:
    - BT HSE policy = 0 accident > policy = 0 short and long-term problem: an effective policy would consider both the immediate danger (which are often high-risk) and the long-term one (low risk on a short-term period but can become serious over time).
12. No rules on how to pick bins:
    - Same as 11.
13. Definition of what should be a Kanban part:
    - Same as 5.
14. No place defined to store empty bins:
    - Same as 9.

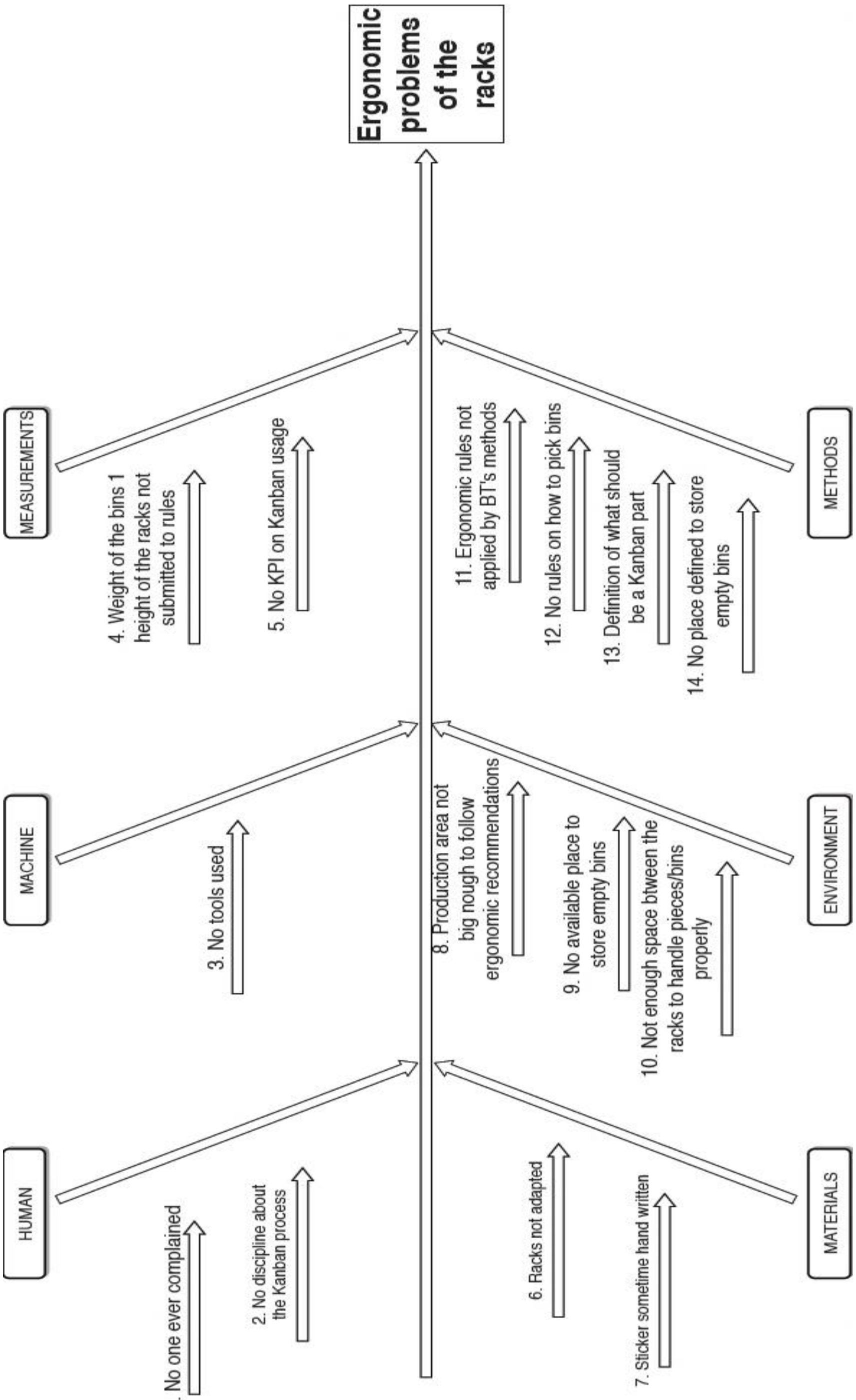


Figure 4.2. Workspace redefinition fishbone diagram

4.1.2 The Kanban bin filling process

The details of the proposed approach are summarized by the Ishikawa diagram in Figure 4.3.

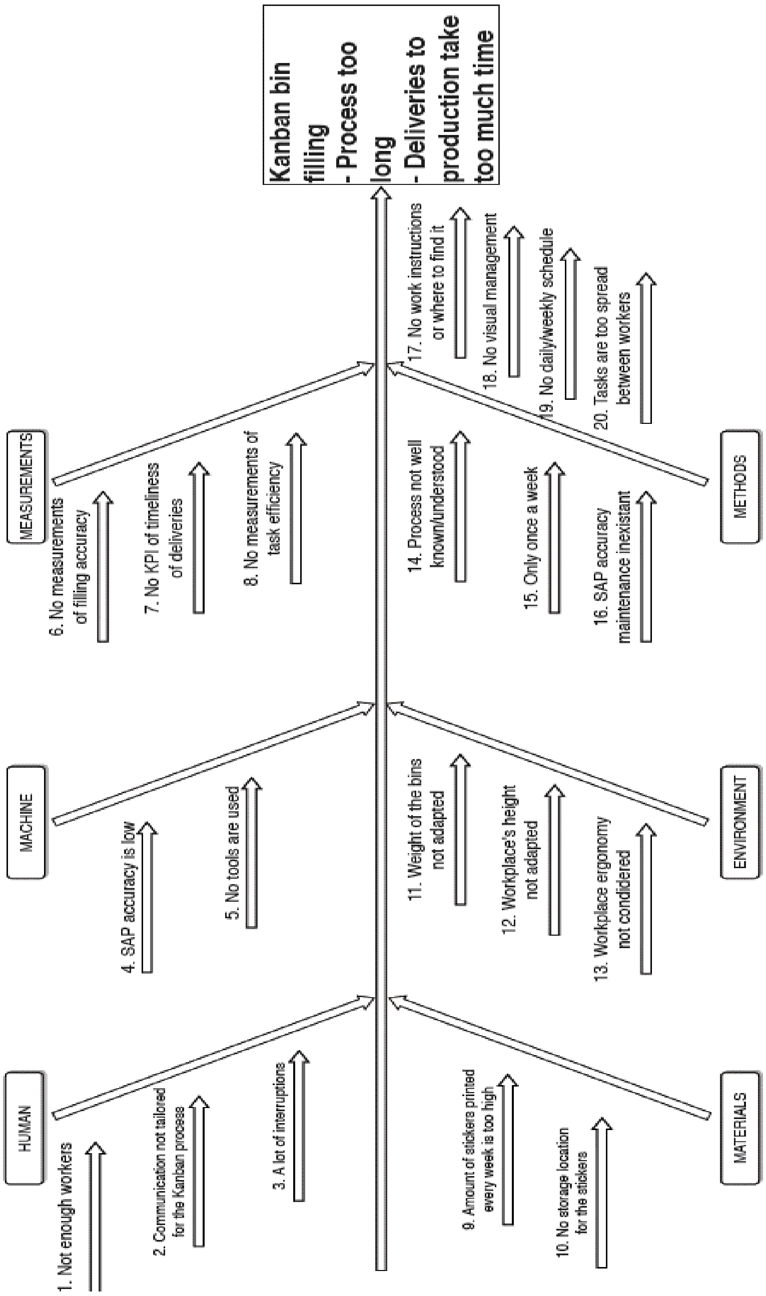


Figure 4.3. Kanban bin filling fishbone diagram

Additional details for the representation in Figure 4.3 are given in the following.

HUMAN

1. Not enough workers:
    - A lot of persons were fired: because of the recent social plan, the workforce has decreased a lot;
    - Because of the social plan, BT had to fire a lot of people, resulting in a workforce too little to handle properly all that must be done, and to make the processes sustainable over time.
2. Communication not tailored for the Kanban process:
    - Process is still what it was before SAP: when SAP arrived, all the former replicable manual tasks should have been cancelled to let SAP deal with the process;
    - The workers are not updated to the new ways of working: the workers keep working like they always did, and no training is made to update their way of doing things;
    - BT Belgium cut the trainings budget: organizing and following up training's costs money, and there is none or little budget allocated to this;
    - Not enough consideration from BT Belgium to update people's skills along with the methods: BT Belgium should set up ways to update its employees on the new ways of working and the new tools that accompany these changes;
    - Company culture: BT Belgium still relies on old practices, while also implementing some new tools, without trainings.
3. A lot of interruptions:
    - They always must ask what to do without a proper planning and a proper process, the employees always must be given punctual tasks;
    - They do not know the Kanban process (provided it exists): as it is not clearly defined or must be adapted to each situation, they cannot know it;
    - Management does not trust them enough to make their own decisions: instead of trusting and giving responsibilities, management infantilizes them into asking all the time their task;
    - They were not trained: as they sometimes do not know, it became a habit to assign them tasks rather than training to follow a planning;
    - Company culture: BT Belgium still relies on old practices, while also implementing some new tools, without trainings.

MACHINES

4. SAP accuracy is low:
    - No empty bins scanning by production: the scanning of an empty is not systematic, resulting in bins not filled up by the warehouse;
    - No responsible for this task (which comes directly before Kanban bin filling): there is no defined responsible for this task, and no follow up;

- BT follows a functional organization rather than a process organization: all equal functions (workers in this case) are accountable for the same tasks, resulting in no one doing this task. The process and a responsible should be defined;
- Process no standardized NO project and NO factories: BT has grown up around projects and developed process for each project;
- Project based development of BT → Project > Process: BT should create a process that applies for all projects.

5. No tools used:
   - They think they do not need any: as they have always worked this way, they do not think it is necessary to change their way of doing things with the existing tools to help them.

MEASUREMENTS

6. No measurements of filling accuracy:
   - They do not know they should measure;
   - No process awareness: the process of KPIs/KPIs follow-up within the warehouse is not known by the workers;
   - Each task is taken individually: the filling of bins is taken individually, and not as part of the "Kanban process";
   - There is no defined responsible of process or task;
   - No resources/awareness: there is no culture about KPIs for operational tasks.
7. No KPI of timeliness of deliveries:
   - Same as 6.
8. No measurement of task efficiency:
   - Same as 6.

MATERIALS

9. Number of stickers printed every week is too high:
   - They print out everything in one go: at a given time during a week, all the stickers are printed out to be used along with the bins being filled up;
   - The Kanban filling process only happens once a week;
   - GIS only delivers once a week;
   - BT's rule;
   - Different project stage.
10. No storage location for the stickers:
    - No storage location defined: there should be a place to store the sticker and to sort them depending on the urgency of the filling of a bin. Currently, the stickers are simply stranded under a metal bar;
    - Process not well defined: currently, the process only happens as pieces/bins come and go. There should a prioritization on the urgency

ENVIRONMENT

11. Weight of the bins not adapted:
    - They do not think it is necessary: the ergonomic culture not being applied in BT, no one knows it is bad for one's health not to be careful;
    - They focus more on emptying the warehouse than on ergonomic: the priority is given to getting the work done instead of getting the work done healthily;
    - Warehouse flooded with articles: the process being not defined enough and happening only once a week, the warehouse finds itself filled with articles that must be put in bins and brought to production;
    - MPS incorrect;
    - MRP not updated to production.
12. Workplace's height not adapted:
    - No ergonomic rules clearly defined: HSE has not defined the standard height of the different levels of the racks;
    - No ergonomic strategy from HSE department: BT has not given this responsibility to HSE;
    - HSE strategy based on existing dangers and not on potential ones: As said before, the strategy of HSE focuses more on punctual hazards than on long-term ones;
    - BT HSE policy = 0 accident > policy = 0 short and long-term problem.
13. Workplace ergonomics not considered:
    - Same as 12.

METHODS

14. Process not well known/understood:
    - Process not defined: regarding the Kanban, there is no clear process defined. Some rules exist, but they are not clear enough for the flow to go smoothly;
    - Not enough time to adapt to M7 rules initially: when this project was agreed, there was no time to recreate a process just for this project (BT should have a NO-project process);
    - M7 schedule was not adapted to BT's processes with current number of engineers: the social plan going on in BT has reduced the number of engineers who could have anticipated the Kanban flow.
15. Only once a week:
    - Same as 9.
16. SAP accuracy maintenance inexistent:
    - People responsible do not work in BT anymore
17. No work instructions or where to find it:
    - Same as 6.
18. No visual management:
    - Warehouse responsible does not have the management basics: there is no training;

- Warehouse job requires other skills than TC job: current warehouse manager used to be a TC and did not have the opportunity to adapt his skills;
- Methods Takes care of visual management usually, but not for the warehouse.

19. No daily/weekly schedule:
    - Warehouse responsible does not have the management basics;
    - Warehouse requires other skills than TC;
    - Planning and methods do the planning and time needed for the tasks.
20. Tasks are too spread between workers:
    - Same as 6.

4.2. Improvement points

Based on the above presented Ishikawa diagrams (Figure 4.2 and 4.3) and the 5 Whys tool developed from there, the solution Impact Effort matrix proposal has been created (Table 4.2). The grading of this proposal considered both the impact and the effort directly related to BT and its workers and cannot be used for comparison with other sites.

Table 4.2. Improvement impact effort matrix

	Improvements	Impact	Effort
1	BT company culture	5	5
2	Project based versus process-based culture	4	4.5
3	Logistical MPR flow definition	4	-1.5
4	Employee morale	1	-3.5
5	Logistics policy	6	2.5
6	BT HSE strategy (0 accidents, not 0 long term problems)	1	1
7	Managerial capabilities	-1	-3
8	Weight to lift/ergonomics policy creation	-1	-4
9	Workspace reorganization Kanban area	4	-4
10	Workspace reorganization rack area	5	3
11	Visual management Kanban area	4.5	-5
12	Visual management rack area	5	3
13	Time schedule for warehouse workers	2.5	-5
14	Rethinking Kanban bin on rack logic	2	2.5

4.2.1 Improvement of the Bombardier Belgium company's culture

BT strategy in project development relies heavily on rework. To bring the project quickly to series production a large amount of retrofit is factored into the process, creating a backlog of items that is not solved directly. While this doesn't pose an issue to the process management, if well defined, there is no clear definition/defined process of which changes should be implemented before the departure of the train from production and which should be applied later in a retrofit phase. This causes a bullwhip effect that starts in the engineering department, where changes are pushed through to the procurement department, from where suppliers are pressured to quickly change drawings and produce with the shortest possible lead-time. As this is usually not possible without going outside the boundaries of the official process, the articles are usually ordered with redlined drawings, with not yet released article numbers and with derogation on the warehouse entry. The warehouse afterwards must manage the influx of items that are, for all intents and purposes, invisible in the system. The stock cannot be booked, the storage location cannot be clearly set in the ERP and the logistical flow of the pieces is not respected (more pieces are warehoused than are supposed to).

If the company is to reduce the variability of this process that causes delays and overstock, then the company culture must change, and late stage changes should be discouraged by penalizations. This however proves to be a large endeavor that would involve changing the mentality of Bombardier international. Because of this, even if the impact would be maximum, the effort is also deemed to be extremely high. It will not serve as a practical goal for this project (Cirjaliu, et al., 2019).

4.2.2. Project based versus process-based culture

Bombardier is a matrix organization with both Project Management as well as Operational management vying for attention and usage of resources. This leads to a constant debate over the correct targets to follow, a doubling of KPIs and a creation of a silo mentality not only between departments, but also between projects. As each project is different there is a slightly different approach each time to the way in which things must be done. While there is no issue for workers to adapt themselves from one project to another if the transition is done completely, but the allocation in parallel of the same worker on multiple projects can lead to mistakes, as standard processes are quickly discovered to not be at all standard.

If the company wants to reduce human errors that occur in the process and steepen their learning curves it must also ensure that all projects run on the same process and that there are no exceptions between them. While this would produce a high impact in terms of reduction of process throughput time, the effort necessary to apply this change is too high and therefore considered not practical for this project.

4.2.3. Logistical MPR flow definition

There is no definition/decision tree/guideline that standardizes the logistical MRP flow placement. The articles are being assigned one flow or another based on the business experience of the MRP controller with, at most, input from the Expediting Manager. The MRP controller checks the drawings and the BOM of the pieces and estimates the lot size and the weight of the lot sizes based on the information he can find within. Afterwards, on a second pass he estimates the price of the piece based on previously purchased similar pieces or on previous prices negotiated for the same pieces. This, together with the other two constraints guide the responsible to the logistical flow to be defined.

In the case of the Just in Time pieces, there is a guiding questionnaire that must be filled in to assess whether the piece is suited for this kind of delivery. This kind of questionnaire does not exist for any other type of flow. The creation of this flow is a straightforward endeavor that will help reduce the articles inappropriately assigned to a logistical flow and will provide a standardized approach to logistical planning. As it is happening so far upstream in the article definition it is deemed very useful and therefore encouraged to be implemented.

4.2.4. Employee morale

Since the company has been facing restructuring on an international level, employee morale has been low for a long period of time. Job insecurity, reduction of personnel, decreasing of production capacity and delays in the production has led to a lack of motivation form the warehouse workers. This, compounded with the reduction of personnel, has led to a loss of process experience and problem-solving capabilities. The delay in production has caused a warehouse overflow and a rise in the material in stores value above the acceptable level. To have the buy in from the workers needed to successfully implement the improvement plans the employee morale must be lifted. From a management perspective this means creating a strong team bond between the remaining workers, understanding their role in the team, and motivating them to engage with their work environment. This requires management training to better understand how to apply motivation techniques in industrial environments as well as how to restructure the current relationship system. While the effort to implement this is reduced, the impact it will have on overall warehouse activities will not be very high. It is however necessary, to not reduce the level of engagement even more.

4.2.5. Logistics policy

In the past suppliers have delivered throughout the day, regardless of hour and with no pre-warning as to when they would arrive. In the recent months, a modification of delivery schedules has been implemented, where suppliers are only accepted before noon. This has been hard to implement as the railway industry deliveries do not work with the same discipline as the automotive industry ones. A lot of deliveries are still happening outside of the allowed time span and suppliers are claiming extra costs for the modification of their delivery window.

While this process of re-educating, the suppliers is taking time and effort on behalf of the expediting team, the only way to organize the warehouse schedule is by making this procedure even stricter. Every moment that the workers spend on waiting for a delivery to clear out is non-value-added time that costs the company money. If there is a clear (and small) delivery window in which the suppliers can drop off their packages, the workers can be assigned other tasks in the meantime. Therefore, even if the effort to change this mentality is going to be high the returns will show in the amount of time saved by the workers.

4.2.6. Aspects of health and safety strategy improvement at Bombardier Belgium (0 accidents, not 0 long term problems)

The currently worldwide Bombardier Health and Safety slogan is "Safety, no exceptions". This is translated into a culture of safety for acute issues. The problems signaled are the ones that can cause accidents, but a lot less effort is put into signaling long term illnesses than can result from the mishandling of pieces, for example. This is because the problems are signaled by the workers and they have no clear understanding about what types of chronic issues can appear from the repetitive warehouse work that is taking place daily.

There are scheduled ergonomics trainings that production and warehouse workers are invited to on a free will basis, but these trainings are not regular, their impact is not monitored, and their efficiency is not measured, therefore it is hard to tell what the workers remember and apply after such sessions. The mentality of the company must change to also consider chronic issues, and this will increase awareness of the issues from daily work the implementation will be very difficult and thus fall out of the scope of the current analysis.

4.2.7. Managerial capabilities

While in the past there have been defined and compulsory trainings for people that get promoted to managerial positions, this activity is currently not being done anymore. With the restructuring process people have moved within the company, some taking leadership roles that they are not trained to properly act in. With no training process that gives workers the skills they need to properly manage their workers there will always be suboptimal processes taking place. To alleviate this issue there is a strong case to be made for a management training process and course material to be created. The effort of implementing such a process would be minimal, while the impact can be significant.

4.2.8. Weight to lift/ergonomics policy creation

During the measurement of the weight of the bins placed on racks, a series of bins were found that exceeded the legal weight limit permitted for lifting activities. Subsequently, the discussion with the HSE responsible showed that there are no internal policies regarding the height at which a specific weight can be lifted. The only existing rule existing within the company an overall upper weight limit of items to be transported, which does not consider any ergonomic rules and recommendations.

The ergonomic principles are not taken into consideration daily and training towards a more ergonomic approach towards work is punctual and sporadic. The creation of a policy regarding lifted weight is not just a recommended improvement, it is a legal requirement. Therefore, even if the policy itself will not change the bad behaviors it is the needed first step to start quantifying activities.

4.2.9. Workspace reorganization Kanban area

The workspace used for Kanban bin sorting is completely improper for the activity that is supposed to take place in its space.

The truck from the supplier does not only deliver bins, therefore the worker must sift through between normal deliveries and bin deliveries and figure out which is which. Once a bin is identified the workers picks it up and takes it to the sorting counter/table. Sometimes human operator picks 2-3 bins at the same time if they are not heavy. The counter/table is not organized. There is no specific place where the bins to be processed are set. There is no visible flow on the processing table. The counter is filled with empty bins, or bins that are in pending status (no stickers for them, unknown articles etc.). Sometimes the worker must push bins aside to make space for his new batch. The stickers are printed out one time a week for all the backorders that are scanned in SAP in one long, connected sticker. They must be separated one by one before the work starts. During the first Gemba session the preparation of the workbench for action took approximately 15 min. After the stickers are ripped, they are arranged based on the last number of the article. There is no clearly visible standardized work instruction, leaving the organization to the latitude of the worker.

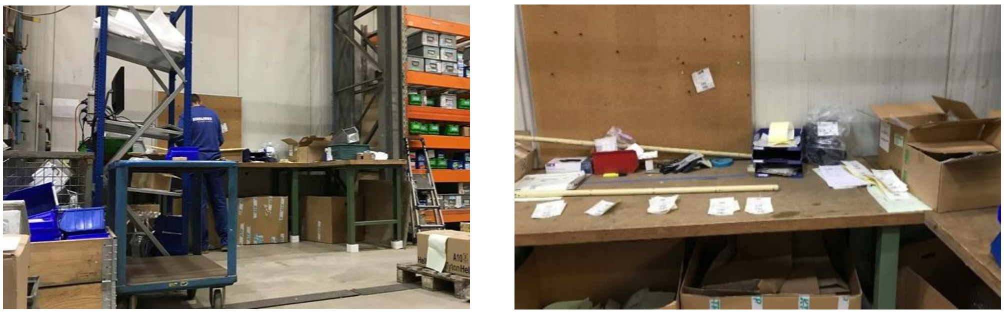


Figure 4.4. Warehouse Kanban sorting area

The workspace needs to first be cleaned up thoroughly, as can be seen from Figure 4.4 the table needs to be replaced with a variable height table to provide a comfortable working environment for all possible workers and a visual management system needs to be created to enable an easy handover of tasks and an intuitive understanding of the process. The point is further detailed in step 11.

4.2.10. Workspace reorganization rack area

The rack area is currently not following BT's own process regarding Kanban work organization. Not all racks contain printed identification numbers-some are manually designated. The empty bin placing location is not found next to every rack aggregation. This causes a disorganization in the Kanban filling process and in the actual production area, degradation in the company's material and a general misunderstanding of the way production is supposed to interact with the warehouse. These two departments are supposed to work along with one another; currently, because of audit observations each does what is the most convenient, not what should be the best practice.

The distance between the racks, as mentioned in the analysis chapter 6a, is not adapted to proper bin removal ergonomics. The reorganization should be paired with a visual management system, further detailed in step 12. One of the main problems this implies is the fact that there seem to be no willingness to change this situation: no one complains, and no one wants to create a standardization of these rules. The workers do not know the importance of good practices at work, for they have not been trained and have always worked this way. Once again, the policy of Bombardier to avoid immediate hazards takes over the principal of avoiding all hazards and long-term issues (such as ergonomics problems which have a slow mode of development).

4.2.11. Visual management Kanban areas

There is currently no visual management applied in the Kanban sorting area. If a warehouse worker were to take over the job, there would be no implicit way of knowing what must be done. There was only one responsible for the process that is well trained therefore some weeks, when that person is on holiday, the deliveries do not get processed on time, as the replacement isn't aware of what he must do. Because the process was not clear for him the process stopped countless times for call to the team coordinator for instructions. Pallets are placed on the ground causing workers to bend constantly to pick pieces up and place bins down, which leads to the worker trying to ignore the heavy bins as much as possible. The delivery to the production area is done in lots of filled pallets so the worker tries to fill up one full pallet before moving to the next one. In general, the work on the bins was not sequential. Empty bins were rearranged in no discernible pattern and for no discernible reason. Workplace clean-up/preparation was interspaced with actual working on the bins. Worker would also stop to do other work if they were so asked.

All these issues are causing a chaotic work environment that can be easily sorted out with the creation of a clear procedure and a series of visual management cues that allow the worker to intuitively understand the process, even when the information received in the training is not very recent in his mind.

4.2.12. Visual management rack area

There is currently no clear way of seeing what is stored in which rack outside of the SAP system. As the workers do not have access to the system there is no way for them to know if they are in front of the correct rack or not. This leads to lost time as the workers try to look for the correct item to pick (to be analyzed together with point 14, the logic used to store the bin on racks). With the creation of a visual management cue system, the worker can be guided to the correct rack location and know the content of the rack via a "rack specific catalogue" that is placed on the rack itself. This will reduce lost time and clarify the process to the workers.

4.2.13. Time schedule for warehouse workers

Warehouse workers currently do not have a set work schedule with set work tasks. While each warehouse worker is responsible for a specific set of tasks there is no set weekly or even daily schedule of when each task must happen. The workers get told by phone call when something needs to be loaded/unloaded/moved from one location to another by the TC. Besides the team coordinator and perhaps the warehouse manager no one is aware of where a specific worker is at any given moment and what kind of work they are doing. This creates a system of firefighting, where the tasks are shared on short term basis and no long-term project can be applied without interruption. Because the TC is the one that assigns the work packages the warehouse manager is often taken out of the loop, which makes overall coordination, KPI management and reporting difficult. The creation of a visual management-based time schedule table can be easily integrated into the daily work and would create a systematic approach to task handling.

4.2.14. Rethinking Kanban bin on rack logic

Currently the Kanban bins are placed on the rack based on the last digit of their article number. While this creates a system of localization, the variation in Bombardier article numbers (numeric or alpha-numeric of various lengths) makes it very difficult to find anything fast. If one looks only by the last digit of the number, one must search through the entire rack before finding the needed bin. There is no sequence in the numbers being placed on the rack and no other way of identifying similar bins. The current system does not guide the eye in any direction towards the needed bin, therefore causes lost time and inefficiency. The logic of the placement of the bins on the racks needs to be rethought in a more user friendly, efficient manner.

The effort to reorganize the racks will be relatively impactful, as each rack must be cleared and then the bins must be reorganized within the location, one by one. Besides the physical move the SAP system needs to be updated if there is inter-rack movement. It will however bring a big improvement in the Kanban picking process, which will compound as the series production starts. The graphic visualization of the grading can be seen in Figure 4.5.

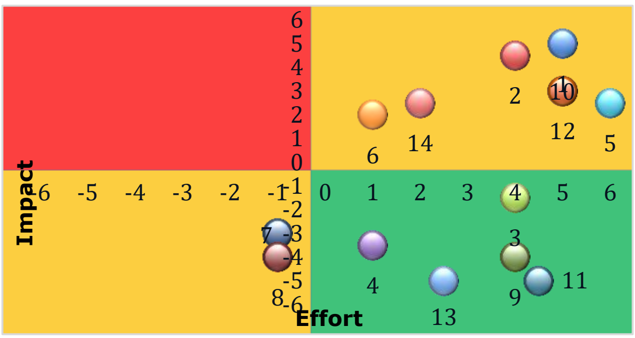


Figure 4.5. Impact effort matrix graph

Table 4.3. Overall efficiency-Traditional improvement

Proposals	Investment priority	Ergonomic efficiency	Training effort	Overall grade
BT company culture	1	1	2	8
Project based versus process-based culture	1	1	2	8
Logistical MPR flow definition	3	3	3	18
Employee morale	4	3	3	21
Logistics policy	4	3	3	21
BT HSE strategy (0 accidents, not 0 long term problems)	3	3	5	22
Managerial capabilities	3	3	1	14
Weight to lift/ergonomics policy creation	3	3	5	22
Workspace reorganization Kanban area	2	4	5	20
Workspace reorganization rack area	2	4	5	20
Visual management Kanban area	5	4	3	25
Visual management rack area	5	4	3	25
Time schedule for warehouse workers	5	3	5	28
Rethinking Kanban bin on rack logic	2	4	5	20

While the impact effort matrix rank solutions against each other there is no absolute preference versus a standard. By applying formula 4.1 the ergonomic impact of each proposal is analyzed and ranked. Based on this Table 4.3 shows the most effective projects to apply, while considering project costs and timing. Based on the overall efficiency calculation, the solutions most recommended can be split into three categories:

1. Quick wins are defined as the implementation of a simple solution to a known issue. The problem is usually limited to one department, the root cause is usually known, and the fix is quick and easy. The projects that fit into this category are:
    - **Employee morale (team building);**
    - **Workplace clean-up and visual management;**
    - **Visual management Kanban area;**
    - **Visual management rack area;**
    - **Time schedule for warehouse workers.**
2. Process improvement is defined as the incremental reduction of defects, cycle time or cost. In these cases, the issue to be analyzed has an unknown cause and no predetermined solutions. The projects that fit into this category are:
    - **Weight/ergonomics policy creation;**
    - **BT HSE strategy (0 accidents, not 0 long term problems).**
3. Process redesign is defined as the overhaul of non-capable existing processes. The process exists, but there is no way to satisfy the requirements of the process even with the help of incremental improvements. The projects that fit into this category are:

- **Changing Kanban bin on rack logic;**
- **Logistics flows policy.**

The current subchapter presented possible classical solutions to the ergonomics issues assessed within Bombardier. With the implementation of workshops, process improvements and visual management, the company can recuperate a lot of the issues that are leading to it is having an unsatisfactory ergonomics level. Before determining which solution should be presented to the company management, an analysis of possible automation and Industry 4.0 solutions to the ergonomic problems will be done. As opposed to the current subchapter, where solutions came in the form of process improvement and training, the following subchapter will focus mostly on tools and machines and how they can be leveraged to increase ergonomic efficiency.

4.3. Automated and Industry 4.0 solutions for improvement

The previous subchapter was focused on explaining the ways in which the problems that Bombardier's production and logistics systems are face with and they could be solved by applying an adequate improvement process (with associate methods and tools). This subchapter will focus on the Automation and Industry 4.0 tools that can be applied (after the development of the investment plan) to reduce the ergonomic impact of the work being done in the analyzed factory.

Belgium is dealing with a series of years in which the number of manufacturing jobs has decreased, most of them being outsourced to lower cost countries (as seen in Figure 4.6 statistics).

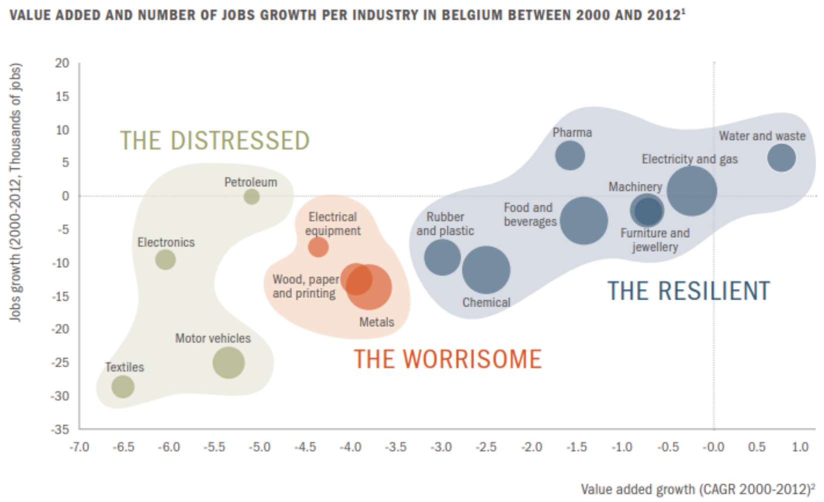


Figure 4.6. The impact of de-industrialization on Belgian industries (Tshidimba et al., 2015)

In this market environment the competitiveness of a company, or a country is based either on a cost advantage, a favorable business context or a differentiating capability. This is the reason why Belgium as a whole, and Bombardier should work on its differentiating strategy by investing in solutions that increase productivity and help create superior products, like the ones provided by automation and Industry 4.0 solution adoption. Solutions like smart resource management and augmented operators can not only help with pure ergonomic issues but can also increase productivity and subsequently lower manufacturing costs (Tshidimba et al., 2015).

The same points, aspects presented in the previous subchapter will be analyzed related to the present proposed improvement perspective.

4.3.1. Lifting of large weights from uncomfortable heights

Problem: The height of the rack is too big for manual picking and the weight of the bins is too big;

Resulting risks:

1. The bins are removed in an unsafe way;
2. Workers climb on the rack to pick pieces and risk injuring themselves.

Possible technical solutions:

"*Vertical parts carousel*: The solution considers a series of bins or trays linked together to create a continuous chain, mounted on an elongated vertical oval track. It is a type of automated storage and retrieval system (ASRS) that revolves until it brings the appropriate bin, tray, or other carrier to the operator. Once the carousel has stopped, its operator can pick the required product from its shelf, thus requiring no movements from the operator's side. This can help reduce the ergonomic strain caused by having to lift items from heights. However, the system is most efficient when placed in an area with vertical accessibility, as standard options have a minimum height of 3 m. While it is possible to find that height in the warehousing area, the production line where the analyzed shelves are placed has a limited available height of 2 m. If the solution were to be chosen, the warehousing solution would have to be rethought" (Mocan and Draghici, 2019a).

"The part-to-picker method uses three organizational elements: a storage area, a picking area, and a material handling system. The automation level of the material handling system may vary, along with the technical solution, but the result of the system is that the products are moved from the storage area and delivered to the picking areas. The picking operator then collects the products after they are delivered to their area and continues to fulfil their jobs. This type of setup requires heavy automation and is usually suited for large warehousing facilities with high SKU picking needs. It can also cause wasted labor because picking operators may find themselves waiting for items to be delivered to their picking location. If the solution were to be chosen a compounded storage area for the manufacturing line would have to be decided to keep the financial investment to a minimum" (Mocan and Draghici, 2019a).

4.3.2. Inconvenient manoeuvring spaces between racks

Problem: The space between racks is not big enough to safely remove bins;

Resulting risks:

1. The bins are removed in an unsafe way;
2. Workers pick the pieces from different bins giving incorrect usage views in SAP.

Possible technical solutions:

"Gliding pallet racks, as visualized in Figure 4.7, are a type of high-density moving pallet shelf storage systems that save space in warehouses by eliminating static forklift aisles and transforming them into a dynamic, mobile storage. This type of tool allows better space usage by facilitating gliding the storage areas to suit ergonomic picking needs better. The movement can be further automated by integrating a package location system that automatically moves the racks to reveal the correct location upon a worker's approach" (Mocan and Draghici, 2019a).

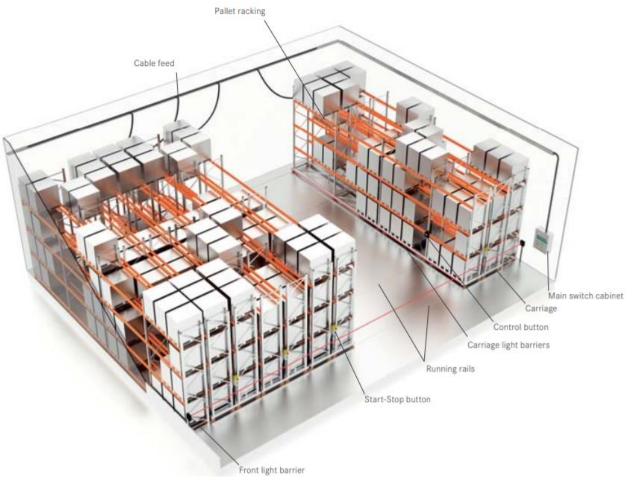


Figure 4.7. STILL sliding rack technical solution[40]

"The automated version might be too big of an investment for the part picking along the production line, but the solution that involves manually moving the racks could be easily implemented and useful. As the analysis investigates automated solutions however, the automated solution will be the one costed in the efficiency table" (Mocan and Draghici, 2019a).

"Autonomous robot carriers (ARC), as visualized in Figure 4.8, are robots that autonomously pick up and drop off carts to any location within warehouses or other locations which have material handling needs. Multiple sensors guide the robot between locations and safety sensors allow it to work alongside people, forklifts, and other material handling equipment. With an average speed of up to 1.5 m/s, the robot can bring the parcels directly to the end user. This solution could provide to be an opportunity to completely remove the storage areas along the production line and have the line feeding occur directly from the warehouse into production, thus reducing

[40] STILL International, https://www.still.co.uk/sliding-racks.0.0.html

the work tasks on the production line and consolidating all of them to a warehouse line feeder" (Mocan and Draghici, 2019a).

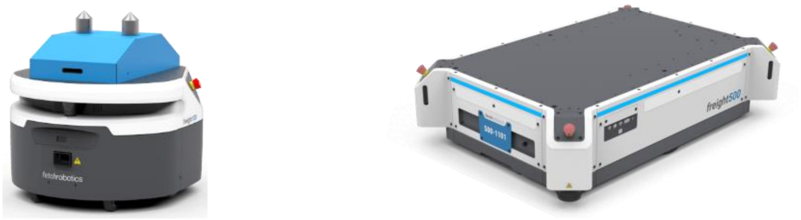


Figure 4.8. Cart and pallet transportation solutions
(solutions from Fetch robotics[41] cite by (Mocan and Draghici, 2019a))

4.3.3. Difficulties in reading labels and unorganized labels

Problem: Labels are hard to read and/or are not organized;
Resulting risks:

1. The wrong item might be picked;
2. Workers waste time trying to find the piece they need.

Possible technical solutions:

"*Pick to light*, as visualized in Figure 4.9, improves order fulfilment performance by reducing the time spent walking between items required by an order, and removing the errors associated with reading paper pick lists. The solution reduces errors by having the location of the manually scanned picking list items light up to guide the picker. This solution is fast to implement and required minimal training, while reducing typical picking errors and eliminating the need for labels altogether" (Mocan and Draghici, 2019a).

Figure 4.9. Pick to light system solutions
(solutions from Atoxgrupe[42]; Lightning Pick[43] cite by (Mocan and Draghici, 2019a))

"*Pick to voice*: Are a hand free, eyes free operation where workers head instructions via a headset and do not have to look down at a part picking list. The voice terminal interacts in real time with the warehouse management system and guides the operator with increased accuracy to the picking point. Companies that

[41] Fetch robotics, https://fetchrobotics.com/
[42] Atoxgroupe, http://www.atoxgrupo.com/website/en/
[43] Lightning Pick, https://lightningpick.com/

provide this service have presented anywhere from 10% to 60% picking improvement as a result (Cassis, 2019)". "In the case of pick-by-light or pick-by-voice options, from a technological standpoint there is no definitive answer as to which is better. It is highly dependent on the type of work being done in the warehouse and the overall business requirements. Pick-to-light also makes sense in warehouses or distribution centres that have lower SKU counts, mostly because a smaller environment helps reduce the costs. Since the price of pick-to-light is directly tied to the number of SKUs needed to be picked (because the lights must be physically installed on every rack and pick location) the smaller environment thus leads to lower costs (Stackpole, 2013)" (Mocan and Draghici, 2019a).

"Pick by vision: The most advanced version of semi-automated picking leverages the usage of augmented reality to reduce picking errors by overlaying graphical images over worker's line of vision and enhancing objects with additional information in real time. As providers of such solutions have mentioned, this solution also offers the possibility to train employees and to enhance automated warehouse planning (Glockner et al., 2014; deloitte, 2016)". "The technology is easily scalable and allows quick picking of items with almost no chance of mistake and with no requirements for warehouse relocation or current setup changes, as visualized in Figure 4.10" (Mocan and Draghici, 2019a).

Figure 4.10. Bastian solutions AR picking technology[44] (Mocan and Draghici, 2019a)

"As with all technologies presented so far there is a stark trade-off between implementing the solution by rack or by picker. Given the current setup of the production line adjacent warehousing area (many small groups of independent warehousing spaces, with large distances in between), the balance would tip towards implementing solutions by picker if the setup is not changed. If the setup is changed and the storage facilities are removed from the production line, then the recommendation would be to automate the racking. As further detailed in Table 4.4, the advantages of each system in terms of technical capabilities are made along with accompanying recommendations" (Mocan and Draghici, 2019a).

[44]Bastian solutions, Innovative hands-free order picking, https://www.bastiansolutions.com/solutions/service/supply-chain-software/augmented-reality-picking-wearable-technology/

Table 4.4. Technological capabilities (Mocan and Draghici, 2019a)

	Gliding pallet racks	Autonomous robot carriers	Vertical parts carousel	Part to picker	Pick-by-Vision	Pick-by-Voice	Pick-by-Light	Manual picking
Flexible to use and expand	✓	✓	✓	✓	✓	✓	X	✓
Location-independent use	X	✓	X	X	✓	✓	X	✓
Location determination	✓	✓	✓	X	✓	✓	X	X
Hands-free	-	-	-	-	✓	✓	✓	X
Strict visual and mobile process guidance	X	✓	X	X	✓	X	X	X
Real-time verification	X	X	X	✓	✓	X	X	X
Zero fatigue	✓	✓	✓	✓	✓	X	✓	X
Error rate virtually zero	X	✓	X	✓	✓	X	X	X
Integrated barcode scanner	✓	✓	✓	✓	✓	X	X	✓
Intuitive operation	X	✓	X	✓	✓	X	✓	X
Seamless integration	✓	✓	✓	✓	✓	✓	X	✓
Usable in all areas of order picking	X	✓	X	✓	✓	X	X	✓
Serial number scanning	✓	✓	✓	✓	✓	X	X	X
Automatic transport jobs	X	✓	X	✓	✓	X	X	X
Permanent inventory	X	X	X	✓	✓	✓	X	X

4.3.4. Articles not placed in the correct storage location

Problem: All articles that do not go in the PPF flow are brought to the Kanban area. These are not only Kanban pieces, but also DOL and D20 articles, which pollute the Kanban flow, as they cannot visually be differentiated from other flows. The issue is discovered when the articles need to be sorted and the worker realizes that SAP does not have the possibility to release a sticker for the article in the bin. If the flow of the piece is D20 and location is set to PM40 then the piece must be announced to the Team leader and await managerial decision. The team leader must alert the MRP controller to change the flow and the process goes to a standstill. If the piece is PPF then it is brought back to the goods reception area and awaits sorting. There is no process-imposed way to keep track of the articles not yet sorted.

Resulting risks:

1. The process cannot be fulfilled in all conditions without outside help;
2. Backlog of articles not yet sorted is not trackable.

Possible technical solutions:

"Radio-Frequency Identification (RFID) is a powerful technology that offers businesses increased supply chain and inventory visibility for greater operational efficiency, with reduced inventory and out of stocks" (Attaran, 2007). Thus, "the automation of planning and coordinating of a company's supply chain, reduces costs in areas such as inventory, distribution, and logistics delays. As opposed to barcodes, which can store around 1.1 bytes of data, an RFID can store around 128 kb, enough to provide information about the product's characteristics, its storage location, and its process flow. "This information can be used to improve inventory management at the retail store and along the supply chain" (Attaran, 2007).

Operationally RFID allows data from a tag attached to a pallet, case, or individual product to be captured by a reader device, which can determine its location and characteristics at a specific time, as shown in Figure 4.11. The application of this technology will reduce mis-picking and misallocation of goods with the inventory reduction as final goal (Niederman et al., 2007).

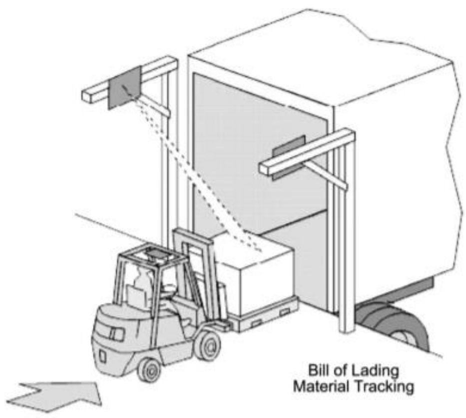


Figure 4.11. RFID tags identifying a pallet of trade items (Attaran, 2007)

As such RFID can be used in the product distribution within Bombardier for receiving and check in. An RFID portal, as specified in Figure 4.11, can be mounted at the entrance of the distribution center for the purpose of reading tags and automatically updating inventory quantities and signaling which pieces are delivered in Kanban flow versus which pieces are not. This process would free-up the labor involved in checking the articles, printing the stickers, reviewing checklists, and making comparisons between incoming product lists and the purchase order. The RFID enabled location check would remove the incorrect articles stored in the Kanban processing area and reduce the need for put away drivers and operators to search for loads at specific locations. "Dropped-off loads will be automatically located, and clerks will be freed from conducting any more product scans or verification procedures" (Angeles, 2005).

4.3.5. Articles delivered with wrongly mentioned article number

Problem: Article delivered without BT article number comprising of:

- Supplier delivering pieces ordered by BT without a valid article number;
- Supplier delivering pieces articles with the article drawing number instead of the article number;
- Supplier delivering pieces marked with the supplier's own article number.

Resulting risks:

1. This causes confusion as there is no way for a worker to check the accuracy of a delivery via anything other than a BT specific article number.
2. The physical stock and computer mentioned stock are not in line

Possible technical solutions:

As mentioned in the previous paragraph, RFID has many applications within the supply chain, one of them being the automatic update of inventory levels based on RFID signals. The confusion caused by a lack of mentioned article number in the physical delivery can be removed by replacing the request to mark articles with an article number with requesting to mark it with an RFID tag. "The incoming merchandise will be matched against the correct purchase order and discrepancies will be identified much more easily" (Angeles, 2005; Attaran, 2007).

"The added benefit of this method is that in the course of fulfilling orders, pickers will be directed to the correct picking locations so that they can retrieve the ordered cases or items and place them on the appropriate material-handling equipment. Once the cases or items are picked up, the system will automatically verify that the correct products in the correct quantities have been removed and the inventory files will also be automatically updated because of that action. Pickers will be freed from having to manually update inventory databases. Alerts will be activated if pickers remove inappropriate quantities of cases or items from inventory" (Angeles, 2005; Attaran, 2007).

4.3.6. Article information in SAP not completed

Problem: Article description in SAP does not like the delivered article's appearance: the warehouse workers have issues comprehending the article that gets delivered if it doesn't look like the article description specified in SAP, and don't process it for fear of wrong delivery. The article is set aside until confirmation from the team coordinator about appropriate action. The correction of an article description in SAP requires a Change Request (CR) and subsequent actions that can take a few months for approval, therefore the confusion can reappear for all deliveries throughout this period.

Resulting risks:

1. Backlog in the articles getting processed
2. Risk of misidentification of pieces

Possible technical solutions:

As most warehouse workers do not have the technical knowledge to read the 2D drawings stored in SAP and be able to compare the delivered article with the ordered one, another solution must be found. Additive manufacturing could prove to be the solution.

Additive manufacturing (AM) is the "process of joining materials to make objects from 3D model data, usually layer upon layer" (ASTM, 2012). It also goes by the name of rapid manufacturing (Levy et al., 2003) or rapid prototyping (Kruth et al., 1998). It manufactures pieces by adding materials to create a final shape, thus distinguishing itself from conventional manufacturing techniques which work by removing material from a larger stock of raw product (such as is the case for stamping or machining). Additive manufacturing by design makes efficient use of raw materials and, depending on the quality of the printer, provides very good geometric likeness. While AM technology can be used extensively in the supply chain to reduce lead times, setup times and changeover times, leading to a lean supply chain with low cost (Tuck et al., 2007; 2010; Huang et al., 2013) the proposal for Bombardier is to use the technology for its prototyping capabilities.

Having a physical or VR prototype stock for mid volume mid-size pieces that can be used as an "example piece check" would reduce doubts related to descriptions and mis-storage of pieces.

Combining physical and AR/VR technology could also prove to be a solution that by-passes the cost of purchasing and storing a 3D printer capable of creating large dimension pieces common for the railway industry. As a large size 3D printer can cost upwards of €220.000 an analysis should first be done on article level to define the financial optimum of which pieces can be prototyped and which pieces should be available via VR technology. As the discussion is referring to pieces in the Kanban flow versus D20 or DOL, maximum dimensions would not exceed 100 mm on any axis. This size is considered when making the cost recommendations. While the prototyping is suggested for ease of supply chain sorting and storing, the technology could first and foremost be used by engineers to improve the product designs and afterwards have the secondary capability to help supply chain workers in their tasks.

4.3.7. Articles not placed in the correct storage location

Problem: Received quantity too high in comparison with bin quantity: the lot size of a bin is defined in SAP, but the minimum order quantity of suppliers is not always in line with this quantity. Since some of the suppliers do not deliver in bins, but in their own packaging, this causes either extra sorting/storage capacity to be needed in the warehouse in Bombardier or extra articles to be stored in bins. Neither of these situations can be easily reflected in SAP and require a lot of rework from the MRP controller and the warehouse workers and negotiations that must take place between the buyer and the supplier regarding the MOQ.

Resulting risks:

1. Stock discrepancies between the SAP system information physical realities.
2. Manual rework expected from warehouse workers, causing delays and backlog.

Possible technical solutions:

IoT packaging: So far packaging has been viewed as extra overhead, meaning that the cost is added to the cost of the goods being packaged, but consumers are not too keen on paying for it. Because of this, companies have tried to reduce packaging cost through various methodologies, such as Wal-Mart, who unveiled a "Packaging Scorecard" program in 2006 to improve packaging, reduce emissions and save energy (Wal-Mart Unveils "Packaging Scorecard to Suppliers", 2006). Ericsson's packaging engineers also created a calculation model that can calculate the most effective packaging solution based on the total packaging cost (De La Motte and Persson, 2009). This mentality can change together with the Industry 4.0 solution of having packaging as a tool, instead of a hindrance. Instead of using Kanban bins and SAP based Kanban signals to determine stock levels and reorder points have the packaging itself do the work with the help of integrated RFID technology connected via internal emitting sensors to the local SAP system and via external emitting modems to the supplier's ERP system. This would support during the project start-up phase by reducing the need for manual registration of goods, manual removal of packaging and manual stock counting. With the development of roll to roll gravure (Jung et al., 2014), a technique that allows the seamless integration of sensing capabilities via Near-Field Communication (NFC) into the packaging material itself, makes the need for additional RFID tagging also disappear and allows the packaging material itself to provide the needed electronic sensor connections to the processing software, thus increasing the roles of the packaging, visualized in Figure 4.12.

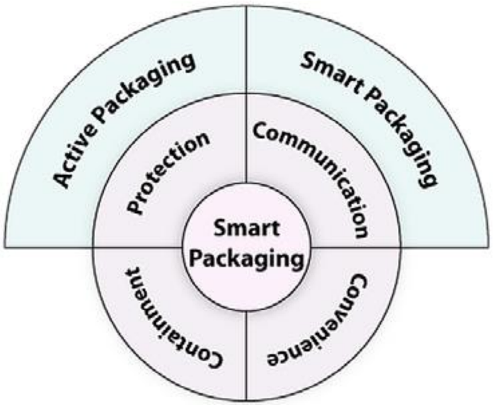


Figure 4.12. The roles of packaging (Maksimovic et al., 2015)

This can reduce costs both related to RFID tag infrastructure as well as for disposable packaging in the long term but is currently not a good investment for low volume processing companies, such as Bombardier, given the high cost of the printing machines.

4.3.8. Process flow and article type definition not understood by the people in the process

Problem: The workers do not understand the full process ramifications. The worker during the first audit session did not understand the process and the full 1-hour worth of work observed had to be redone later. Since the process was not clear for him the process stopped countless times for call to the team coordinator for instructions. The size of the determined storage bin in SAP is also not accurate 100% of the time, as the MRP controller does not always have a drawing in SAP from which he can measure the size of the pieces and how they fit in the bins.

Resulting risks:

1. The bins must be changed mid process to fit the articles being delivered causing backlogs in the process;
2. Workers revert to the TC every time there is a variation in the standard process, causing the process to stop and facilitating delays.

Possible technical solutions: Augmented reality (AR) and virtual reality (VR) training

The reason AR technology could be used to make environments more productive and interactive is related to its capability of engaging in new ways with the surrounding environment (Lee, 2012). Environment interactivity is the main way through which AR training takes place. The simplicity of the experience leads learners to accept the skills that they are being taught. The means of utilizing AR also contextualizes the environment, providing more gainful content for the experience. The technology's capability to provide information at the right time and place also increases the effectiveness and efficiency of the, leading to the conclusion that on-site learning experiences are enhanced and better utilized. VR and AR technologies can be used to train workers in assembly tasks and industrial maintenance. "VR allows the user to manipulate objects without the use of the real objects and hence offers benefits in applications such as manufacturing, where operators can be trained to assemble a product before the product has been physically manufactured. AR however improves performance time as the training is conducted on the real objects" (Boud et al., 1999; Schwald and De Laval, 2003).

According to Andt Trainor, Walmart's senior director of Walmart U.S. Academies, a company that uses VR to train its employees, "*The great thing about VR is its ability to make learning experiential, […] We've also seen that VR training boosts confidence and retention while improving test scores 10 to 15 percent – even those associates who simply watched others experience the training saw the same retention boosts*" (Incao, 2018). Ford uses VR technology to examine the entire exterior and interior of a car design, as well as to drill right down to how an element looks, such as a dashboard or upholstery with last year marking more than 135,000 examined details, on 193 virtual vehicle prototypes (King, 2014). Companies such as Swisslog, "are currently developing a SynQ Virtual Reality (VR) Training Manager which allows end users and trainers to learn and enhance picking process skills in a virtual environment at workstations that enables both regular retraining of staff for continuous improvement of warehouse picking without impacting on live operations in a busy warehouse”[45].

4.4. Conclusions

For studied aspects for improvement have been provided solutions from the classical perspective of Lean Six Sigma methods and tools and from the Industry 4.0 technologies. In synthesis, Table 4.5 “gathers the tools so far presented and ranks them based on their overall ergonomic efficiency, training effort and investment impact calculated as presented in formula (4.1)” (Mocan and Draghici, 2019a).

Table 4.5. Overall efficiency-Automation and Industry 4.0 (Mocan and Draghici, 2019a)

Topic	Technology	Investment	Ergonomic efficiency	Training effort	Overall grade
Large weights lifted from uncomfortable heights	Vertical parts carousel	1	3	5	16
Small/limited maneuvering spaces for workers between racks	Gliding pallet racks	1	3	4	14
Hard to read/ unorganized labels	Pick by light	3	3	5	22
	Pick by voice	3	3	4	20
	Pick by sight	2	3	5	19
	Part to picker	1	3	4	14
Articles not placed in the correct storage location	RFID	1	3	3	12
Articles delivered with wrongly mentioned article number					
Article information in SAP not completed	Additive manufacturing	1	2	5	15
Articles not placed in the correct storage location	IoT Packaging	1	2	4	13
Process flow and article type definition not understood by the people in the process	AR/VR Training	1	4	4	15

[45] Retrieved from: https://www.swisslog.com/en-sg/industry-40/big-data-intelligent-services

Due to the high cost of the tools presented, the overall grades calculated are lower than the ones related to using traditional improvement methods. "Industry 4.0 tools do not provide a fix all solution that many would hope it would. The main draw of smart devices (or consolidated smart warehouses is that they offer process automation and interconnectivity. Smart Warehouses work to eliminate the use of manual labor and input wherever possible, thus reducing costs and manpower needs. The concept of smart devices is that they open the possibility for more data mining and process optimization (3PL Central, 2014)" (Mocan and Draghici, 2019a).

"But process automation cannot be applied without stability in the already existent processes. The additional investment in smart technology does not bring an equal improvement in business activities if those activities were not stable in the first place. Because of this, merely using smart devices to gather more data while not knowing how to use that data to improve the process and train the people is suboptimal. As noticed during the Bombardier audit, the company did not lack in formal process flows and training, but it did lack in employee understanding of the issues, informed managerial guidance, and risk response structure. The constant firefighting responses of the company did not allow for stable processes and countered the continuous improvement mentality implemented just a few years earlier" (Mocan and Draghici, 2019a).

"While the presently done analysis and improvement points recommended are valid in the context of the study, the results from the suggested improvements would be punctual to the Belgium Bombardier entity" (Mocan and Draghici, 2019a). Furthermore, the suggested improvements would bring the company at a level in which processes would be stable enough to allow the implementation of Industry 4.0 solutions, but no further." Because of this, a general approach to ergonomic problem solving needs to be developed to open access to ergonomics problem solving outside of the studied case" (Mocan and Draghici, 2019a).

As has been shown throughout the chapter, Industry 4.0 solutions are feasible to be seamlessly implemented to improve ergonomic efficiency of the work being done, but they cannot be implemented before process stabilization. The tools used for analysis (Ishikawa, 5 Why, Process mapping) are Lean Six Sigma tools developed for process improvement with a focus on quality and not ergonomics, therefore might not offer the most ergonomically efficient solution.

"To be able to improve ergonomics, managers need to easily grasp what their current ergonomic state is, what areas to focus their effort on improving and how to track the improvement process as it goes along" (Mocan and Draghici, 2019a). Furthermore, to support in this endeavor, in the next chapter, a standardized ergonomics improvement model will be presented that could help management guide themselves through an iterative ergonomic improvement process without external ergonomic specialist help. The model will try to leverage existing managerial and improvement techniques (such as the usage of Lean Six Sigma process improvement tools) to create a relatively familiar analytical environment that would help create buy in from the necessary decision functions.

5. A THEORETICAL APPROACH FOR DESIGNING AN ERGONOMICS MATURITY MODEL AND THE RELATED ASSESSMENT TOOL

As touched upon in Chapter 1, the logistical sector is currently undergoing a radical change. Along with the exponential growth of online shopping and customer requirements for faster delivery dates the strain on the supply chain is heavily felt. As consumers constantly become more connected, the warehouse environment has felt the need to evolve to keep up with this behavior. One of the ways this has happened has been through the beginning of wearable computers adoption. Wearable computers can capture information about the wearer that can be used to optimize the picking process and increase worker viability.

However, as presented in Chapter 4, the application of Industry 4.0 technology in warehouses where processes are not well defined and ergonomics is not monitored with a view on improvement, bring little advantage. The issues of the process cannot be solved by the investment in new technology, as it ends up being underused and misunderstood. To use Industry 4.0 principles to its full advantage, a strong procedural basis needs to be present.

The purpose of this chapter is to focus on a step-by-step approach to the creation of an ergonomics strategy improvement model that can be applied for furthering management's understanding of the importance of the topic, as well as offering them concrete and direct tools for applying ergonomics in their environment.

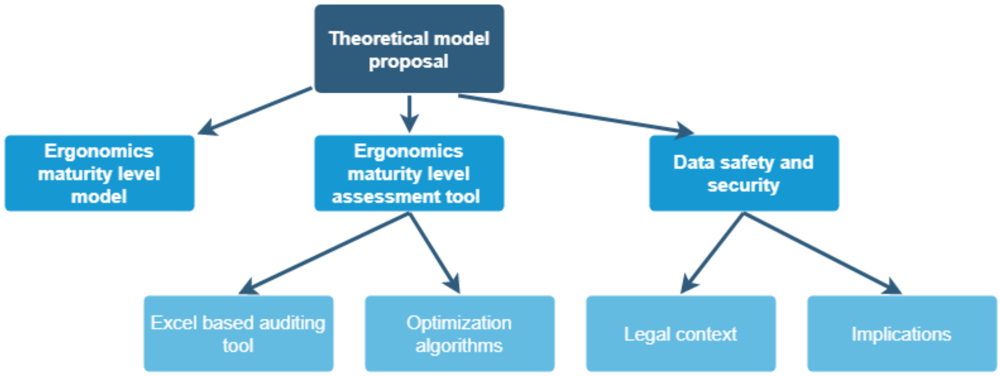


Figure 5.1. Chapter structure (the conceptual map)

In this chapter therefore, a maturity model is proposed through which companies can assess the level they are currently at and show what items they still must fulfil to achieve the highest level of performance. In direct link to the model an assessment tool is presented that offers users a concrete document that they can apply to guide their improvement path. The tool firstly provides questions with which the ergonomic application processes in one's company can be graded. Secondly, the tool also presents the sequence of improvement most easy to follow by the company to bring their ergonomic improvements to the topmost level. The last part of the chapter will present the legal framework surrounding the application of wearable computers that measure user data. The technical and theoretical feasibility of this technology notwithstanding, the application of it in a live factory environment is predicated on its described legality and the ease with which the data can be used by the company to improve its processes.

The chapter will end with conclusions regarding the applicability and usability of the developed model and tool as well as the changes that need to be done from a legislative point of view to allow the application of Industry 4.0 wearable technologies in an industrial context.

5.1. Ergonomics application maturity level

The research presented in this subchapter was developed between February 2018 and June 2019 and the results were disseminated through two articles (Mocan and Draghici, 2018b; Mocan and Draghici, 2019c).

New generation, connected warehouses must be able to bring real time visibility on stocks, people and transactions over a varying level of industries. From consumer goods to automotive, to food processing and healthcare, all customers are expecting high response rates, low response times and correct on time deliveries every time. Warehouse professionals are therefore now tasked with choosing how to upgrade their warehouse in a way that boosts productivity, reduces transportation costs and increases expediting shipments. As can be seen in Figure 5.1 the logistics sectors are transitioning to "best-of-breed" warehouse management systems that automate as many processes as possible. Mentioned previously in Chapter 3, RFID is used to increase real time inventory visibility, while barcode scanning is planned to increase with 67% over the next 5 years (Zebra, 2016). Big data is used to analyze future stock outs and react accordingly. Tablets will replace the need for pen paper, giving full real time access to the warehouse management systems. IoT technology will be used to interconnect machines and retrieve real time analytics, leading to a 6% increase in load optimization in the next few years. These technologies also create the possibility of real-time workforce interaction while increasing route tracking precision throughout the supply chain.

Besides presenting the investments being done in the logistics industry, Figure 5.2 brings to attention the wide scope of tools being used in the warehousing environment with no one system being the clear leader in the "investment run". This is caused by two main issues:

1. The warehouse environment is broad and eclectic, where the size of operations, the assortment of goods being stored and the industry it operates in create different environments that require specific solution; thusly, it does not benefit from one single type of application or process as a fix-all solution. By this logic it is normal to see such a broad

investment panel, as each individual type of warehouse is executing its own trial and error exercise, until the most appropriate tool(s) or combination thereof are found and given sole investment focus.

2. There is a general lack of industry wide strategy or roadmap regarding the Industry 4.0 disruption, the warehousing industry being no different. As people are trying to understand what the defining features of the Industry 4.0 paradigm are and the way in which they can be used to benefit the logistical sector, the wide range of investments is caused by a lack of understanding of each tool's purpose and capability. So far, no strategy has become the leader of the pack, leaving users no decisional framework that allowed them to understand what works for them.

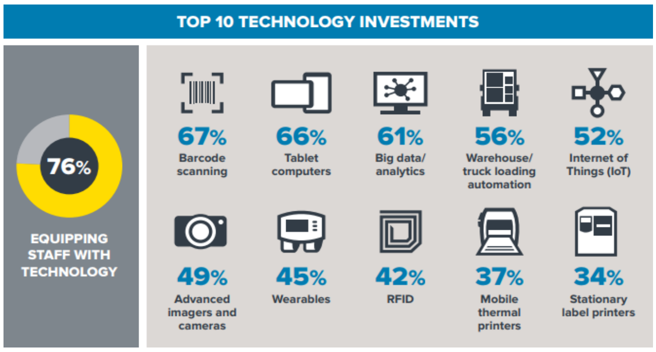


Figure 5.2. Top 10 technologies investment (Zebra, 2016)

Both issues are typical for ergonomics design, and the way we learn about how to improve our working environment. As it has been presented in previous works (Karwowski, 2005; Salvendy, 2012), ergonomics theory is developed in two separate types of approaches. The theoretical basis of ergonomics can be developed because of the practice of ergonomics. This is a structured trial and error methodology, in which from the practiced activity, the theoretical information is extracted and standardized (Figure 5.3).

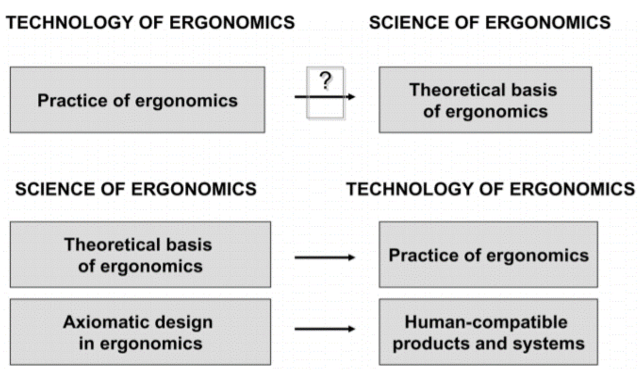


Figure 5.3. Science technology and design in ergonomics (Salvendy, 2012)

The second approach is forming a theoretical basis of ergonomics based on axiomatic design that leads to the practice of ergonomics. Axiomatic design is one of the two ways in which it is possible to deal with design and complexity (the other being algorithmic design). While algorithmic approach is useful on the lower levels of a process, as "it is founded on the notion that the best way of advancing a given field is to understand the process by following the best practice, it is difficult to implement it in large scale situations. And that's where axiomatic design comes into play. The axiomatic approach says that there are general principles that govern the underlying behavior of the system being investigated. Thus, they create new abstract concepts and help identify the common elements that are present in all good designs" (Suh, 2003).

"The Axiomatic Design theory has been used, among other things to (Suh, 2003)[46]:

1. To provide a systematic way of designing products and large systems;
2. To make human designers more creative;
3. To reduce the random search process;
4. To minimize the iterative trial-and-error process;
5. To determine the best designs among those proposed."

The reason why it is preferred is because "when large systems are designed and developed by traditional means, the cost of development is very high while the reliability remains questionable" (Suh, 2003). The axiomatic approach in ergonomics, presented graphically in Figure 5.4, implies the translation of customer requirements into functional ones. These functional requirements get mapped into the physical domain by appraising the types of products that can satisfy said requirements. Finally, the process is built around the compatible physical products that satisfy the customer need. It is a sturdy process which allows efficient and effective design of systems, so much so that is has been lauded as the way to go forward in an industry landscape that is increasingly more complex (Helander and Lin, 2002; Suh, 2007).

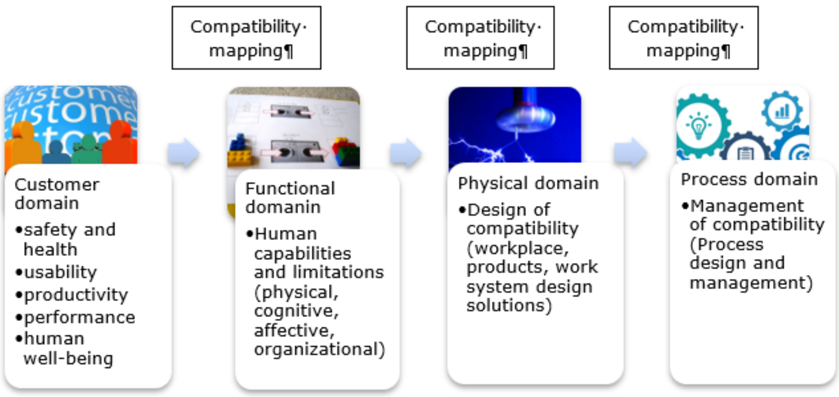


Figure 5.4. The four domains in axiomatic design ergonomics

[46] Retrieved from: http://mspde.usc.edu/inspiring/resource/bioengineering/Namsuh.pdf

The issue however with using this method from the very beginning is the fact that it targets ergonomic process and product design directly. As presented in Chapter 1 the level of application of ergonomics in most warehouses is that of legal compliance and nothing more. The "tips and tricks" article and the "safety pamphlet" are two of the most used techniques of ergonomics training and improvement that exist in this environment. While this is not relegated to the warehouse industry alone, there is a large amount of warehouse managing personnel that are dealing with ergonomic illiteracy (Karwowski, 2005). While this is dangerous in any circumstance, the warehouse environment, as opposed to office work, can prove more dangerous when a lack of ergonomics design is applied.

If ergonomics is going to be structurally applied within the warehouse environment there must be an overhaul of existing mentalities. The reason for this is that, as presented by Karwowski (2005), ergonomics is dealing with an uphill battle. It lacks a distinct identity and credibility among other sciences due to its wide-ranging subject matters. Because of this it is very difficult to be simplified as a concept, leading to a poor application funding by managers and decision makers. This is caused by the limited understanding they have of the topic and the benefits it can bring to the socio-economic improvement of society in general. Because of this, a vicious circle is created that leads to a very limited professional educational base. It is up to researchers to find a way out of this vicious circle as the critical mass needed to shift the focus on the topic cannot come from managers that do not comprehend the issue. A clear system must be put in place to educate management authorities on the benefit of ergonomics and the way in which it can be applied in their environments. This is a priority in the current Industry 4.0 environment as the fast advance of technology limits the possibility for applying a purely experienced based trial and error methodology. The technological turnover time will decrease so much that just "feeling it out" and seeing what works will lead to project delay and ultimate failure, cost overrun and unhappy customers.

The industry is increasing its competitive demands. Implicitly, all warehouses must learn to deal with shorter lead times, lower costs, and higher satisfaction of customers. That is why it is imperative that a framework gets created to help them navigate their new environment.

The exiting literature on the topic, while far reaching, does not provide an easy starting point for a working professional. There is no clear starting point that can lead to a straight-line learning path. Therefore, a lot of non-practitioners might find the task daunting and time consuming. This helps create a wall between theoretical, academic knowledge and applied practical one. This does not bring a benefit to either party, therefore the desire of the author of this thesis is to create a methodology that sacrifices as little as possible from the complexity of ergonomics research topics while also providing a clear learning and application path for decision makers that are interested in finding out more about the topic. The topics further presented will be applied on an auditing tool very similar to the already existing "Global Materials Management Operational Guidelines/Logistical Evaluation" (MMOG/LE) audit. As presented in the previous chapter the Global Materials Management Operational

Guidelines/Logistical Evaluation is a supplier self-assessment and continuous improvement tool that improves materials management efficiency and accuracy while reducing costs from errors and waste. It is the global standards for supply chain management processes that provide industry best practices. It is intended to establish a common definition of materials practices to facilitate effective communication between trading partners"[47].

The purpose of the strategy is to increase managerial understanding of ergonomic aspects in their field, by using a widely spread auditing tool as the backbone of the endeavors. This will lead to a more easily understood improvement process. This methodology will remove the initial fear of beginning the endeavors, by presenting the analysis in a more familiar process and by reducing the weight of the pure theoretical aspects of the study as much as possible. Focusing first on applicability, the new practitioner can gain an understanding of the topic and a quick ability to apply the knowledge learned. After a degree of comfort is built with the topic at hand the purpose is to afterwards turn each manager into a willing developer of ergonomic strategy and theory within their own field. This will facilitate the creation of academic-business relationships that can benefit both sides of the discussion and help reduce the current cliff between the knowledge base in the two fields.

The first step in the analysis is the understanding of the level of current ergonomic development within the company. To these means the process tasks of the company are split in three areas as shown in Figure 5.5.

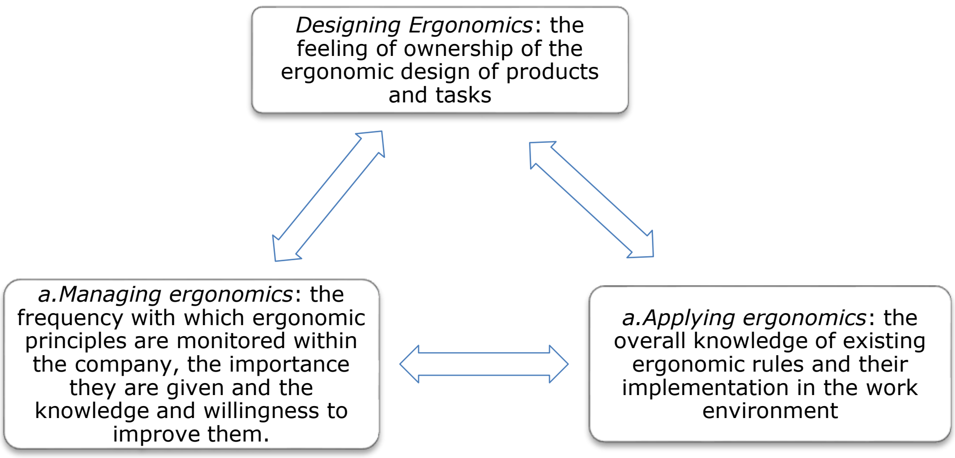


Figure 5.5 The three areas of ergonomics

The three steps are interrelated. We cannot apply something that is not designed, and in turn we cannot manage the application of something that does not exist. While there is an initial sequence in the process (i.e. first we design then we

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[47] AIAG, Automotive Industry Action Group, Retrieved from: https://www.aiag.org/staticcontent/files/Supply-Chain-Flyer-1.pdf

apply then we manage), a functional ergonomic strategy has balance out all three activities to thrive. The level of complexity at which a company develops these three steps is determined by the ergonomics maturity level that the company possesses. The maturity level can be split into four stages, as shown in the Figure 5.6.

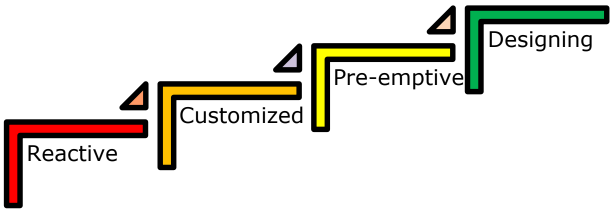

Figure 5.6. The four stages of ergonomic maturity

The reactive phase - The lowest maturity phase in the assessment, the reactive phase can be described as only following the letter of the law. Once a problem occurs the direct risk are identified, the solution put in place and that kind of problem will not repeat again. The analysis is done with keeping in line to the letter of the law, but no extra effort is added, no standardized analysis is put in place and no structural process is followed or defined to make sure that similar issues to not occur in the same way.

The customized phase - The second maturity phase can be described as reducing the ergonomic issues by putting the adequate person in the right job. Before the activity is being manned an analysis of the job and the existent personnel is performed. The allocation of personnel to the task is done based on standardized best fit models, where the person is fitted to the job. The allocation process is structural, but not fool proof, as there will never be 100% fit to the job available to any of the workers. This reduces some of the injuries that appear in the environment but does not fully eliminate them.

The pre-emptive phase - The third maturity phase can be described as trying to fit the job to the person. The work environment is modified after structural injury and workstation-worker interaction analysis. The existing work areas are modified in accordance to models that minimize work injuries and overall improve the working environment. The process is structured, the analyzes defined and implemented regularly, the process improvement constantly taking ergonomics into consideration. "When you consider that around 60% of the factory payroll and indirect labor is involved with materials handling, you can certainly improve productivity by arranging departments in a good way" (Ettinger, 2015).

The designing phase - The last and highest maturity phase implies creating the working environment with ergonomics in mind. Instead of trying to fit the person to the job, or to modify the work environment to suit the person, the work environment is specifically created with the worker in mind. Workstations strive to be personalized, workflows consider worker capabilities and all possible manner of supporting machinery is implemented or possible to be implemented. Ergonomics has not been a prime plant design consideration for many industries in the past, but nowadays, it should make sense that "a design based on the premise that everything in a workstation should be within reach of the operator is the most efficient use of the floor area, but also the most efficient use of the people"[48] (Stone, 2014). The plant should be designed around the workers and not the other way around, reducing extra handling and unnecessary movements (Ettinger, 2015).

The characteristics analyzed to assess the level the company is at are presented in Table 5.1. If no characteristics are present at all, the company is considered reactive. All characteristics must be present in the reactive phase for the company to advance to the next stage - customized. If the company has all "customized" specific characteristics fulfilled but is missing one or more "reactive" specific characteristics, then the company is labelled "reactive".

Table 5.1. Ergonomic characteristics for each development level

Ergonomic characteristics	**Ergonomics Development Level**			
	Reactive	Customized	Pre-emptive	Designing
Standardized injury assessment	x	x	x	x
Standardized injury assessment repository	x	x	x	x
Standardized injury assessment KPIs	x	x	x	x
Standardized return to work process	x	x	x	x
Standardized return to work metrics	x	x	x	x
Standard job-related ergonomic training		x	x	x
Standardized job-related ergonomic knowledge assessment		x	x	x
Standardized job-related ergonomic knowledge assessment KPIs		x	x	x
Standardized job matching analysis		x	x	x
Standardized physical demands analysis		x	x	x
Standardized functional capacity evaluation		x	x	x
Standardized functional capacity evaluation testing interval			x	x
Standardized risk assessment procedure			x	x
Standardized risk assessment repository			x	x

[48] Retrieved from: https://www.thomasnet.com/insights/imt/2014/09/18/10-simple-warehouse-safety-hacks/

Standardized risk assessment KPIs			x	x
Standardized risk elimination tools			x	x
In-company product design guidelines				x
In company warehouse process design guidelines				x
Standardized design gate review processes				x
Clearances and reach distances measurements of existing workforce				x
Force requirements of process execution				x
Continuous improvement in ergonomic aspects				x
Managerial incentive for ergonomic design implementation				x
Standardized participative ergonomics educational process				x
Ergonomic guideline periodical review				x

For a company to be able to climb up the ladder of ergonomic development the first step is to assess the current level of implementation that the company is at. The assessment of said level can be done with the help of an Ergonomics Development Level Assessment Sheet as created by the author and that can be found in Annex 3. This assessment sheet should be filled in by an ergonomics specialist after auditing the entirety of the factory and discussing with both the workers directly involved in the process as well as the company upper management and facility designing departments (if any) or responsible.

The reason for this is related to the fact that, often in large companies not all departments are on the same level. There is a mismatch between the work being done on the shop floor and the work being done in the upper echelons of management, therefore in order to make sure that everyone is on the same level of preparation, it is important to separate the functions from one another. If one is to optimize the overall ergonomic perception within a company one first must make sure that the individual processes are all aligned on the same level and then bring them all together into a higher level of performance.

The audit does not judge the practical solution for the characteristics assessed, only its presence and usage. Each company is free to fulfil the requirements in any practical way that conforms to their existing processes and there should be no bias on the part of the assessors towards a practical solution over another.

5.2. Proposed analysis tool

As a result of the theoretical concepts developed above, the Ergonomics Development Level Assessment Sheet should be filled-in to assess the company's ergonomic level. The following paragraphs will explain the proposed analysis tool and the benefits it brings. The Excel based tool contains 4 sheets. A visual presentation of the sheets is included in Annex 6.

5.2.1. The Excel based auditing tool

The first sheet contains the questionnaire. As one cannot improve what is not measured, a series of 43 questions separated in 5 chapters and 11 subchapters are meant to serve as the backbone of the Ergonomics maturity level Audit.

The 16 columns of the audit contain the following information:

- **Chapter / Subchapter**: The cells in this column inform about the split between the chapters of topics;
- **Requirement / Criterion No**: The cells in this column link the requirements to a unique code that afterwards will be used in the score calculations;
- **Weight**: The cells in this column specify the weight of the question. The questions have 3 possible weight categories. Design: 3 points; Apply: 2 points, Manage: 3 points;
- **Requirement / Criterion**: The cells in this column contain the text of the requirement;
- **Compliance**: The cells in this column mark if the compliance to the requirement is confirmed or not;
- **Current State and Supporting Evidence**: The cells in this column "should be used to record any information regarding the assessment response. For example, the assessor could record details of any objective evidence, the reason for a non-compliance, or any other information that might assist in understanding the operating conditions at the time of the assessment"[49];
- **Gap / Continual Improvement**: The cells in this column "should be used to record what the organization needs to do to become compliant or if the organization does not intend to become compliant for this criterion;
- **Action Plan**: The cells in this column should be used in conjunction with the Gap / Continuous Improvement to record the steps that will be taken to become compliant;
- **Target Date**: The cells in this column should be used in conjunction with the Action Plan to record the date that the organization intends to become complaint. The target date must be a date in the future;

[49] Idea presented by Volvo Group, too. Retrieved from: https://www.volvogroup.com/en-en/home.html

- **Completion Date**: The cells in this column should be used to record the date that the organization became complaint. The completion date must be today's date or a date in the past;
- **Business Function**: The cells in this column allow an organization to record which department or title was, or should be, interviewed for each criterion. The Business Function column can be especially helpful when performing ongoing annual assessments. This column can be filtered to group the responsible business functions/titles and associated criteria to be interviewed during the assessment;
- **Responsibility**: The cells in this column should include the responsible person's name and/or title who is the owner of the criterion response and/or delivery of the action plan, and any associated details that need to be recorded for both the initial and ongoing annual assessments;
- **Cost**: The cells in this column should be used to record any costs associated with making the criterion compliant"[50];
- **Team size:** The cells in this column should be used to specify the amount of people assessed to be needed for the implementation of the action plan;
- **Team cost:** The cells in this column should be used to specify the associated cost of the team that will work on the action plan;
- **Customer Response**: The cells in this column should be used to record any relevant customer feedback for future reference.

To support the auditor in their job the information presented above is also present as cell comments in the tool itself. The visible columns are meant to be filled in by the auditor. They are followed by a series of 17 hidden columns that translate the word heavy explanation columns into binary or sum values that will be later used to aggregate the data and support the coding process of the business report. The auditor will have the responsibility to assess the company's compliance to the requirements based on the proof that the company brings for each requirement. The information should be marked in the "current state and supporting evidence" and, if possible, added to the Annex of the Audit report. The chapters that form the Audit sheet are organized as presented in Table 5.2.

Table 5.2. Audit chapters and their relevance

#	Subchapter	Relevance
1. Strategy and improvement	1.1 Vision and Strategy	A vision Requirement is not about what the company currently is, but what the company aspires to become. The organization's Ergonomic vision and strategy should be a fundamental part of the overall business vision and strategy including a culture of continual improvement. They must strive to cause no accidents, have no risks, and allow no professional diseases to affect their workers

[50] Global MMOG/LE Introduction and Instructions Version 4.0, Issued 5/2014. Retrieved from: https://www.odette.org/mmogle/resources/0_MMOG_LE_Introduction.pdf

	1.2 Continuous improvement	Specific areas of improvement need to be identified throughout the production chain to support organizations to remain competitive and continue reduce cost.
2. Training and education	2.1 Job-related ergonomic training	As more information come to light with regards to human health and safety and the workplace changes to keep up with automation technologies, employees must be updated on the correct behavior to minimize work-related strain.
	2.2 Job-related ergonomic knowledge assessment	People forget information at different rates, so to ensure that all workers have the same level of knowledge, periodical monitoring is necessary
	2.3 Participative ergonomics educational process	To evolve as a company, the knowledge of Ergonomics also must evolve from classic risk and injury prevention into collaboration between cross functional teams
3. Injury assessment	3.1 Injury assessment process	A basic request of ergonomics is to reduce injury rates. This cannot be done without a robust assessment process
	3.2 Return to work process	To reduce the number of working days lost per injury and help reintegrate a worker into their job environment the company must have a robust return to work process.
4. Job assessment	4.1 Functional evaluation	To ensure a good work that fit to all employees there should be a job assessment process in place for all types of jobs available.
	4.2 Risk assessment	While reducing injury is a reactive way of managing workplace dangers, risk assessment strives to eliminate the possibility of injuries even happening. A good risk assessment strategy will ultimately reduce the injury rate as well
5. Product and process design	5.1 Product design	Ergonomics should not only exist as a work floor issue, but should also be implemented in the design department as part of the overriding mentality to make products that are ergonomically easy to use by customers, ergonomically easy to produce by factories and ergonomically easy to manipulate in the supply chain.
	5.2 Process design	Processes should be developed considering human beings at the center. To do this, ergonomic factors need to be taken into consideration before a new process is released into practice.

The second sheet presents the assessment scoring summary, based on the information filled in the "Assessment" tab. The sheet is organized in three parts:

1. The summary of the scoring: In the first table a quick overview of the total score the company has reached is presented, along with the percentage that the achieved score is in comparison to the maximum achievable one. The second table presents a more detailed look at the amount of compliant and non-compliant questions based on their weight. The final table presents the letter classification the company gets based on its score.

2. The criteria of the scoring: to offer an understanding of the grading methodology the second part of the sheet is dedicated to the presentation of the weighting criteria and the classification of the grading system.
   a. The weighing criteria: *M marked questions* An Ergonomics process that is a fundamental "that demonstrates an additional level of control of operational processes, contributing to the organization's overall competitiveness. Complying with P3 criteria contributes to the organization's long-term sustainability and/or competitiveness. *A question* A Supply Chain Management (SCM) process that demonstrates control of operational processes"[51] and has significant importance for the operations'

      efficiency-effectiveness within the organization. If a P2 criterion is not met, both organization's performance and customer satisfaction are negatively influenced. *D questions* "A Supply Chain Management (SCM) process that demonstrates an additional level of control of operational processes, contributing to the organization's overall competitiveness. Complying with P3 criteria contributes to the organization's long-term sustainability and/or competitiveness".
   b. The classification of the grading system: If the assessment results in a grade "A" for the company that means "that the organization is compliant in all key criteria and can demonstrate that the ergonomics processes in use at the facility are best practice. Annual assessments are carried out with the goal of ensuring sustainable and best practice processes. In support of continual improvement, the development of an action plan should be considered to eliminate any remaining unmet criteria". If the company is assessed as being a "B" that means that "although most of the fundamentals of risk and ergonomic management are demonstrated, the organization is deficient in several areas that compromises the efficiency of internal performance and may impact its ability to support the needs of the workers. An action plan should be developed and implemented in a timeframe that meets the needs of the business and its customer(s)". Finally, if the assessment results in a "C" grading, then the organization is deficient in one or more key areas of Ergonomics theory and practice. The situation creates a high work risk and demonstrates a lack of efficiency and control of internal processes within the existing ergonomics strategy. Management commitment is needed to create, prioritize, and implement efficient and effective action plans with respect of deadlines and time schedule. Thus, managers will avoid serious or prolonged problems with the custom;

[51] Inspired by the idea presented at MMOG-LE Webinar 3rd March 2014. Retrieved from: https://www.industryforum.co.uk/wp-content/uploads/sites/6/2014/02/Webinar-slides-MMOG-LE.pdf

3. The chapter by chapter detail of the scoring: The third part of the sheet presents an in-detail question by question look at the grades. It defines the weight of each question, the score, and the percentage of compliance per chapter and subchapter level. The result is calculated as the multiplication of the scored criteria with the weighed criteria.

The purpose of the sheet is to provide a clear view of the gaps that the company has in its ergonomics process and how much must be improved for them to reach full compliance. It also offers the management team the further possibility to choose which path of improvement they would prefer. Either a subchapter by subchapter scoring optimization or an ergonomics characteristics-based optimization. The latter will be further explained in the presentation of the fourth Excel sheet of the Audit tool as well as in chapter 5.2.2 where a broader explanation of the optimization algorithm will be made.

The third sheet presents the radar chart compiled based on the "Scoring summary" information. It offers a visual description of the scoring results. It is also separated in three parts:

1. The summary of the scoring: A repetition of the quick overview summary present in the "Scoring Summary" sheet to allow the reader to understand what radar performance is linked to what overall score.
2. The subchapter radar chart: The first table presents the more detailed scoring of the 11 subchapters that are included in the audit in percentage points. On the right of the table the radar chart visualizes the scoring. This is used as the basis of the iterative optimization automation that will be further presented in chapter 5.2.2. Details are given in Figure 5.7.
3. The chapter radar chart: The second table present the overall chapter scoring in percentage points and visualizes the gaps with the support of the radar chart on its left.

Radar Chart - by Subchapter	
1.1 Vision and Strategy	57%
1.2 Continuous improvement	100%
2.1 Job-related ergonomic training	100%
2.2 Job-related ergonomic knowledge assessment	100%
2.3 Participative ergonomics educational process	100%
3.1 Injury assessment process	50%
3.2 Return to work process	100%
4.1 Functional evaluation	83%
4.2 Risk assessment	100%
5.1 Product design	100%
5.2 Process design	0%

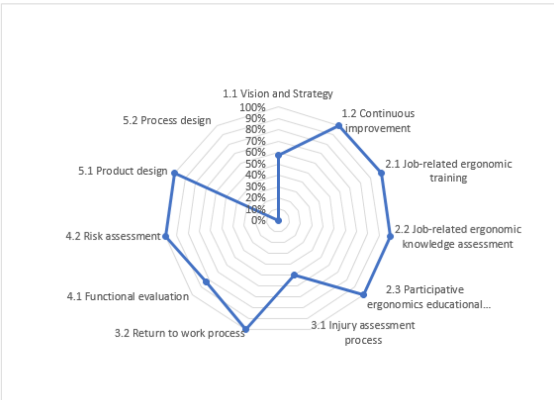

Figure 5.7. Radar Chart by subchapter

The following sheet contains the ergonomic characteristics described in Table 5.1 and related to the four stages ergonomics maturity model. Each characteristic is related to a specific ergonomics development level and each characteristic is tested with the help of audit questions. The table present the link between which characteristics are linked with which audit questions and the overall optimization sequence that a company should follow if they want to apply the development model correctly. This optimization sequence is used as the basis for the development level-based optimization presented in subchapter 5.2.2.

The last two sheets contain automation matrixes, where the user can request, upon clicking a series of buttons, the calculation of all the intermediate improvement steps that they should follow, in sequential order, to bring all of their characteristics to completion and have a 100% audit score.

5.2.2. The optimization algorithms

The following subchapter will present the optimization algorithms created during the audit tool development for the purpose of supporting managerial decisions by providing a pre-calculated improvement path. Once the auditing phase is completed, the company must start creating an action plan to improve the points that are not yet fulfilled. This should be done with the help of a classical project planning team that clearly defines how much time, budget and people are necessary to be involved in the improvement process.

Because this is a daunting task for many, the auditing tool itself will aid. Based on the grading received during the audit, the weight of each characteristic and the logic desired to be used (overall iterative optimization or ergonomics development level based sequential optimization) the user can, with the click of a button, request an improvement pathway, which specifies the step by step approach to improving the audit assessment by improving individual audit requirements one at a time. The code for the two optimization algorithms can be found in Annex 4.

5.2.2.1. The overall iterative optimization

The first proposed path is a priority based, clustered iterative maximization. The automated program checks the noncompliant questions per subchapter. In the subchapter with the lowest grading the program loops through the noncompliant questions and proposes the improvement of the question that will bring the highest impact on score increase: first "M" weighted questions, then "A" rated questions and finally "D" rated questions.

The process continues with each iteration, bringing the lowest scored subchapter to the level of the second lowest subchapter, gradually increasing the subchapter rating until it reaches 100%.

The program highlights the improvement step in each subchapter by coloring in the cell, to make the report easily readable, as can be seen in image 5.9. For ease of usage, the report was fitted with action buttons, linked to the respective Visual basic macros that will Clear the pre-existing analysis, Initialize the measurement by noting the current audit rating of the company analyzed and run the Optimization, as can be seen in Figure 5.8.

Figure 5.8 Automation buttons

The Bombardier case study used for the analysis shows that to achieve maximum ergonomic efficiency there would be 10 iteration steps needed. The first three of these iterations' steps are presented in Figure 5.9.

	requirement	weight	valueWeight	Initial iteration	Iteration 1	Iteration 2	Iteration 3
updated Rquirement							
1.1	1.1.1.1	M	3	1	1	1	1
1.1	1.1.1.2	A	2	0	0	0	0
1.1	1.1.1.3	D	1	1	1	1	1
1.1	1.1.1.4	D	1	0	0	0	0
1.2	1.2.1.1	A	2	1	1	1	1
1.2	1.2.1.2	A	2	1	1	1	1
1.2	1.2.1.3	A	2	1	1	1	1
2.1	2.1.1.1	M	3	1	1	1	1
2.1	2.1.1.2	D	1	1	1	1	1
2.1	2.1.1.3	A	2	1	1	1	1
2.1	2.1.1.4	D	1	1	1	1	1
2.2	2.2.1.1	D	1	1	1	1	1
2.2	2.2.1.2	A	2	1	1	1	1
2.2	2.2.1.3	A	2	1	1	1	1
2.3	2.3.1.1	A	2	1	1	1	1
2.3	2.3.1.2	D	1	0	0	0	0
3.1	3.1.1.1	M	3	1	1	1	1
3.1	3.1.1.2	A	2	0	0	1	1
3.1	3.1.1.3	A	2	0	0	0	0
3.1	3.1.1.4	D	1	0	0	0	0
3.1	3.1.1.5	A	2	1	1	1	1
3.2	3.2.1.1	A	2	1	1	1	1
3.2	3.2.1.2	A	2	1	1	1	1
4.1	4.1.1.1	A	2	1	1	1	1
4.1	4.1.1.2	M	3	1	1	1	1
4.1	4.1.1.3	M	3	1	1	1	1
4.1	4.1.1.4	A	2	0	0	0	0
4.1	4.1.1.5	D	1	1	1	1	1
4.1	4.1.1.6	D	1	1	1	1	1
4.2	4.2.1.1	M	3	1	1	1	1
4.2	4.2.1.2	A	2	1	1	1	1
4.2	4.2.1.3	A	2	1	1	1	1
4.2	4.2.1.4	A	2	1	1	1	1
4.2	4.2.1.5	A	2	1	1	1	1
4.2	4.2.1.6	A	2	1	1	1	1
4.2	4.2.1.7	D	1	1	1	1	1
4.2	4.2.1.8	D	1	1	1	1	1
5.1	5.1.1.1	M	3	1	1	1	1
5.1	5.1.1.2	A	2	1	1	1	1
5.1	5.1.1.3	A	2	1	1	1	1
5.2	5.2.1.1	M	3	0	1	1	1
5.2	5.2.1.2	A	2	0	0	0	1
5.2	5.2.1.3	D	1	0	0	0	0

Figure 5.9 Iterative optimization report output (the first three iterations' steps)

With the help of this tool the audited company has a support in their improvement process that guides them step by step in a mathematically optimized way to reach the maximum possible rating. The plus side of this methodology is that the company first works on their most inadequate characteristics first, making sure that it increases all characteristics at least to the same level, ensuring that no special attention is given to one to the detriment of the other.

The downside of this methodology is that the improvement effort might increase because the optimization is mathematical and not ergonomically. For example, the optimization could require the improvement of the ergonomic vision and strategy without the company even having an ergonomic measurement system to begin with, thus making the optimization harder to apply. Because of this, while the solution is interesting from a theoretical purpose, its application in real life situations is limited and not directly recommended.

To try and fix this issue a second optimization algorithm was created, to propose a more ergonomically feasible improvement path, based on the growth model presented in chapter 5.1 and further detailed in 5.2.2.2

5.2.2.2. The ergonomic model-based sequential optimization

The second proposed optimization bases itself on the ergonomic model presented in chapter 5.1 The automated Visual Basic macro takes into consideration the improvement sequence (presented in Annex 5) and the questions related to each ergonomic maturity level. Based on this information, the algorithm proposes the improvement path based on the improvement sequence, ensuring that all first maturity level questions are compliant before moving to the second maturity level and so on (Figure 5.10).

As opposed to the purely mathematical optimization, the ergonomic model based on offers a logical progression of optimization that is feasibly implementable in a company without creating difficulties in organization. The tools will hopefully be able to support in the ergonomic improvement process within factories by providing a guiding line to managers who would like to improve how business is done but have so far lacked the proper incentive. Both have their strengths and weaknesses and their application should be guided by an ergonomic expert, but they give much more free range to managers to take ergonomic improvement into their own hands and more importantly give them a structured process that they can put in place within their companies.

	requirement	weight	valueWeight	Initialized	Iteration 1	Iteration 2	Iteration 3	Iteration 4
updated Rquirement								
1.1	1.1.1.1	M	3	1	1	1	1	1
1.1	1.1.1.2	A	2	0	0	0	0	0
1.1	1.1.1.3	D	1	1	1	1	1	1
1.1	1.1.1.4	D	1	0	0	0	0	0
1.2	1.2.1.1	A	2	1	1	1	1	1
1.2	1.2.1.2	A	2	1	1	1	1	1
1.2	1.2.1.3	A	2	1	1	1	1	1
2.1	2.1.1.1	M	3	1	1	1	1	1
2.1	2.1.1.2	D	1	1	1	1	1	1
2.1	2.1.1.3	A	2	1	1	1	1	1
2.1	2.1.1.4	D	1	1	1	1	1	1
2.2	2.2.1.1	D	1	1	1	1	1	1
2.2	2.2.1.2	A	2	1	1	1	1	1
2.2	2.2.1.3	A	2	1	1	1	1	1
2.3	2.3.1.1	A	2	1	1	1	1	1
2.3	2.3.1.2	D	1	0	0	0	0	0
3.1	3.1.1.1	M	3	1	1	1	1	1
3.1	3.1.1.2	A	2	0	1	1	1	1
3.1	3.1.1.3	A	2	0	0	1	1	1
3.1	3.1.1.4	D	1	0	0	0	1	1
3.1	3.1.1.5	A	2	1	1	1	1	1
3.2	3.2.1.1	A	2	1	1	1	1	1
3.2	3.2.1.2	A	2	1	1	1	1	1
4.1	4.1.1.1	A	2	1	1	1	1	1
4.1	4.1.1.2	M	3	1	1	1	1	1
4.1	4.1.1.3	M	3	1	1	1	1	1
4.1	4.1.1.4	A	2	0	0	0	0	1

Figure 5.10 Iterative optimization report output (ergonomic model-based sequential optimization, results of the four successively iterations)

5.3. Data safety and security

While the methodology can be used to understand the ergonomics development level of a single company in a black box environment, real life implies a series of interactions that have so far not been considered in the analysis. The biggest constraining factor, regardless of whether the methodology is applied in a single production entity or transversally in the whole production footprint of the corporation, is still the overlying legal framework. Technological developments that have facilitated the intrusion into a worker's private space are ever increasing. While understanding that the quality of work is a driving force for a better economy, that can provide more jobs and improve society, it is also clear that this change should not come at the expense of the personal data of employees. As the ergonomics legal framework landscape on an international level is both too complex and out of scope for this thesis, only a brief presentation of the existing legal framework of Belgium (the country in which the ergonomics audit was done) will be presented. A discussion will follow as to the way in which this affects the presented methodology.

One of the purposes of wearable computers, as has been presented and analyzed until now, is to monitor biological cues. The processing of this data in a scientific environment is protected with the help of legislation that is not often practiced in a private working environment. Due to this there is a need to analyze the possibility to use this technology to track employee data from a legal perspective.

As the study was performed in Belgium a first introduction will be done regarding the general EU laws and directives and a more focused approach will be given to the legislation landscape of Belgium.

5.3.1. Legal context

All member states of the European Union have a general right to privacy, the expression of which is determined by national legal specifics. The two major EU directives that have guided the data protection legislation on a European level have been the Directive 95/46/EC [52](General Data Protection Regulation), applied from 1995 until 2016 and the regulation that superseded it, the Regulation 216/679[53] of the European Parliament and of the Council, passed on the 27 April 2016. Regulation 216/679 was deemed necessary to reduce the fragmentation of the implementation of Directive 95/46/EC, as well as the different levels of protections that were granted in member states in their internal legislation based on the Directive. This inequality led to issues with the free flow of personal data throughout the Union and behaved subsequently as an obstacle for Union level economic activities. There was also a need for updated language and regulation pertaining to the information age, where data transfer and collection is pervasive in almost every aspect of day to day life. According to art. 4 of Regulation 216/679 "personal data" is defined as "any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person." With this definition in mind data collection is governed by a series of principles and rules enshrined in the text of the law.

Data collection is covered by two major principles which are used to govern the type and amount of information needed for employment purposes:

- **"Principle of relevancy** implies that the employer's right to investigate is not absolute and that legitimate interest must be properly balanced with employment privacy"[54]. Because the right for an employer to information cannot infringe upon the right of the employee for privacy, the investigation and collection of information can be done in as much as the information is relevant to the employment. Article 5, of the Regulation, section (c) states that data collection must be "adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed ('data minimization')". This is put into law in Belgium with the help of "Article 11 of

[52] Retrieved from:
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31995L0046
[53] Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32016R0679
[54] Definition retrieved from: https://ec.europa.eu/social/BlobServlet?docId=2507&langId=en

Collective Bargaining Agreement no° 38[55] regarding recruitment and selection which states that the private sphere of the applicant will be respected during the selection procedure and that questions with regard to the private life of the applicant may only be justified if such questions are relevant in light of the nature of the job and/or the conditions of performance of the function". ("*De persoonlijke levenssfeer van de sollicitant zal bij de selectieprocedure worden geëerbiedigd. Zulks impliceert dat vragen over het privéleven slechts verantwoord zijn indien zij relevant zijn wegens de aard en de uitoefeningsvoorwaarden van de functie"*);

- **Principle of proportionality**: while the principle of relevancy deals with the justification of requesting private information the principle of proportionality is judged on a case by case basis. In Belgium there are no laws or rules that explicitly define what can and cannot be asked during a selection procedure. Paragraph (4) of the Regulation mentioning that "The processing of personal data should be designed to serve mankind. The right to the protection of personal data is not an absolute right; it must be considered in relation to its function in society and be balanced against other fundamental rights, in accordance with the principle of proportionality";
- **Principle of tendency companies**: Refers to the companies that are biased in certain ways, and which require more information from their employees upon hiring. For example, a religious organization would like to know the religious leanings of its employees, a political party would like to know the political ones, etc. Therefore, some biased information is required to be supplied. This is a principle applied in Germanic law nations, such as Belgium partly is.

The European directives have been passed down on a national level through the implementation of Data protection laws. In Belgium, historically, a data processing law came into force in 1993 regarding data protection applicable to labor relationships. This law was amended in 1998 to bring it in line with the European Directive 95/46/EC. This law has since been abolished by the 2018 Data protection law which comprehensively covers, in 286 Articles, the issue of the processing of all personal information, in a totally or partially automated way as well as the non-automatic treatment of personal data found or planned to be added to a file ("Art. 2. *La présente loi s'applique à tout traitement de données à caractère personnel, automatisé en tout ou en partie, ainsi qu'au traitement non automatisé de données à caractère personnel contenues ou appelées à figurer dans un fichier"*[56]). In its "implementing measures Belgian data protection law has added some elements to the protection offered by the European Directive. The Belgian Law on Data Protection does not know a system of prior authorization (by the Data Protection Authority) of sensitive data processing, but provides that processing of sensitive data is allowed if the data subject has given his written consent to the processing of those data, yet in the understanding that the

[55] http://www.cnt-nar.be/CAO-COORD/cao-038.pdf
[56] https://www.cnil.fr/fr/reglement-europeen-protection-donnees/chapitre1

consent may be withdrawn by the data subject at any time. According to the Law on Data Protection 114 consent is defined in the sense of the Directive and means" "any freely given, specific and informed indication of his wishes by which the data subject signifies his agreement to personal data relating him being processed".

Beyond the issue of data collection, the second set of applicable rules relate to various aspects of data protection. **Data protection** implies that "the general data protection principles are also applicable in an employment context. Some states have expanded or deviated from the measures or provisions in Member States' data protection laws that would further develop on or deviate from the general data protection principles laid down in the European Directive". As it is currently stated in the Regulation, the current data protection aspects considered in the legislation are:

- **Legitimacy:** Article 6 of the Regulation, paragraph (1), subsection (f) states that "processing is necessary for the purposes of the legitimate interests pursued by the controller or by a third party, except where such interests are overridden by the interests or fundamental rights and freedoms of the data subject which require protection of personal data". In subsections (b) and (c) it is clear that processing of data is required in an employment environment as "processing is necessary for the performance of a contract to which the data subject is party or in order to take steps at the request of the data subject prior to entering into a contract" or "processing is necessary for compliance with a legal obligation to which the controller is subject". The way in which the processing proves to be legitimate or not is determined based on the relevancy principle explained above;
- **Consent: "**According the European Regulation, and the Member States data protection laws, as far as processing data regarding workers is concerned, an informed consent is required". Article 4 of Regulation 216/679 defines consent as "any freely given, specific, informed and unambiguous indication of the data subject's wishes by which he or she, by a statement or by a clear affirmative action, signifies agreement to the processing of personal data relating to him or her;". According to Article 6.1 "Processing shall be lawful only if and to the extent that at least one of the following applies:(a) the data subject has given consent to the processing of his or her personal data for one or more specific purposes". In the clarifications, point (42) also adds the important mention that "Where processing is based on the data subject's consent, the controller should be able to demonstrate that the data subject has given consent to the processing operation. In the context of a written declaration on another matter, safeguards should ensure that the data subject knows and the extent to which consent is given". Point (43) also continues this point by mentioning that "for consent to be informed, the data subject should be aware at least of the identity of the controller and the purposes of the processing for which the personal data are intended. Consent should not be regarded as freely given if the data subject has no genuine or free choice or is unable to refuse or withdraw consent without detriment";

- **Transparency:** Even though total transparency for natural persons for the processing of employee data is not required by law, individual employees are still protected under the articles 10 and 11 of Directive 95/46 to be provided with a minimum amount of information. Clarification paragraph (39) also specifies that "It should be transparent to natural persons that personal data concerning them are collected, used, consulted or otherwise processed and to what extent the personal data are or will be processed. The principle of transparency requires that any information and communication relating to the processing of those personal data be easily accessible and easy to understand, and that clear and plain language be used" (information repeated in the 58th paragraph);
- **Access:** Article 12 of Directive 95/46 provides the access to or recertification of personal data as added meanings to the concept of transparency. This is continued under article 12 of the 216/679 Regulation which specifies that the information being gathered should be communicated "to the data subject in a concise, transparent, intelligible and easily accessible form, using clear and plain language, in particular for any information addressed specifically to a child. The information shall be provided in writing, or by other means, including, where appropriate, by electronic means. When requested by the data subject, the information may be provided orally, provided that the identity of the data subject is proven by other means." The clarifications also mention in paragraphs (59) and (63) that "A data subject should have the right of access to personal data which have been collected concerning him or her, and to exercise that right easily and at reasonable intervals, in order to be aware of, and verify, the lawfulness of the processing" and that " Modalities should be provided for facilitating the exercise of the data subject's rights under this Regulation, including mechanisms to request and, if applicable, obtain, free of charge, in particular, access to and rectification or erasure of personal data and the exercise of the right to object".

The risk of circumvention is prevented by stating that the protection of data is "technologically neutral and should not depend on the techniques used". According to the General Data Protection Regulation (GDPR) [57] introduced in 2018, the "protection of natural persons should apply to the processing of personal data by automated means, as well as to manual processing, if the personal data are contained or are intended to be contained in a filing system" (Tempelman and Slager, 2017). This brings us to the point of interest in this research. The wording of this paragraph means that the current legislation would also apply to data gathered with the help of a wearable computer.

The legislation thusly provides a good framework for the means through which data can be collected from employees. This provides a considerable roadblock in the application of emerging technologies for ergonomic monitoring purposes. European

[57] http://www.privacy-regulation.eu/en/r15.htm

law however presents a certain amount of unclarity when discussing the amount and type of data to be recorded.

According to clarification point 162[58] "Where personal data are processed for statistical purposes, this Regulation should apply to that processing. Union or Member State law should, within the limits of this Regulation, determine statistical content, control of access, specifications for the processing of personal data for statistical purposes and appropriate measures to safeguard the rights and freedoms of the data subject and for ensuring statistical confidentiality. Statistical purposes mean any operation of collection and the processing of personal data necessary for statistical surveys or to produce statistical results. Those statistical results may further be used for different purposes, including a scientific research purpose. The statistical purpose implies that the result of processing for statistical purposes is not personal data, but aggregate data, and that this result or the personal data are not used in support of measures or decisions regarding any particular natural person". As wearable computers collect large amount of both continuous and discrete data, aggregate companywide statistical data can be gathered for measurement purposes. This can only happen if that data, according to clarification 26, has been anonymized and in that case "the principles of data protection should therefore not apply".

However, according to the recommendations of the Article 29 Working Party[59] (Art. 29 WP), the advisory body made up of a representative from the data protection authority of each EU Member State, "it is technically very difficult to ensure complete anonymization of the data. Even in an environment with over a thousand employees, given the availability of other data about the employees the employer would still be able to single out individual employees with particular health indications such as high blood pressure or obesity". There is also concern that given the financial dependence of the worker on the employer and the nature of health data, workers aren't really "free" to give their consent anyway (Opinion 5/2014 on Anonymization Techniques[60]; Opinion 2/2017 on data processing at work[61]).

"Like in other countries, also in Belgium the question has arisen whether workers can lawfully give their consent in the individual employment contract. In principle, the answer is affirmative. Apart from the issue of the 'freedom' of consent, data protection law does not prevent contractual clauses in the employment context whereby the informed consent is given by an employee. Along with the introduction of Royal Decree of 13 February 2001"[62] it has also been specified that "the processing of personal data relates to sensitive or health-related data and is only made lawful on the basis of the consent of the data subject, this processing is still prohibited if the

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58 https://gdpr-info.eu/recitals/no-162/

59 https://ec.europa.eu/newsroom/article29/news.cfm?item_type=1358

60 https://ec.europa.eu/justice/article-29/documentation/opinion-recommendation/files/2014/wp216_en.pdf

61 https://ec.europa.eu/newsroom/article29/item-detail.cfm?item_id=610169

62 www.dataprotectionauthority.be/sites/privacycommission/files/documents/Royal_Decree_2001.pdf

controller of the processing is the current or potential employer of the data subject". The reason for this addition is clarified "in an official explanation of this Royal Decree where it is stated that in article 2, h) of Directive 95/46/EC consent is understood as a free expression of the will and such a relationship cannot exist between an employer and an employee"[63].

In "Belgium, under the Data Protection Act, one of the grounds which make the processing of sensitive data lawful, is the situation where processing is necessary for the purposes of preventive medicine or medical diagnosis, the provision of care or treatment to the data subject or one of his relatives, or the management of health-care services operating in the interest of the data subject, and if those data are processed under the supervision of a health professional. Labor law imposes a duty of care on the employer regarding health and safety. However, the performance of medical examinations in the employment context are delegated to a specific corporate medical practitioner. Belgian labor law specially regulates so-called 'company medicine'. This is an arrangement introduced by the law to enhance the health and safety or the wellbeing of employees in the workplace. It is concerned with prevention. This company medicine is realized by the company practitioner (*médecin du travail*). This is a medical doctor hired or paid by the employer, who takes care of the health of the employees. The relevant provisions can be found in the General Rules on Labor Protection (GRLP). In particular, the GRLP regulates medical examinations. As far as all these legally prescribed medical examinations are concerned, it must be noted that every employee is obliged to undergo the examination (if he or she wants to keep his or her job). The idea is, however, that these examinations are unconcerned with selection, but are provided for the own interests of the workers as well as for society at large. It must be stressed that the company practitioner is bound to observe his professional secrecy. No medical information, gathered during the prescribed examinations, may be communicated to the employer, except for the conclusion whether the employee is fit for the job". This is strengthened by Personal data protection law of 30.07.2018.[64] which states in Art.9 that the only people that should have access to the personal data resulting from biological and biometric readings should be the controller themselves, categories of persons that are designated by the controller with a clear description of their function in relation to the processing of the data concerned[65].

This means that even if both the EU and the Belgian legislation permits the processing of worker data, if consent is give, Belgium specifies that the person who can process worker data if this data is deemed medical in nature cannot be the employer of the person whose data is being processed. This effectively makes wearable computer data unusable in a Belgian work environment if that data is medical. If this is however still done the people responsible will be found in violation of the law.

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[63]https://ec.europa.eu/social/BlobServlet?docId=2507andlangId=en
[64]http://www.ejustice.just.fgov.be/eli/loi/2018/07/30/2018040581/justel
[65]https://gettingthedealthrough.com/area/18/jurisdiction/31/labor-employment-2017-belgium

As one study found, the "violations of the employee's right to privacy are not necessarily efficiently sanctioned". As "most sanctions arise from specific laws addressing specific issues of privacy or data protection", the law mostly enforces the application of these issues through criminal sanctions and/or administrative fines if made aware of the issues. "While data protection authorities and labor inspectorates have sometimes wide investigation competencies", they are not necessarily efficient in investigating issues as this is not their core practice. It also it not directly evident how to produce evidence of the unlawful data processing in situations where the worker is not aware that the data is even being collected about them. The "issue of workers' data protection seems to give rise to so-called silent violations, i.e. employees, their representatives or official bodies are not always aware of the existence of a violation of data protection principles or, generally, of privacy" (Hendrickx, 2002).

In countries such as the United States, more direct legislative actions, such as "PEIA Go365" have started appearing to encourage employees to use fitness trackers (Buoy, 2018). The implementation of worker tracking devices is forecasted to grow from 166,000 units in 2013 to 27.5 million by 2020. While in 2013, enterprise and industrial wearables only accounted for 1% of total wearable device revenues, by 2020, they are expected to account for 17% of total wearable device revenues (Kaul and Wheelock, 2015). The legal context in the US is therefore not putting any blocks to the utilization of wearable computers for employee tracking, regardless of the kind of data that is gathered in these conditions.

5.3.2. Implications for wearable computer applications

The legislative environment as presented above shows that the European Union has set a series of limitations in the practical application of wearable computers such fitness trackers. While the technology is becoming ever more pervasive in the work area the limitations of the law are not clear cut.

It is not clear where the limit is drawn between what is medical data and what is not. In some cases, one can make an educated guess, deciding unilaterally that the measured heartbeat and calories calculated are health related data. It is however not legally cautious to make these hard-hitting business decisions in such a manner. The minimum research that should be done would be to ask legal counsel. However, even lawyers cannot create information that is not there in the law. Since the very recent application of Data Privacy laws, litigation cases have not shown up in court to help define the limits of the law and the way in which they can be interpreted. While scientists are cautioning each other regarding the pitfalls of the new regulation (Orel and Bernik, 2018). There is no such information available for the affected industry players. Even worse, some reports have found that only 20% of companies were GDPR compliant after the May 2018 deadline, meaning that even without the added complexity of Industry 4.0 technology, companies are still struggling to meaningfully integrate the regulations within their processes (GDPR Report, 2018). To simplify the issue, from a legal perspective, in Belgium one can only gather personal information about a worker if they have given their full informed consent of said worker about the full extent of the data they are collecting. They can analyze the data for statistical purposes only if it is anonymized. However, if this data is medical in nature, only a medical professional or someone assigned by a medical professional can collect and access this information and it cannot, even under anonymized circumstances be presented to someone who is or could be the employer of the affected worker. It is not defined though the extent to which data can be defined as medical.

Another blocking point to implementing this new technology is related to the worker union situation in Belgium. Belgium is the country with the 6th highest[66] worker union density (proportion of employees who are union members) in the European Union. This is influenced by the fact that unemployment and other social benefits such as union bonuses are normally paid out through the union, boosting the numbers high above even other neighboring countries such as France (8%) or Germany (18%). The unions have been able to increase their membership by 13% between 2001 and 2010 while the proportion has remained (Faniel and Vandaele, 2012). Because of this very high membership percentage the power of the unions is very significant in this country. That can lead to additional roadblocks when it comes to discussing the aspects of worker monitoring of any kind. This idea would be amplified even more so if this monitoring is explained as being used for optimization of processes. Due to the high cost of labor in Belgium, the unions are wary of any new technology that might make the workers obsolete or that might help to reduce the need for the current number of workers as is.

Even if the legislation would be clarified regarding the data collection and processing, it is the author's opinion that the unions would pose an even stronger blocking point in the application of this new technology. As such, while the results of the research are valid and the possibility of applying wearable computers in warehouse environments is one worth further exploring, as the current legal and para legal situation stands, there is no possibility for further industrial application of the technology for the time being. It is the recommendation of the author that a legislative review take place either on a European or Belgian level where the grey areas be clarified, at the very least by adding a clear definition of what "medical data" is. Similarly, while the rights of the workers should continue to be protected, it is also worth noting that a large amount of manufacturing jobs are leaving Europe and moving to Asia (Bussolo et al., 2018). If the trend continues there will be no more manual labor job to protect. As such Europe must change its mentality one way or the other if it wants to continue to be able to compete with the US or China in terms of economic power. One of those ways is by being able to implement new technologies to improve the ergonomic aspects of worker's lives without having to deal with para-legal roadblocks and opposition.

In conclusion, the chapter presented a viable ergonomics maturity level model and assessment tool. Further research should be dedicated to the developing of the assessment tool for easier use and more efficient lines of questioning, but the current

[66] http://archive.uva-aias.net/207

chapter has shown that the assessment tool is usable, and its results can help with strategic planning. Once a company is aware of the level of ergonomics it is currently at it will be easy for it to define, together with an ergonomics professional, if it can investigate applying Industry 4.0 technologies, such as wearable computers or Io linked infrastructure. Of course, the large-scale application of such technology is not yet feasible in the current legislative environment.

6. CONCLUSIONS AND CONTRIBUTIONS

In this final chapter of the PhD. thesis, the research conclusions are displayed. Afterwards, the transfer and the completion of the latest state of research in the field are discussed. Finally, a critical appreciation and limitation of the research results will be presented.

6.1. Overall conclusions of the research

The present PhD thesis offers an approach and assessment model that is easily understood in non-academic environments. The large understanding gap between the business and the academic environment was not to the advantage of managers, who did not have a readymade tool to use in their internal ergonomic assessments. Based on the interim results of this research, necessary methods and concepts were described in detail to fulfil a holistic approach of ergonomics maturity with the creation of the *Ergonomics Maturity Model*. The thesis itself offers a full view of the state of ergonomics in warehouse logistics as it is currently being applied and can be used to understand the types of ergonomic issues experienced by warehouse workers in their daily job, both from a physical as well as from a mental point of view. The direction of Industry 4.0 based ergonomic measurement systems is presented and the link between their current scientific utility and their emerging industrial utility is made. The science is clear on the fact that improving ergonomics will lead to a reduction in company costs and that ergonomics itself can benefit from the usage of Industry 4.0 developed tools. This implied that it would be beneficial to investigate the interaction between the two topics and how the synergy between them could be exploited for the mutual benefit of the worker as well as the employer.

To do this, a case study company was chosen, and its internal warehouse organization was analyzed. The workers and engineers were questioned, and it resulted that firstly engineers do not consider it their responsibility to design ergonomically advantageous parts, and secondly that warehouse workers were not treated according to both the external as well as internal ergonomic regulations. The application of ergonomics was done unevenly and only to the level that the law was requiring it to be done. This led to a chaotic environment where the implementation of wearable computers and automated technology, while shown to have been beneficial on an individual basis, would have failed in a systemic implementation. If there is no structure to which the new technology can cling, the technology itself will not prove useful and may even deter managers from further using it, as they will not see direct improvements.

It is because of this that an ergonomics maturity model was developed. With the aim of supporting managerial decisions, the ergonomics maturity model and associated auditing tool can clearly show the level at which a company is operating and the means through which it can be improved in the future. The tool could be a powerful tool if properly and constantly used, which offers management a view on what is being improved upon, and what the next steps to tackle would be.

Ergonomics is a highly interdisciplinary field of science, so within the present thesis numerous scientific disciplines were considered. As a result, there is a possibility to expand the presented model to other non-industry related actors that would be equally interested in assessing their ergonomic maturity, such as public institutions or even some NGOs. In the meantime, the model and the corresponding tool can be of support in reorganization projects where significant organizational and layout changes are to be managed from an ergonomic perspective.

By using the *Ergonomics Maturity Model* and tool in large scale organizations the involved parties can visualize their improvement capabilities and plan accordingly.

6.2. The original contributions of the research

The original contributions are reflected by the ***research results achieved*** in different stages of the PhD program and that were included in the PhD thesis as following:

- The analysis and synthesis of the main and relevant references in the field of supply chain management and the ways in which the business is developing with the advent of the Industry 4.0 paradigm to better meet customer needs and expectations (similar with a state-of-the art in the field) - Chapter 2;
- Application of ergonomics approach and principles within the field of warehouse logistics. The split was made between physical and mental workloads and it concluded that the current level of ergonomic knowledge and application in warehouses is minimal, that worker health and safety are not seen as anything more than legal compliance topics - Chapter 2;
- Providing Industry 4.0 ergonomic solutions; they were presented and categorized in solutions that monitor the worker and solutions that improve the worker’s job by making it more ergonomic - Chapter 2;
- Diagnosis and analysis of the supply chain environment related to the case study company (the research context definition with details on the process flow). The warehouse environment was audited and presented in detail, noting the particularities of the related industry - Chapter 3;
- Design and implementation of four preliminary studies within the company’s premises (research results being published in important articles):
    - Engineering responsibility in ergonomics design;
    - Kanban rack weight distribution and its ergonomic implications;
    - Cycle time of Kanban bin filling;
    - Fitbit usability and data gathering capabilities.

These preliminary researches enabled a better understanding of the ergonomic gaps within the company’s processes and assessed the possibility of applying Industry 4.0 solutions in the company’s warehousing reality - Chapter 3;

- Development of an ***ergonomic approach based on an efficiency formula*** used to analyze the ergonomic benefits of the automation and Industry 4.0 improvements (together with the identification of company improvement possibilities based on the initial diagnosis, audit) - Chapter 4;
- Designing of the ***Ergonomics Maturity Model*** and an associated software tool to support the practical exploitation of the created model. The tool offers the user a guiding line through the process of understanding their current ergonomic standing, the points they should strive to improve and the time and effort it would take them to complete such an improvement. This is the main theoretical contribution to the mass of research – Chapter 5;
- Analysis of the legal environment in the EU and Belgium and how this may contribute and impact the industrial level application of worker monitoring wearable computers– Chapter 5.

Different research approaches with the related results have been the subject of several ***dissemination activities*** (followed by a peer review process). Thus, 18 articles were published in international conferences' proceedings and journals, from which 1 in ISI journal, 6 in ISI proceedings and 7 BDI index papers. All the articles were published in the period 2017 – 2020 and the complete list of them can be seen in the Annex 7 of the present PhD thesis.

Finally, there have been considered the original ***contribution and exploitation of these research results for didactical purposes,*** mainly for the *Occupational Health and Safety* subject of study in the context of the master program, Engineering and Management for Competitiveness and Quality (developed at Politehnica University of Timisoara, Faculty of Management in Production and Transportation, since the academic year 2019-2020).

6.3. Critical review of the research

The current PhD thesis was based on the practical research done in a low volume, high complexity assembly plant in Belgium. The project chosen specifically for analysis was in the start-up phase, meaning that the parameters measured during the analysis may not be fully representative of a serial production environment, which is the more common state of a project. Future research should repeat the measurements in a serial production environment. Furthermore, additional studies with more participants would improve the validity of the results.

Due to the high amount of improvements that needed to be done to the company's ergonomic state, and the limited amount of time available for the PhD research, it was not possible to repeat the initial measurement in an improved environment to see how and if this environment improves for the workers and allows for more efficient utilization of Industry 4.0 investments to be made. This type of measurement should be repeated so that the efficiency of the improvement ideas can be assessed, and the course of the company's improvement journey could be corrected should they prove to not be efficient.

Each improvement possibility was analyzed independently. That means that the interaction between applying various combinations of improvements is not clear. It should be researched to understand if the combinations increase each other's potency or if they are detrimental to one another.

The theoretical model and tool have only been applied to the case study factory. The validity of the concepts explained should be tested in multiple environments to assess their weaknesses and suggest possible improvements/modifications. On top of this the audit tool can be easily improved by moving the coding environment from VBA to a more visually capable language, thus offering a better user interface and experience to the utilizer. The current tool does not take into consideration the time, effort, and money necessary to improve a specific process. The tool would provide a lot more support to the user if this information were readily available, either benchmarked from the industry or calculated for each company based on the input the user gives.

Finally, the legal framework analysis done for the possibility of applying data gathering technology at a European level would benefit from a cross country comparison, in order to understand the ways in which the EU legislation is being interpreted at a national level. This should be done in hopes of creating a cross European view on the points which every country agrees with and where national understanding of European legislation differs.

6.4. Ethical implications of the research

As the research dealt with the gathering of personal and medical data for scientific purposes it is necessary to state the ethical clearances that were done for the protection of the gathering and the processing of workers' data.

Firstly, the research was developed independently and impartially. The author was present in the factory premises on a consultant contract, with the specified goal of analyzing the AS-IS situation in the company's incoming logistics setup, from the procurement of the parts to the moment the pieces are delivered to the production line with the purpose of installation. The consultancy services ended with the delivery of the consultancy report, part of which was used with consent within this thesis.

The confidentiality of the participants was ensured by anonymizing data directly at the gathering site. The observation sheets and questionnaires used were not filled in with participants' names or any defining characteristics, opting instead for giving them ordinal numbering that cannot be traced back to the person who filled the information in.

The company's management was requested access to the company's workers in written format before any contact was taken with them. The participant to the survey and the questionnaire voluntarily answered the request for collaboration. All their responses were recorded under anonymity and only aggregate data is presented in the final thesis.

Informed consent was requested from the warehouse workers who wore the Fitbit™ tool and the data presented in the thesis and the consultancy report does not make mention of name or function.

The information gathered during the measuring campaigns was presented to the workers directly involved and insights were shared into how it was possible to utilize the same measurement equipment in their private lives as well, in order to change their lifestyle and health related behavior.

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ANNEXES

Annex 1 "Attitudes about ergonomics in engineering" – Questionnaire offered to Bombardier engineering

Hello! My name is Anca MOCAN and I am a PhD student researching ergonomics application logistics. As part of my thesis I must analyze the attitude towards ergonomic practices in an industrial setting to set up an "AS IS" background for future research.

Thank you for taking the time to complete this survey. It should take no more than 15 minutes of your time. Your responses are voluntary and will be confidential. Responses will not be identified by individual. All responses will be compiled together and analyzed as a group.

The results of this questionnaire will be used to identify future ergonomics training needs for engineers as well as define the structure of this training.

1. What is the highest level of education you have finished?

   ☐Bachelor

   ☐Postgraduate

   ☐Masters

   ☐PhD

2. What engineering specialization do you have? (select all that apply)

   ☐Chemical engineering

   ☐Civil engineering

   ☐Electrical engineering

   ☐Mechanical engineering

   ☐Software engineering

   ☐Systems engineering

   ☐Transportation Engineering

   ☐Other: ____

3. How many years have you been employed full time after finishing university?

   ☐1-5

   ☐5-10

   ☐10-20

☐20+

4. How many different companies have you worked in?
   ☐1-2

   ☐3-4

   ☐5-6

   ☐6+

5. To your best knowledge, how many hours of dedicated ergonomic design principles have you participated in during your studies?

   ____

On a scale of 1 to 5, 1 being the smallest and 5 being the highest please rate the following statements

6. Ergonomic product design is my responsibility
   ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

7. I have received post university training on the importance of ergonomic product design
   ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

8. I have participated in NO functional design teams
   ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9. I have been encouraged by management to take into consideration the ergonomic aspect of my product design
   ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

10. When redesigning/designing a product, I consider the following factors: (please number them from most to least important)
    Ease of maintenance

    Final product integration

    Usability

    Ease of production

    Final product cost

    Ease of transportation

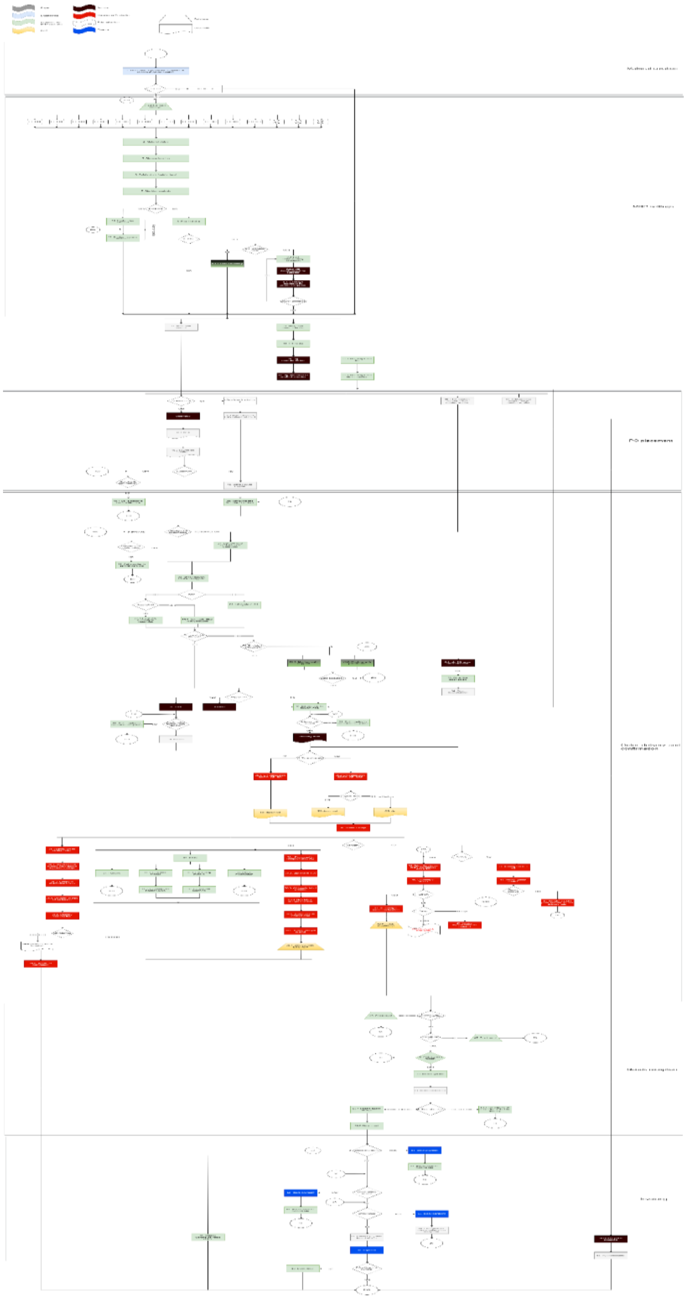
    Aesthetics

    Modularity

    Design time

Thank you for your time!

Annex 2 Bombardier process flow from "Article number release" to "Delivery in production" and "Payment"



The AS-IS process beginning the article number release up until the goods are delivered, stored and paid will be described in the below paragraphs.

The process has a few parallel streams because the theoretical process is sometimes followed sometimes not. The main process flow considered is the one according to Bombardier standard. Afterwards, all the steps that are added to the normal flow when facing a problem were added, resulting in an overall flow containing all the possible ways to get from the article release to the payment.

Material creation (1)

1. Lead time of production supplier OR Release of Article number

Beginning of the flow. Whenever an FOA is created, it is agreed with the supplier when the pieces will be produced/delivered, thus, Lead time of production supplier. Or when we have a special need, methods must provide procurement with an article number which has to be ordered to the supplier, thus, Release of Article number.

MRP settings (2 to 11)

2. CS 12E MRP settings

After discussion with the supplier, the scheduling agreement (when the pieces will be delivered) is implemented in SAP.

It is then decided which of the following flows will be used to deliver the pieces.

3. Logistical flows

3.1. KBE: Kanban eigen pieces are manufactured internally in Bombardier and are stored and supplied in Kanban bins to production

3.2. KBP: Kanban paint pieces are manufactured externally, delivered to the chemical warehouse and brought into production in Kanban bins

3.3. KBS: Kanban store pieces are manufactured externally, delivered in packages to Bombardier who places them in Kanban bins and brings them like this into production

3.4. KBV: Kanban vendor pieces are manufactured externally, delivered to Bombardier in specific bins and are put by the internal workers into the Kanban process.

3.5. 2BO: Completely externalized VMI Kanban process with goods reception in SAP

3.6. PPF: Pick parts fremd pieces are manufactured externally and delivered to Bombardier where they are stored in the warehouse and only get delivered to production on a basis of a call-off

3.7. D20: Pieces with higher value than Kanban pieces, where the amount brought into production is equivalent to 20 days of stock

3.8. DOL: Pieces with Just in Time delivery in the production. No warehousing activity for these pieces

3.9. 2BN: Completely externalized VMI Kanban process without goods reception in SAP – no stock visible

3.10. F99: Items without an assigned flow

3.11. NOT: Items no longer used

3.12. PPE: Pick parts eigen pieces are manufactured internally in the shop and they get stored in the warehouse only to get delivered to production on a basis of a call-off

3.13. SAD: Subassembly delivery online are subassembly pieces with just in time delivery in the production without warehouse storage.

3.14. SAS: Subassembly stores are subassembly pieces stored in the warehouse and delivered in production based on a call-off

4. Material status

4.1 A active
4.2 ZA active
4.3 M Assembled material
4.4 G blocked
4.5 ZG blocked
4.6 Z2 Blocked for Purch reject
4.7 Z1 Blocked for Purchasing
4.8 Y2 Blocked for task list/BOM
4.9 ZP Chk Mat.Master Duplicate
4.10 D1 Dangerous Goods
4.11 D2 Dangerous goods rejected
4.12 YK DWA do not calcualte
4.13 ZE excess stock
4.14 Y4 FAGA-closed by FQ
4.15 YD FHM Receipts printed
4.16 YF FHM free
4.17 YU FHM Check
4.18 GE Locked change service
4.19 GR Locked procurement type
4.20 GD Closed by Disposition
4.21 GP Locked for demand planning
4.22 L Goods sold by the metre
4.23 ZD In development (E)
4.24 I inactive
4.25 ZI inactive
4.26 K KANBAN material
4.27 ZL last buy
4.28 S Other material
4.29 RP Repair
4.30 R replaced material
4.31 YR replaced material
4.32 ZR replaced material
4.33 RW Rework
4.34 SC Scrap
4.35 ST Stop
4.36 U under revision
4.37 ZU under revision
4.38 W Warehouse material

5. Storage location

It must be decided where the pieces are going to be stored once delivered, and this information must be uploaded into SAP.

6. Safety stock (safety days)

It must be decided the quantity of the safety stock (in case we need extra pieces). In BTB, the safety stock is replaced with safety days: we must know the supplies lead time delivery to anticipate a need and order in time. The goal is to not stock to much just for the sake of stocking, but to be as lean as can be.

7. Stacking analysis

Is a check done internally in BTB to see which suppliers can be put together in the same delivery truck and if all of one's suppliers' articles can fit in one truck or if multiple trucks must be arranged for transportation

8. Fixed lot size

In this case, the delivered lots will always be of the same size.

9.1.1. Direct delivery

In the case of a DOL without standing trailer, there is a direct delivery.

9.2.1. Jig manufacturing constraints

In the case of a DOL with standing trailers, we first must provide the Jigs manufacturer with the existing constraints that must be respected in order for the jigs to follow our expectations.

9.2.2. Jig development by BTB jig supplier

After the definition of these constraints, BT's jig supplier starts developing the jigs that will be used.

9.2.3. Design feedback by product supplier

BT's product supplier (user of the jigs) gives his feedback on the jig, regarding the feasibility and the technicality.

10. Kanban bin creation

Before filling the Kanban, a special must be assigned to the piece, according to the size and place of usage of the piece

11. Kanban bin size definition

If the chosen delivery method is Kanban, the size of each lot is to be defined, according to the needs of the production lines.

Outside Bombardier (12 to 17.2)

12. Price offer request

Once everything is agreed on all the previous points, the purchasing department must ask the jig supplier for a price offer on this order, which may or may not be accepted.

13. Price offer request for jig

If a JIG is needed, a price must be agreed upon before ordering.

14. PO for jig

If the price was agreed upon, then a purchase order must be filled to get the jigs.

15. Jig manufacturing

After agreement on the price, the jig supplier starts manufacturing the ordered jigs.

16. Jigs delivered to product supplier

Once the jigs are manufactured, they are delivered to the product supplier who will use them to produce what BTB has ordered.

17.1. Standing trailer file

The file shows the planning of which trailers will arrive to the supplier's side at which date and what must be sent to BTB by which date. It gets updated with each schedule update.

17.2. Send standing file to supplier

PO placement (18 to 19)

18.1. FOA creation and FOA without Art nb = 1

The buyer in charge must create a FOA to order the pieces, but this FOA will not have articles numbers (this is to be fixed afterward).

18.2 FOA

If we have both a price offer and an article number, then a regular FOA is created.

18.3. Source list creation

When a regular FOA is created, the buyer always must create a source list.

18.4. Call supplier to confirm item line

If the supplier uses SupplyON but the line was not confirmed, we cannot move forward into the flow, as there is a need to agree with the supplier on the item line, so that he confirms it.

19. Send FOA to supplier + 20. Retrieving info from Colorbook

In the case the supplier does not use SupplyON, the buyer must send him the FOA, then retrieving the info from the Colorbook, which is a visual aid file that shows the delivery date of each expected article in the next 3 months and the items that are in backorder.

Order and delivery confirmation (20 to 34)

20. Retrieving info from Colorbook

See 20.

21. Delivery date confirmed via Colorbook

In the case SupplyON is not used, the delivery date is confirmed via the Colorbook.

22. Call supplier to confirm item line

See 18.4.

23. Check delivery date from supplier

The expeditor must check with the supplier if he will be able to honor the delivery date.

24.BO = YES →

Fill in info in BO list

If we are in the case of a backorder, the expeditor must fill in the BO list.

25.1. Fill in info in manually Colorbook

If it is not a backorder and SupplyON is not used, then the expeditor must fill in the Colorbook.

25.2. Automatic filled in in Colorbook

If it is not a backorder and SupplyON is not used, then the Colorbook is filled in automatically.

26.1. Meeting with supplier AND 26.2. Meeting with production

If a date is not agreed upon between supplier and production, the buyer and the expeditor must keep in touch with both the production and the supplier to define a suitable delivery date.

27. ASN (advanced shipping notification)

In the case the supplier works with SupplyON, he must confirm the order by sending an ASN.

28. Call supplier to confirm delivery date

If the delivery date has not been confirmed, the expeditor must keep calling the supplier to get a confirmation.

29. Invoice

Once the delivery date is confirmed, the supplier can send BTB the invoice related to the PO.

30. Ask supplier for delivery note

When the supplier does not use SupplyON or if there is no ASN, the expeditor must ask the supplier for a delivery note, which is the document that confirms the terms of the PO (delivery date, quantity, article number, etc.).

31. Call supplier to confirm delivery note

When the supplier does not use SupplyON or if there is no ASN, if the delivery note is not filled in, there is a loop that appears forcing the supplier to fill in the delivery note. Otherwise, the flow is blocked.

32. FOA creation without an Art nb or offer

If Art nb OR Price Offer received→

In the case we do not have the article number, or the supplier did not give us a price offer, we still create the FOA (55xxxxxxxx) or the PO (45xxxxxxxx).

33. Order line modification

In the case seen at point 32., when we do receive the article number or/and the price offer (depending on what was missing), the matching line in the FOA must be changed accordingly.

34. Price/Stock regularization (e.g., the case of a receiving invoice that is blocked)

In every case where an article was received before the price or the article number were written in SAP, the price or stock must be regularized with the help of the regularization list.

Goods reception (35 to 50.3)

35.1 GR transaction (MIGO_GR: IM)

SAP transaction used to book non-physical goods reception in the warehouse.

35.2 GR transaction (MIGO_GR: WM)

SAP transaction used to book physical goods reception in the warehouse.

36.1 to 36.6. in parallel with the rest of the flow, the planning of production and warehouse being independent of the procurement one when the pieces are delivered

36. Goods receipt

After all the previous steps, we must wait for the goods to be delivered in BT. When it is done, the warehouse as to acknowledge the fact that the pieces have been indeed delivered, resulting in a document called the good receipt (GR, document stating that the delivery respects the PO).

36.1. Reception of picking order

Once the GR is done, the pieces must be stored in the correct location. The document containing the information needed is called the picking order.

36.2. Separation of picking order based or production days

The picking orders are issued to reflect the production needs.

36.3. Sorting in distribution boxes

The pieces to be stored are sorted into categorized distribution boxes (dimensions, weight, material…).

36.4. Decision of type of packaging

Some pieces require a special type of packaging, depending on their fragility, preciousness… that must be agreed upon before the pieces are brought to production.

36.5. Delivery to production

Once all the previous steps done, we can deliver the pieces where they will be mounted: the production.

36.6. Return to warehouse

When the quantity brought to production exceeds its actual needs, warehouse retrieves the pieces to store them somewhere where they are supposed to be kept in good shape and ready for usage

Pieces is a Kanban (37 to 38.7)

37. If Kanban flow = YES → COGI check

37.1. Quantity change: due to changing of Methods installation procedures the number of pieces in a bin is increased or decreased

37.2.1. Location change: due to changing of Methods installation procedures the piece is moved from one PM to another for easy installation

37.2.2 Create new Kanban cycle: When a piece is removed or added into the Kanban flow, or the size of the bin of a piece already existing in the flow is modified, there is a need to create a Kanban bin cycle in SAP to allow the system to register the change/addition.

37.3.1. Scanning mistake: Correction of all scanning mistakes (bin scanned empty or full incorrectly)

37.3.2. Manual scanning: If the piece is physically not present in production anymore but the bin has not been scanned empty, the MRP controller manually scans the bin empty to allow the warehouse to receive a replenishment signal

37.4. Flow modification: If the piece is not compatible with the real Kanban system then the request is passed on to the MRP controller to switch the item flow

38.1. Pieces put in reception area 902

The goods reception area of the warehouse for all incoming goods waiting to be sorted and delivered to production.

38.2. Approval of TOs

The Kanban process demands to constantly update the articles that are in too little quantity in production so that the TOs can be approved and the pieces prepared and sent to production. Approving a TO sends an automated message that leads to the following step.

38.3. Automatic label printout

All the approved TOs are transformed into a printout of the label that will be placed on the box containing the Kanban pieces.

38.4. New labels brought to pallets

All the labels are brought to area 902, waiting to be placed upon the boxes.

38.5. Pallets placed in transit area

Once a pallet is full and ready to be brought to production, it is stored in a transit area, where it will be picked up for delivery once needed.

38.6. Pallets brought in prod

Once production scans a bin empty, the pallets are brought where the pieces will be needed to be stored.

38.7. Bins scanned full in SAP

After the delivery is done, all the bins that ware filled are scanned empty in SAP to let people know this piece is now available.

39. Bring the pieces in the Warehouse with a TO

All piece movements in the warehouse must happen with a TO from one location to another

40. Counting of pieces

First check to be done is assess the correctness of the number of pieces delivered versus the delivery note

41. Scanning of pieces on location

Once the quantity is confirmed, the pieces are scanned at the location to update the SAP system to their whereabouts.

42. Invoice regularization list updated

If the physical number of pieces received is not the same as the number of pieces mentioned on the delivery note regularization must occur under the lead of expediting and purchasing.

43. Printing out of a TO

44. Pieces quality control

The pieces are checked first for quality defects as per the latest NCRs that blocked the stock and secondly for new possible quality issues.

45. Warehouse QC prints out new TO and delivery note

46. Close regul

The line opened in the regularization file must be closed within maximum 48 hours of opening

47. Stock regul

If the physical number of pieces received is not the same as the number of pieces mentioned on the delivery note regularization has to occur under the lead of expediting and purchasing.

48. Check goods receipt

In the case the order has been passed on an item possessing an article number, we must check if the good receipt is present in SAP and if he matches the order. If it is OK, skip steps 40, 41 and 42. If not, go to next step.

49. Fill in regul info

The regularization of items is done with the help of a goods receipt document, in which the issue is logged for future tracking. Each issue opened in the regularization document must be closed within 48 hours.

50. Warehouse check

To know what the problem exactly is, it is required to check the actual stock, so that we can correct the mistake

50.1. Update goods receipt

The goods reception input is updated with the correct number of pieces in the warehouse, or, at the explanation of the expeditor, with the number of pieces that will be received in a subsequent delivery.

50.2. Close regul

The task created in the regularization file has to be closed once the necessary actions have been completed, in order to track which open items still exist and how long a task is open for.

50.3. Ask supplier to deliver the rest of quantity

We just need the supplier to deliver what is missing so that everything matches the PO.

Invoicing (51 to end)

51. Block payment

In case the is a problem (quantity, price, WBS element, missing GR…) on an invoice, it is sent to the responsible buyer/expeditor for them to solve the issue and allow the accountancy to pay the supplier.

52. Ask supplier for missing info

If the problem comes from the information on the invoice itself, the buyer/ expeditor contacts the supplier to get the missing information supposed to solve the invoice.

53. Block payment

If an invoice is blocked, the payment is blocked as well, as they have to be linked in SAP.

54. Check goods receipt

If the problem comes from what we received, we need to recheck the goods reception.

55. Block payment

Same as 53.

56. Change PO and Price regularization list update

If the prices in SAP are the cause of the problem, the buyer changes them and proceed with the regularization of the goods reception (see TRAINING MATERIAL MODIFICATION FORM OF AGREEMENT 5FOA)).

57. Unblock payment based on info

After fixing the problem and based on the information, the buyer/expeditor can release the invoice in the web cycle.

58. Payment

Once everything is cleared, the accountancy department can proceed with the payment.

59. Stock regul

If the problem concerns a special article (P in SAP), the buyer/expeditor needs to ask for a GR to be done in the stock regularization file.

60. FOA creation without an Art nb or offer

Same as 32.

61. PO modification

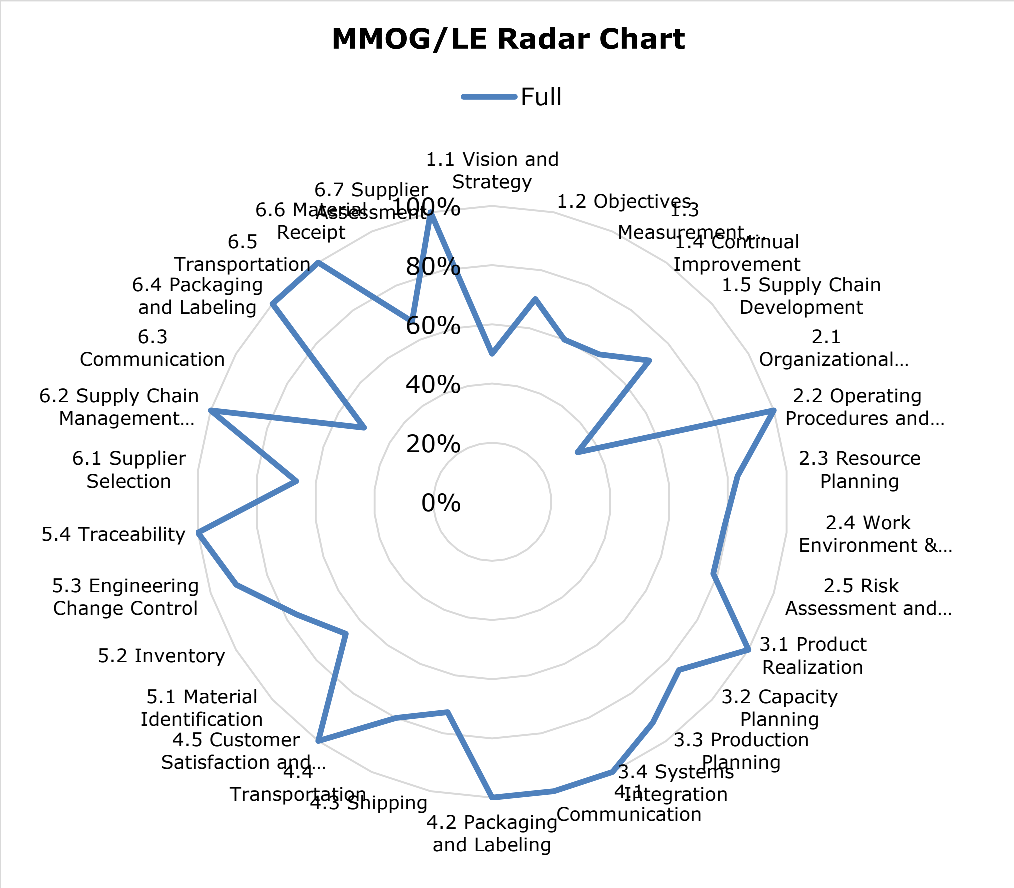
When the article number or/and the price offer is received, the buyer can change the purchasing document

62. Weekly warehouse value check

Each week, the value of the stock in the warehouse is checked.

Annex 3 MMOG/LE subchapter assessment and radar chart

MMOG Bombardier Assessment.xlsx



Annex 4 Optimization algorithms

Iterative optimization based on small step growth

```
Sub InitializeHiddenMatrix()
    Dim hiddenMatrixSheet As Worksheet
    Dim matrixRange As Range
    Dim MatrixCell As Range
    Dim matrixRequirement As String
    Dim assessmentSheet As Worksheet
    Dim assessmentRange As Range
    Dim assessmentCell As Range

    Set hiddenMatrixSheet = Sheets("Hidden Matrix")
    Set matrixRange = hiddenMatrixSheet.Range("B3:B45")
    Set assessmentSheet = Sheets("Assessment")
    Set assessmentRange = assessmentSheet.Range("C2:C63")

    For Each MatrixCell In matrixRange
        matrixRequirement = hiddenMatrixSheet.Range("B" and MatrixCell.Row).Value
        For Each assessmentCell In assessmentRange
            If assessmentCell.Value = matrixRequirement Then
                hiddenMatrixSheet.Range("E" and MatrixCell.Row).Value =
assessmentSheet.Range("F" and assessmentCell.Row).Value
            End If
        Next assessmentCell
    Next MatrixCell
End Sub

Sub Calculate()
    Call ClearHiddenMatrix
    Call InitializeHiddenMatrix

    Dim nextSubChapter As String
    Dim currentColumn As Range
    Set currentColumn = Range("E1")
    Dim col As String
    col = currentColumn.column
    nextSubChapter = FindNextSubChapter(currentColumn.column)
    Do While nextSubChapter <> ""
        Call CopyHiddenMatrixRow(currentColumn.column, currentColumn.column +
1)
        Set currentColumn = currentColumn.Offset(0, 1)
        Call MarkNextRequirementInSubChapter(nextSubChapter,
currentColumn.column)
```

```
        nextSubChapter = FindNextSubChapter(currentColumn.column)
    Loop
End Sub

Sub ClearHiddenMatrix()
    Dim hiddenMatrixSheet As Worksheet
    Dim LastColIndex As Integer
    Dim LastCol As String
    Dim LastRow As Integer
    Dim DeletionRange As Range

    Set hiddenMatrixSheet = Sheets("Hidden Matrix")
    With hiddenMatrixSheet
        LastColIndex = .Cells(5, .Columns.Count).End(xlToLeft).column + 6
        LastRow = Cells(Rows.Count, 3).End(xlUp).Row
        LastCol = Split(Cells(1, LastColIndex).Address, "$")(1)
        Set DeletionRange = hiddenMatrixSheet.Range("E1:" and LastCol and
LastRow)

        'clear cells (including formatting)
        DeletionRange.Clear
    End With
End Sub

Sub CopyHiddenMatrixRow(sourceRowIndex As Integer, destinationRowIndex As
Integer)
    Dim hiddenMatrixSheet As Worksheet
    Dim firstRow As Integer
    firstRow = 3
    Dim LastRow As Integer
    Dim sourceRowLetter As String
    Dim destinationRowLetter As String
    Dim sourceRange As Range
    Dim destinationRange As Range

    Set hiddenMatrixSheet = Sheets("Hidden Matrix")
    With hiddenMatrixSheet
        LastRow = Cells(Rows.Count, 3).End(xlUp).Row
        sourceRowLetter = Split(Cells(1, sourceRowIndex).Address, "$")(1)
        destinationRowLetter = Split(Cells(1, destinationRowIndex).Address, "$")(1)
        Set sourceRange = hiddenMatrixSheet.Range(sourceRowLetter and firstRow
and ":" and sourceRowLetter and LastRow)
        Set destinationRange = hiddenMatrixSheet.Range(destinationRowLetter and
firstRow and ":" and destinationRowLetter and LastRow)
```

```
        sourceRange.Copy
        destinationRange.PasteSpecial (xlPasteValues)
    End With
End Sub

Function FindNextSubChapter(columnIndex As Integer) As String
    Dim hiddenMatrixSheet As Worksheet
    Dim matrixRange As Range
    Dim MatrixCell As Range
    Dim currentsubChapter As String
    Dim currentsubChapterValue As Integer
    Dim currentsubChapterMaxValue As Integer
    Dim resultsubChapter As String
    Dim resultsubChapterValue As Integer
    Dim resultsubChapterMaxValue As Integer

    Set hiddenMatrixSheet = Sheets("Hidden Matrix")
    Set matrixRange = hiddenMatrixSheet.Range("B3:B46")

    For Each MatrixCell In matrixRange
        If currentsubChapter = "" Then
            resultsubChapterValue = 999
            resultsubChapterMaxValue = 999
            currentsubChapter = hiddenMatrixSheet.Range("A" and MatrixCell.Row)
            currentsubChapterMaxValue = hiddenMatrixSheet.Range("D" and
MatrixCell.Row)
            'currentsubChapterValue = hiddenMatrixSheet.Range("D" and
matrixCell.Row) * hiddenMatrixSheet.Range(column and matrixCell.Row)
            currentsubChapterValue = hiddenMatrixSheet.Range("D" and
MatrixCell.Row) * hiddenMatrixSheet.Cells(MatrixCell.Row, columnIndex)
        Else
            If currentsubChapter = hiddenMatrixSheet.Range("A" and MatrixCell.Row)
Then
                'currentsubChapterValue = currentsubChapterValue +
hiddenMatrixSheet.Range("D" and matrixCell.Row) *
hiddenMatrixSheet.Range(column and matrixCell.Row)
                currentsubChapterValue = currentsubChapterValue +
hiddenMatrixSheet.Range("D" and MatrixCell.Row) *
hiddenMatrixSheet.Cells(MatrixCell.Row, columnIndex)
                currentsubChapterMaxValue = currentsubChapterMaxValue +
hiddenMatrixSheet.Range("D" and MatrixCell.Row)
            Else
```

```
            If (currentsubChapterValue / currentsubChapterMaxValue <
resultsubChapterValue / resultsubChapterMaxValue) Then
                resultsubChapterValue = currentsubChapterValue
                resultsubChapter = currentsubChapter
                resultsubChapterMaxValue = currentsubChapterMaxValue
            End If
            currentsubChapter = hiddenMatrixSheet.Range("A" and MatrixCell.Row)
            'currentsubChapterValue = hiddenMatrixSheet.Range("D" and
matrixCell.Row) * hiddenMatrixSheet.Range(column and matrixCell.Row)
            currentsubChapterValue = hiddenMatrixSheet.Range("D" and
MatrixCell.Row) * hiddenMatrixSheet.Cells(MatrixCell.Row, columnIndex)
            currentsubChapterMaxValue = hiddenMatrixSheet.Range("D" and
MatrixCell.Row)
         End If
      End If
   Next MatrixCell
   If resultsubChapterValue = 1 Then
      FindNextSubChapter = ""
   Else
      FindNextSubChapter = resultsubChapter
   End If
End Function

Sub MarkNextRequirementInSubChapter(subChapter As String,
currentIterationColumn As Integer)
   Dim hiddenMatrixSheet As Worksheet
   Dim subChapterRange As Range
   Dim subChapterCell As Range
   Dim currentMaxWeight As Integer
   Dim currentMaxWeightRowIndex As Integer

   Set hiddenMatrixSheet = Sheets("Hidden Matrix")
   Set subChapterRange = hiddenMatrixSheet.Range("A3:A46")
   currentMaxWeight = 0
   currentMaxWeightRowIndex = 0

   For Each subChapterCell In subChapterRange
      If subChapterCell.Value = subChapter Then
         If hiddenMatrixSheet.Range("D" and subChapterCell.Row).Value >
currentMaxWeight And _
            hiddenMatrixSheet.Cells(subChapterCell.Row,
currentIterationColumn).Value = 0 Then
            currentMaxWeight = hiddenMatrixSheet.Range("D" and
subChapterCell.Row).Value
```

```
            currentMaxWeightRowIndex = subChapterCell.Row
         End If
      End If
   Next subChapterCell

   If currentMaxWeight > 0 Then
      Dim Cell As Range
      Set Cell = hiddenMatrixSheet.Cells(currentMaxWeightRowIndex,
currentIterationColumn)
      Cell.Value = 1
      Cell.Interior.Color = vbRed
   End If
End Sub
```

Iterative optimization based on growth model steps

```
Sub InitializeHiddenMatrix2()
   Dim hiddenMatrix2Sheet As Worksheet
   Dim matrixRange As Range
   Dim MatrixCell As Range
   Dim matrixRequirement As String
   Dim assessmentSheet As Worksheet
   Dim assessmentRange As Range
   Dim assessmentCell As Range

   Set hiddenMatrix2Sheet = Sheets("Hidden Matrix2")
   Set matrixRange = hiddenMatrix2Sheet.Range("B3:B45")
   Set assessmentSheet = Sheets("Assessment")
   Set assessmentRange = assessmentSheet.Range("C2:C63")

   For Each MatrixCell In matrixRange
      matrixRequirement = hiddenMatrix2Sheet.Range("B" and
MatrixCell.Row).Value
      For Each assessmentCell In assessmentRange
         If assessmentCell.Value = matrixRequirement Then
            hiddenMatrix2Sheet.Range("E" and MatrixCell.Row).Value =
assessmentSheet.Range("F" and assessmentCell.Row).Value
         End If
      Next assessmentCell
   Next MatrixCell
End Sub

Sub Calculate2()
```

```
    Call ClearHiddenMatrix2
    Call InitializeHiddenMatrix2

    Dim nextSubChapter As String
    Dim currentColumn As Range
    Set currentColumn = Range("E1")
    Dim col As String
    col = currentColumn.Column
    nextSubChapter = FindNextSubChapter(currentColumn.Column)
    Do While nextSubChapter <> ""
        Call CopyHiddenMatrix2Row(currentColumn.Column,
currentColumn.Column + 1)
        Set currentColumn = currentColumn.offset(0, 1)
        Call MarkNextRequirementInSubChapter(nextSubChapter,
currentColumn.Column)
        nextSubChapter = FindNextSubChapter(currentColumn.Column)
    Loop
End Sub

Sub ClearHiddenMatrix2()
    Dim hiddenMatrix2Sheet As Worksheet
    Dim LastColIndex As Integer
    Dim LastCol As String
    Dim LastRow As Integer
    Dim DeletionRange As Range

    Set hiddenMatrix2Sheet = Sheets("Hidden Matrix2")
    With hiddenMatrix2Sheet
        LastColIndex = .Cells(5, .Columns.Count).End(xlToLeft).Column + 6
        LastRow = Cells(Rows.Count, 3).End(xlUp).Row
        LastCol = Split(Cells(1, LastColIndex).Address, "$")(1)
        Set DeletionRange = hiddenMatrix2Sheet.Range("E1:" and LastCol and
LastRow)

        'clear cells (including formatting)
        DeletionRange.Clear
    End With
End Sub

Sub CopyHiddenMatrix2Row(sourceRowIndex As Integer,
destinationRowIndex As Integer)
    Dim hiddenMatrix2Sheet As Worksheet
    Dim firstRow As Integer
    firstRow = 3
```

```
    Dim LastRow As Integer
    Dim sourceRowLetter As String
    Dim destinationRowLetter As String
    Dim sourceRange As Range
    Dim destinationRange As Range

    Set hiddenMatrix2Sheet = Sheets("Hidden Matrix2")
    With hiddenMatrix2Sheet
        LastRow = Cells(Rows.Count, 3).End(xlUp).Row
        sourceRowLetter = Split(Cells(1, sourceRowIndex).Address, "$")(1)
        destinationRowLetter = Split(Cells(1, destinationRowIndex).Address,
"$")(1)
        Set sourceRange = hiddenMatrix2Sheet.Range(sourceRowLetter and
firstRow and ":" and sourceRowLetter and LastRow)
        Set destinationRange =
hiddenMatrix2Sheet.Range(destinationRowLetter and firstRow and ":" and
destinationRowLetter and LastRow)

        sourceRange.Copy
        destinationRange.PasteSpecial (xlPasteValues)
    End With

End Sub

'start looking from here

Sub FindNextSubChapter2()
    Dim hiddenMatrix2Sheet As Worksheet
    Dim ErgoCharacteristics  As Worksheet
    Dim matrixRange As Range
    Dim improvementCell As Range
    Dim MatrixCell As Range
    Dim improvementRange As Range
    'Dim currentsubChapter As String
   ' Dim currentsubChapterValue As Integer
    Dim offset As Integer
    Dim tmp As Range

    Set hiddenMatrix2Sheet = Sheets("Hidden Matrix2")
    Set ErgoCharacteristics = Sheets("Ergonomic characteristics")
    Set matrixRange = hiddenMatrix2Sheet.Range("B3:B46")
    Set improvementRange = ErgoCharacteristics.Range("K3:K45")

    'currentsubChapterValue = hiddenMatrix2Sheet.Range("E3:E43").Value
```

```
    offset = 3
    For Each improvementCell In improvementRange
        For Each MatrixCell In matrixRange
            If improvementCell.Value = MatrixCell.Value Then
                If MatrixCell.offset(, offset).Value = 0 Then
                    'Set tmp = hiddenMatrix2Sheet.Range(, MatrixCell.offset(,
offset).Column)
                    Set tmp = hiddenMatrix2Sheet.Columns(MatrixCell.offset(,
offset).Column)

                    tmp.Copy
                    offset = offset + 1
                    'Set tmp = MatrixCell.offset(, offset).Column
                    Set tmp = hiddenMatrix2Sheet.Columns(MatrixCell.offset(,
offset).Column)
                    tmp.PasteSpecial (xlPasteValues)
                    MatrixCell.offset(, offset).Value = 1
                    MatrixCell.offset(, offset).Interior.Color = vbRed
                    Exit For
                End If
            End If
        Next MatrixCell
    Next improvementCell

End Sub

Sub MarkNextRequirementInSubChapter(subChapter As String,
currentIterationColumn As Integer)
    Dim hiddenMatrix2Sheet As Worksheet
    Dim subChapterRange As Range
    Dim subChapterCell As Range
    Dim currentMaxWeight As Integer
    Dim currentMaxWeightRowIndex As Integer

    Set hiddenMatrix2Sheet = Sheets("Hidden Matrix2")
    Set subChapterRange = hiddenMatrix2Sheet.Range("A3:A46")
    currentMaxWeight = 0
    currentMaxWeightRowIndex = 0

    For Each subChapterCell In subChapterRange
        If subChapterCell.Value = subChapter Then
            If hiddenMatrix2Sheet.Range("D" and subChapterCell.Row).Value >
currentMaxWeight And _
```

```
            hiddenMatrix2Sheet.Cells(subChapterCell.Row,
currentIterationColumn).Value = 0 Then
            currentMaxWeight = hiddenMatrix2Sheet.Range("D" and
subChapterCell.Row).Value
            currentMaxWeightRowIndex = subChapterCell.Row
         End If
      End If
   Next subChapterCell

   If currentMaxWeight > 0 Then
      Dim Cell As Range
      Set Cell = hiddenMatrix2Sheet.Cells(currentMaxWeightRowIndex,
currentIterationColumn)
      Cell.Value = 1
      Cell.Interior.Color = vbRed
   End If
End Sub

Sub MM()

Dim r As Long, ws As Worksheet
Set ws = Sheets("Consolidation")
For r = ws.Cells(Rows.Count, "C").End(xlUp).Row To 2 Step -1
   If ws.Range("C" and r).Value = "Chain" Then
      ws.Range("AE" and r).Value = 0
   End If
Next r
End Sub
End Sub
```

Annex 5 Optimization sequence and related questions

Ergonomic characteristics	Ergonomics Development Level				Questions					Optimization sequence
	Reactive	Customized	Preemptive	Designing						
Standardized injury assessment	x	x	x	x	3.1.1.1	3.1.1.2				3.1.1.1
Standardized injury assessment repository	x	x	x	x	3.1.1.3	3.1.1.4				3.1.1.2
Standardized injury assessment KPIs	x	x	x	x	3.1.1.5					3.1.1.3
Standardized return to work process	x	x	x	x	3.2.1.1					3.1.1.4
Standardized return to work metrics	x	x	x	x	3.2.1.2					3.1.1.5
Standard job-related ergonomic training		x	x	x	2.1.1.1	2.1.1.2	2.1.1.3			3.2.1.1
Standardized job-related ergonomic knowledge assessment		x	x	x	2.2.1.1	2.2.1.2				3.2.1.2
Standardized job-related ergonomic knowledge assessment KPIs		x	x	x	2.2.1.3	2.1.1.4				2.1.1.1
Standardized job matching analysis		x	x	x	4.1.1.1					2.1.1.2
Standardized physical demands analysis		x	x	x	4.1.1.2					2.1.1.3
Standardized functional capacity evaluation		x	x	x	4.1.1.3					2.2.1.1
Standardized functional capacity evaluation testing interval			x	x	4.1.1.4					2.2.1.2
Standardized risk assessment procedure			x	x	4.2.1.1					2.2.1.3
Standardized risk assessment repository			x	x	4.2.1.2					2.1.1.4
Standardized risk assessment KPIs			x	x	4.2.1.3					4.1.1.1
Standardized risk elimination tools			x	x	4.2.1.4	4.2.1.5	4.2.1.6	4.2.1.7	4.2.1.8	4.1.1.2
In-company product design guidelines				x	5.1.1.1	5.1.1.2				4.1.1.3
In company warehouse process design guidelines				x	5.2.1.1	5.2.1.2				4.1.1.4
Standardized design gate review processes				x	5.1.1.3					4.2.1.1
Clearances and reach distances measurements of existing workforce				x	4.1.1.5					4.2.1.2
Force requirements of process execution				x	4.1.1.6					4.2.1.3
Continuous improvement in ergonomic aspects				x	1.2.1.1	1.2.1.2	1.2.1.3			4.2.1.4
Managerial incentive for ergonomic design implementation				x	5.2.1.3					4.2.1.5
Standardized participative ergonomics educational process				x	2.3.1.1	2.3.1.2				4.2.1.6
Vision and strategy				x	1.1.1.1	1.1.1.2	1.1.1.3	1.1.1.4		4.2.1.7
										4.2.1.8
										5.1.1.1
										5.1.1.2
										5.2.1.1
										5.2.1.2
										5.1.1.3
										4.1.1.5
										4.1.1.6
										1.2.1.1
										1.2.1.2
										1.2.1.3
										5.2.1.3
										2.3.1.1
										2.3.1.2
										1.1.1.1
										1.1.1.2
										1.1.1.3
										1.1.1.4

Annex 6 Audit tool (details)

	Chapter / Subchapter	Requirement / Criterion No	Weight	Requirement / Criterion	Compliance	Current State & Supporting Evidence	Gap / Continual Improvement	Action Plan	Target Date	Completion Date	Business Function	Responsibility	Cost	Team size	Team cost	Customer Response	Chapter	Requirement No	M	A	D	Compliant	Non Compliant	Missing Action Plan	Missing Target Date	Missing Completion Date	Missing business Function	Missing responsibility	Missing cost	Missing team size	Missing team cost	Points Max	Actual Points
	1. STRATEGY AND IMPROVEMENT																1	H	1	4	2	5	2	7	4	7	7	7	3	3	3	13	10
1.1.1	1.1 Vision and Strategy	1.1.1	Requirement: The organization has a documented Ergonomics Vision and Strategy.			Why is this important? A vision Requirement is not about what the company currently is, but what the company aspires to become. The organization's Ergonomic vision and strategy should be a fundamental part of the overall business vision and strategy including a culture of continual improvement. They must strive to cause no accidents, have no risks and allow no professional disseases to affect their workers											1	1.1.1	1	1	2	2	2	4	1	4	4	4	0	0	0	7	4
1.1.1.1	1.1 Vision and Strategy	1.1.1.1	M	There is a documented vision which includes an ergonomics strategy that supports the organization's overall business objectives. The strategy should incorporate ergonomic requirements, continual improvement, and a review at planned intervals.	1								60 EUR	6	50 EUR		1	1.1.1.1	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	3	3
1.1.1.2	1.1 Vision and Strategy	1.1.1.2	A	The vision and ergonomics strategy are communicated to and understood by all employees within the organization.	0				Dec 20, 2019				100 EUR	2	100 EUR		1	1.1.1.2	0	1	0	0	1	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	2	0
1.1.1.3	1.1 Vision and Strategy	1.1.1.3	D	The Ergonomics strategy specifies the language to be used for all forms of communication, including corporate and day-to-day operations.	1								200 EUR	1	5 000 EUR		1	1.1.1.3	0	0	1	1	0	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	1	1
1.1.1.4	1.1 Vision and Strategy	1.1.1.4	D	There is a periodic review process of all ergonomic guidelines	0				Sep 10, 2019				500 EUR	2	7 500 EUR		1	1.1.1.4	0	0	1	0	1	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	1	0
1.2.1	1.2 Continuous improvement	1.2.1	Requirement: The organization has a documented Continuous improvement strategy. Actions are taken to remove, reduce or minimize constraints			Why is this important? For organizations to remain competitive and reduce cost, specific areas of improvement need to be identified throughout the production chain.											1	1.2.1	0	3	0	3	0	3	3	3	3	3	3	3	3	6	6
1.2.1.1	1.2 Continuous improvement	1.2.1.1	A	There is a continuous improvement process applied in all ergonomic aspects	1												1	1.2.1.1	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
1.2.1.2	1.2 Continuous improvement	1.2.1.2	A	The organization has the ability to adapt its human resources in order to manage and balance workload (e.g. flexibility agreements, peak hours, absenteeism, and different industrial calendars) in compliance with customer requirements.	1												1	1.2.1.2	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
1.2.1.3	1.2 Continuous improvement	1.2.1.3	A	There are procedures and/or work instructions in place that define a structured problem-solving process that prevents recurrence of ergonomics issues. The process includes: timely identification, response, containment, and corrective actions. Management prioritizes corrective and preventive actions and provides the resources needed to resolve each deficiency.	1												1	1.2.1.3	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
H	2. TRAINING AND EDUCATION																	H	1	4	4	8	1	9	9	9	9	9	9	9	9	15	14
2.1.1	2.1 Job-related ergonomic training	2.1.1	Requirement: The organization has a documented Human Resources evolution strategy in terms of Ergonomic knowledge.			Why is this important? As more information come to light with regards to human health and safety and the workplace changes to keep up with automation technologies, employees have to be updated on the correct behaviour to have in order to minimize work related strain.											2	2.1.1	1	1	2	4	0	4	4	4	4	4	4	4	4	7	7
2.1.1.1	Standard job-related ergonomic training	2.1.1.1	M	There is an obligatory job-related ergonomic training	1												2	2.1.1.1	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
2.1.1.2	Standard job-related ergonomic training	2.1.1.2	D	There is a standard theoretical job-related ergonomic training	1												2	2.1.1.2	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
2.1.1.3	Standard job-related ergonomic training	2.1.1.3	A	There is a standard practical job-related ergonomic training	1												2	2.1.1.3	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
2.1.1.4	Standard job-related ergonomic training	2.1.1.4	D	There is an assigned work function exclusively responsible for monitoring company ergonomics	1												2	2.1.1.4	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
2.2.1	2.2 Job-related ergonomic knowledge assessment	2.2.1	Requirement: The organization has a documented way to check on the current knowledge levels of employees regarding Ergonomic topics.			Why is this important? People forget information at different rates, so in order to ensure that all workers have the same level of knowledge, periodical monitoring is necessary											2	2.2.1	0	2	1	3	0	3	3	3	3	3	3	3	3	5	5
2.2.1.1	Standardized job-related ergonomic knowledge assessment	2.2.1.1	D	There is a standardized assessment of worker's theoretical ergonomic knowledge	1												2	2.2.1.1	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
2.2.1.2	Standardized job-related ergonomic knowledge assessment	2.2.1.2	A	There is a standardized assessment of worker's practical ergonomic knowledge	1												2	2.2.1.2	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
2.2.1.3	Standardized job-related ergonomic knowledge assessment KPIs	2.2.1.3	A	There is a standardized set of metrics used to periodically follow up on a worker's ergonomic knowledge	1												2	2.2.1.3	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
2.3.1	2.3 Participative ergonomics educational process	2.3.1	Requirement: The organization offers more than just basic Ergonomics training.			Why is this important? In order to evolve as a company, the knowledge of Ergonomics also has to evolve from classic risk and injury prevention into collaboration between cross functional teams											2	2.3.1	0	1	1	1	1	2	2	2	2	2	2	2	2	3	2
2.3.1.1	Standardized participative ergonomics educational process	2.3.1.1	A	There is a participative ergonomics training process	1												2	2.3.1.1	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
2.3.1.2	Standardized participative ergonomics educational process	2.3.1.2	D	There is an assssment process to determine which workers can access the participative ergonomics training path	0												2	2.3.1.2	0	0	1	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	0
H	3. INJURY ASSESSMENT																	H	1	5	1	4	3	7	7	7	7	7	7	7	7	14	9
3.1.1	3.1 Injury assessment process	3.1.1	Requirement: The organization has a documented Injury assessment process			Why is this important? A basic request of ergonomics is to reduce injury rates. This cannot be done without a robust assessment process											3	3.1.1	1	3	1	2	3	5	5	5	5	5	5	5	5	10	5
3.1.1.1	Standardized injury assessment	3.1.1.1	M	There is a standard document for injury assessment	1												3	3.1.1.1	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
3.1.1.2	Standardized injury assessment	3.1.1.2	A	There is a standardized documented process for injury assessment	0												3	3.1.1.2	0	1	0	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	0
3.1.1.3	Standardized injury assessment repository	3.1.1.3	A	There is a documented process and location for storing injury assessment documentation	0												3	3.1.1.3	0	1	0	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	0
3.1.1.4	Standardized injury assessment repository	3.1.1.4	D	The organization archives injury records as defined by the management or for a time period relevant to any potential disputes. The archived records should be easily retrievable and readable.	0												3	3.1.1.4	0	0	1	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	0
3.1.1.5	Standardized injury assessment metrics	3.1.1.5	A	There is a defined set of metrics that the company uses to monitor its injury assessment situation	1												3	3.1.1.5	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2

3.2.1	3.2 Return to work process	3.2.1	Requirement: The organization has a documented return to work process			Why is this important? In order to reduce the amount of work days lost per injury and help reintegrate a worker into their job environment the company has to have a robust return to work process.	3	3.2.1	0	2	0	2	0	2	2	2	2	2	2	2	2	4	4
3.2.1.1	Standardized return to work process	3.2.1.1	A	There is a standardized return to work process for previously injured workers	1		3	3.2.1.1	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
3.2.1.2	Standardized return to work metrics	3.2.1.2	A	There is a defined set of metrics that the company uses to monitor its return to work process	1		3	3.2.1.2	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
H	4. JOB ASSESSMENT							H	3	7	4	13	1	14	14	14	14	14	14	14	14	27	25
4.1.1	4.1 Functional evaluation	4.1.1	Requirement: The organization has a documented Job assessment process			Why is this important? In order to ensure a good work fit for all employees there should be a job assessment process in place for all types of jobs available.	4	4.1.1	2	2	2	5	1	6	6	6	6	6	6	6	6	12	10
4.1.1.1	Standardized job matching analysis	4.1.1.1	A	There is a standardized job matching analysis	1		4	4.1.1.1	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.1.1.2	Standardized physical demands analysis	4.1.1.2	M	There is a standardized physical demand analysis	1		4	4.1.1.2	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
4.1.1.3	Standardized functional capacity evaluation	4.1.1.3	M	There is a standardized functional capacity evaluation	1		4	4.1.1.3	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
4.1.1.4	Standardized functional capacity evaluation testing interval	4.1.1.4	A	There is a standardized functional capacity testing interval	0		4	4.1.1.4	0	1	0	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	0
4.1.1.5	Clearances and reach distances measurements of existing workforce	4.1.1.5	D	There is a clearance and reach distance measurement of the existing workforce	1		4	4.1.1.5	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
4.1.1.6	Force requirements of process execution	4.1.1.6	D	There is a force requirement analysis for process execution	1		4	4.1.1.6	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
4.2.1	4.2 Risk assessment	4.2.1	Requirement: The organization has a documented risk assessment process and risk strategy in place			Why is this important? While reducing injury is a reactive way of managing workplace dangers, risk assessment serves to eliminate the possibility of injuries ever happening. A good risk assessment strategy will ultimately reduce the injury rate as well	4	4.2.1	1	5	2	8	0	8	8	8	8	8	8	8	8	15	15
4.2.1.1	Standardized risk assessment procedure	4.2.1.1	M	There is a standardized risk assessment procedure	1		4	4.2.1.1	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
4.2.1.2	Standardized risk assessment repository	4.2.1.2	A	There is a documented process and location for storing risk assessment procedures	1		4	4.2.1.2	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.2.1.3	Standardized risk assessment KPIs	4.2.1.3	A	There is a defined set of metrics that the company uses to monitor its risk assessment situation	1		4	4.2.1.3	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.2.1.4	Standardized risk elimination tools	4.2.1.4	A	There is a defined set of tools and processes that the company uses to reduce and eliminate its risk situations	1		4	4.2.1.4	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.2.1.5	Standardized risk elimination tools	4.2.1.5	A	Workers are aware of the risk assessment procedure and are empowered to use it themselves	1		4	4.2.1.5	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.2.1.6	Standardized risk elimination tools	4.2.1.6	A	There is a standardized risk assessment testing interval	1		4	4.2.1.6	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
4.2.1.7	Standardized risk elimination tools	4.2.1.7	D	A process is in place to conduct ad hoc risk audits based on the frequency and severity of discrepancies between targeted risk values and current actual ones	1		4	4.2.1.7	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
4.2.1.8	Standardized risk elimination tools	4.2.1.8	D	The organization archives audit records as defined by the management or for a time period relevant to any potential disputes. The archived records should be easily retrievable and readable	1		4	4.2.1.8	0	0	1	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	1
H	5. PRODUCT AND PROCESS DESIGN							H	2	3	1	3	3	6	6	6	6	6	6	6	6	13	7
5.1.1	5.1 Product design	5.1.1	Requirement: The organization has a documented ergonomic assessment of product design			Why is this important? Ergonomics should not only exist as a workfloor issue, but should also be implemented in the design department as part of the overriding mentality to make products that are ergonomically easy to use by customers, ergonomically easy to produce by factories and ergonomically easy to manipulate in the supply chain.	5	5.1.1	1	2	0	3	0	3	3	3	3	3	3	3	3	7	7
5.1.1.1	In-company product design guidelines	5.1.1.1	M	There is a company specific product design guideline	1		5	5.1.1.1	1	0	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	3
5.1.1.2	In-company product design guidelines	5.1.1.2	A	There is a process in place to ensure that ergonomic impact is taken into account when accepting engineering changes	1		5	5.1.1.2	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
5.1.1.3	In-company product design guidelines	5.1.1.3	A	The design of a product is discussed in cross-functional teams before final approval	1		5	5.1.1.3	0	1	0	1	0	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	2
5.2.1	5.2 Process design	5.2.1	Requirement: The organization has a documented ergonomic assessment of process design			Why is this important? Processes should be developed with human beings at the center. In order to do this ergonomic factors need to be taken into consideration before a new process is released into practice.	5	5.2.1	1	1	1	0	3	3	3	3	3	3	3	3	3	6	0
5.2.1.1	In-company warehouse process design guidelines	5.2.1.1	M	There is a company specific process design guideline	0		5	5.2.1.1	1	0	0	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	3	0
5.2.1.2	Standardized design gate review processes	5.2.1.2	A	There is a company specific design gate review process	0		5	5.2.1.2	0	1	0	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	2	0
5.2.1.3	Managerial incentive for ergonomic design implementation	5.2.1.3	D	Ergonomic product and process design is incentivized by official managerial guidelines	0		5	5.2.1.3	0	0	1	0	1	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	1	0

Maximum Score	81
%	80%

Compliant	8	18	7	33
Non Compliant	4	5	1	10
Σ	12	23	8	43

B

Weighting:	D	1	An Ergonomics process that is a fundamental that demonstrates an additional level of control of operational processes, contributing to the organization's overall competitiveness. Complying with P3 criteria contributes to the organization's long-term sustainability and/or competitiveness.
	A	2	A Supply Chain Management (SCM) process that demonstrates control of operational processes and has significant importance to the efficiency and effectiveness of the organization's operations. If an P2 criterion is not met, the organization's performance and/or customer satisfaction may be seriously affected.
	M	3	A Supply Chain Management (SCM) process that demonstrates an additional level of control of operational processes, contributing to the organization's overall competitiveness. Complying with P3 criteria contributes to the organization's long-term sustainability and/or competitiveness.

Classifications:	A	1) Compliance to all M criteria 2) A total score of 90% or higher	The organization is compliant in all key criteria and can demonstrate that the ergonomics processes in use at the facility are best practice. Annual assessments are carried out with the goal of ensuring sustainable and best practice processes. In support of continual improvement, the development of an action plan should be considered in order to eliminate any remaining unmet criteria.
	B	1) A total score greater than or equal to 75% and less than 90% 2) Compliance to at least 85% of M criteria	Although most of the fundamentals of risk and ergonomic management are demonstrated, the organization is deficient in several areas that compromises the efficiency of internal performance and may impact its ability to support the needs of the workers. An action plan should be developed and implemented in a timeframe that meets the needs of the business and its customer(s).
	C	1) A total score less than 75%	The organization is deficient in one or more key areas of Ergonomics. The situation creates a high work risk and demonstrates a lack of efficiency and control of internal processes within the existing ergonomics strategy. Management commitment will be required to create, prioritize and implement action plans in a timely manner to avoid serious or prolonged issues with the customer.

Scoring Summary - Chapter Details

Chapter No	Requirement No	Result (Criteria scored x Weight of criteria)																Actual Score	Max Score	% Comp	Assessor's Name	Verifier's Name
		1	Weight	2	Weight	3	Weight	4	Weight	5	Weight	6	Weight	7	Weight	8	Weight					
1	1.1.1	1	M	0	A	1	D	0	D									4	7	57%		
	1.2.1	1	A	1	A	1	A											6	6	100%		

Chapter Summary

	D	A	M
Compliant	1	3	1
Non Compliant	1	1	0

Total Chapter 1	
Actual Score	10
MAX Score	13
% Compliant	77%

Chapter No	Requirement No	Result (Criteria scored x Weight of criteria)																Actual Score	Max Score	% Comp	Assessor's Name	Verifier's Name
		1	Weight	2	Weight	3	Weight	4	Weight	5	Weight	6	Weight	7	Weight	8	Weight					
2	2.1.1	1	M	1	D	1	A	1	D									7	7	100%		
	2.2.1	1	D	1	A	1	A											5	5	100%		
	2.3.1	1	A	0	D													2	2	100%		

Chapter Summary

	D	A	M
Compliant	3	4	1
Non Compliant	1	0	0

Total Chapter 2	
Actual Score	14
MAX Score	14
% Compliant	100%

Chapter No	Requirement No	Result (Criteria scored x Weight of criteria)																Actual Score	Max Score	% Comp	Assessor's Name	Verifier's Name
		1	Weight	2	Weight	3	Weight	4	Weight	5	Weight	6	Weight	7	Weight	8	Weight					
3	3.1.1	1	M	0	A	0	A	0	D	1	A							5	10	50%		
	3.2.1	1	A	1	A													4	4	100%		

Chapter Summary

	D	A	M
Compliant	0	3	1
Non Compliant	1	2	0

Total Chapter 3	
Actual Score	9
MAX Score	14
% Compliant	64%

Chapter No	Requirement No	Result (Criteria scored x Weight of criteria)																Actual Score	Max Score	% Comp	Assessor's Name	Verifier's Name
		1	Weight	2	Weight	3	Weight	4	Weight	5	Weight	6	Weight	7	Weight	8	Weight					
4	4.1.1	1	A	1	M	1	M	0	A	1	D	1	D					10	12	83%		
	4.1.2	1	M	1	A	1	A	1	A	1	A	1	A	1	D	1	D	15	15	100%		

Chapter Summary

	D	A	M
Compliant	4	6	3
Non Compliant	0	1	0

Total Chapter 4	
Actual Score	25
MAX Score	27
% Compliant	93%

Chapter No	Requirement No	Result (Criteria scored x Weight of criteria)																Actual Score	Max Score	% Comp	Assessor's Name	Verifier's Name
		1	Weight	2	Weight	3	Weight	4	Weight	5	Weight	6	Weight	7	Weight	8	Weight					
5	5.1.1	1	M	1	A	1	A											7	7	100%		
	5.2.1	0	M	0	A	0	D											0	6	0%		

Chapter Summary

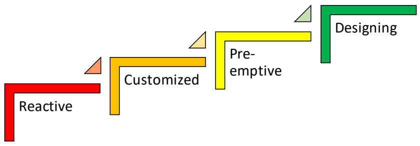
	D	A	M
Compliant	0	2	1
Non Compliant	1	1	1

Total Chapter 5	
Actual Score	7
MAX Score	13
% Compliant	54%

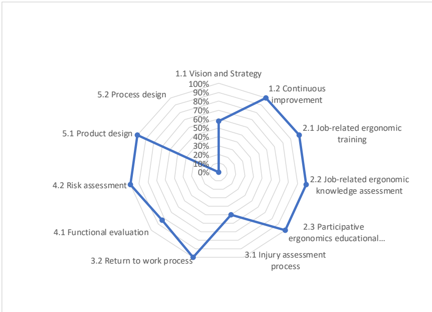
TOTAL score	**65**
Maximum Score	**81**
%	**80%**

	D	A	M	Σ
Compliant	8	18	7	33
Non Compliant	4	5	1	10
Σ	12	23	8	43

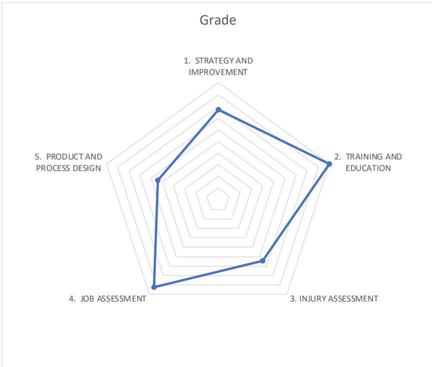
Classification
B



	Radar Chart - by Subchapter	
1.1	1.1 Vision and Strategy	57%
1.2	1.2 Continuous improvement	100%
2.1	2.1 Job-related ergonomic training	100%
2.2	2.2 Job-related ergonomic knowledge assessment	100%
2.3	2.3 Participative ergonomics educational process	100%
3.1	3.1 Injury assessment process	50%
3.2	3.2 Return to work process	100%
4.1	4.1 Functional evaluation	83%
4.2	4.2 Risk assessment	100%
5.1	5.1 Product design	100%
5.2	5.2 Process design	0%



	Radar Chart - by Subchapter	Grade
1	1. STRATEGY AND IMPROVEMENT	77%
2	2. TRAINING AND EDUCATION	100%
3	3. INJURY ASSESSMENT	64%
4	4. JOB ASSESSMENT	93%
5	5. PRODUCT AND PROCESS DESIGN	54%



Annex 7 CV and the Publications List

ANCA MOCAN
Supply Chain and Process improvement engineer

anca.mocan@student.upt.ro; ancamocan2003@yahoo.com

WORK HISTORY

Practice Lead *Brussels, Belgium*
Amaris *Sep 2019 to Present*
Responsible for qualifying and implementing process improvement projects worldwide
Contacting customers to present the Amaris process improvement offers
Technically qualifying process improvement needs
Creation of personalized offer
Implementation and follow up of the project

Senior Consultant *Brussels, Belgium*
Amaris *Jan 2017 to Present*
Supply Chain and Process Improvement consultant in the automotive and public transportation industry.
From 08/2019 To 01/2020 Logistics planning and methods Customer: Audi
From 01/2019 To 08/2019 Supplier relationship manager Customer: Volvo Trucks
From 05/2018 To 12/2018 Project manager process improvement Customer: Bombardier
From 02/2017 To 12/2018 Technical buyer metal and C parts Customer: Bombardier

Supply Chain Analyst *Brussels, Belgium*
Bridgestone Europe *Nov 2014 to Dec 2016*
Product industrialization management for OE developments in the European factories
Management of new product introduction by balancing RandD input with Business strategy
Liaising between the Key Account managers needs and the logistics deployment team
Managing production facility and development engineering constraints
Updating production sourcing and sales and operation planning databases based on cross-functional team meetings

Student tutor *Vienna, Austria*
Wirtschaftsuniversitat Wien *Sep 2013 to Jul 2014*
Educational support for the students of the Supply Chain Management master's course
Working together with the course professor and assistant to shape the syllabus
Creating and correcting student homework assignments
Liaison between students and teaching staff
Helping students understand the course material and prepare for the exam

Junior Consultant *Timisoara, Romania*
Expert Consulting *Sep 2008 to Jul 2012*
Administrative support in a small business consultancy firm
Maintaining and updating information of the firm's website
Creating promotional materials for the firms within the Expert Consulting group, including the trademark sign for Expert International and Expert Consulting Company
Translation of documents from and into English, French and Romanian

EDUCATION

GoLeanSixSigma *Brussels, Belgium*
Black Belt *2018*
Axelos *Brussels, Belgium*
Prince2 Foundation Qualification *2017*
TUV Rheinland
ISO 9001 Internal auditor *2010*
Wirtschaftsuniversitat *Vienna, Austria*
Masters in Supply Chain Management *2012 to 2014*
Politehnica University *Timisoara, Romania*
Faculty of Management in Production and Transportation *2008 to 2012*
Engineer
(specialization Industrial Engineering and economics)

TECHNICAL SKILLS

Industrialization and production: lean, six sigma, data driven evaluation
Project Management: design, scheduling, risk management, negotiation, quality management, budgeting, monitoring and controlling
Supply Chain and Logistics: warehouse design, global supply chain design, sourcing strategy
Process analysis and re-modelling: process modelling, to-be business procedures, process information documentation, business process optimization

LANGUAGE SKILLS

- Romanian-Native
- English-Fluent
- French-Fluent
- Dutch-Fluent
- German-Fluent

SOFTWARE/SYSTEM SKILLS

Microsoft office, Minitab, Gephi
SAP: ERP, SMP, VMI, VCM

LISTA PUBLICAŢIILOR REZULTATE ÎN URMA CERCETĂRII DOCTORALE (PUBLICATE SAU ACCEPTATE SPRE PUBLICARE SUB AFILIERE UPT)

MSc. Ing. Anca MOCAN

1. Lucrări ştiinţifice publicate în reviste indexate ISI

1. Cirjaliu, B., **Mocan, A**., Boatca, M. E., and Draghici, A. (2019). A propose approach for continuous improvement using ergonomics and quality management knowledge and methodologies, Quality-Access to Success / Calitatea: Acces la Success, vol. *20* (Supplement 1), 135-140 (WOS:000459686300024).

2. Lucrări ştiinţifice publicate în volumele unor manifestări ştiinţifice (Proceedings) indexate Web of Science- WoS (ISI) Proceedings

1. **Mocan, A.**, and Draghici, A. (2018). Participatory ergonomics training for a warehouse environment - a process solution. In: Arezes, PM; Baptista, JS; Barroso, MP; Carneiro, P; Cordeiro, P; Costa, N; Melo, RB; Miguel, AS; Perestrelo, G (Eds.), Occupational Safety and Hygiene VI (pp. 19-22), Proceedings of the 6th International Symposium on Occupational Safety and Hygiene (SHO), 26-27 March, Guimaraes, PORTUGAL. CRC Press. (WOS:000460606900004)
2. **Mocan, A.,** Draghici, A., and Mocan, M. (2018). Ergonomics in Train Transportation within Belgium. In: Soliman, KS (Ed.), Proceedings of the 32nd International Business Information Management Association Conference (IBIMA), (pp. 247-255), Nov. 15-16, 2018, Seville, Spain, IBIMA Publishing. (WOS:000508553200021)
3. **Mocan, A.**, Daniel, Ș. C., and Draghici, A. (2017, September). Analyzing Warehouse Ergonomics Using Smart Textiles. In: Hajek, P; Vit, O; Basova, P; Krijt, M; Paszekova, H; Souckova, O; Mudrik, R (Eds.), Proceedings of the International Conference of Central-Bohemia-University, CBUIC (22-24 March, Prague, Czech Republic), vol. 5, pp. 1181-1184 (WOS:000439408200206)
4. Draghici, A., Ivascu, L., Gaureanu, A., and **Mocan, A**. (2017). The ergonomics interventions evaluation. A study based on usability. In: Bondrea, I; Simion, C; Inta, M (Eds.), Proceedings of the 8th International Conference on Manufacturing Science and Education (MSE 2017) - Trends in New Industrial Revolution (07-09 June 2017, Sibiu, Romania), MATEC Web of Conferences (Vol. 121, p. 11008). (WOS:000435283800127)

3. Lucrări ştiinţifice publicate în reviste de specialitate indexate BDI

1. Paschek, D., **Mocan, A.**, Dufour, C. M., and Draghici, A. (2017, December). Organizational knowledge management with Big Data. The foundation of using artificial intelligence. Balkan Region Conference on Engineering and Business Education, vol. 3(1), pp. 301-308. De Gruyter Poland (eISSN: 2391-8160).

(SCOPUS, EBSCO, Google Scholar, ProQuest etc.) doi: https://doi.org/10.1515/cplbu-2017-0039

2. **Mocan, A.**, Draghici, A., and Mocan, M. (2017). A way of gaining competitive advantage through ergonomics improvements in warehouse logistics. Research and Science Today, no. 2/2017 (eISSN 2285-9632). (DOAJ, EBSCO, ProQuest, CEEOL, EconPaper, Index Copernicus etc.)
3. Bere–Semeredi, I., and **Mocan, A.** (2019). A review of the Europe indicators on climate change-industry, innovation and infrastructure, 9th International Conference on Manufacturing Science and Education – MSE 2019 "Trends in New Industrial Revolution" (Sibiu, Romania), MATEC Web of Conferences, vol. 290, p. 06001 (eISSN: 2261-236X), EDP Sciences. (EBSCO, Google Scholar, Inspec, DOAJ etc.) https://doi.org/10.1051/matecconf/201929006001
4. **Mocan, A.**, and Draghici, A. (2019). Automation possibilities in a low rotation warehouse of a Belgian manufacturing plant. A case study, 9th International Conference on Manufacturing Science and Education – MSE 2019 "Trends in New Industrial Revolution" (Sibiu, Romania), MATEC Web of Conferences, vol. 290, p. 02006 (eISSN: 2261-236X), EDP Sciences. (EBSCO, Google Scholar, Inspec, DOAJ etc.) https://doi.org/10.1051/matecconf/201929002006
5. Neag, P. N., Ivascu, L., **Mocan, A.**, and Draghici, A. (2020). Ergonomic intervention combined with an occupational and organizational psychology and sociology perspectives in production systems, 9th International Symposium on Occupational Health and Safety (SESAM 2019, Petrosani, Romania), MATEC Web of Conferences, vol. 305, p. 00031) (eISSN: 2261-236X), EDP Sciences. (EBSCO, Google Scholar, Inspec, DOAJ etc.) https://doi.org/10.1051/matecconf/202030500031
6. **Mocan, A.**, and Draghici, A. (2018). Reducing ergonomic strain in warehouse logistics operations by using wearable computers, Prostean G., Bakacsi G., Leduc S., Brancu L. (Eds.), Proceedings of the 14th International Symposium in Management (SIM 2017) - Challenges and Innovation in Management and Entrepreneurship, Procedia-Social and Behavioral Sciences, 238, 1-8 (ISSN 1877-0428). (SCOPUS, Google Scholar, ScienceDirect) https://doi.org/10.1016/j.sbspro.2018.03.001

4. Lucrări ştiinţifice publicate în volumele unor manifestări ştiinţifice (Proceedings) indexate BDI

1. **Mocan, A.**, and Draghici, A., (2019) Maximizing data gathering opportunities by using fitness trackers during ergonomic assessments - a case study, Proceedings of the MakeLearn and TIIM International Conference 2019 - Thriving on Future Education, Industry, Business and Society (MakeLearn and TIIM 2019), pp. 95-102, ToKnowPress (EconPaper, RePEC, Google)
2. Paschek, D., **Mocan, A.**, and Draghici, A. (2019). Industry 5.0 – The Expected Impact of Next Industrial Revolution, Proceedings of the MakeLearn and TIIM International Conference 2019 - Thriving on Future Education, Industry, Business

and Society (MakeLearn and TIIM 2019), pp. 125-132, ToKnowPress. (EconPaper, RePEC, Google)

3. Gaureanu, A., **Mocan, A.**, Weinschrott, H., and Dufour, C. (2017). A proposed model for evaluate organizational safety culture, Management Challenges in a Network Economy: Proceedings of the MakeLearn and TIIM International Conference 2017 (MakeLearn and TIIM 2017), pp. 285-292, ToKnowPress (EconPaper, RePEC, Google)
4. Feniser, C., Jitarel, A., **Mocan, A.**, and Draghici, A. (2017). Aspects Related to Business Ethics for Small and Medium Size Companies in Romania. In Management Challenges in a Network Economy: Proceedings of the MakeLearn and TIIM International Conference 2017 (MakeLearn and TIIM 2017), pp. 597-604, ToKnowPress (EconPaper, RePEC, Google)
5. Bejinariu, A. C., Jitarel, A., Sarca, I., and **Mocan, A**. (2017). Organizational Change Management–Concepts Definitions and Approaches Inventory. In Management Challenges in a Network Economy: Proceedings of the MakeLearn and TIIM International Conference 2017 (MakeLearn and TIIM 2017), pp. 321-330, ToKnowPress. (EconPaper, RePEC, Google)
6. **Mocan, A**., Draghici, A. (2019). A proposed ergonomics maturity level framework and assessment tool for easy business application, In Springer Proceedings in Business and Economics from 2019: 15th International Symposium in Management. (in curs de publicare și indexare Springer)

5. Lucrări ştiinţifice publicate în volumele unor manifestări ştiinţifice internaţionale (Proceedings) din străinătate

1. **Mocan A.**, Draghici A. (2016). Ergonomic Design Responsibility in the Engineering Field. A Case Study, 7th International Ergonomics Conference ERGONOMICS 2018 – Emphasis on Wellbeing June 13-16, 2018, Zadar, Croatia. Published under the Croatian Ergonomics Society, Zagreb, Croatia (ISSN 1848-9699, available at the National and University Library in Zagreb), Printed by: Tiskara Zrinski d.d., Cakovec, pp. 275-282.