Università Politecnica delle Marche

Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria

Corso di Dottorato in Ingegneria Industriale

Developing sustainable manufacturing in the era of IoT: a methodology to achieve social sustainability in connected factories

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XXX edition – new series

Università Politecnica delle Marche

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Corso di Dottorato in Ingegneria Industriale

Manifattura sostenibile nell'era digitale: una metodologia per garantire la sostenibilità sociale in impianti produttivi connessi

Tesi di Dottorato di:

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to Monica

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Finally, I think that what matters most in life is happiness. Both in workplaces or at home. The latter simple statement pushed this work, beyond the Industry 4.0 and the sustainable manufacturing topics. The Research has the role to improve human development and guarantee the best places to live both on this Earth and elsewhere.

Ancona, November 2017

Abstract

One of the most actual and consistent driver for industry is sustainability. This topic opens at different problems according to the three sustainability pillars: environment, costs, people. Regarding the last sustainability pillar, the social one, there is a lack for methodologies and tools to assess in an objective way social relapses of product, processes or services on human.

Moreover, industries are crossing today a crucial transition in terms of technologies. The so called fourth industrial revolution is ongoing. This is a second challenge for industries that need to be competitive reducing their time to market integrating new technologies on their production sites.

From these perspectives, this work aims at highlighting the role of the humans under the paradigm of the fourth industrial revolution. In particular, this work focuses on the development of methods and tools that permit a company to be more sustainable form a social point of view in the present era of digital manufacturing.

The first part of this document will be focused on the development of a method to estimate social impacts of a product (S-LCA).

The second part of the work is process oriented. A methodology to favour development of sustainable production systems is provided. The latter permits to design connected environment (IoT environments) aimed at measuring and promoting sustainability on production sites.

Each methodology will be tested by a case study for the related validation. The first case study is related to the S-LCA applied to an Italian industry. The second case study is related to the improvement of the productivity of a production

system passing by the increasing of the social sustainability of work places; here an IoT framework will assess the social sustainability of an Italian production site.

The main outcome of this work are two tools that a company should exploit to assess its production from a social point of view.

The work remarks the productivity-social sustainability binomial. If a social development is guaranteed in a production site even productivity should be positively affected. The binomial has a crucial role from the perspective of Industry 4.0 where the operator is requested newer competencies and skills.

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List of Abbreviations

ACGIH	Association advancing occupational and environmental health
AM	Additive Manufacturing
API	Application programming interface
BMI	Body mass index
BR	Breathing rate
CDM	Comfort design matrix
CPS	Cyber Phisical Systems
CVD	Cardiovascular diseas
DALYs	Disability Adjusted Life Year
EEG	Electroencephalogram
EFFRA	European Factory of the future research association
EOG	Electrooculographic potential
EoL	End of life
ERP	Enterprise resource planning
EU-28	European Union 28 member states
FOF	Factories of the future
HCD	Human centred design
HCL	Human centric lighting
HR	Heart rate
ICC	Industrial Internet Consortium
IoT	Internet of Things
ILO	International Labour Organization
ISO	International Organization for Standardization

LCA	Life Cycle Assessmet
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
MES	Manufacturing Execution System
MDU	Methylene diphenyl diisocyanate
MSD	Musculoskeletal disorders
MWL	Mental workload indicator
NDA	Non-disclosure agreement
OPA	Occupational physical activity
PPP	Public-Private Partnership (PPP)
PU	Polyurethane
S-LCA	Social Life Cycle Assessment
S-LCIA	Social Life Cycle Impact Assessment
TBL	Triple bottom line
UN	United Nations
UNEP	United Nations Environment Programme
VDT	Video terminal
VMU	Vector magnitude unit
VR	Virtual Reality
VOC	Volatile compounds
WBGT	Wet bulb globe temperature
WHO	World Health Organization

1. Introduction

This first part of the 21th century will be remembered as the “digital era”. The digital transformation is having a huge impact in every sector: economy, technologies, communication, society and industry. Going in deep with this last sector it is possible to identify the fourth industrial revolution, consisting in digitalization of processes. Technologies as VR equipment, cloud computing, AM systems are only a few of possibilities that are now available and quite mature for industrial applications.

This global transformation can’t neglect the main driver of development that governments has settled: sustainability. The latter is in fact the main driver of UN strategies for a proper development as stated by the 2030 Sustainable Agenda. Those drivers are particularly valid in the context of industries where few problems occur every day and resources needed to complete activities and realize products are increasing due to the increasing of demands.

Another actor of the present digital era is the IoT. The IoT market is having a huge impact on people; smartphone was the first approach between people and connected devices. Now connected phones are only the tip of the iceberg of the IoT revolution. Factories are now adopting IoT technologies moving towards the paradigm of connected factories. A connected factory is a manufacturing site where not only raw materials, energy or products flow within a plant. The new “flowing thing” are data. Data as already stated by few entrepreneurs are the “new gold”; a correct data management should mean a fast track to win.

Few companies are then riding this digital rush. Results are often huge amount of investments and technologies that are implemented in a manufacturing site without a proper growth strategy. Sometimes the introduction of innovations and new technologies do not directly mean a growth in terms of productivity. Moreover, there is another problem concerning with the digital transformation, it is the request of new competencies to manage digital systems within manufacturing. Workers become operators 4.0. Considering manufacturing systems, workers are now required new work competencies in order to define the new cyber physical systems. As stated by Cotet at al. in 2017 it is really challenging for a company to hire new people with competencies compliant to industry 4.0. In the same way it is difficult to understand if employers are compliant too. There is no a clear procedure to match people and Industry 4.0 needs. Nielsen et al. in 2017 underlined the complexity in implementing new CPS in a manufacturing system and big challenge of robot adaptability. Then, how it is possible to measure the performance of the new CPS and related human relapses? Which is the best way to develop a new manufacturing system, adopting 4.0 technologies that matches plant sustainable requirements?

The present work is aimed at matching sustainability and IoT in manufacturing site. The objective is to identify a methodology for a proper sustainable development of factories in this new manufacturing era, where Industry 4.0 is emerging. Two methodologies will be proposed concerning in particular the social sustainability pillar.

A clear state of the art on the concept of Industry 4.0 and sustainable manufacturing will be proposed. Then, there will be a specific attention on the concept of ergonomics. This is an important scientific basis for the present work. The ergonomics will be presented declined in all its aspects. Moreover, will be introduced the topic of social life cycle sustainability.

On the basis of the state of the art two new methodologies will be proposed.

The first method concerns products development. A S-LCA methodology will be developed in order to assess social relapses of a product during the whole life cycle. The method is based on semi-quantitative analysis that defines social scores. Through the method it is possible to measure the social sustainability that is an hard issue at the present. This method will be exploited to assess the social impact of a product developed though an EU Life+ project.

The second methodology proposes an approach to proper connect systems within a production site in order to produce data that should drive to sustainable innovations. The methodology proposes the IoT as the enabler of social development within a company. A structured methodology permit to implement an IoT framework within a production site in order to acquire data for sustainable assessments. The case study will focus on social sustainability; a real plant will be sensorized in order to measure performances of humans and inefficiencies of processes from a social sustainability perspective.

The work tends to demonstrate that Industry 4.0 can't neglect social issues. Social sustainability is strictly related to performance and a sustainable system should mean a more productive manufacturing site. The 4.0 technologies need to simplify life of humans; this should be also valid when dealing with production systems.

2. Research and background

2.1. Sustainable manufacturing

In 1999, Elkington in his book introduced the concept of TBL. He defines this concept, that incorporates the three sustainability pillars: environment, social and economic. These three aspects should be taken into account when dealing with sustainability. From an industrial perspective, this aspect should be declined for product, processes and services.

Sustainable manufacturing is aligned with the 17 sustainable development goals defined by UN in 2015 and reported on the 2030 Sustainable development Agenda. In particular goal 12 is related to the concept of sustainable consumption and production and focuses attention on energy efficiency. The same agenda defines the concept of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". A better understanding of environmental and social impacts of products and services is needed, both of product life cycles and how these are affected by use within lifestyles.

In this perspective companies have an important role in sustainable development and their production systems should be developed in respect of the latter statement.

The sustainable manufacturing has not a single definition and passes through different topics. Garetti and Taisch in 2012 recognized the "manufacturing", as the main pillar of the civilised lifestyle. It will be strongly affected by the sustainability issues playing an important role in establishing a sustainable way ahead. An interesting literature review about this topic was proposed by Moldavska and Welo in 2017.

Sustainable manufacturing is often driven by cost factors. It is well known that in the TBL perspective, the economic is the most important factor for companies. In the work of Asiedu and Gu of 1996 there is an interesting state of the art about the product life cycle cost analysis. This is the most relevant analysis when dealing with the economic pillar. Another approach to cost analysis was proposed in 2015 by Garbie. He proposes a model that permits enterprises optimize internal sustainability taking into account time and costs. Costs considered refers also to environmental and social aspects (e.g. cost for eliminating manufacturing pollution, time required to improve work management). However, cost it is not the most important pillar of the TBL and should not define completely the sustainable state of the art of a company.

In 2003 Kaebernick et al. argued about the environmental requirements related to product development and manufacturing. The Figure 1 from the latter document, sums a whole product life cycle, defining few methodologies for each stage that decision makers should adopt for a sustainable manufacturing. They focus on sustainable product development as a mix of methodologies that permits to lower the environmental impact of a product, passing by a cleaner production system or EoL sustainable strategies (e.g. reuse, recycle, etc.).

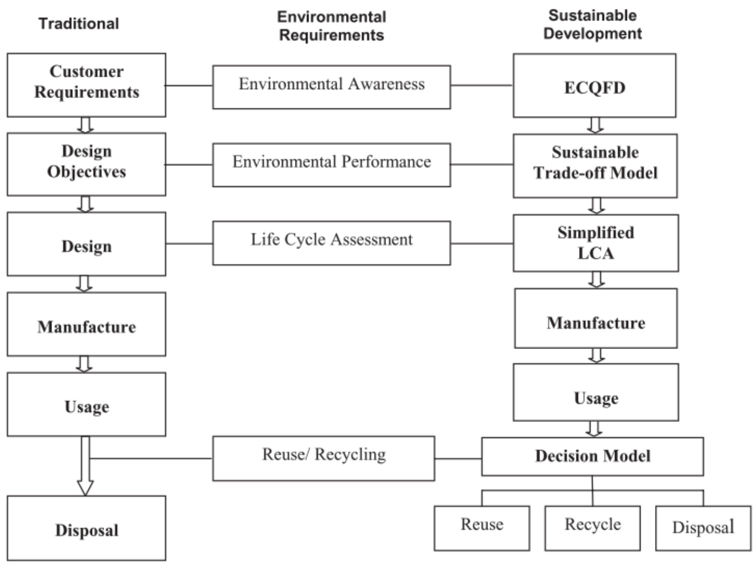

Figure 1. Stages of product lifecycle (Kaebernick et al., 2003)

In 2016 Rödger et al. proposed a Sustainability cone (Figure 2). It is a holistic framework to integrate sustainability thinking into manufacturing. The idea is to merge life cycle perspectives with product and production in order to optimize the latter in the early design stages.

In 2016 AlGeddawy focused on the energy management in the sustainable manufacturing perspective. The paper proposes a production design method that tends to optimize energy consumptions. The theme of environmentally sustainable manufacturing was also remarked by Zhai et al. in 2012. They propose a method that addresses the sustainability issues of manufacturing from a pollution prevention standpoint, considering the three key components of manufacturing: technology, energy, and materials.

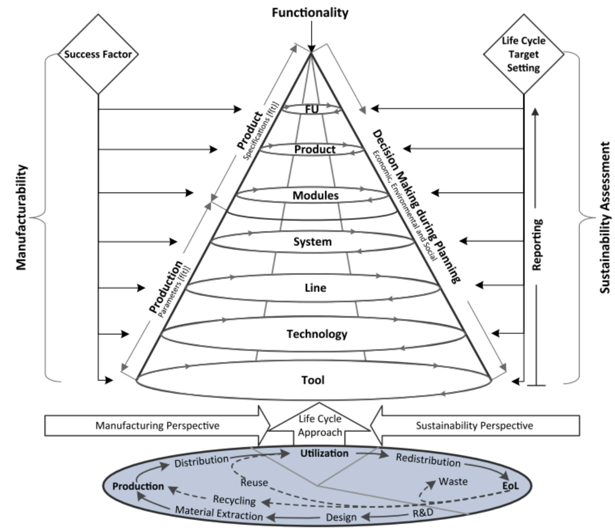

Figure 2. Sustainability cone (Rödger et al., 2016)

In 2014 Zink focuses on the needs of sustainable production system and argues about the topics should be considered. He focused mainly on human factors (the social pillar of TBL) defining that a correct design of a production system, from the perspective of sustainability, should include the human and social capital (e.g. skills, knowledge, health, motivation, participation, trustworthiness, identification). He also proposes a new triangle model of sustainability (Figure 3) that has 3 dimensions, including the time one. This model should clarify interdependencies between the three sustainability pillars.

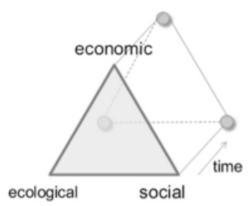

Figure 3. Sustainability triangle model (Zink, 2014)

The latter paper, takes also into account the work of Dochery et al. from 2009. The paper states that the opportunity to develop as a person, a professional and a member of a society through work experiences is a basic human right. It is also highlighted that the sustainability of human and social resources is one of the foundations of economic sustainability. Finally, sustainability at work is one of the foundations for social development and sustainability of whole societies. Sustainability of human and social resources is needed to secure ecological sustainability, because only people and groups who operate sustainably are able to grasp, prioritize, and work to- ward ecological sustainability. Human factors are considered as well in the work of Siemieniuch et al. of 2015. They explored the impact of global drivers (e.g. population demographics, food security; energy security; community security and safety). They stated the important role of sustainability engineering to mitigate these. They remarked the central part of human even looking forward to the factory of the future.

In general, independently to the driver, sustainable manufacturing should create great value for a company as stated by Badurdeen and Jawahir in 2017. The latter work presented a procedure to evolve the manufacturing strategies, according to sustainable principle in order to gain value in a company.

Song and Moon in 2016 focused the discussion on new technologies system. They discussed about the benefit of cyber manufacturing systems and their role in the future development.

Finally, in the work of Stock in 2016 is remarked the opportunities of sustainable manufacturing in the context of Industry 4.0. He stated that the paradigm Industry 4.0 will be a step forward towards more sustainable industrial value creation. He argues about several aspects around the sustainability topic and focuses also on the social dimension. He remarked that the ICT technologies could increase value creation for workers, improving their social sustainability and productivity. This opinion is one of the ideas that stimulated the present work.

This idea completely matches the EU strategies from the sustainable manufacturing perspective. Taking into account the FoF 2020 multi-annual roadmap (EU, 2013) it is clear that manufacturing is a key enabler for Europe's grand societal challenges. Challenges passes through sustainability pillars. Economic sustainability will require a redesign of products and production processes respecting the manufacturing conditions and strengths of Europe. From an environmental point of view, reducing the consumption of energy, while increasing the usage of renewable energy, is crucial as nearly one third of global energy demand and CO2 emissions are attributable to manufacturing (European Community, 2009). This requires considering energy efficiency from a more systematic point of view in the design phase of manufacturing equipment. This also requires consideration of the factory-level and the exploitation of innovative energy-efficient actuators and components to their full extent while also considering the entire supply chain, from raw material manufacturing stages up to the final component manufacturing process. Social topic is also considered in the document.

According to the FOF Multi Annual roadmap, the Europe 2020 strategy emphasises the need for organising and designing manufacturing in a way which ensures that manufacturing enterprises will remain socially sustainable while still achieving global competitiveness. To resolve these issues, interdisciplinary research and innovation is needed to provide the basis for the design of adequate manufacturing environments and workplaces. The balance between cost-efficient automation and intelligent use of human capacities in manufacturing will determine the choice for future production and factory location. Efforts are needed to design factory processes for locations that used to be high-labour costs regions, e.g. Europe. To achieve competitive and sustainable manufacturing here, performance must be radically increased by smart and semi-automated manufacturing systems.

This is why the sustainable production has to meet the digital technologies proper mix.

The key role of sustainability in manufacturing was underlined by EFFRA in 2016. In fact, they described the following as a set of key priorities for the FoF 18-19-20 Work Programme:

- Agile value networks: Lot-size one – distributed manufacturing;
- Excellence in manufacturing: Advanced manufacturing processes and services for zero-defect and innovative processes and products;
- The human factor: Developing Human competences in synergy with technological progress;
- Sustainable value networks: Manufacturing driving the circular economy;
- Interoperable digital manufacturing platforms: supporting an eco-system of manufacturing services.

2.2. The Industry of things

In 2013 McKinsey Global institute developed a report where defined the IoT as one of top three technological advancements of the next decade (together with the mobile internet and the automation of knowledge work). There are several definitions of IoT, according to the review of Madakam in 2015, but the first and most recognized is the one stated by Kevin Ashton in 1999 where he defines IoT as a network that not only connects people, but also the objects around them. This network has resulted the expansion of the connected device market. Gartner, Inc. in 2016 forecasted that 8.4 billion connected things will be in use worldwide in 2017, up 31 percent from 2016, and will reach 20.4 billion by 2020. Total spending on endpoints and services will reach almost $2 trillion in 2017. This idea, according to the IoT Analytics study of 2014, should have relapses in several sectors such as home, industries, health, manufacturing, cities (Figure 4). In recent years, concepts as smart cities, smart wearables and smart industries have been widespread. Focusing on the industrial applications, IoT has enabled the Industry 4.0, the so-called industry of things.

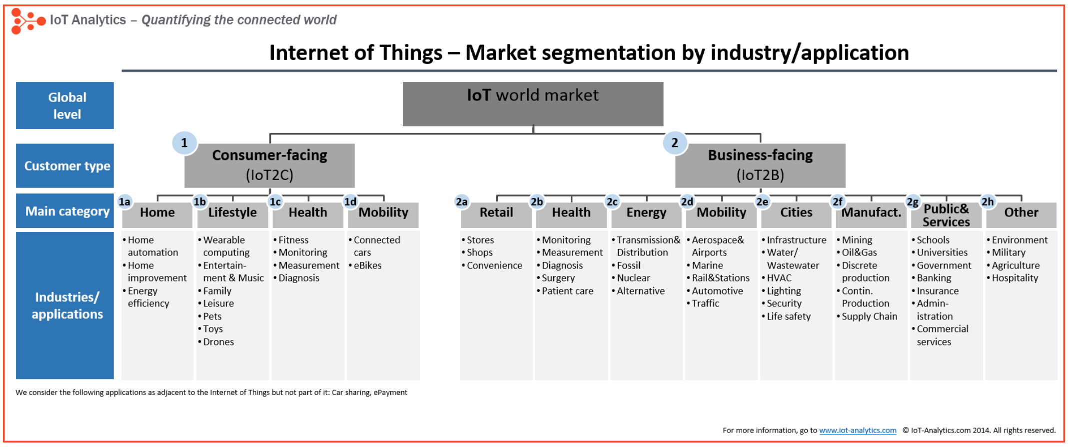

Figure 4. IoT market segmentation (IoT Analytics report, 2014)

In 2011 Kagerman introduced a paradigm with the name "Industrie 4.0". With Industry 4.0 it is defined the fourth industrial revolution consisting in connection between physical and digital systems in a factory. This opens to CPS that are engineered systems that built from, and depend upon, the seamless integration of computational algorithms and physical components. This was the very beginning of a new manufacturing era, with a shift of attention in many different contexts. Policies, founding framework opened to the opportunities set from this industrial revolution. At European level, we could find the PPP for FoF, EFFRA, in US there is the ICC. In Italy, there is the "Piano Industria 4.0" where guidelines and national target for industries were defined.

Industry 4.0 was discussed in the work of Zezulka et al. in 2016. They summed the importance of the phenomenon for principally three factors: digitization and integration of any simple technical – economical relation to complex technical – economical complex networks, digitalization of product and services, new market models.

The work of Hermann et al. in 2016 clearly define design principles for the Industry 4.0. In their review, they clustered the nine most common topic that Industry 4.0 tends to revolution; these are interconnection, collaboration, security, data analytics and more. These are the plans where the challenge of the industrial revolution will propagate. The collaboration one is will be an important focus for that work.

The new paradigm, in fact, is changing the traditional manufacturing relationship within a plant. The Figure 5 show the fourth transition in terms of relationship between human and processes. Today many operators are involved in the manufacturing system and only a few, designers and managers, are outside the workshop. The present revolution proposes a new scenario were fewer operators are directly involved on the process and more people have to manage data of processes. This new kind of interaction opens to new competencies. Two of these were explained in 2015 on the report of Boston Consulting Group. There is a need of Industrial Data Scientist and Robot Coordinator. The first extract and prepare data, conduct advanced analytics, and apply their findings to improve products or production. The second figure require competencies to oversee robots on the shop floor and respond to malfunctions or error signals. These are only a few of the competencies required for the digital industry that, according to the latter paper, will affect the evolution of 40 job families in 23 industries. Those data follow the EU Agenda of Europe stats. In 2013 32 million people were employed in the manufacturing sector as a whole across the EU – 28. By 2025 the number of jobs in manufacturing as a whole requiring high - level qualifications is projected to rise by 1.6 million. Automation of production processes will see the number of low - and medium - skilled jobs decrease by over 2.8 million. 90 % of jobs will require some level of digital skills whatever the sector; all jobs will change and many will disappear. 40 % of enterprises trying to recruit ICT professionals have difficulty doing so (EU Commission, 2017).

Then, the integration of CPS within the plant is a very crucial point in this new manufacturing paradigm and the principal actor of this challenge is the human. Multiple robot interactions are reported in Figure 6. The latter figure describes the transition from Industry 2.0 (assembly line), passing to Industry 3.0 (Robot Automatization), toward 4.0 (CPS). CPS were argued by Lee et al. in 2015. In that paper was discussed a 5 levels structure for a proper integration within a plant. They in fact underlined the importance of a validation at a configuration level in order to assess the real added value of the system that should interoperate with the whole system. Even Shariatzadeh et al. in 2016 argued about the integration of digital model within the factory. The paper proposes an approach to achieve interoperability of the systems within the plant.

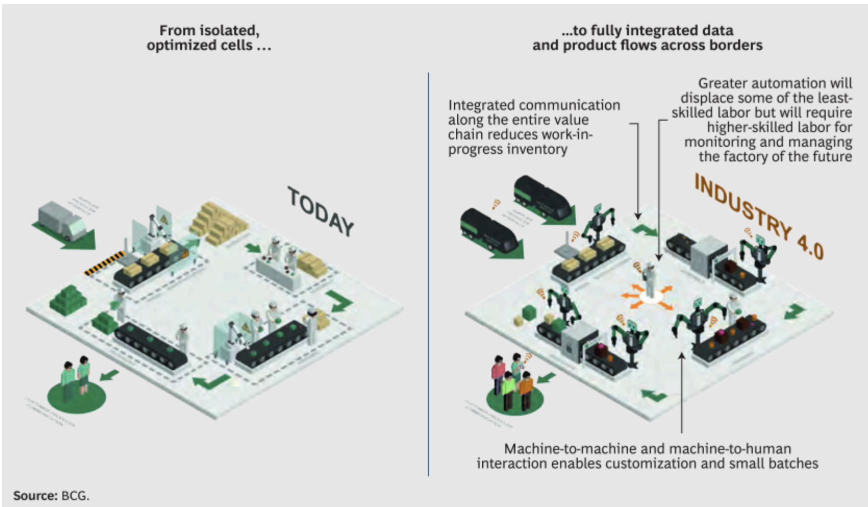

Figure 5. Manufacturing interactions (BCG, 2015)

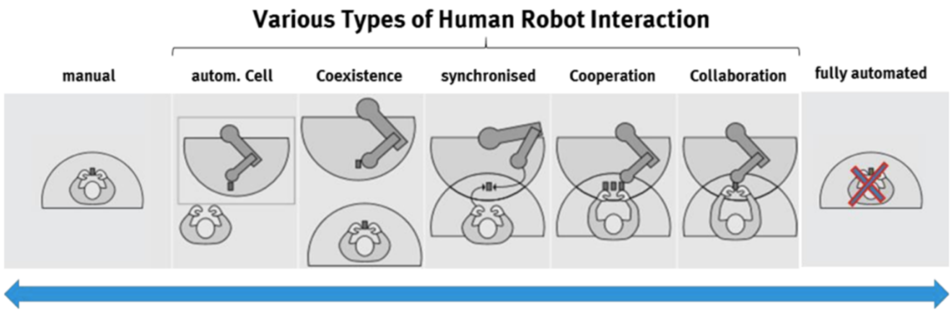

Figure 6. Multiple robot interactions (Festo AG & Co. KG, Manufuture 2017)

Another concept that walks together the industry 4.0 is the Smart Factory topic. This concept was defined in 2010 by Zuehlke. The document argues about a pilot factory where cabling is no longer required. This embed the concept of a plant where smart object interacts toward a factory-of-things. For making a factory-of-things work all elements must become smart, i.e. they must offer a thin web server functionality to act as a service provider in a factory network. Besides the evaluation of the various embedded sensors (e.g., temperature, brightness, humidity, speed, acceleration, location), in the plant are recorded all relevant product and operating data and, in the sense of an Internet of things, exchanging this information with other products, with their surroundings, and even the users. The vision for this future factory is also named ‘‘Digital Factory’’. The vision of digital factory will drive the method that is proposed below where an approach to define the factory of the future will be defined.

In the recent era, the IoT applied in industry is also called the Industrial Internet of Things. Jeschke et al. in 2017 summed up in their chapter many works arguing about this concept. In particular, few important topics emerged: CPS modelling, Communication and Networking, Artificial Intelligence and Analytics, and Evolution of Workforce and Human-Machine-Interaction. There are also few industrial case studies such as the one in that chapter from General Electric about their concept of brilliant factory. The brilliant factory is a mix of digital technologies and Lean principles; it tends to be the model for future application in the IIoT perspective. Another example of IIoT is the Scharnhausen Technology Plant FESTO. In that plant FESTO tried to collect few principles of Industry 4.0 such as human and robot collaboration, transparency in data, flexible manufacturing. These examples demonstrated that there is no a single formula to perform Industry 4.0 actions.

In literature are not present work that states how to develop connected factories in compliance with human workers. The Table 1 reports few recent works and related topics according to human - Industry 4.0 relationship.

Table 1 – Topics of interest on human - Industry 4.0 relationship

Authors	Title	Year	4.0 Skills	Aging workers	Smart technologies for manufacturing	Human-CPS evaluation	Human centred design for manufacturing	Augmented/ Virtual reality
Peruzzini and Pellicciari	A framework to design a human-centred adaptive manufacturing system for aging workers	2017		x			x	
Pacaux-Lemoine et al.	Designing intelligent manufacturing systems through Human-Machine Cooperation principles: A human-centered approach	2017		x			x	
Ras et al.	Bridging the Skills Gap of Workers in Industry 4.0 by Human Performance Augmentation Tools – Challenges and Roadmap	2017	x				x	x
Caputo et al.	Human Posture Tracking System for Industrial Process Design and Assessment	2018				x	x	

Authors	Title	Year	4.0 Skills	Aging workers	Smart technologies for manufacturing	Human-CPS evaluation	Human centred design for manufacturing	Augmented/ Virtual reality
Venkatapathy eta al.	Human Machine Synergies in Intra-Logistics: Creating a Hybrid Network for Research and Technologies	2017					x	
Gershwin	The future of manufacturing systems engineering	2017					x	
Kharchenko et al.	Emerging curriculum for industry and human applications in Internet of Things	2017	x					
Rajnai et al.	Labor market risks of industry 4.0, digitization, robots and AI	2017	x					
Assunta et al.	Man-CPS interaction: An experimental assessment of the human behavior evolution	2017				x	x	
Illankoon et al.	Identifying Significance of Human Cognition in Future Maintenance Operations	2018				x		
Bauer et al.	Working Life Within a Hybrid World – How Digital Transformation and Agile Structures Affect Human Functions and Increase Quality of Work and Business Performance	2018				x	x	
Longo et al.	Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context	2017			x	x		
Gorecky et al.	Human-Machine-Interaction in the Industry 4 . 0 Era	2014				x		x
Chryssolouris et al.	Manufacturing systems: Skills & competencies for the future,	2013	x					
Hao et al.	The role of wearable devices in meeting the needs of cloud manufacturing: A case study	2015			x			x

				4.0 Skills	Aging workers	Smart technologies for manufacturing	Human-CPS evaluation	Human centred design for manufacturing	Augmented/ Virtual reality
Authors	**Title**	**Year**							
Hwang et al.	Developing performance measurement system for Internet of Things and smart factory environment	2017				x			
Kõrbe Kaare	Smart health care monitoring technologies to improve employee performance in manufacturing	2015				x			

It has to be noted that the most of them argues on the human centred design topic. This confirm the importance of the present work that tends to define a structured method to design CPS according to operators needs. The present work will have a focus on human sustainability and CPS relapses for human. For this reason, it is introduced below a state of the art on ergonomics and related norms. This information will be propaedeutic for the application of the method in a social context.

2.3. Ergonomics and related Norms

2.3.1. Ergonomics and social sustainability

Many companies, nowadays, have shifted their point of competitiveness view on sustainability, considering it as a significant component of the operational strategies. The new philosophical asset of the organization needs to integrate economic, environmental, and social aspects of the production processes (Jasiulewicz-Kaczmarek, 2013).

Social sustainability is characterised by concepts such as preventive occupational health and safety, human-centred design of work, empowerment, individual and collective learning, employee participation, and work-life balance. All these concepts aim to preserve or build up human capital, and they represent a conscious way to deal with human resources.

Ergonomics is one of the principle aspects integrated into the health and safety requirements.

The principle normative institution reference about ergonomics is the ISO. The latter proposes a series of norms presenting the general ergonomics approach and specifies basic ergonomics principles and concepts. The term ergonomics concerned with the study of work to fit with people. Workers come first, considering their capabilities and limitations. Ergonomics can be also considered as an approach adapting tasks, work stations, tools, and equipment to fit the worker, it can help reduce physical stress on a worker's body and eliminate many potentially serious, disabling work-related MSDs or cognitive and mental workload.

ISO 26800:2011 brings together in one document the basic principles and concepts of ergonomics. In everyday life activity and products ergonomics principles are almost same. Those principles are essential to the design process to integrate the human actors and needs in the design phase. The latter standard describes the ergonomics principles to improve safety, functionality and the use of products in terms of efficacy, efficiency and personal satisfaction providing human wellbeing. The ISO standard provides the ergonomics and HCD requirements to understand the importance and relevance in the design process. Machinery designers have a wide list of standards one of those is the ISO 12100:2010, which specify basic terminology, principles and a methodology for achieving safety in the design of machinery.

The same does the Safety Machinery Standards which are specific to each machinery design considering ergonomics as one of the requirements to guarantee workers' safety and adequate health conditions. Following the standard, workers' health and safety working conditions are achieved including in the design process the essential ergonomics requirements.

All those aspects are not just related to machinery but also to the whole working environment. In fact, ergonomics can be extended to the entire organization every time human factors are involved into the design production process. Machineries are a part of the working environment and characterised it as well as the plant layout, job design and working organization.

Ergonomics is a multiple factor notion in which physical ergonomics, cognitive ergonomics and social or organizational ergonomics live together.

Those three mainstays suggest the integration of ergonomics in the design of a production system.

Human factors parameters in machinery design are respected when respond positively to the ergonomics assessment. Ergonomics concern physical and cognitive aspects. Ergonomic design comprehends both physical and cognitive elements based on the job design, instructions, warnings, man-machine relationships, operation, height, layout, lighting, controls, layout, clarity and interactions.

2.3.2. Physical ergonomics

Physical ergonomics concerns with the study of the relation between anthropometric, physiological and biomechanical characteristics, and the dynamic, or static, parameters of physical effort at work. The most significant features include safety and health risk factors such as working postures, materials handling, repetitive movements, which are possible causes of the work-related musculoskeletal disorders (Karwowski, 2006).

Ergonomic exposures typically include hazards based on physical demands and changes in work organization (i.e. work schedules, work teams, work locations).

The importance of those risk factors is due to their association with the probability of workers to go through work-related physical functional impairment. Silverstein in 1987 examined the relationship between force and repetition in industrial job tasks. Researchers found that workers in high-force, high-repetition jobs were 15 times more likely to have developed carpal tunnel syndrome than workers in low-force, low-repetition jobs. This study formed a basis for examining case definitions, methods, and interpreting results relative to MSDs exposures. A later compilation of well-documented research attributed the high prevalence of MSDs to job tasks involving postural loads at the neck and shoulders, awkward postures, and long hours of repetitive and static work along with organizational factors (Bernard, 1997).

A healthy and safe workplace, machinery or workstation should be designed for and around people. The concept of "human centred design" takes into account the needs and limitations of the people who occupy them. Human factors issue is a topic of workplaces which focuses on a range of elements including ergonomics, workplace safety, the reduction of human error, product design, human capability and human-computer interaction.

MSDs which include back pain, arthritis, bodily injuries and osteoporosis, are re-ported by people more than any other health condition. In 2016 in Italy, the MSDs complaints was about 40000 of the total 60000 occupational diseases complaints (INAIL, 2016). Furthermore, MSDs have one of the most invalidating consequences in terms of DALYs. Work-related adverse health effects which cause the most loss of life years in the whole EU-28 have been classified in cancers, followed by muscular and skeletal illnesses, circulatory diseases, and injuries (EU-OSHA, 2017).

The topic has also a relevance considering the increase of aging of the working population. The latter is a new issue which companies must deal with to integrate those people getting older with the new production strategies. Various international standards outlined references about anthropometric measurements and risk assessment strategies concerning the safety and comfort requirements of the workplace, specifically to machinery design (ISO 12100).

Human body is a complex structure made of 206 bones, with associated connective tissues and articulations. The tissue which generates force and movement between bone linkages is the muscle tissue.

Muscle and bones are connected thanks to tendons. Ligaments permits the connection between bones and provide capsules around joints. Another important tissue is the cartilage which is a viscoelastic flexible material located at the ends of the ribs, as discs between the vertebrae, and in general, as articulation surfaces at the joints (Chaffin, 1999).

Thanks to those tissues and their interconnections, mobility or flexibility of the human body is possible, indicating the extent of angular displacement in body articulation that can be achieved voluntarily.

The angular displacement and its endurance are the main measures to consider preventing the arise of MSDs.

According to Bell (2009), low back pain is one of the most MSDs claimed and costly forms of musculoskeletal pain. The individual lifetime prevalence of low back pain is approximately 49-90% (Scott, 2010) and approximately 25% of patients presenting for care with low back pain will have another episode within one year (Hoy et al., 2012). The World Health Organization announced in 2009 that “37% of back pain is attributable to occupational risk factors” and it is the “main cause of absence from work, generating economic losses” (Driscoll et al., 2014).

Physical activity is another element which, if monitored can lead to ergonomic solutions avoiding physical and physiological overload.

The parameters to study physical activity are:

- Heart Rate (HR) and target heart rate
- Breath Rate (BR)
- VO_{2max} consumption

HR, or target HR, and BR are easier measurable than VO_{2max}. The latter, is not easy to assess.

Heart rate

HR consists in the number of heartbeats per unit of time, usually per minute. The heart rate is based on the number of contractions of the ventricles (the lower chambers of the heart). The pulse is a bulge of an artery from waves of blood that course through the blood vessels each time the heart beats. The pulse is often taken at the wrist to estimate the heart rate. Taking under control this parameter is important to prevent heart illnesses and CVDs. Kang et al. in 2015 have found that OPA in aging workers increases CVD risks.

Predicted maximum heart rate was calculated using the age-predicted formula: 220 – age (Astrand & Rodahl, 1986).

Percent maximum heart rate range (Rogers, 1986) was determined for each subject based on the

following formula:

$$100 \text{ x } \frac{Avarage\ HR\ on\ Job - Resting\ HR}{Predicted\ HR\ \ max - Resting\ HR} = \text{Percent Maximum HR Range Required by the Job}$$

The percent maximum heart rate range is an estimate of the percent of aerobic capacity (oxygen consumption) (Rogers, 1986).

Breath rate

BR consists in the number of breaths per minute or, the number of movements indicative of inspiration and expiration per unit time. In practice, the respiratory rate is usually determined by counting the number of times the chest rises or falls per minute.

Oxygen consumption and physical activity

The VO_{2max} expresses maximum aerobic capacity of a subject and may be absolute (l/min) or body weight (ml/kg/min). Maximum oxygen consumption (VO_{2max}) occurs when in response to an increase in energy demand there is no increase in oxygen consumption. VO2 max varies according to gender, age, level and type of training. Improvements in aerobic capacity after an adequate training period range from 5% to 25%. However, there are documented cases of increases of up to 50%.

Given the complexity of finding appropriate conditions for conducting direct test maximum ceilings for the calculation of VO_{2max}, indirect methods have been developed. The latter, can be implemented with the other parameter to it is strongly correlated; the cardiac output (quantity of blood that the heart pumps into the circulatory system per minute, bpm).

The ratio of VO_2 to cardiac output has a constant linear pattern and this is the same as it is the product of the systolic range (pumped blood) for heart rate (frequency) of blood pulsations the same linear relationship can be established between VO_{2max} and heart rate, thus enabling us to make a reliable estimate of the parameter.

Karvonen (1974) reported in a survey the metabolic rates of various occupational activities. The Table 2 illustrates the various values, converted in Kcal/min, for a man of 77kg to different activities.

Table 2 – Occupational activity and energy expenditure classification, Karvonen 1974

Task Description	Energy expenditure
Sitting Crane Operator	3.37 kcal/min
Light Welding	4.04 Kcal/min
Masonery, painting, paper hanging	5.39 Kcal/min
Walking	5.39 Kcal/min
Arm lifting (10-19 kg) (20-29 kg) (30-38 kg) (39-45 kg)	 6.06 Kcal/min 8.08 Kcal/min 10.11 Kcal/min 11.45 Kcal/min
Shovelling, picking	10.78 Kcal/min
Laying railroad truck	9.43 Kcal/min

In occupational health and safety approach, the interest in calculating the physical activity provide another measure to prevent physical and physiological overload. Once the exercise category has individuated, the shift setting should be implemented to reduce the exposure level at the physical overload.

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2.3.3. Ergonomics on operation management

The market requires high levels of efficiency and competitiveness, companies out of that business are quickly excluded from it. For this last reason, the companies have to focus on an accurate optimization of internal resources in order to maintain or achieve an additional advantage in the business.

In manufacturing the main reference approach to achieve performance optimization is the operation management model (OM). OM consists of any methodological procedure or application enhanced in the manufacturing plant which, improves productivity and logistics performance.

The analysis of operations management dealt with operational aspects, optimizing the performance of management systems. Operational management performance optimisation (OMPO) models generally use simplified assumptions as far as human operating characteristics are concerned, although they are a part needed for the production systems (Lin et al., 2014). The analysis of the operations management usually does not include causes and effects of work-related health problems.

Operations Management Performance Optimization (OMPO) models consist in analytical methods used in many areas of supply chain management and manufacturing systems. OMPO models optimize the performance of systems while considering resources, involved in their operations.

OMPO models make the performance of systems more efficient, taking resources and performance into account. The models study machine features such as productivity, runtime and breakdowns. Rarely do analyses include variability in workforce capacity and qualitative reduction due to work-related health problems, although ergonomics studies have shown that occupational health problems can reduce employee performance (Meerding et al., 2005). Some research has attempted to integrate operations management and work-related disturbs (Azizi et., al, 2010; Costa et al., 2009), but rarely consider the effects of occupational risk factors on operational costs indicators of operating systems.

Otherwise, occupational ergonomics primarily studies the occupational health and safety characteristics of a system in order to reduce the incidence of these matters on workers (Dul and Neumann, 2009). Studies on the subject, do not consider the optimization of the performance of a system and do not take into account the operational aspects of the system such as demand, workplace interactions, and suppliers (Neumann and Dul, 2010). Ergonomics is not included in organizations' planning and monitoring processes to maintain enterprise performance.

Some studies integrated human factors and operational management, in particular job competences and capabilities through the human resource management (HRM) (de Menezes, Wood and Gelade, 2010), with no consideration on human health and safety problems. Other analysis considered operation performance in concert with safety management. Veltri et al. (2007) concluded that workers who do not feel safe about their work are not able to perform their work properly, analysing the relationship between the performance of occupational safety management and performance management in system operations.

OMPO studies, when considering a human being, usually use assumptions aimed at simplifying the operational characteristics of workers in the workplace. Nevertheless, these assumptions do not adequately take into account the complexities of changes in employee performance due to occupational health and safety problems, as would be the case in a real system (Boudreau et al., 2003). Human operational characteristics are considered a constant and without tiredness or productivity loss. For this reason, it is essential to develop approaches for integrating aspects of ergonomics into OMPO models in order to monitor the causes and effects of employee health-related performance changes in system-wide analysis.

Ergonomic risk factors in the workplace can be accurately quantified. These risks are inherent in decision-making at the design stage. The workload depends on workstations organization and the errors in estimating material supply. Ergonomic risks are associated with the duration of the workload and are determined in particular by production times and work organisation (Neumann, Ekman and Winkel, 2009).

The human factors integration into a company's technological planning processes is a strategic choice for the industrial accident and occupational sickness prevention of employees in production sites.

The development of the product is a specific aspect of company management and planning processes, which comprises a number of steps from the concept to the new product. The logical approach of the preventive strategy is that many important decisions are made when developing a new product, which have a consequence on working conditions at the time of production. These impacts are due to product design decision-making, materials, production ideas, processes, etc. by project managers, designers and other key stakeholders.

Ergonomic risks also include psychosocial factors arising from the combination of elements resulting from system design. The ergonomic approach therefore proactively manages the reduction of these risks throughout the design process, especially in relation to choices of strategy. The introduction of ergonomics in the first developing phases requires changing both groups and individuals' responsibilities in the system. This approach appears possible, but it is challenging and still a strategy lacking in use to create a sustainable competitive edge.

Moreover, ergonomics goes beyond health and safety concepts and supports the management of the company performance. The ergonomic approach enters all stages of a product's manufacturing and the workplace environment in which it is produced. For this reason, it is essential to define the ergonomic conditions of the system in the decision-making process. Ergonomics also supports the machinery design and production system elements, as well as the management of people with their skills, in such a way that the company's goals and interests are carried out without any adverse effects on workers well-being. Manufacturing ergonomics, focused on the human-centred design of the workplace can also be synonymous with innovative production processes. From this point of view, ergonomics relates to the management of operations choices and process innovation to provide production objectives and the health and safety of workers.

Operation management, lean manufacturing and production business are defined as the main strategies to cut costs and improve productivity, as well as they possibly reduce workers well-being (Kivimaki et al., 2001; Pepper et al., 2003, Landsbergis et al., 1999). A case in point is Toyota, who played a part in the revolution in lean production implementing tools and techniques based on a more in-depth business insight founded on human comprehension and commitment. The operational excellence of the Toyota results the holistic ergonomic approach with its successful performance.

Ergonomics can contribute to different strategies and business results, but ergonomics is an important characteristic of the strategy development and realization process. Therefore, be aware of the ergonomics involvement is an important part of how a company delivers its competitive edge. It is neither on the line of other strategies, nor is it well integrated to be managed by a separate process. Ergonomics in this sense turns into a tool or method and not merely its own sake.

2.3.4. Cognitive ergonomics

Cognitive ergonomics origins from the concept of cognitive engineering. As claimed by Norman (1987) “Cognitive engineering is meant to combine with the applied disciplines not to replace them […] A new approach ... more than just psychology... more than psychology coupled with engineering. We need all the disciplines of cognitive science, plus engineering.” The latter, is included in the concept of HCD. Cognitive ergonomics is an integral part of the HCD.

Cognitive ergonomics involves psychological processes such as awareness, human information elaboration and movement response, as it concerns human interacting with other system components. Some significant topics include workload, decision-making, perception, attention, motor response, skill, memory and learning as these may relate to human centred design.

According to the EN ISO 10075-1, mental stress is the effect of all conditions with a mental impact on an operator, i.e. either cognitive (e.g. information to be processed) or emotional (e.g. potentially aversive consequences of work activities).

The characteristics of the mental burden are the following:

- Complexity of task
- Variability of task
- Multitasking vs. serial task performance
- Time constraints on performance
- Repetitiveness of task performance
- Intensity of workload
- Temporal pattern of workload
- Cognitive resources required
- Requirements for sustained attention
- Probability of errors
- Consequences of errors
- Adequate design of displays, signals and controls

Cognitive (or psychological) stress can be defined as the result of all aspects impacting on a worker, who can deal with it depending on his resources, capabilities or experiences. Mental effort can assume positive effects, for example, in training or learning circumstances, or have adverse effects, e. g. fatigue, monotony, reduced vigilance or satiation (EN ISO 10075-1). For the latter reason, the job design has not to lead within any adverse effect on the worker's mental load thus, should be as low as possible. For example, tasks requiring sustained attention over prolonged periods of time, where the workload may appear to be low, will lead to monotony and reduced vigilance in the operator, with an associated decrease in performance. At the same way, overloading tasks leading to excessive strain and effort, e.g. due to a high complexity and number of decisions, will lead to fatigue, which is also associated with a decrease in performance.

The Standard emphasizes the need to fit the work system to the user, and in doing this, to utilize his or her experiences and competencies, e.g. by using methods of participation.

These principles should be applied in order to influence the intensity of the workload, and the duration of the exposure to the workload.

An ergonomic design of tasks, jobs, and machinery – regarding displays, controls, and the human-machine-interaction, which should be adapted to the tasks to be performed – can help to control and optimize mental or psychological stress.

Karasek and Theorell in 1990 stated that these working conditions have effects on worker health as well as human performance.

The results of Gonzàlez-Munoz and Gutièrrez-Martìnez study, showed that working hours, mental demand, temporal demand, and frustration may be considered risk factors for job stress when faced with a given task.

Kantowitz in 1985 argued that the role of workers will increasingly be the control and monitoring of processes or machines. Many modern jobs have shifted from physical to mental workloads. As a result, the introduction and complexity of the information the worker acquires and manages has increased. In addition, the mental workload is generated by the task of supervision in automatic systems. In many cases, the high mental workload can affect both system performance and safety.

Accordingly, interest in measuring the mental workload of the worker in complex systems of man-machine interaction increases as automatic technology progresses gradually.

The reason why it is important to measure mental burden in the workplace is related to the fact that it can have a relapse on the physical and physiological condition of the worker, and on his performance.

Intense work-related stress has been frequently associated with an upward cardiovascular disease risk (Lynch et al., 1997; Bosma et al., 1998). The mental workload has long been recognised also as an important factor in human performance in complex systems (Moray, 1979; O' Donnell & Eggemeier, 1986). Optimizing the assignation of mental workload of workers could reduce human failures, improve system security, increase productivity and enhance worker satisfaction (Moray, 1988).

Cognitive workload, or mental stress, can be assessed using questionnaires in which workers self-report their subjective perceptions of the task demand, measuring worker’s performance (e.g. reaction time, number correct, and number detected), and psychophysiological measures (e.g. heart rate, heart rate variability, and brain activity, eye activity). Many studies have shown that changes in pupil dilatation characterize strenuous cognitive processing (Kahaneman, 1973). This has been confirmed through a variety of activities, including reading, troubleshooting and visual research (Ahem and Beatty, 1979; Just and Carpenter, 1993). The pupil dilation measurement is not a very reliable because dependent by the environment and brightness.

Other subjective methods are based on operator rating of the task, involves judgement of effort and reflect the direct opinion of the operator in context of the task environment and skill and experience level of the operator. Workers are aware of their perception and sensations and the results of cognitive processes, although they are nor conscious of the processes themselves. Verbal information and short-term are the only information directly accessible for verbal reports. The workload is experienced as a consequence of many daily tasks. However, a formal requirement to quantify the experience using imposed rating scales is not a natural activity and may also lead to a different qualitative responsibility. The amount of workload, the time pressure under which a task is performed, the level of effort required, success in meeting the requirements of the task, or the psychological and physiological effects of the task are the most typical concepts. Thus, the assessment of a person "workload" can report his or her assessment of the difficulty of the task, whereas another worker could report the level of effort to be made.

In order to be objective in the measurement of mental load, it is difficult to reach a defined data point.

Thanks to technological progress and analysis of the data produced, it was possible to explore other methods for the study of mental load, which were more objective. Those methods are the electroencephalogram and the electrooculogram.

Electroencephalogram

The EEG is a functional neurophysiological investigation technique, which allows a functional, dynamic, real-time exploration of the brain. The EEG consists in a continuous graphic recording over time, according to a precise spatial distribution of the brain's electrical activity, obtained from the electrodes appropriately positioned. The electroencephalography consists in recording the cerebral electrical activity derived from electrodes placed on the surface of the head, using amplifying equipment, the electroencephalograph. The electrical activity of the cerebral cortex generated mainly by cortical neurons.

The EEG is the sum of the unitary activities taking place within a large population of neurons underlying the electrode.

It is a biorhythm influenced by the external and internal environment of the subject, which varies during the Nictemeral cycle and changes according to age. It correlates, in a precise and direct way, with the functional state of the brain and, therefore, with behaviour and changes in the state of consciousness of the individual.

Electrooculogram

The eye is a source of an electrical potential, almost independent of light stimulation (may be detected with the eye in total darkness or closed). It can be described by a fixed dipole with positive pole on the cornea and negative pole on the retina. For this reason, its potential difference is defined as corneo-retinic. It is in the order of 1μV. The origin of this difference in potential is attributed to metabolic processes occurring in the retina. This potential difference and the rotation of the eye allows measurement of a signal known as EOG by means of a pair of superficial periorbital electrodes.

The movements of the eye produce a dipole rotation that gives rise to oscillating potential differences, which can be detected superficially. These signals can be used as an eyepiece motion measurement. With the eye resting, the electrodes are at the same potential and no signal is recorded. A rotation of the eye, on the other hand, causes a potential difference; in particular, the electrode that faces the side to which the rotation takes place becomes positive for the second electrode.

The analysis consists in the investigation of the eye movements. It is possible to identify three basic eye movement types, which can be detected using EOG: saccades, fixations, and blinks (Bulling et al., 2011). In Figure 7 it is possible to identify this kind of movements. Examples of the three main eye movement types are marked in grey: saccades (S), fixations (F), and blinks (B).

Saccades are quick and rapid movements of the eyes, which change suddenly the fixation point. The movements can be small, e. g. when reading, or much larger movements when looking around a room. Saccade may be voluntary, but is the result of a visual reflection whenever the eyes are open, even when fixed on a specific object. Typical characteristics of saccadic eye movements are 20 degrees for the amplitude, and 10 to 100 ms for the duration (Duchowski, 2007). Tokuda et al. in 2011 studied the saccadic intrusions as a MWL. All the participants at his study exhibited more S eye movements when their MWL level was high compared to when their MWL level was low. Some studies indicated also that S are closely related to cognitive activities, such as visual attention and auditory attention (Gowen, Abadi, and Poliakoff, 2005; Engbert, 2006).

Fixation is a state of the eyes during which the eyes hold in a specific and stationary position in the visual scene. Their identification refers to the time between two sacks. On average, fixation lasts between 100-200 ms. The identification of fixation states is a useful method for understanding cognitive and visual processing behaviour (Salvucci and Goldberg, 2000).

The eye blinking is the movement to replenish the tear layer and to dampen the eye surface, because of which reducing in blinking results in dry eye (Polatsek, 2013). Blink rate is conditioned by a combination of environmental parameters including relative humidity, temperature or lightness, and by physical activity, cognitive workload or effort (Schleicher, Galley, Briest and Galley, 2008). On average the blink rate is between 12 and 19 closures per minute (Karson et al. 1981). Schiffman in 2001 stated that the average blink duration lies between 100 and 400 ms.

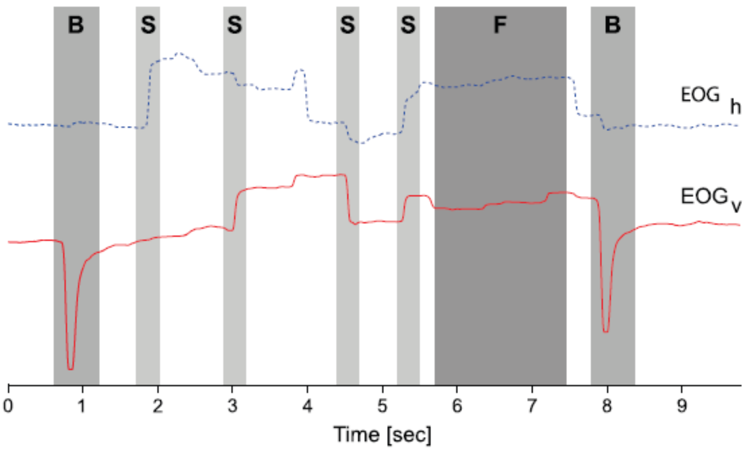

Figure 7. Denoised and baseline drift removed horizontal (EOGh) and vertical (EOGv) signal components. (Bulling et al., 2011)

2.3.5. Environmental ergonomics

Workplace environment for ergonomics is the surrounding where workers spend eight hours per day doing their job. In the workplace, there are many environmental factors, which trigger physiological, psychological and behavioural responses. It is known that working environment influences workers' health and safety, thereby also their performance. The quality of life and the quality of production are both dependent on the working environment (Jokl, 1982). Lamb and Kwok (2016), studied the Indoor Environmental Quality (IEQ) considering noise, light and thermal as comfort factors. Those stressors were related to self-reported workers performance which carried out a notable reduction in cognitive activity on the job and on wellbeing (i.e. changing in physiology response, e.g. headache, mood, musculoskeletal disturbs, etc.), thereby on performance. These factors are not just related to comfort, but also to health disorders or diseases. For example, the exposure to a specific level (threshold) of noise can cause hypoacusia. Other factors which deserve to be considered in a workplace environment are related to the indoor air quality (IAQ). The analysis of air quality includes factors such as ventilation, the presence of high amounts of carbon dioxide (CO_2), volatile organic compounds (VOCs) and particular matter 2.5 (PM 2.5). Those factors have a relevant importance on the comfort side of the workplace environment, but much more in the field of the health and safety.

The sections below describe the environmental workplace factors aforementioned.

Thermal factor

Temperature and humidity have a relevant impact on drowsiness and mental concentration, currently the World Health Organization recommends a maximum working temperature of 24°C although there are no regulations governing high temperature levels in the workplace (Montgomery, 2004).

The combination of temperatures characterizes the thermal comfort, humidity and airflow. Physical comfort in the workplace is possible thanks to the combination of these elements. The airflow temperature and humidity are often the cause of thermal distress and low productivity (Lan, Lian and Pan, 2010). In another study, Lan et al in 2014 found that there was a greater decrease in task performance due to thermal discomfort.

Pilcher et al. using a meta-analytic technique provided a comprehensive, quantitative analysis of the effects of temperature. They considered exposure characteristics to thermal conditions (hot and cold), such as type of temperature exposure, duration of the exposure, duration of the task. The authors confirmed that exposure to low temperatures of 10°C or less, and exposure to warm temperatures of 32.22°C WBGT, or more, has a consequent worsening of performance, whereas temperatures between 21.11°C and 26.61°C WBGT have had a very limited effect on performance. The authors confirmed that exposure to low temperatures of 10°C or less, and exposure to warm temperatures of 32.22°C WBGT, or more, has a consequent worsening of performance, whereas temperatures between 21.11 and 26.61°C WBGT have had a very limited effect on performance. Another possible consideration is the exposure to temperature equal to or above 27°C which has had different effects in the various tasks performed, with the worst effect on concentration, perception and mathematical processing tasks, while exposure to temperatures below 18°C has had the worst effect on reasoning, memory learning tasks.

Kroner et al. in 1992 stated that the ideal temperature in office environments is 21.6°C with a 1-2 percent decrease in performance for every 1°C above or below.

Thermal perception is a subjective response, which in some workplaces can be assist thanks to personal control over ambient conditions, especially temperature, which increases productivity. One research study tracked workers in an insurance company as they moved to a new building with advanced thermal controls in their workstations. The study found that productivity increases of 2.8 percent and it could be attributed to the new workstations (Zijlstra et al., 1999).

Slightly lower temperatures are associated with higher accuracy on simulated tasks and reduced sick leave (Tanabe et al., 2007). The international standards provide a risk assessment to control this parameter and maintain the thermal comfort (UNI EN ISO 7726:1995; UNI EN ISO 7730:2005).

Noise factor

In a workplace noise surrounds the normal occupational activity. People talking produce a level of noise between 55 and 65 dB, whereas a painful level of noise is about 120 dB or more. The noise annoyance is one of the biggest issues in most workplace environments. It can reinforce productivity or disable it, depending on individual preferences and the type of task performed. The importance of noise reduction in workplaces derives also from findings about hypoacusia. The latter, constitutes one of the most common occupational diseases and a major health, social and economic issue afforded by the WHO and the ILO. Exposure to particularly intense noise sources progressively leads to hearing loss due to physiological changes in the hearing system. Many studies reported threshold limits which have been applied by many countries in their occupational health and safety systems. The threshold values indicated are referred to 8h of work, per day, and correspond to: 85dB, or less, as the minimum noise exposure, between 85 and 90dB as a moderate exposure and more than 90dB as a high noise exposure (Hessel & Sluis-Cremer, 1987; Alidrisi et al., 1990; Phaneuf and Hétu, 1990; Sanders and McCormik, 1993; Shaikh, 1996; Hernandez-Gaytan et al., 2000; Osibogun, Igweze & Adeniran, 2000; Sriwattanatamma & Breysse, 2000; Ahmed et al., 2001).

Noise reduction is needed to create an ergonomic working environment: indeed, noise can negatively affect the workers' performance and productivity (Vischer, 2003; Jones and Broadbent, 1998).

Furthermore, persistent noise during complex work, however, require a longer period to reorient, and continued interruptions are likely to have negative effects on mood that reduce the motivation to resume work (Errett et al., 2006). In machinery design, according to the international standards, should analyse the noise factor in the perspective of workers protection. Design engineers meet the safety requirements placing on the market products that respects the maximum noise levels, if provided for that kind of machine or equipment, and need to guarantee the sound power level of machinery according to Standard test and measurement procedure (UNI EN ISO 11690 - 1:1998; UNI EN ISO 11690-2:1999; ISO/TR 11690-3:1997).

Lighting

Visible light is a part of the electromagnetic radiation perceived by eyes. The wavelength ranges from 380 to 780 nm. The use of daylight is important for both the vision quality and the pleasure and acceptance of the occupants, as well as for energy saving. The contribution of natural light to interior lighting allows regulating circadian rhythms, the daily cycles of waking and sleeping hours (Witterseh et al., 2004). Artificial lighting is produced by illuminating bodies intentionally in order to perform the visual tasks required in a specific working condition. Artificial lighting should compensate the absence of natural lighting. The intensity of the light source varies with age; thus, it is important to provide a sufficient level of brightness to guarantee an adequate visual performance.

Workplaces have many different aspects concerning lighting and the work activity.

Considering the VDT workstations and computer activity Aras et al. (2000) identified the main workers physical problems in visual disturbs and musculoskeletal disorders. The lighting factor interests many researchers in order to reduce workers discomfort and health conditions. Ocular impairment and objective symptoms of eye irritation (e. g. the use of eye drops) have had noticed to be more frequent in VDT operators, thus the association between high luminance contrasts between the screen, the document and the environment with an increased oscillating luminance of characters on the screen (Hunting, Laubli and Grandhean, 1981). Dainoff et al. also found a relatively high incidence of the symptoms of eye fatigue due to glare and illumination of the office in which work required the use of video terminals. Houshang (1982) noted the importance of individual differences, requiring adjustment of screen and workplace illumination between employees.

Industrial environments are different compared to the office workspaces. Tasks carried out are more repetitive, and in particular for some categories of work, such as electronic and jewellery, the task requirements are precision and visual concentration on a tiny surface (Untimanon et al., 2006). Workers' performance can be reduced by inadequate visibility due to light, resulting in visual strain and fatigue and sometimes leading to physical symptoms such as headaches. The latter causes, can be attributed to low light intensity, glare and an unbalanced brightness level compared to the work environment and the task performed by the worker.

Also lamp flicker is considered a stressor on worker activity, which increases the incidence of headaches (Wilkins et al., 1989). Lighting is also important in preventing accidents and errors (Reinhold and Tint, 2009).

The study carried out by the Commission for Architecture & the Built Environment (CABE) and the British Council for Offices stated that adequate lighting and having proper daylight can decrease absentee rate by 1% (Hill, 2005). Also, productivity increased by between 28 per cent and 20 per cent. An interesting issue is the HCL, which expresses the positive effects of light and lighting on health, well-being and productivity, through the correct control of the lighting. In workplaces, it helps the biorhythm in nightshift workers, or in precision tasks or in reducing errors due to repetitive tasks.

The international standard UNI EN 12464-1:2011 suggests the best material surfaces to prevent the glare effect. In a workplace or at a workstation these are some of the features to take into account: luminance (influences the visual effort and consequently visibility and comfort), illumination (calculated threshold value below which the average illumination on a specific surface cannot drop below), glare (distracting and potentially disabling effect of bright light in an otherwise relatively dark scene, which interferes with visual attention and selection), and apparent light heat (different shade of light depending on the spectral distribution of the emitted radiation and is characterized by its own colour temperature). The lighting requirements are determined by the satisfaction of the following three criteria:

- visual comfort: the feeling of well-being perceived by workers also indirectly contributes to high levels of productivity;
- visual performance: workers can perform their visual tasks even in difficult and protracted circumstances;
- safety.

Indoor Air Quality factor

Today's organizations are a focused on health, safety and comfortable workplaces. Consequences of poor investments on health and safety issues are the productivity reduction and the quality of life (Heerwagen, 1998). Indoor pollutants can be five times higher than the outdoor levels. The causes are related to the maintenance of the air condition system (heating, cooling and humidification), possible material combustion depending on the manufacturing sector, building materials, machinery and equipment materials. Some epidemiologic studies demonstrated the association between the indoor air quality and the sick building syndrome (SBS). The World Health Organization characterized the SBS with these symptoms: eye, nose and throat irritation; a sensation of dry mucous membranes and skin; erythema; mental fatigue; headache; a high frequency of airway infections and cough; hoarseness; wheezing, itching and non-specific hypersensitivity; nausea and dizziness. SBS is often also characterized by other non-specific symptoms such as: nasal dryness; nasal congestion; nasal excretion; pharyngeal symptoms; difficulty in concentration; and difficulty in breathing and tight chest.

Furthermore, the final materials, or intermediate materials, of production processes might contaminate the air. The latter, should be controlled and measured through a risk analysis following the procedures of the international standard (EN ISO 14123-1:2015, EN ISO 14123-2:2015).

In office workplaces the parameters detected are CO, VOCs, PM2.5. In other workplaces contexts the parameters considered depends on the production sector.

CO_2 Carbon Dioxide

Accordingly, to the American Conference of Governmental Industrial Hygienists (ACGIH, 1991) CO_2 has not the connotate to be a direct cause of health effects. On the other hand, the Health and Safety Executive (HSE, 2005) gave some indications as work exposure limits (WEL) to a long-term exposure (8 hours) and a short-term exposure (15 minutes). These limits are respectively of 5000 ppm and 15000 ppm.

Indoor workplace CO_2 concentration is due to the presence of workers in the workplace and the equipment used, and even the CO_2 from the outdoor. From studies in Seppanen (1999) review the most common outcome was the prevalence of the SBS.

CO carbon monoxide

It is well known that CO is a poisoning. The absorption is through inhalation and the exposure may due to different aspects. The development of carbon monoxide is caused by a combustion process in which fuels (e.g. petrol, kerosene, coal, etc.) are not completely burned. Some of its characteristics are that it is odourless, colourless and tasteless, therefore not perceptible to human senses. In addition, carbon monoxide has a high reaction with elements such as oxygen, with which it can trigger even violent explosions, as well as with nitrous oxide, acetylene, fluorine and chlorine. Sources of carbon monoxide emissions into the living and working environment can result from incomplete combustion of car fuels, i. e. more concentrated in trafficked roads or covered car parks; inside the living or working environment derive from stove or heat sources such as gas or wood stoves, it can also penetrate the outdoor environment (Howard, 1991). In residential homes, under normal conditions, the levels are between 1,5 and 4,5 mg/m^3. In the presence of combustion processes such as heating and cooking systems or tobacco smoke and inadequate ventilation, internal concentrations may exceed external concentrations and reach levels of up to 60 mg/m^3. Carbon monoxide intoxication can be the result of short-term single or repeated high concentration. Carbon monoxide poisoning is the principal responsible of death from poisoning. The immediate effect of the CO poisoning is the hypoxia (Coburn, Forster and Kane, 1965).

In workplace environments, exposure to carbon monoxide is produced by the facilities in the plants, or it can be a product of a process (i. e. compressed carbon monoxide). The safety limit for workers exposed to CO, such as TLV-TWA, is 25 ppm, i. e. 29 mg/m^3 (limit indicated by ACGIH, American Conference of Governmental Industrial Hygienists). Accordingly, to the Directive 2017/164/EC the new list of indicative occupational exposure limit values submits for CO different exposure thresholds, based on the period exposure: for periods of 8 hours the limit is 23mg/m^3 (20 ppm), and for a short-term exposure of 15 minutes is 117 mg/m^3 (100 ppm).

PM2.5 particulate matter

Airborne particulate matter is defined as the collection of solid and liquid airborne particulate matter suspended in the air. The term $PM_{2.5}$ identifies particles with an aerodynamic diameter less than or equal to 2.5µm, a fraction of smaller aerodynamic dimensions than the PM_{10}, and contained in it. $PM_{2.5}$ particulates are also called' fine particulate matter', a designation opposed to' coarse particulate matter' which indicates all suspended particles with an aerodynamic diameter greater than 2.5µm or, within the PM_{10} fraction, those with an aerodynamic diameter between 2.5 and 10µm. Sources of fine particulate matter are somewhat all types of combustion, including those of car and motor vehicle engines, power plants, wood for domestic heating, forest fires and many other industrial processes. Health outcomes investigated in studies, associated $PM_{2.5}$ to cardiopulmonary disease and death (Samet et al., 2000; Schwartz and Dockery, 1992; Schwartz, 1997). In addition, studies have confirmed the negative effects of exposure to $PM_{2.5}$ on the heart rate variability (Magari et al., 2001; Chen et al., 2006).

The PM2.5 particulate indicator is based on the $PM_{2.5}$ concentration values in the atmosphere, measured at national monitoring stations and collected by ISPRA as part of the Exchange of Information (EoI) procedures laid down in Directive 97/101/EC and 2001/752/EC. According to the European Environmental

Commission the annual average limit imposed is equal to 25 μg/m3 in atmosphere. The same limit is considered for occupational exposure.

VOCs volatile organic compounds

Volatile organic compounds (VOCs) are any organic compound having a vapour pressure greater on equal than 0,01 kPa, at 20°C. VOCs is contained in a large part of the materials in the outdoor and indoor environment, from construction to tools or objects used every day or at work. The major VOCs, which occurs and are classified by the European Commission INDEX are: formaldehyde, benzene, toluene, xylenes, styrene, acetaldehyde and naphthalene (Sarigiannis et al., 2011). Exposure to these compounds may give serious health outcomes or not, i. e. carcinogenic or not-cancerogenic effects. In workplaces, limit values for certain volatile organ compounds exist as a potentially carcinogenic source for humans. The European Scientific Committee has set occupational limits for formaldehyde (SCOEL, Scientific Committee on Occupational Exposure Limits UE, 2008): TLV-TWA (8 hours): 0.3 ppm~370 $\mu g/m^3$ and TLV-STEL (15 min): 0.6 ppm~740 $\mu g/m^3$. Indoor pollutants come from the environmental exposure of wood products used as building materials and in furniture (e.g., formaldehyde resin; formaldehyde foam insulation (no longer used but still present in some buildings); tobacco smoke; ozone-initiated chemical reactions with common indoor VOCs. (Godidsh, 2000; Hodgson, Beal and McIlvaine, 2002; Weschler, 2006; Singer et al., 2006).

Benzene is another compound considered cancerogenic and the thresholds suggested by the ACGIH, and by the national laws, are 3.25 $\mu g/m^3$, or 1ppm, referred to a period of 8 hours of exposure. The presence of benzene in indoor environments is due to substances such as tobacco smoke; some furnishings, paints, coatings, wood products, from stored gasoline or vehicle operation or evaporation from hot engines in attached garages (outdoor air also an important and often predominant source) (Tucker, 2000).

Toluene is a substance obtained by refining crude oil and tar, and like benzene, it is a component of petrol. Once released into the atmosphere it degrades and enters the reaction mechanisms of photochemical smog, degrading into other substances at different levels of toxicity, including formaldehyde. In the industrial field, it is used for the synthesis of other chemical compounds and is an important solvent for paints, adhesives and inks, in which it has replaced benzene, due to its lower toxicity. Toluene is a common indoor pollutant and its concentration in indoor locations may be higher than the outdoor environment. Toluene is currently classified as non-human carcinogenic. The legislation on national employment security has set threshold values for toluene, as indicated by European legislation, of 192 $\mu g/m^3$ 50 ppm for an eight-hour occupational exposure (UNI EN 12619; UNI EN 13526; UNI EN 1364).

Xylene is an organic solvent widely used in the industrial sector to produce other chemical agents and as an intermediate of different production cycles (pesticides, food, plastics, paints) and is used as solvent in printing, rubber and leather processing. It is found in oil, in tar and is produced in combustion at very high temperatures such as forest fires. It is a harmful compound, and the high industrial use requires careful monitoring of workers' exposure. Occupational exposure thresholds are 221 $\mu g/m^3$, or 50 ppm, for an 8h exposure, and 442 $\mu g/m^3$ 100 ppm for a brief exposure, 15 minutes, according to the national and European directives.

The other VOCs considered is the styrene. The latter, is one of the products of petrol, and is also known as vinylbenzene. Styrene is classifiable as a not human carcinogen, but other adverse effects can occur such as sleepiness, headache, nausea and emesis. The workers threshold exposure of styrene, according to the regulations, are 85 $\mu g/m^3$ 20 ppm in an 8 hour-shift, and 170 $\mu g/m^3$ 40 ppm in a 15 minutes period of exposure.

Acetaldehyde it is used for the production processes of drugs, plastics, other important chemical compounds such as acetic acid (or ethanoic acid). Acetaldehyde is classified as a compound for which there are no obvious correlations of carcinogenicity in humans, but there are in animals (ACGIH and International Agency for Research on Cancer-IARC). The health outcome may be the irritation of the respiratory tract, tear irritation due to vapours, conjunctivitis and serious eye irritation. The occupational limit indicated in the safety data sheet of this compounds is 25 ppm, according to the ACGIH recommendations.

Naphthalene is a volatile organic compound and polycyclic aromatic hydrocarbon; its presence is both in indoor and outdoor environments. Naphthalene is found in discharge products (e.g. vehicle exhaust, evaporated gasoline, cigarette smoke), but also in work products such as pesticides, or in the daily use, i.e. deodorants. Industrial use of naphthalene regards mothball manufacturing and resins (Pressus, Angerer and Drexler, 2003). The IARC classified naphthalene as a possible cancerogenic, hence the threshold values for professional exposure, in eight-hour shift is 50 $\mu g/m^3$, or 10 ppm. The health outcomes studied on animals are tumours in the upper respiratory tract, respiratory tract lesions and hemolytic anemia in humans. (Batterman et al., 2012).

2.3.6. Organizational ergonomics

Organisational ergonomics is based on interdisciplinary work, which affects the social, cognitive, relational and physical aspects of the working environment. In this field, in addition are involved developing methodological studies and suitable tools for the prevention, assessment and evaluation of emerging psychosocial diseases (stress, mobbing and burn out, in particular), ergonomics also provides principles and models for ergonomic design of work environments, with the aim of improving the quality of life and well-being in the workplace. Relevant topics include human–system considerations in communication, crew resource management, work design and management, teamwork, participatory design, cooperative work. Social or organizational ergonomics is a transversal element which concerns with the optimization of work systems, including their organizational structures, policies and processes.

The issues that may affect the ergonomics of the organisational structure are related to the work organisation in terms of shifts, working time and breaks. Shift workers is demonstrated that have adverse health outcomes such as disturbs of the circadian rhythm, gastrointestinal disease (e.g. constipation and diarrhoea) (Scott and LaDou, 1994), CVD (Alfredson, Karasek and Theorell, 1982; MacNamee et al., 1996; Steenland and Fine, 1996; Bøggild and Knutsson, 1999), cancer (Taylor and Pocock, 1972; Cos and Sanchez-Barcelo, 2000), diabetes and metabolic disturbances (Theorell and Åkerstedt, 1976; Peternel et al., 1990; Netterstrom et al., 1996; Nakamura et al., 1997), pregnancy problems (Uehata and Sasakawa, 1982; Mamelle, Laumon and Lazar; 1984; MacDonald et al., 1988; Armstrong, Nolin and MacDonald, 1989; Axelsson, Rylander, and Molin 1989) and other matters due to sleep deprivation which can change medical prescriptions or worsening of existing pathological conditions such as epilepsy (Pratt, Mattson, Weikers and Williams, 1968).

Also work organization has outcomes in stress reaction. Melin et. al (1999) demonstrated that a flexible work organisation induces less stress than the traditional assembly line and that women workers have more benefit from the flexible form of work organisation.

About breaks during the working time in knew a few, but what is stated is that the presence of breaks reduces the accumulation of fatigue and physical functional impairments (Hamed, Jaradat, and Easa, 1998; Tucker, 2003; 2006; Arlinghaus et al., 2012).

Organizational ergonomics is also called social ergonomics because it involves the entire organizational structure and every modification and implementation on assets has consequences for workers, who are the backbone of a well-organized company that relies on them to ensure their health, safety and performance improvement.

2.4. Social life cycle assessment

Sustainable development consists in satisfying present needs without compromising future generations growth (WCED, 1987). With this perspective, it is crucial to consider many sustainable issues, including social aspects. The ISO 26000:2010 introduced the topic of social responsibility as the willingness of an organization to incorporate social and environmental considerations in its decision-making. It includes a list of subjects and issues relevant for the field. In this study, social considerations are analysed with a life cycle perspective, to assess social impacts of a product/process, namely the social life cycle assessment (S-LCA). S-LCA is well explained within the UNEP/SETAC guidelines (Andrews et al., 2009). This analysis aims at assessing the socio-economic impacts of products along their life cycle, from "cradle to grave". The work provides a roadmap to conduct the whole analysis. Furthermore, the methodological sheets of sub-categories for S-LCA (UNEP/SETAC, 2013) provide a deep investigation of the actors of the analysis, namely the stakeholders. Subcategories are introduced, as topics to take into account during the analysis. The methodology proposed in the present paper sets its basis on the UNEP framework considering also the S-LCA methodological sheet.

In 2011, Zamagni et al. stated that the same product, produced in different parts of the world, could cause different social impacts not only in terms of different values for a specific indicator but also for different relevant indicators. This consideration inspired also the present work: customized but replicable S-LCA analyses are needed. Moreover, literature proposes few studies that consider the S-LCA guidelines; inventory and interpretation of data are identified as the less robust part of the method. Franze and Ciroth in 2011 developed one of the first studies on S-LCA: a comparison between the production of roses within different geographical scenarios (i.e., Netherland and Ecuador). In this case impact results were proposed, but only in a qualitative manner. Other studies can be identified in literature considering different kinds of functional units (e.g., PET bottles, e-waste recycling, citrus farming) (Foolmaun and Ramjeeawon, 2013; Umair et al., 2015; De Luca et al. 2015). All these works strictly follow the UNEP guidelines.

Also, Labuschagne and Brent in 2016 introduced social criteria within South African process industry, with a new framework. A social impact calculation was carried out. In the latter study, calculations are mainly based on statistics; consequently, social footprint for some categories is missing. Moreover, Macombe et al. in 2013 came up with a relevant outcome: in many cases a comprehensive S-LCA could not be carried out by the limits of actual tools and knowledge. Furthermore, Martínez-Blanco et al. performed a study in 2014 in which social aspects were integrated with environmental ones, and Ekener-Petersen in 2013 proposed a new method to define impacts assessment. The case study encompasses a laptop computer studied with a life cycle approach from cradle to grave. All the phases were analysed from resource extraction to disposal. Data exploited are a mix of general remarks and detailed information. Detailed data were mainly related to raw materials needed for manufacturing. Those data didn’t drive to detailed results, but permitted to gain a general assessment through several hotspots.

A critical review on consistent S-LCA works was made by Chhipi-Shrestha in 2015: the paper analysed more than 40 studies related to the social life cycle assessment. They identified the need of S-LCIA method development to assess both positive and negative social impacts with a more objective point of view. Another literature review was proposed by Russo Garrido et al. in 2016: the paper focused on the lack of impact pathways that directly link company modelling to social benefit. Moreover, in the majority of works, the product is not completely taken into account during a social analysis (Martinez Blanco et al., 2015). More recently, Zamagni et al. in 2016 underlined the need of more structured frameworks and additional impact pathways for social assessment in manufacturing; a particular attention was paid to "what" has to be measured, which is a critical point of social assessment. Moreover, the stakeholders' involvement is a fundamental part of every social assessment. In this view, Souza et al. in 2014, proposed a methodology about the selection of LCSA impact categories, in accordance with stakeholders, taking into account socio-economic aspects. LCSA includes LCC analysis, environmental life cycle assessment analysis LCA and S-LCA. Ramirez et al. In 2014 pointed out that methods already present in literature were not so effective to include all the subcategories within the social assessment. Therefore, they tried also to develop an objective subcategory assessment method to avoid the subjectivity while evaluating social behaviours of stakeholders. Finally, indicators are also an "on-going" issue within S-LCA techniques; Jorgensen in 2008 highlighted the disputability of categorization indicators due their superficial description within the UNEP guideline. Indeed, UNEP guidelines highlight research areas that needs to be studied in deep, recognizing the actual weaknesses of the method. In 2017 Zimdars et al. focused on the big issue of measurability in social life cycle assessment. They defined a method to overcome the limitation of standard studies that, to have measurable data, exploit working hours as a single metric. Even their studies, as stated has limitation because their method is based on a social hotspot database that is not representative for every production system. Then, as the latter document, the present thesis tries to overcome measurability limits of S-LCA proposing an improved S-LCA method, that tends to obtain measurable results by semi quantitative data.

3. Methods

3.1. Methods for product-process sustainability

The challenge of sustainability covers different aspects as stated previously. For what concern industry, with a lifecycle approach there are several stages where decision makers could intervene to mitigate sustainable aspects. Following methods are aimed at helping company decision makers toward sustainable actions.

The first methodology is set to understand social sustainability of a product from a lifecycle perspective. The second method is aimed at defining sustainable production systems in the perspective of digital manufacturing. The first method should be exploited for a better product design; the second one permit designing new production systems with a sustainable approach.

3.2. An Improved S-LCA Method

When dealing with product life cycle there are several features that a designer must take into account. In a sustainable design perspective, the work should be harder because other characteristics has to be taken into account. Designers already have few tools should help them in accounting economic and environmental issues of products. Regarding the social topic, the challenge is completely open. Today is really hard for a designer to develop a socially sustainable product. Social sustainability, as stated has problems related to "measurability" and objectivity in parameters. Here is proposed a method that help a designer to take into account the social pillar during the product development phase.

An improved method to perform social life cycle assessment analysis is proposed. This method fills the gap of the previous literature works that follow step by step the UNEP/SETAC procedure.

The strength of this new method is related to the development of an improved analysis in the inventory phase to obtain more effective results. In fact, a custom data identification procedure is driven by the specific analysis goal, and the procedure opens to a more thoughtful analysis. In other words, decisions that influence the analysis itself can be undertaken, pointing out certain social related topics. Moreover this procedure encourages the acquisition of specific data for each real use case.

The method takes into account the challenge of social assessment and aims at supporting an efficient enterprise modelling to collect and interpret S-LCA data. Stakeholders are those organizations and individuals having interests in organization activities (ISO 26000). A according to UNEP guidelines, five categories of stakeholders should be considered in this method: Workers, Local community, Society, Consumers, and Value chain actors.

There are two main strengths of the proposed method: a deeper inventory phase that allows to model the enterprise under investigation by quantitative and semi-quantitative surveys, and the quantification of collected data towards social scores definition. The scope of such an analysis is firstly to point out those social related topics according to the goal, which can be quantified through social scores. Decision makers will analyse scores and will implement corrective actions to boost social sustainability. The structure of the proposed S-LCA methodology is presented in Figure 8. It represents the workflow to carry out a detailed social life cycle analysis within an industrial context. Four main phases can be highlighted, as follows:

1. Goal definition
2. Inventory
    a. Stakeholders selection
    b. Areas of interest definition
    c. Surveys definition
    d. Stakeholders filling
3. Data aggregation/interpretation
4. Impact indexes definition

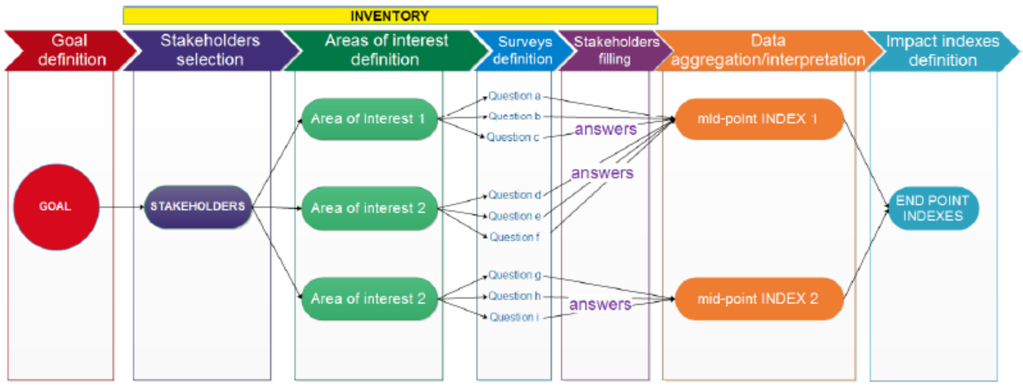

Figure 8. The S-LCA methodology structure

Following such a procedure, the social assessment includes both the product under investigation and the related processes by measurable data. In fact, no qualitative data are expected for the inventory phase, but only semi-quantitative data are required. The challenge here undertaken is to convert semi-quantitative data to quantitative ones. Now each phase is studied in deep.

3.2.1. Goal and scope definition

Analysis can concern social consequences of a product, process or service. It is important to precisely determine the goal to perform a correct and lean inventory analysis. Within this phase also system boundaries are defined. Choices taken at this stage are fundamental, as they will affect data needed for the inventory phase. Defining a boundary instead of another affects the final results of the analysis. The goal and scope definition has the same importance as the “functional unit” definition in an E-LCA (environmental life cycle assessment).

3.2.2. Inventory

The inventory phase is the most labour-intensive activity to carrying out a S-LCA, since it mainly consists in accurately and methodically collect data that will be further used for the impact assessment phase. It is crucial to follow a defined structure in data collection in order to avoid inadequate situations in further steps. The methodology considers the inventory phase as a group of four consequential actions: stakeholder selection, area of interest definition, surveys definition, and surveys compiling.

Stakeholder selection consists of selecting a set of life cycle stakeholders for the consider case study. The UNEP guidelines doesn’t help in defining the stakeholders for the analysis. It is then necessary to clearly identify specific stakeholders for each analysis considering UNEP categories. The inventory phase of the present methodology starts with this task. Actors of the analysis, namely the stakeholders, are selected depending on the S-LCA goal. In this regard, the UNEP/SETAC joint committee developed the aforementioned methodological sheet regarding stakeholders and their sub-categories. It provides a measurement “prototype” for each of the subcategories. In the present research work, the stakeholder categories provided by UNEP/SETAC have been adapted to industrial survey specifically; Consumers, Society, Local community, Value chain actors and Workers are the categories proposed in the methodological report. A deep explanation of these categories is provided by UNEP/SETAC Methodological Sheet. These are people related to a product/project along its whole lifecycle. Workers are people from the production plan that directly act on the product object of the assessment (e.g. manufacturing and assembly works). Local community includes all the people living nearby the latter company. Society is a particular stakeholder; it is not a matter of people but only a matter of rules. In fact, such stakeholder will be described without surveys but assessing whether social rules and standard are compliant to the product. Consumers are all those people that interacts with a product during the use phase of the latter. For value chain actors are intended all those people working in a supplier of the company. In regards of surveys for those stakeholders sample depends on the project and data available. Minimum Sample size for each stakeholder is calculated considering the 80% total number of each stakeholder. As an example, if a production of a product affects 20 workers of a plant, it is important that at least 18 of them will answer the survey.

The present work classifies them in two main clusters: active actors and passive ones. The first category concerns those acting directly on the subject of analysis (i.e., product), namely the Workers, Consumers and Value chain actors. Actions of those people lead directly to social relapses. While passive ones are those socially influenced by the value chain. These latter are not directly interacting with it, namely the local community and the society. However, in the current status, Society has not been further considered in the proposed approach. In practice, a point of strength of the method is to deal with customised data, coming from the field. In this perspective, society represents a very large dimension, which can hardly be depicted by small quantities.

Area of interest definition consists in defining the so-called Area of Interest (AoI) for each of the stakeholders' categories. AoIs are anovelty of the present work. AoIs are defined as topics related to socio-economic consequences of the subject of the assessment. AoIs are defined according to the goal. For each stakeholder multiple AoIs could exist, therefore it is important to correctly define them, for a proper data inventory. Some AoIs could be "shared" among different stakeholders. AoIs are thought to be either generic (and replicable in future assessment) or case study tailored. This step "substitutes" the sub-category selection in the UNEP/SETAC methodological sheet. The adaptation of AoI instead of sub-categories it is not only a matter of terms definition but it is one of the core points in the presented methodology. More specifically, the need of customised AoIs is one of the main outcomes from the peer review of the methodological sheet. Moreover, the main idea is to keep the focus on the goal and scope definition when defining the AoIs in order to address representativeness of collected data. By the case study presented below few AoIs for each stakeholder are identified. Some of these could be replicable in future assessments due to different goals. For a matter of space, AoIs for each stakeholder category would not be listed.

Surveys definition consists in drawing up specific surveys for those stakeholders previously mentioned, according to AoIs. Surveys are interpreted as the most important tool to obtain data for the assessment. From a methodological point of view, surveys have a twofold purpose: i) to collect objective data, and ii) to transform semi-quantitative information characteristic of social aspects, into quantitative data needed for result analysis. Each AoI is depicted by two or three questions; multiple questions characterize an AoI. The AoIs will be undisclosed within surveys: only the surveys evaluator will know the association between AoIs and questions. Questions proposed are designed with the aim to minimize subjectivity. In addition, no open answers are required or accepted in order to ease the transition to quantifiable data. Generally, data are intended to be semi-quantitative or quantitative. In practice, they are expressed only by yes/no (i.e., Y/N) and measurable data (e.g., costs, hours). Each stakeholder has a customized survey. It is fundamental to accurately organise each survey with the same structure (e.g., number of questions and type of questions), in order to favour the data interpretation step. Further details on the questionnaire will be displayed in next sections.

Stakeholder filling is the last step of the inventory phase. It practically consists in handing on surveys to each stakeholder and let them fill in the surveys. Answers are anonymous, for privacy matters, in order to gain objective responses, not affected by external factors. Once surveys have been completed, questions have to be collected and classified in work sheets in order to prepare the data interpretation phase. At this stage, it is fundamental to engage the largest sample in order to obtain robust and accurate results.

3.2.3. Data conversion

Data conversion phase aims at transforming all the surveys results into measurable data. The huge issue of data subjectivity is overcome through this transformation method. The procedure helps in interpreting survey results. Techniques are developed in order to convert the raw score into a normal score and define the percentile rank of agree for every question. These ranks will be used later for the mid-point index definition. Data required by surveys are mainly of two types: yes/no (Y/N) answers and 5-point Likert scale answers. Survey outputs are managed in similar ways in both kinds of questions. After the stakeholder filling, every survey has to be classified and collected data has to be aggregated in worksheets. These two data sets are merged together throughout the following procedure. For every question, the steps to be performed are as follows:

1. Identifying the number of answers
2. Calculating the mean value of the answers (on the related number of answers)
3. Calculating the standard deviation (on the related number of answers)
4. Identifying a benchmark test value for the z-score identification
5. Calculating the standard score (Z score)
6. Calculating the normal distribution
7. Defining the ranking

For 5-point Likert scale answers, the benchmark value is assumed as 4. It means that the 80% of the maximum scale is accepted as positive value (5 * 0,8 = 4). This assumption is confirmed by Nielsen and Levy. For Y/N answers, zero point is assumed for "No" answers and 1 point for "Yes" answers, and 4 the benchmark value is settled on 0.8. Such a procedure is applied to each question for each stakeholder within the S-LCA analysis in order to obtain normalized results. Step 1 and 2 are mainly classification steps. Surveys are at first collected then classified on a work sheet; the mathematical procedure starts from step 3. This step aims at calculating the standard deviation of results for each question within every survey. The collected standard deviation is calculated by (1):

$$st.dev = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (1)$$

where *n* is the sample and x_i the relative score of each survey.

Going further, step 4 depends on the question type, according to previous considerations. The benchmark value is a comparative value assumed as positive threshold for the answers. In both cases, Nielsen assumptions drive the identification of the benchmark value. In step 5 the standard score z is calculated by (2):

$$z = \frac{mean - bench}{st.dev} \qquad (2)$$

where *mean* is calculated according to number of answer for each question and *bench* is the benchmark value, instead, that changes according to the question type as previously explained. The result of the calculation will be a percentage, namely the ranking. This value is assumed as the score, calculated for each question of every survey. The more is the percentage, the more is the social sustainability guaranteed.

3.2.4. Score definition

The final assessment is achieved by interpreting the results obtained from the survey, according to the previous steps. In practice, quantitative data must be aggregated and handled into qualitative categories, which express social indicators. The outcome of this stage is the creation of social indexes. The most intensive part consists of identifying the best mathematical algorithm to aggregate survey results and to correctly interpret questions. Answers are grouped according to their impacts to different stakeholders. In other words, such groups would define the mid-point indexes. For each stakeholder, questions that target similar social aspects are grouped and the average mean of the total score is calculated as the mid-point value for the specific social issue. The same question could affect different mid-point indexes. Mid-point indexes are measurable value, embedding impacts by similar social issues (AoIs).

At this point mid-point indexes are converted to end-point indexes. In this case, both sides involve qualitative concepts that must be somehow measured. End-point indicators serve as conclusive output of the entire methodology, thus they should be comprehensible and representative. End-point indexes are made by multiple mid-points, representing a value related to socio-economic impacts. Applying this procedure to all the stakeholders lead to the global S-LCA score. The ISO 14040:2006 details an impact category as a class that represent environmental issues, in relation with results assignment. The present method follows the ISO standard. For purpose of clarification the indicator "Growth" includes three mid-point indicators: eco interest, sustainability value and performance consistency. Its value is the mean of those three mid-points scores. Eco-interest is in turn the mean of the percentage rank of different questions. Mid-point and end-points here identified are not definitive. A final score for the whole analysis will be available when the stakeholder filling and the data interpretation will be done for all the involved categories. The indicator presented here seems to be more realistic and consistent than the actual present in literature.

The method is validating by an industrial case study, where finally both mid-point and end-point indexes are defined.

This method produced few scientific publication and has been discussed with S-LCA experts (Gregori et al. 2015; Peruzzini et al. 2017). This was defined as a valid method but was remarked that social sustainability assessment is mainly an economic tool. With those feedback with an iterative approach it was studied in which stage of the lifecycle of a product a company could make influent decisions social oriented. With an industrial approach the phase that was identified was the manufacturing one. In fact, this involves many people which sustainability could be really mitigated according to effective company decision and behaviours. Moreover, simply considering the S-LCA, the most robust information can be achieved by internal surveys on employees and workers. In the same way the most of improvement action having a relapse on social sustainability can be performed on the production site and related activities.

3.3. A design method for connected sustainable factories

As discussed, the S-LCA have the limit of a standard enumerable metric. Since a standardization will not exist it is quite difficult to compare different systems by S-LCA studies. What emerged by the method previously explained is that from a social point of view, a company could manage sustainability mainly managing in a proper way the manufacturing processes of a good.

With this perspective, the best "social" choices a company should perform are within the manufacturing area where many people act: employers and workers.

With this focus, the method that is going to be shown has a focus on the production site. With a broader view, the present method could assist a company to grow in a proper sustainable way. The aim of this methodology is to help designers to define sustainable and innovative plants. It is clear, in fact, that sometimes companies whether they are SMes or large companies approaches to innovation without a structured way. This method permits to walk the path toward innovation considering sustainability pillars.

A big discussion on Industry 4.0 is taking place but the path toward the 4.0 passes through a proper implementation of already known concepts (e.g. energy efficiency, elimination of scraps, etc.). 4.0 technologies consist in solutions that solve many problems but only if manufacturing problems are well identified. Then, the methodology is a structured path to the factory of the future where sustainability has a crucial role.

The method tends to define future and sustainable factories with the exploitation of IoT frameworks. Those frameworks will help in data acquisition during the life cycle of a plant. Following this method, a company should improve its productivity passing by a proper data management system based on sustainable drivers. Data will be the basis of development choices. The framework will be implemented in production sites will help decision makers while improving the production system, analysing advantages in implementing 4.0 technologies. The method consists in the formalization of the steps needed to improve a production site from the definition of the problem to the corrective action implementation. Many times, industries asked academia to improve a process from a sustainability perspective. Only when a structured methodology was applied the problem has been solved. Moreover, improvements is a matter of data management and many companies, especially in the Marche Region, has lacks in terms of data availability. Then this method was thought in order to perform process analysis and improvements through the connection of the factory itself.

Steps identified for the method are the following.

1. Factory Assessment
   a. Plant layout
   b. resources mapping (plant layout, flows identification, human resources identification, asset analysis)
2. (Re)design goal and boundaries
3. IoT configuration
   a. Define framework aims
   b. Identify variables of the environment
   c. Identify sensors on the market
   d. Select the sensors minimizing the equipment
   e. Create the framework
   f. Convey all data in a single device
   g. Set rules to improve the environment
   h. Install actuators in the system

4. Implementation and assessment
    a. Measurement campaign planning
    b. Data analysis
5. Identify corrective actions (new technologies, process redesign, organizational improvements)
6. Cost assessment of novelties

These six steps should permit a company to define effective strategies for innovative plants. Few steps consist in deeper tasks. Figure 9 represents the general steps of the method. With a design perspective, the "Factory Assessment" is the first step of the analysis. The method is thought as a loop. In fact, with a continuous improvement approach the factory should embed new processes and IoT framework as well. IoT design is an iterative approach.

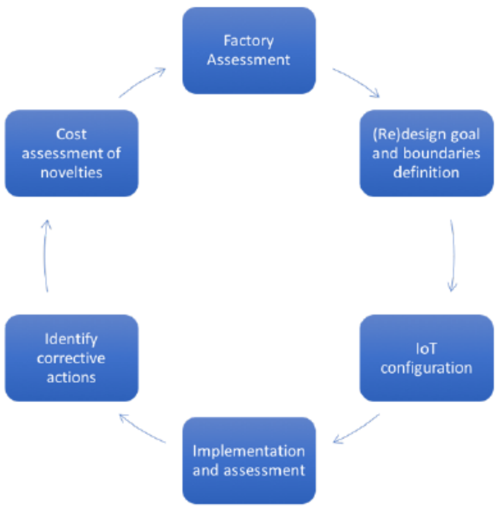

Figure 9. Design method for connected factories

Now the method is explained in deep.

The first step of the methodology consists in the definition of a clear State of the Art of the plant by a complete “Factory Assessment”. By the experience, in fact, many companies have a base line not clearly defined. With a focus on Italian manufacturing companies, they are growth fast in last 30 years but not in a homogeneous way; new technologies live together with old procedures and inefficient buildings or the opposite. This means that a structured innovation plan was not developed meaning lack of industrial culture and loss of money. The first step of the method permits to analyse this kind of situation understanding in a clear way the plant in terms of structure and resources. Understanding the plant from a structure point of view means identifying the layout of the plant considering also all spaces available. For this kind of analysis, the map and layout of the plant has to be acquired. Knowledge about resources permits to identify a clear picture of the competitive advantage of a company including human resources. Resources are mainly energy and raw materials. Diagram or reports related to them are useful to define the company asset. For what concerns energy, it means to understand also if auxiliary systems as photovoltaic panels or other energy storage system are available in the plant. Actually, there are many forms of diagram but none of them is related to the human resource state of the art. Understand human resources consist in mapping all man and woman working in a plant considering their skills, age and experience. Also, an asset analysis should be performed in order to understand all machineries of the production plant. Last part of this analysis is the production flow analysis, this permits to understand all the manufacturing stages of the plant. For what concerns this kind of analysis it means to define the complete process layout by IDEF0, Value Stream Mapping or any other diagram should define the plant work flow and management system. This phase permits to completely understand the company and related improvement opportunity on a general level.

The second step consists in defining the main driver of the (re)design strategy. It is in fact important that the design process is driven by a main scope. It should consist for example in reducing the environmental impact of the plant or developing a more efficient layout of the same. In this first step, it is then important to have a general overview on the main opportunity of a redesign. Step three consist in defining the IoT environment. This step will be explained in deep in next section. This step is the most important part of the method. It consists in connecting the systems of the factory in order to acquire data for certain analysis.

When the IoT environment is correctly configured step four should ran. In this step, it is performed the measurement campaign. Before proceeding with the measurement, it is important that all people related to the process are aware of the measurement in order to not perform actions should collide with the measurement (e.g. process shutdown). Data acquired depends on the IoT framework aim. In this step it is also chosen taken into account the goal of the assessment. The assessment should be compliant with the aim of the IoT (e.g. if the aim of the IoT is only energy monitoring it is impossible to perform a social assessment). After completing the data acquisition phase and performing a data analysis will be possible to define improvement actions depending on inefficiencies.

A cost analysis will define the opportunity to implement certain actions, according to problems identified.

The method is iterative and the IoT framework should be improved over time.

3.3.1. IoT Plant monitoring framework

The proposed method embeds the core idea of an IoT infrastructure aimed at acquiring parameters from the plant. This kind of infrastructure tends to create an intelligent environment that permits a designer to elaborate decisions in a faster and precise manner. It really happens in fact that data are available but there is no intelligence between raw data and the decision maker. Considering only a single machine in a factory environment, there are several data that should be acquired on it; energy consumptions, speed, lube state, vibrations are only few data that could be monitored. Sometimes companies are driven by data in a wrong way. The frustration to acquire data, only creates a huge amount of information that no one is capable to analyse. Data analysis is in fact a specific job; Industry 4.0 opens to this specialization. The work of an analyst should be facilitated by a proper digitalization of processes. The digitalization has to be on focus (according to the method) that the IoT infrastructure should have too. The idea of an intelligent IoT framework consists in a proper management of all the flows can occur in a plant. There are machines, products, environment and human resources. Each of them has a leading role in the manufacturing game. Therefore, digitalizing processes means digitalizing each of this entities with an efficient approach that the proposed method tends to be. To do this an efficient methodology to develop 4.0 factory system should be formalized. The present method tends to formalize steps that are required to shift the plant toward Industry 4.0. With this perspective under the paradigm of Industry 4.0, the IoT framework, defined by the present method, consists in a set of connected sensors on each entity speaking with a central server. This server embeds the intelligence to manage all the data, storing all the information with an algorithm that favours the decision maker interaction. Moreover, it is well known that companies already work according to MES or ERP that are the main controller of the production systems. These kinds of platforms will be integrated with information by the central server. It is possible to think to a situation where an ERP programs a certain production plan. If no tracking system of raw materials exists, can occur that production has to stop for a while (days or weeks). This is a common problem of SMEs where no integrated systems were developed and production systems are a sort of puzzle that has not a clear picture.

The proposed IoT platform takes into account lack of data and suggest integrating all available data in a central brain. With a broader view, it is possible to store all the data in a web platform should be controlled remotely. The general idea described is represented by the Figure 10. In the latter figure it is possible to understand as the central Server is the conveyor of all the data available in the plant. The new data flow that is here presented is the one related to the humans. Completing the central server information with data from humans permits to manage the production in a proper way considering all the process variables. With this approach, a decision maker should improve the production system considering also human capabilities. This is the real Industry 4.0 scenario where all the interactions are considered. The decision maker (that in the future should be an AI) could manage the production site according to all the data stored real-time in the central server. According to this idea it means for example to manage the lighting system in the plant (data from environment), depending on presence and characteristics of workers (data from humans) or defining a proper job rotation according to process features (data from machines) and workers capabilities (data from humans). This kind of framework open also to the smart working for decision maker. In fact, with a cloud storage a decision maker could interact with process variables from all over the world. Security issue should emerge and has to be taken into account while defining the framework. The IoT security is out of scope of the present work.

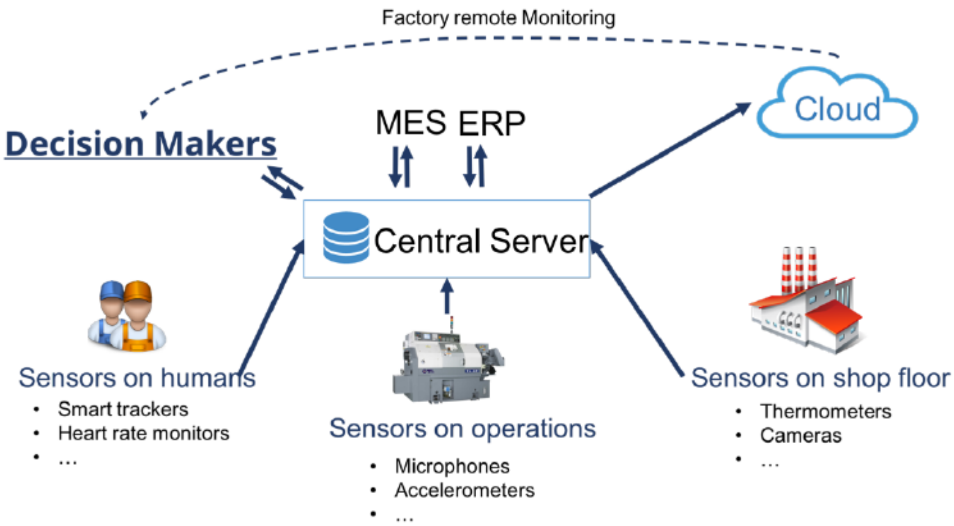

Figure 10. Smart framework for plant monitoring

Number and types of sensor will be defined following the steps of the method. This framework tends to be incremental. Implementing a complete network in a single stage could be very cost consuming for a company and no economical returns should be obtained. Defining an innovation action plan after a clear definition of real plant inefficiencies should be more effective. Inefficiencies should be defined in terms of scraps, wasted energy, complex processes, company organization. The IoT configuration method is now analysed.

3.3.2. IoT environments configurations method

Here will be reported how an environment should be configured. An IoT environment allows to realize an intelligent ecosystem where data generates corrective actions that should be executed manually or automatically. The configuration deserves a set of connected sensor in order to acquire raw data from the system. In each environment, there are a bunch of data that should be measured. Thinking on a simple empty office there are many environment variables: temperature, humidity, luminance, area, height, etc. All of these belong to different topics. Moreover, if it is considered a standard condition, the office should be populated by workers and variable increases: number of workers, vital signs, etc. This means that each IoT configuration needs a driver for a proper design. In the next table are reported two IoT design drivers. Each driver tends to define an IoT aimed at measuring certain variables. Each driver has its own variables. To measure variables specific sensors are required. In the table are reported values according to experience and previous analyses. There are many drivers for an IoT design and the table should be expanded when experience increase.

Table 3 – Variables/sensors matching

Environment	Driver	Variables	Sensors
Factory	Enegy efficicency	consumptions [kWh]	Network Analyzer
		type of operation	Video Camera / PLC info
		Productivity [pieces/hour]	EMS/ERP
	….	….	….
	Thermal Comfort	Temperature [°C]	Thermometer
		Humidity [%]	Humidity Sensor
		Pollution [CO2 ppm]	Pollution Sensor

Considering the method in section 3.3 of the present work, a deeper explanation is now proposed for the 3rd step of the same. The method in step 3 reported few sub-steps to create the IoT infrastructure for the plant. These steps are:

1. Define IoT framework aims
2. Identify variables of the environment

3. Identify sensors on the market
4. Select the sensors minimizing the equipment
5. Create the IoT framework
6. Convey all data in a single device
7. Set rules to improve the environment
8. Install actuators in the system

Those steps are defined in order to better structure the complete method in section 3.3. IoT environments are one of the opportunity according to Industry 4.0 tools. A connected factory is not only an innovative plant but it has to be a more productive and competitive industry that exploit Industry 4.0 enabling tools.

The first step consists in defining the aim of the framework has to be developed. In fact, an IoT environment has to be correctly structured. A proper sensorized environment embeds correct sensors depending on the variables need to be measured. Defining the aim of an IoT environment means understanding which are the variables have to be mastered within an environment. For each aim, a different set of sensors will be embedded in the IoT environment. For each environment, multiple aim should be defined (e.g. a home where energy efficiency and home automation should be achieved). With a proper IoT network it is possible to monitor few signals then increase the related intelligence and choice automation. Second step consists in identifying the variables of the system according to the first step. It is a crucial step because all the variables should affect the aims has to be taken into account. Each aim should have multiple variables that charachterize the same (e.g. thermal comfort should depend on humidity, temperature, co2 particles, etc.). From this perspective it is important to understand all the varibles should have importance for certain aims. Data acquired should be correlated in order to define proper results. According to the variables a technology scouting has to be done in order to acquire correct sensors related to the data to acquire. The latter market research it is suggested on the third step of the present procedure. This consists in identifying all the sensors that could be interconnected in order to acquire specific data. The market research should have multiple driver such as costs, data accuracy, transmission protocols. The decision consists in identifying the best trade-off between the variables. It is suggested to prefer sensor that has the same transmission protocols (e.g. ZigBee, Z-Wave, Bluetooth, etc.). This will simplify the network configuration. With a quick view on actual factories and processes it is not uncommon to see advanced manufacturing systems that are able to acquire data on consumptions but only for a real-time view without the opportunity to store them for future analysis. This is the case that has to be avoided following this procedure. Going on with the procedure the step four consists in minimizing the costs and the equipment. Simpler is the network, simpler will be data interpretation. To simplify here do not means to have less information. Simplify means avoiding infobesity. The better choice is to identify sensor that could have connected each other, communicating with the same protocol. If a sensor permits to acquire different data with an acceptable accuracy should be preferred instead of two different sensors with the same accuracy. In fact, the complexity of the framework depends on the number of sensor. Then in order to optimize the complexity of the network it is important to minimize the number of sensor. This optimization should also reduce the cost of the whole IoT framework. In a lifecycle perspective, more sensors mean more maintenance, more update: more IoT variables. Then when a simplification has been done the framework should be assembled in the environment. The creation of the framework (step 5) is strictly correlated to step 6. In fact, it is necessary to convey data in a single device (e.g.: database manager) in order to collect properly and classify data opening to proper analysis. These eight steps permit to create an intelligent environment. The last two steps should be considered an improvement. In fact, performing those two steps permit to exploit data collected by the sensor to improve the system with proper actions. Here is the difference between a sensorized environment and an intelligent environment. In a sensorized environment, looking to the previously mentioned office, the temperature sensor acquire data and show a countable number (eg. 18°C). Human when feeling cold, check the number and increase the temperature since it feels good. In an intelligent environment, there is a sensor in the environment and the human too. If the temperature of the human is under a certain threshold the thermostat automatically increases. This is the intelligent environment. Actions are executed automatically according to rules. This methodology should be conducted by a precise profile that could be, looking forward to the future factory, the IoT Engineer. This profile should be an expert of both sensors and processes. Each process has in fact a proper set of sensors that permits to monitor it.

4. Case Studies

4.1. Social life Cycle Assessment of a kitchen sink

The S-LCA method previously proposed has been exploited to calculate the social impacts of a product that is developed, manufactured and assembled in Italy during the project Green Sinks.

Green Sinks, "Realization of green composite sinks substituting organic and mineral primary materials by recovered waste" is a project funded by the Life+ Programme of the European Commission. The product analysed, is made of acrylic composite materials, composed by methyl methacrylate (MMA), poly-methyl methacrylate (PMMA), and a mineral filler (quartz or cristobalite). The aim of the project is to experiment and demonstrate feasibility of 100% substitution of primary resources by treated waste and recycling of 80% of scraps and refuses produced by the process. This will allow to future market introduction of the first Green Sinks in the world. Recovered MMA, PMMA and mineral filler will permit the preservation of landscapes and primary resources use, recycling a large variety of pre- and post-consumer waste (PMMA, glass, quartz from stone industries). LCA methodology has been used both to evaluate the environmental benefits achievable, and to complete the evaluation of the overall sustainability. To discover social impacts, a S-LCA analysis has been prepared with the method previously proposed.

The product is manufactured in Montecassiano (MC – Italy) from the company Plados Delta.

The social analysis of the product life cycle had the aim to understand the impact that Green Sinks have on all those actors which interact with it over its life cycle. The considered system boundaries refer to the whole value chain of the production of the kitchen sink, “from cradle to grave”. The Figure 11 represent the system of the S-LCA case study. Each stakeholder is involved in terms of people.

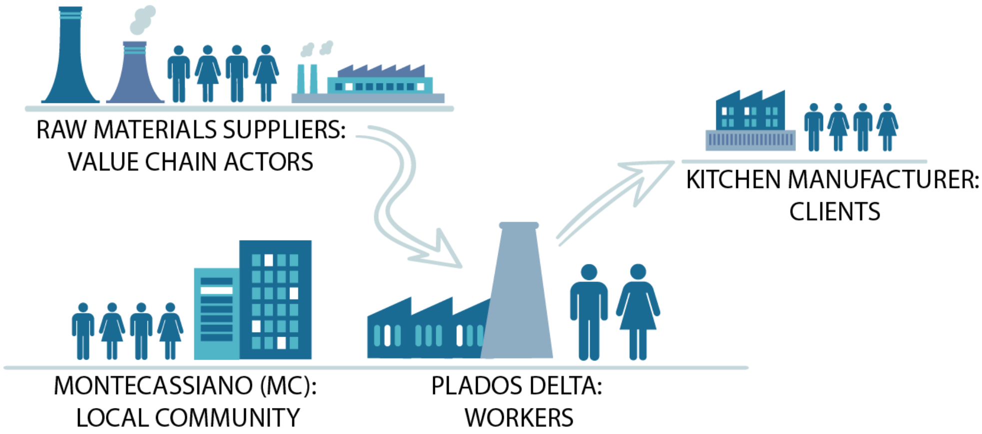

Figure 11. System of the analysis

Following this approach, 4 main actors have been identified in the framework of the project:

- Workers
- Value chain actors
- Clients
- Local community

Each of these stakeholders interacts with the product, even if indirectly. Indeed, if workers and clients interact directly with the product, this does not apply to local community, which only deals with it indirectly, through the proximity to the production site.

Specific questionnaires have been developed to get qualitative and quantitative information on the fallout of the project over people involved with it.

Questionnaires have been done in anonym form, so as not to influence the expressed judgment.

4.1.1. Workers assessment

The questionnaires for the workers have the purpose to define the working condition, highlighting the workers satisfaction, health, safety, and other related social topics.

A deep study was performed on social theme in production sites. After an iterative research with the company AoI were generalized and developed. AoIs were discussed with the human resources responsible considering the knowledge of the company on the social theme. This knowledge was merged with the skills of academia on that topic. These areas, in facts, tends to be valid in general for any workers assessment with the exploitation of the present method. Through this case study it was possible to identify them for the first time. In future assessments, the AoIs identification should be driven by the experience and past work, as the present, should be exploited.

For this stakeholder category, the following areas of interest are identified. *Professional training:* considering the continuous request of qualified work, the people training within the industry plays an important role in the growth of employees skills. In this view, it is important to evaluate how many training hours are spent to also improve the employers' knowledge of standards and best practices about sustainable manufacturing.

Professional growth: the personal satisfaction is also related to this area, during the working period in the industry. The professional training done and the possibility to improve personal skills, making different activities can improve this topic.

Economic satisfaction: the salary is one of the most important aspects related to the worker satisfaction: the wage permits the worker to realise itself outside the industry, supporting himself and (eventually) his family. The trade-off among salary, the type of work and the number of work hours is a fundamental issue.

Social inequality: different treatment of the workers can bring to social inequality. Discriminations regarding sex, nationality, religion, are important themes debated over the last decades. In this area, also the possibility for the worker to freely aggregate and set up associations, etc., can be included. In many cases the social inequality is related to different trade union representatives.

Risks at work: The aim of this area is to evaluate the risk level along the manufacturing activities. Risk is related to the environment in which the people work and the worker's behavior. The number of accidents and injuries quantifies the risk level.

Diseases related to work: A crucial aspect is the birth of occupational illnesses. In fact, risks can be related also to operations that bring to diseases such as carpal tunnel syndrome, respiratory diseases, sight reduction etc.

Employment scenario: Social sustainability is also related to the stability of the workplace. The growth or the decrease of the workers employed can be measured by absolute values (trend of employment during 5 years for example) and relative values that represent rate of layoffs and hiring; the number of employees could remain the same but there is a continuous change of the people.

Work opportunities for the local community: To guarantee a proper social growth the local community must be involved. In this case the number of employees who live in the local area represents the local involvement.

These AoIs were then defined by few questions that should define in a qualitative way a certain area. The survey proposed to the workers is composed of few questions that tends to describe all the areas identified. The question development required two weeks of work with the company in order to identify the best semi-quantitative questions that should remove subjective and not interpretable answers.

As far as workers concerns, 12 Plados employees have been interviewed. The sample resulted to work for the company by, on average, 5 and a half years. To each of them the following questions were asked:

- How much do you feel rewarded to work for an R&D intensive enterprise?
- To what extent do you value the commitment of an enterprise toward green and eco-compatible products?
- Do you know what “green product” stands for?
- Which is your role within Delta?
- How many years have you been working for Delta?
- Are you aware of what happens upstream sink production process, such as materials supply?
- Are you aware of what happens downstream sink production process, such as treatment of manufacturing scraps and refuses?
- Are you aware of the Green Sinks project, financed under the LIFE Programme?
- Are you aware of the environmental benefits which might result from its commercialisation?
- Are you pleased to work for an enterprise whose mission is to become more environmentally sustainable?
- To what extent do you think Green Sinks might increase company competitiveness?

Questions were targeted to understand the impact of the new sink on those who are entitled to produce it. Staff from R&D, design and production departments were involved. Answers, which includes personal opinions, were concurring. All the employees have a positive opinion about development opportunities connected with the product. Furthermore, employees had been able to explain in detail the environmental benefits arising from the project, which shows an increase of the culture and knowledge bound with it. Worker satisfaction has also been investigated through a series of questions which were intended to understand their effective working condition. Overall, as far as the worker category is concerned, the project can be considered sustainable.

4.1.2. Customers assessment

Once the sink has been realised, it is sold to a kitchens' manufacturer. This company is identified as the first customer of the sink manufacturer and in this study, it represents the customer.

Three different areas of the company structure have been identified according to the functional organization model structure of a company: Purchasing, Manufacturing and Sales departments. These three company sectors have been chosen as they all interact with the kitchen sink from different point of views. Three different questionnaires have been here revise. For each subcategory one or more questions are proposed. The final customer, the one who buys the kitchen, is not included in this area of interest.

These are the area of interest identified for the customer stakeholder. These were identified as stated for the workers. It was discussed with Plados manager and marketing specialist which should be the most important values that the clients require to the company. According to some discussion the AoIs were identified.

Health: The product traded should not influence in any case the state of health of the workers that are directly or indirectly related to it. Kitchen sinks are included within the ISO 19712-1:2008, which establishes a classification system for solid surfacing materials according to their performance. The model under analysis is supposed to be compliant to the present regulation. There should be a sign "label" that confirms the approved status of the product.

Safety: The product should not be harmful for any operator that directly or indirectly operates with it. In this context, the list of possible interactions with the sink should not exclude the final customer (the one who buy the kitchen), even though he is out of the system boundaries. Potential danger should not be allowed. When this is not possible due to the nature of the product itself, it should be clearly stated which parts, or actions could procure safety issue.

Feedback: The customer should be able to express a feedback on every purchase. The customer should not be scared to externalize his opinion. The seller should also give instruments and possibilities to do so. For example, the seller could ask for feedback on a traded product by using questionnaires and it should make the buyer comfortable in expressing his opinion.

Privacy: In order to foster a successful partnership and to ease the interaction between seller and customer, a certain amount of information must be shared. Nevertheless, privacy should always be respected. Meaning that the customer should always feel "safe" in sharing information with his seller. As an example, the kitchen sink manufacturer should provide a form that describes how sensible data from customer are treated.

Transparency: The customer is able to evaluate the performance of the product in a strict correlation to the social responsibility perspective. The seller/producer is able to show in a transparent way his attitude respect to sustainability issues. The customer on his side, is aware of the position undertaken by the producer/seller and thanks to that is able to think about political choices undertaken by the producer. For instance, the seller could show to his customers which sustainability actions or strategies have been undertaken in order to realise the kitchen sink.

Responsibility shares concerning after-use treatments: The producer sends production scraps for further treatment in developing countries. These wastes might be seen as potential danger for poor people that look for high value things into landfill plants. The producer should follow regulations concerning end of life management. As an example, the kitchen sink manufacturer could provide documents concerning the disposal of the product.

Imagine perceived from the final customer: The product contributes to define a positive image or a solid attitude towards sustainability issues. By acquiring/using the product, the customer itself is perceived from the outside, as someone which is aware of the importance of environmental issues.

Knowledge and awareness: The customer gains knowledge and expertise in the field of sustainable products. Its involvement in the "green" economy is enhanced by the trade of the kitchen sink or in general by the collaboration with the producer/seller. For instance, knowledge and expertise gained by the kitchen sink manufacturer could be shared as an aspiring action toward the involvement of "green" reaction within the kitchen assembler.

Post purchase engagement: The relation between the two parties is kept "alive" also when the transaction is over. The liaison is not merely constricted in the pure economic ambient but it goes beyond. The relationship level is deep and therefore involving both parties in a solid way, fostering future collaborations and initiatives. As an example, from the trade of the "green" kitchen sink, a collaboration in financed projects for sustainability could be proposed from both sides.

According to those AoIs, questionnaires were developed and administered to 22 companies among Delta's clients. Each of them asked the person who is more directly in contact with Plados to answer to the following questions. Each question or cluster of questions defines an AoIs (e.g. knowledge and awareness AoI is defined by question 1, 2, 3). The interviewed is not aware on AoIs. Only the person who will interpret the data knows this combination. Question developed are the following.

- Do you consider important that a company is environmentally and socially sensitive?
- Does your company might be interested in promoting eco-sustainable products?
- To what extent do you consider product eco-sustainability an added value for your company?
- Would you appreciate if Green Sinks would mention in their labels the environmental impact of the product (such f.e. Co2 emission)?
- Are you aware of potential benefits (such as less pollution, reduced mineral extraction and landfilling) connected with the purchase of a Green Sinks with respect to more conventional products?
- Are you aware of the methods for composite sinks disposal at the end of their lifecycle?
- Do you expect the green sinks having performances and quality levels comparable to those of composite sinks made of virgin materials?
- Do you think that a product made of recycled materials could fully satisfy customer requirements?
- To what extent your customer base is sensitive to environmental sustainability and interested to use eco-sustainable products within its dwelling?
- To what extent do you think market is ready to distribute sustainable product which may compete with traditional ones at the same price?
- To what extent the Green Sinks proposition may influence positively the image of your company and your relationships with your customers?

- Green sinks may contribute to a better environmental awareness of consumers?
- Considering that in the future environmental protection will necessarily become a driver for design and consumer choices, to what extent the introduction of eco-sustainable products might increase your company competitiveness and attractiveness?
- Do you think that a green design/production approach of new products might bring economic benefits to your company?

1	Ritiene importante che un'azienda sia sensibile ai temi della sostenibilità ambientale e sociale?	SI			NO		
2	La sua azienda potrebbe essere interessata a promuovere prodotti ecosostenibili?	SI			NO		
3	Quanto considera la eco-sostenibilità di un prodotto un valore aggiunto per la sua azienda?	0	1	2	3	4	5
4	Gradirebbe che sui lavelli GREEN SINKS fossero apportate delle etichette che indichino l'impatto ambientale del prodotto, come ad esempio l'emissione di CO2?	SI			NO		
5	È consapevole dei possibili benefici (quali il minor inquinamento, ridotta estrazione di minerali, ridotto uso delle discariche per gli scarti aziendali) legati all'acquisto del prodotto GREEN SINKS rispetto ad altri lavelli più convenzionali?	SI			NO		
6	È a conoscenza dei metodi di smaltimento dei prodotti quali i lavelli in materiale composito a fine ciclo di vita?	SI			NO		
7	Si aspetta dal prodotto GREEN SINKS delle performance e dei livelli qualitativi paragonabili ai lavelli in materiale composito realizzati con materie prime organiche ed inorganiche vergini?	SI			NO		
8	Pensa che un prodotto realizzato con materiale riciclato possa soddisfare a pieno i requisiti che i consumatori richiedono?	SI			NO		
9	Quanto la sua clientela è sensibile al tema della eco-sostenibilità e quanto è interessata all'utilizzo di prodotti eco-sostenibili all'interno della propria abitazione?	0	1	2	3	4	5
10	Quanto ritiene pronto il mercato a distribuire prodotti eco-sostenibili che possano competere con quelli tradizionali a parità di costo?	0	1	2	3	4	5
11	Quanto la proposta del lavello verde può influenzare positivamente l'immagine della sua azienda e le relazioni con la sua clientela?	0	1	2	3	4	5
12	I GREEN SINKS possono contribuire ad una maggiore conoscenza da parte dei consumatori dei temi ambientali?	SI			NO		
13	Considerando che in futuro la tutela ambientale sarà necessariamente un driver di progettazione e scelta dei nuovi prodotti da parte dei consumatori, l'inserimento di prodotti eco-sostenibili quanto possono aumentare la competitività e l'attrattività della sua azienda?	0	1	2	3	4	5
14	Ritiene che un approccio "green" alla progettazione/produzione di nuovi prodotti possa dare benefici anche economici alla sua azienda?	0	1	2	3	4	5

Figure 12. Filled anonyomus survey in Italian language

The Figure 12 represent a copy of a survey filled by a client. It is possible to identify that all the questions are semi-quantitative in order to remove the subjectivity of the person interviewed.

The questions were obtained by a two weeks work with Plados marketing specialist. Their knowledge permitted to develop the best questions to define the AoIs according to the stakeholder category.

It is proposed for this stakeholder category the interpretation process. A similar process has been developed for surveys concerning the other stakeholders. This is why this procedure will be showed only in this section and tends to be as example for the other stakeholder interpretation phase.

Each question by the procedure will have a score according to the method. Scores of each question for the present stakeholder are summed in the next table.

Table 4 – Variables/sensors matching

Question	Score
1	1,00
2	0,91
3	0,28
4	0,86
5	0,77
6	0,23
7	0,77
8	0,73
9	0,07
10	0,32
11	0,24

12	0,90
13	0,33
14	0,10

Firstly, the answers showed that 100% of the respondents considers corporate social and environmental responsibility as fundamental (question 1). Only two companies (9% of the companies involved) do not consider interesting the commercialization of eco-sustainable products. On a scale from 1 to 5 (with 5 being the highest satisfaction), the importance of a product eco-sustainability obtains on average 3,5 points.

These scores should now be converted into mid-point then to end point.

The conversion was done with a deep study in combination with social experts. This process was done firstly associating question to a midpoint. The midpoint list was obtained by identifying the crucial information that a question embeds. A list of 10 midpoints emerged. Each question could contribute to many mid-points. Each midpoint is defined by the arithmetic average of the related question scores. The global index for each stakeholder category is defined by the average of the end-points score. In that case the Global sustainability score for the stakeholder customer is 0.61.

Table 5 – S-LCA score for stakeholder customers

MID point	related question	mid-point score	End point score	END - point
social awareness	1	1,00	0,68	Culture
eco awareness	1,11	0,95		
labeling usage	4	0,86		
product perception	9	0,07		

dissemination	6,7	0,50		
eco interest	2,3,10,13	0,38	0,49	Growth
sustainability value	12	0,33		
performance consistency	7,8	0,75		
labeling usage	4	0,86	0,68	Responsibility
dissemination	5,6	0,50		

The Table 5 reports the complete scoring system for the stakeholder customer. For instance, the indicator "Growth", include the mid points eco interest, sustainability value and performance consistency: it is the mean of those 3 mid-points scores. Eco-interest is in turn the mean of the percentage rank of the questions 2, 3, 10 and 13. Performing this linkage for all the stakeholders permits to develop the global S-LCA score.

As far as customers are concerned it is thus possible to define as positive the social impact of the product. The increased knowledge with emerges from the interpretation of results is surely positive for human growth and can thus be considered as a social positive fallout.

4.1.3. Value chain actors assessment

Further questionnaires have been drafted to addressed to value chain actors. Value chain actors are mainly the suppliers of the central company, in that case the PLados Delta. With a broader view also other actors are concerned to that stakeholder category (e.g. shipping companies, energy providers, etc.). In this category have been considered all the providers acting within the supply chain which leads to the realization of the green sinks. The following questions have been gathered into a questionnaire which was administered to 8 companies for the present case study. As other stakeholders, these were identified through an intensive work with plados.

- Company size
- Number of employees
- In the case it is not a multinational company, where your company is located?
- Indicate the main countries of origin of the materials used by your company
- Indicate the main countries where your company is commercially present
- Do you consider important that a company is environmentally and socially sensitive?
- Does your company might be interested in promoting eco-sustainable products?
- To what extent do you consider product eco-sustainability an added value for your company?
- Do you know what “industrial symbiosis” means?
- Do you use or intend to use shortly secondary materials?
- Green sinks might contribute to increase the knowledge of suppliers on environmental themes?
- Do you think that a green approach the supply of new products might bring benefits to your company also in economic terms?
- Does your company considers human resources as an important asset?
- Do you think that Delta Green Sinks might bring benefits to your business, including in creating new employment opportunities?

- Does your company devote time and economic resources to train employees?
- Do you think that after the green sinks project your relationship with Delta might improve and bring to increasing volumes of sales?
- How much do you consider rewarding/stimulating having supply relationships with a “green” company?

Once surveys were filled the data interpretation was performed.

One of the first aspects emerging from questionnaires is the international dimension of the realities involved. Indeed, respondents have commercial presence in the whole European Union, north America, India and China. Most of the companies are aware of the concept of industrial symbiosis, which denotes an innovative concept of product realization. 50% of the companies interviewed is actually using secondary materials. This index shows a growing sensitivity toward the optimization of resources. Within the sample different opinions emerged, indicating the difficulty of extending sustainability over the entire value chain of the product. The international dimension of the sample shows how different realities still have very different sensitivities on sustainability topics.

4.1.4. General results and discussion

Based on the more or less positive correspondence of the answers, the project shows the following marks for sustainability:

Table 6 – Social index results

Employees	**Customers**	**Value chain actors**
0.92	0.61	0.47
SOCIAL SUSTAINABILITY INDEX: 0.66		

Considering the total positivity of the answers as equal to 1, it was calculated the average of the answers for each of the three groups interviewed, defining a total index of social sustainability of the initiative. The metrics used in the present analysis, also depending on the state of the art of this kind of analysis, offered good results from a qualitative point of view.

The approach permitted to narrow the problem and define the index shown in Table 6. These results were considered interesting for the present project. In fact the report was attached to the LIFE+ report and evaluated positively by EU commission. The procedure has highlighted the difficulty to acquire data directly from the field. If the method tends to remove subjectivity (through semi-quantitative assessment), it was very difficult to standardize the questionnaires and propose the same to stakeholders. Moreover, as written, questionnaires related to stakeholders external to the company resulted poor information and sometimes filling was rejected. This method tends to define a simplified procedure for the S-LCA in order to gain in a fast manner measurable results.

Anyway, It was noted that the analysis required a huge amount of time. From a designer point of view, it is not simple to identify improvement actions for the product following the results. Moreover, potential corrective actions are more in the field of economics. These findings have pushed the present research towards the identification of social issues in the field of pure manufacturing, with an approach "gate to gate" within the company. Moreover, S-LCA research was stopped when this case study was concluded. This decision was taken because the theme at a global level has continued toward a pure economic path that is quite distant from competencies and aim of the present research group.

4.2. An IoT environment for social assessment

The second methodology presented was related to the development of sustainable plants according to Industry 4.0 tools. In order to understand the effectiveness of the methodology a case study was performed. This was developed in an Italian large company, Eurosuole, who produces soles. This company is settled in the middle of Marche Region where many companies related to shoes supply chain have growth. Eurosuole is one of the worldwide top player for rubber soles and polyurethane soles. These are in fact the main departments of the company.

The present study was defined according to company's growth plan. In fact, for a proper sustainable growth the company requested the knowledge of the Università Politecnica delle Marche in order to clearly define actual criticalities of the internal processes to understand a clear innovation path. This should permit proper innovation actions that tends to establish a sustainable development of the plant. The full method was applied in order to establish principal strategies for a proper and sustainable manufacturing innovation.

4.2.1. Factory assessment

The first step suggested by the method is a factory assessment. This permits to understand the state of the art of the Eurosuole company in terms of plant layout, flows and available resources. The plant layout is shown in Figure 13.

The whole plant consists in 55000 sq.m. and is divided into 7 different blocks. The plant consists mainly in the following departments:

- Polyurethane Hot Stamping
- Rubber Hot Stamping
- Sample laboratory
- Finishing and painting
- Painting mixture lab

- General Warehouse
- Offices

Each department aims at a specific step of the manufacturing of the sole product.

Figure 13. Eurosuole Plant Layout

The plant produces daily 70000 polyurethane sole pairs and 35000 of the same in rubber. The main manufacturing processes are:

- Rubber sole production

- Polyurethane sole production
- Rubber and Polyurethane sole production
- Painting mixing

An accurate plant assessment allowed to go in deep with the most important phases of those processes.

The Rubber preparation (formulation) department is made of four mixers. Those permits to obtain a rubber coil that is cut according to the sole model. Those rubber pieces are extruded to be ready for the forming phase. In rubber forming phase there are 25 double floor compression presses and 56 injection presses. Shapes are heated over 150°C in compression presses, the operator load the preformed rubber then executes the compression to activate the product vulcanization. The press will be opened and the product is extracted. For what concerns the injection, the operator only controls the process because there is an auto loading system of raw material (rubber).

The polyurethane formulation is performed by 16 external silos that contains Methylene diphenyl diisocyanate, resins, polyether and glycol. These are mixed in a certain quantity (that is not reported here according to an NDA) in order to obtain the polyurethane polymer. The Figure 14 represents the mixing steps.

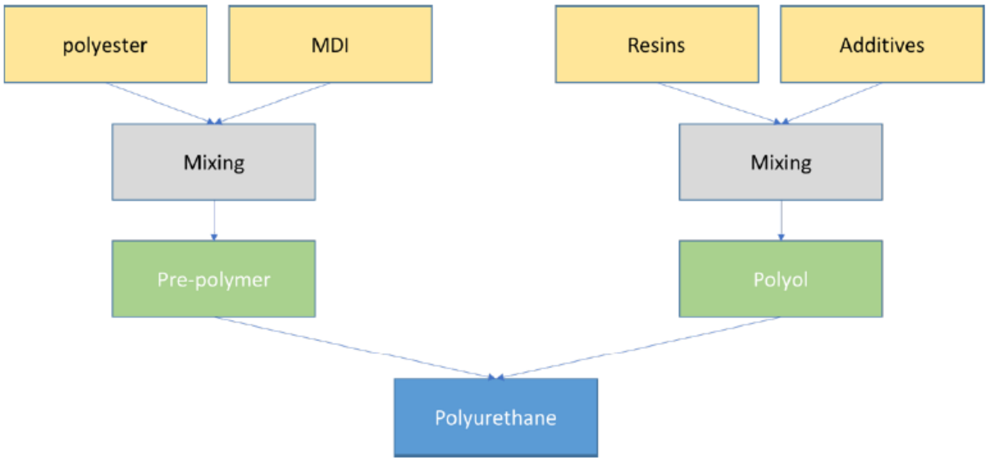

Figure 14. PU mixing phases

The PU has 3 ways: storage for internal use, storage for shipping, direct flow in stamping machines. The PU stamping is performed in a specific department. Here are the stamping carousels. These consists in rotating machine where PU flows in shapes. The shape is composed by 2 parts. After PU flows in the lower shape the upper one closes on the other one to make the compression. During the rotation PU expands and takes the final shape. The Figure 15 represents the system has been described.

Figure 15. PU forming carousel Eurosuole

Each shape has a specific RF-ID to guarantee tracking. After a complete turn, the shape opens and a robot remove the product. Sole are then put on a transport system moving them to the storage site. They will be automatically stored in boxes according to their size. Both the PU and the rubber soles needs to be refined with finishing processes such as refinement and painting. Refinement consists in removing exceeding material from the soles. Painting could be performed in two different ways: spray painting and immersion painting.

4.2.2. Goal and boundaries definition

At the present moment, the factory is planning a factory redesign with a related expansion in terms of land use. According to this opportunity was discussed the driver of the redesign matching the needs of innovation and sustainability. One of the most important added value of the company is the people. In the factory, there are 3 general managers, 28 employees and 170 workers. Considering the different processes explained, the most of workers (40%) are involved within the finishing processes. Following this state of the art the re-design was focused on the finishing area. Then the goal of the analysis was to improve and innovate the finishing area of the plant from a social point of view with the perspective of digital manufacturing. That means for the company to match the opportunity of Industry 4.0 with needs of the operators. The scope of the case study is to define the social relapses of the as-is process understating the opportunity of a redesign of the same. The assessment has to focus particularly on the packaging operation. This choice has been driven by the innovation plan of the company. This is in fact a completely manual operation that could be boosted by innovation. Before innovation and digitalization occurs, inefficiencies have to be defined by the present analysis. According to the method it is now proposed the procedure that drove to the definition of the IoT monitoring framework.

4.2.3. Social assessment Variables identification

According to the goal, the boundaries, and the method, all the variables related to the assessment are now defined. This will drive the IoT configuration. Considering the driver chosen for the analysis (social sustainability), are now identified all the parameters to monitor. Firstly, the standards and norms related to human workers are taken into account to understand which are the main rules that regulates the plant according to the social issue. A study was conducted considering few norms related to the social issues on plants.

A collection of international standards on the design of machinery and working environments has been carried out taking into account the specifications laid down in the Machinery Directive. The standards have been classified according to the level of design specificity. The norms were studied and classified as in Appendix A. This first huge classification permitted to identify potential problems that have social relapses. The classification tends to be valid for further social assessment.

According to this study it was also developed a comfort design matrix (Table 7). The matrix is the result of a deep study of norms and literature concerning the social topic in factories. It tends to be an abstract of the knowledge related to the health and safety norms in order to simplify the work of a designer during its daily work for a plant redesign. It is a "decision matrix" since it considers different parameters, and it has been called "comfort" since it is inspired by the literature concerning the assessment of comfort topics. This matrix not only permits to understand which parameters has to be considered while dealing with social topic, it also suggests a comfort strategy in consideration of the suggestions by the norms. According to this deep study it is possible to identify the variables of a plant social assessment as the following:

- Physical Ergonomics
- Cognitive Ergonomics
- Environmental Ergonomics

Related parameters were deeply discussed in the state of the art. With this knowledge, in the present case study, the social assessment will consider:

- HR
- Thermal comfort
- Environmental Pollution
- Posture

- EOG

Table 7 – CDM

Parameter	General considerations	Comfort Strategies
Thermal comfort	21.6°C with a 1-2 percent decrease in performance for every 1° C above or below	- Provide individual control of air flow - Provide zoned temperature controlled - Optimize sunlight, airflow and temperature control providing windows which could be opened if necessary
	Regardless of business size, the minimum temperature for indoor workplaces is 20°C and the maximum is 24°C. The acceptable range for indoor humidity is between 20 and 60 percent.	
Noise	− minimum noise exposure: <85 dB(A) 8 hour per day − moderately high noise exposure: 85−90 dB(A) − high noise exposure: >90 dB(A)	− the work process (including tools and machinery): for example, install quieter equipment, promote good maintenance; − the workplace: for example, use noise enclosures or acoustic equipment; − the workers: for example, set up work practices and other administrative controls on noise exposures, and provide audiometry tests and hearing protection, and workers' education programs. - Provide protective equipment
Lighting	- Surface materials - Windows position - Artificial lighting disposition - Lighting control and progressive regulation based on the natural light intensity	- Windows should be located where do not represent a risk for workers - Use glass where visual privacy is not required. - Give preference of natural views - Local lighting support the task
Indoor air quality	- Final product materials - Intermediate product materials - Airborne materials - VOCs - CO - CO_2 - PM10 - PM2.5	- Enclose processes with dangerous volatile material - Consider intake systems - Use alternative material to the dangerous ones

Human factors and ergonomics	- Postures (neck, back, upper limbs, lower limbs) due to workstation design - Anthropometric measures - Working spaces specification - Physical effort - Cognitive effort - Work organization - Job design - Human-machinery interaction - Protection systems	- Provide adjustable furniture such as adjustable chairs, task lights, sit-to-stand desks and keyboard trays - Provide technologic aid lifting equipment - Provide efficient technology to enable efficient work in all work settings provided - Ensure technology is "user-friendly" and provide instructions clearly visible to the user - Equip employees with tools and technologies that encourage mobility in the workplace - Provide employees with laptops and mobile devices - Provide VoIP phones that allow workers to easily move between desks or rooms and still make a call - Provide technologic protection systems to prevent impacts with human part of the body

4.2.4. IoT configuration for social assessment

The previous identified variables have to be acquired through a proper connected framework. The opportunity is to define a structured IoT system aimed at acquiring information from the plant. Designing the framework includes identifying all the elements needed, including a platform to collect data toward a proper interpretation. Connecting information permits to simplify the data analysis process.

The IoT for the present case study will include:

- A network connectivity
- A hardware to collect data
- Connected sensors

Going in deep with the network a research of technologies was performed in order to develop the best IoT framework for the present case study. Taking into account the variables, a market research of sensors that permits to understand values was performed. The research was performed on the market through fairs partecipations and web scouting. All the technologies deserved by the analysis were classified and clustered. In this perspective and according to the social variables, the framework will be composed by:

- Video Camera
- Steps Counter
- Heart rate sensor
- Cognitive stress sensor
- Posture sensor
- Temperature Sensor
- Humidity Sensor
- Pollution Sensor
- Tripod
- WiFi router
- Cables for A/C connectivity

As mentioned it is important to optimize the system. Then after the market research the framework has been simplified by:

- 1 Camera
- 1 pair of smart glasses for mental load recognition
- 1 smart Heart sensor
- 1 smart pollution detector
- 1 step monitor
- LTE router
- PC for data storage
- Tablet for real time monitoring

The camera permits a visual control of the operations in order to identify all the single working task of the operator. Camera has to be installed on a tripod with a complete view on the testing area. This permits to control the system real-time or, after the test, to interpret and align data to the operations. It is in fact important to understand what a signal means in terms of operations. Without the vision data, there is a lack of information. The camera exploited for this framework is a SONY RX100 pocket camera. It permits to record 30min of video continuously, has a 4-hour battery and a wide-angle lens. This kind of lens permits to have a wider view of the environment where the assessment has to be performed.

To assess in an objective manner the mental load of the operator a pair of smart glasses has been provided. In fact, after a deep research on the market it was identified the JINS MEME Smart glass. In particular the academic version was acquired in order to manage raw data. These non-corrective glasses permit to perform the electrooculogram analysis that has been discussed previously. The idea is to understand mental workload by the electrooculogram. These glasses have 3-point electrooculography sensor (Figure 16, Figure 17) that permits to capture eyes movements then mental workload. This particular choice has been driven by the need of a tool that doesn't affect the everyday work of the operator. These glasses have a built in Bluetooth module that sends data real-time to a PC. There is a USB module connected to the PC that collects signals from glasses. A Windows Software, the JINS MEME Data Logger was provided with the glasses; it permits to visualize or store in a ".csv" file the data. This software, which interface is shown in Figure 18, proposes 3 graphs: accelerometer, gyroscope and electrooculography. This device in fact permits to understand the orientation of the head of the user by a gyroscope embedded on the glasses. For the present analysis only the electrooculogram was exploited. This kind of analysis register the ΔV that generates the eye movements. In particular the threshold is $\pm 1200 \mu V$. Signals refers to eye orientations: each movement generates a ΔV. According to literature are taken into account only blinks that are related to fatigue. Left/right movements can be tracked by the glass but are considered useless for the present analysis. The glasses have a 8 hour battery life.

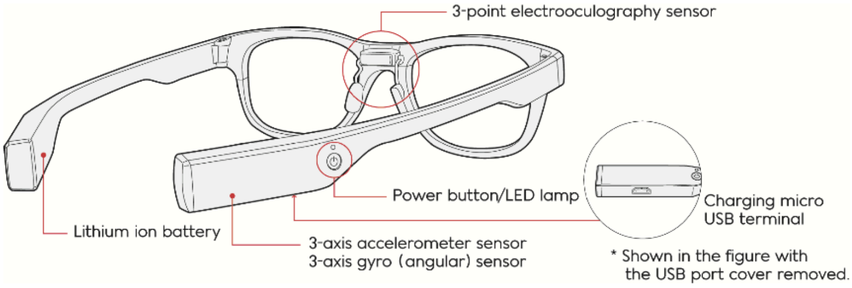

Figure 16. Smart glasses features (JINS MEME)

Figure 17. Smart glasses electrooculography sensors on a JINS product

Figure 18. JINS Data logger interface

A smart sensor that collects multiple parameters has been identified to monitor vital signs of the operator. The device will be exploited is the Zephyr BioHarness 3 (Figure 19). It is a band that embeds a Bluetooth sensor. It has to be installed on the chest of a patient to monitor vital signs. In particular it collects the following data:

- HR: heart rate (BPM)
- HR%: heart rate percentage (%) is the instantaneous heart rate on the maximum heath rate available (e.g.: max hr=185, instant heart rate=137 then percentage is 76,11)
- RtoR dist: distance in ms between 2 breaths
- BR: Breathing rate (BPM)
- Posture: -180 -180 (°)
- Activity (VMU): vector sum of activity counts in three orthogonal directions

Figure 19. Zephyr Bioharness sensor and band (lab photo)

Vector Magnitude Units (VMU) are used to indicate activity level. They are expressed in 'g' - units of gravity, 9.81m/s^2

- 0.2g - roughly equivalent to a walking level of activity
- 0.8g - roughly equivalent to a running level of activity

The BioHarness contains a 3-axis accelerometer which can record values of ±16g in the X (subject vertical), Y (subject lateral), or Z (subject sagittal) axes.

Data from the sensor can be monitored real-time through a Tablet app then a data download can be performed through a PC software that permits to analyse data off-line (Figure 20). A smart step monitor was identified for monitoring operators movements across the different areas. It is the Withings Pulse sensor that permits to monitor steps. The sensor consists in a belt accessory that the tester puts on its waist in order to collect data.

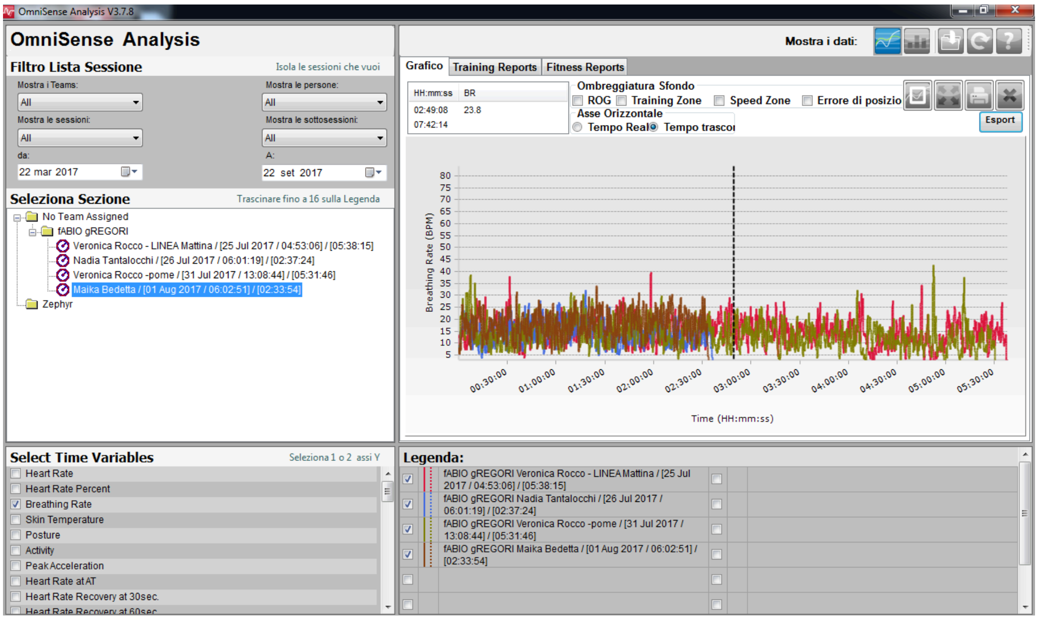

Figure 20. Bioharness data analysis software (pc screenshot)

To acquire data from the environment the tool identified was the Foobot Smart Air Quality Monitor Figure 22. It is a Smart tool that embeds multiple sensors giving data on:

- Temperature
- Humidity
- Fine Particles
- Total VOC
- Carbon Dioxide

The tool can measure fine particles from 0.3µm to 2,5µm (PM 2,5). Range is from 0 to 1300 µg/m^3 with a precision of ±20%. Temperature range is -40 to +125°C with accuracy of 0.4°C. Humidity range is 0 to 100% with accuracy of 4%. It needs to be connected to an A/C plug in order to work.

It has a WiFi connectivity aimed at a remote control through a proper Smartphone App. This was also selected thanks to its alert functions. In fact, it has a built-in lighting system that changes from blue to red according to the air quality status. Intense blue indicates a healthy environment, intense red indicates bad air quality. Moreover, this sensor permits to notify remotely when there are air quality issues. Data can be monitored real time with a time step of 5 minutes. Data are stored in a personal cloud and can be visualized only though the App. It was a limit that has been overcome through an interface with Google Drive. It was in fact developed a function to automatically send data to a worksheet in order to collect and classify data in a proper way (according to step 6 of the IoT configuration phase). The developed framework was thought as portable in order to move it through the production site in order to assess different working areas. To identify those sensors it was performed a market research (according to the IoT development method presented). The JINS is the only electrooculography connected device that is available on the market. For what concerns the environmental sensor it was analysed on the market the available IoT sensors, it was found that few sensors exist (Awair, Foobot, Neatatmo) but the Foobot is the only one having open API permitting to extract raw data and store the same on a cloud.

The other IoT tools identified were already available in the University.

Figure 21. Foobot Smart Sensor (lab photo)

4.2.5. Plant Social assessment

Testing Area analysis

Once the framework was defined the preparation occurs. Before the test a technical discussion with the plant manager occurred in order to make he aware about the test has to be performed. The framework had to be installed in order to not affect the everyday working of the plant. An added value of this kind of testing was in fact the opportunity to continue the normal production, without affecting the productivity, during the measurement campaign. The two-specific testing area were identified and the configuration was done as follow. The first testing area was at the end of the painting line where the packaging is performed. This area consists in a 70sqm area where 2 operator works. These 2 operators take soles from a conveyor belt and pack them into boxes. That conveyor belt is the last part of the painting machine where few soles flows after the automatic painting and drying phases. The conveyor belt proposes 1100 soles per hour. Soles are produced in lots. This mean that on the conveyor belt there is always the same product in turns. The operator should only select the correct size and side (1dx and 1sx). Operator selects the soles and, after the box filling and classification they move it to a temporary storage area where they stack up few boxes. With a certain occurrence, a forklift removes boxes from storage area in order to proceed with the final box storage. Packaging operation has few sub-tasks that will be studied during the assessment and reported later. A representation of the area is shown by two views in Figure 22 and Figure 23.

Figure 22. Painting line Packaging Area (conveyor belt, photo onsite)

Figure 23. Painting line Packaging Area (storage area, photo onsite)

The second area where the framework had to be installed, according to the goal of the analysis, was the carousel packaging area. This area consists in a 90sqm where few operators act. The area is shown in Figure 24. The operators here perform similar operation in comparison with operators in the painting line packaging area. In fact, if on the line there was a conveyor belt, here operators pick soles from a carousel. The carousel has 2 side, on one side a manual painting is performed. When painting is completed, an operator puts the sole on the carousel. The carousel turns in order to permits the sole to be completely dry. After half a turn, on the other carousel side, the packaging specialist took the product in pairs and proceed to packaging. The carousel has a speed of 1m/min. Another peculiarity of this kind of packaging is that the operator manages 2 or three boxes at the same time. In fact, carousel transports, different products in different sizes at the same time. The carousel has 9 layers where the soles should be picked.

Figure 24. Painting Carousel Packaging Area (photo onsite)

This general analysis permitted to proceed with the test planning phase according to the different environment variables.

The two testing areas are then clearly defined. It is to note that the areas are in the same department but between these 2 areas there are 30m of distance. These were useful information in order to schedule and arrange tests.

Measurement campaign planning

This phase was developed though a deep analysis with shift and work force responsible. Focus in this phase is on identification of the best scheduling strategies for tests. The goal is to optimize data acquisition time, taking into account IoT network features. In fact, considering that few wireless systems will be exploited for the data acquisition campaign, duration has to fit the battery time of devices. Moreover, taking into account the operations will be monitored, few attentions has to be pointed out.

The packaging at the end of the painting line has 2 operators but they do a slight different work. In fact, if they both pack the items, only one proceeds to the VDT interaction. In fact, only one operator access to the PC, in order to check the lots and print the label that will be put on the boxes. The same will proceed to the count of the boxes asking the forklift intervention when a stack is complete. This operation works on 2 shifts 5 days a week. The first shift starts at 5 am to 1 pm. The second Shift is 1 pm to 9 pm. For each shift, there are always two operators. After four hours from the start there is a 15 minutes pause.

Considering the carousel there are two operators acting together performing the same operations. They both manage also a VDT to print labels for boxes. This operation works on a single shift on 5 days. It starts at 6am to 2.15pm.

This pre-analysis was necessary also to identify the sample of the test. In fact, according to the particular kind of test that involves direct measurement on the human, an agree from the workers themselves has to be provided.

This part is very crucial; in order to obtain accurate data, it is necessary that the operator agrees positively to the assessment. In fact, if the assessment is not completely shared in terms of values, data can’t be classified as valid. An altered behaviour from the worker makes the analysis not accurate. It is important to let the workers understand the win-win opportunity for the analysis. In fact, the analysis permits to identify criticalities for the operator. Those criticalities mean inefficiencies and costs for the company. Optimizing the human works permits to improve the quality of the working condition while improving efficiency of the production system. This last sentence it is the very important value of the proposed analysis. If values are not shared between company and worker it is a useless analysis due an intrinsically data manipulation. In fact, if a worker assumes that the analysis is aimed at controlling him and its efficiency, it should have a behaviour, whether it accepts the test, that compromises results.

This is why the potentially involved operators were called up to communicate them the opportunity of the test. In consideration of shifts and operation, six operators could be involved within the test. Two of them rejected the assessment: two operators from painting line. The four remaining workers have been informed about the analysis and the related opportunities. All of the four remaining operators agree. It is to be noted that the operators were completely happy of the opportunity to improve their working and were aware that an accurate monitoring should mean better improvements.

Once the agree was signed, another meeting with the board was conducted in order to focus the analysis according to the whole variables fostering the potential goal. With this scenario 3 goal were set.

- Identify the human relapses of in line packaging operations
- Identify the human relapses of carousel packaging operations
- Compare the work of the 2 operators on packaging line in order to identify a synergy strategy between them
- Identify common problems
- Propose improvements with/without technological investments

Considering these goals, the scheduling of the test is proposed in Table 8. From the scheduling should be noted that only 3 operators will be involved in the analysis. The scheduling was developed in order to optimize the data acquisition time and the effort required by the analysis. It was found the best trade-off between tool battery lifetime and working shift. In fact, according to the goals, on the painting line has to be identified human relapses. With this aim, the decision to assess only one operator has been taken. In fact, as mentioned before the two operators makes different operation on painting line. One of them makes only a subset of operation then the other. This is why for the assessment of the painting line packaging phase only one operator (the one who makes all the tasks) was considered. This permits to optimize resources for acquisition, in accordance to the stated goals.

Table 8 – social assessment data acquisition scheduling

Day	DAY ONE	DAY TWO	DAY TWO
Morning	Painting line op.1	Carousel Line op.2	Carousel Line op.3
Afternoon		Painting line op.1	

Painting line packaging assessment

On the first day of data acquisition campaign, the painting line packaging assessment was performed. Real names of the operator are hidden for privacy issue in this research and each one will be classified with an acronym; on that day the operator is classified as OPL_1. The operator has been monitored in this specific test is a female packaging specialist. In the Table 9 is shown the operator profile.

Test propaedeutic operations begun at 4.15 am in order to set up the data acquisition tools. This test was developed in the area shown by Figure 22. The camera for a visual monitoring of the operation was put on the tripod near the convey belt Figure 25. It permits to see the operator in action both on the product picking and during the box transport phase.

It has been important to have a brief talk with the subject before the test in order to make him comfortable despite the tools he has to wear. Then the operator was asked to wear all the sensor needed for data acquisition. After the smart band and related sensor installation, the subject was asked to wear the glasses. Last sensor the operator had to wear was the Step Monitor. Once his comfort has been verified the shift then the measurement has begun. At 5 am the shift begun and the data acquisition was started. During the campaign, the observation has been done in a safe area where there was no obtrusion with the working operations.

The first day of assessment has been fundamental not only to track the operator and the environment but also to understand each sub-task he performs.

In Figure 26 it is possible to visualize the measurement configuration during the test. In that figure, there is a tablet on the front. It reports real time data taken from the operator (women in white t-shirt). On the upper left of the same figure it is possible to visualize the environmental monitoring system (Foobot) that communicates via WiFi to a cloud storage service. The operator wore the smart band under her shirt; it communicates with the tablet while storing data in the internal memory. The supporting band should be wear as in Figure 27.

Table 9 – Painting line operator profile

Painting line Operator [OPL_1]		
	Gender	F
	Height	160 cm
	Weight	80kg
	BMI	31.5 kg/m^2(I lev obesity)
	Birth	29/06/96
	Experience in the same operation	November 2016

Figure 25. Wide view of the painting line testing area (onsite photo)

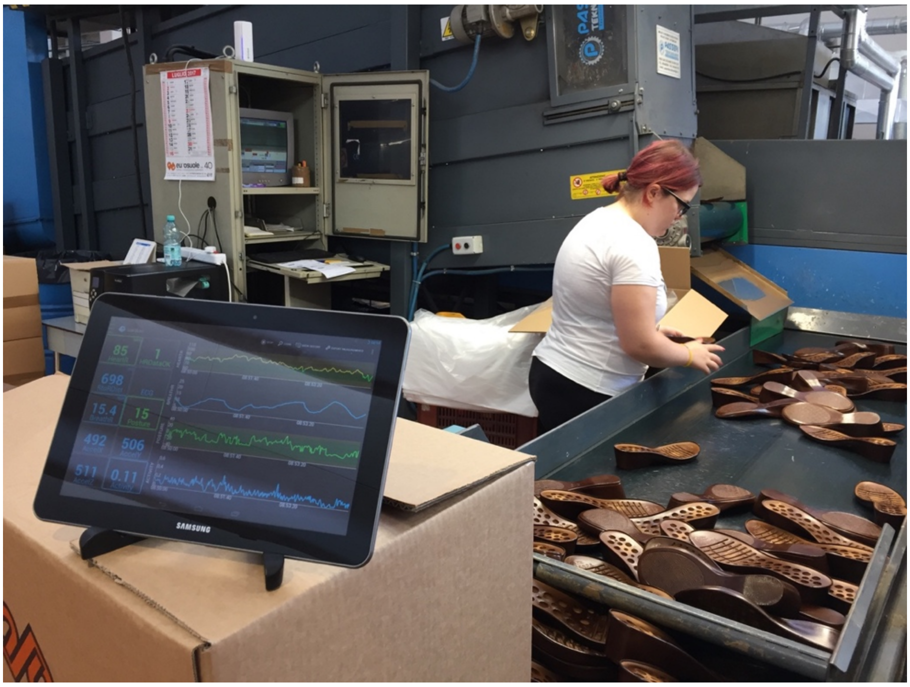

Figure 26. Painting line real time Data monitor (onsite photo)

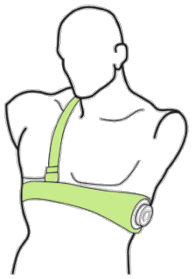

Figure 27. Smart Band proper installation (Bioharness manual)

During the test were firstly identified all the tasks the operator performs. In particular, these are all the tasks identified.

1. Box preparation
2. Label printing (via VDT device)
3. Box classification by label
4. Soles picking
5. Defects identification
6. Soles packing with related equipment
7. Soles count
8. Box closing
9. Box transport
10. Boxes count
11. Work report

It is a numbered list in fact, the operation has that sequence that will be repeated for the whole duration of the shift. At the beginning of the shift and during a product change on the machine, there are no soles on the conveyor belt. During this time, the operator prepares a “box wall” (Figure 28) in order to optimize working time. This wall permits a faster boxes preparation phase (task 1) that consists in arranging a box on the box stand. The stand is located near the conveyor belt and is composed by a metal frame aimed at containing the box during the filling. This frame is on a red plastic box. This should permit the operator conduct the operations ergonomically. This configuration is shown in Figure 29. When the box is ready on its stand, the operator proceeds to the VDT device to print box label. The PC device is located near the box stand, in the left of Figure 29. Here the operator prints the correct label according to the production scheduling. Each box has its own label where the sole model and the size is reported. OPL_1 is the only that interacts with this PC in the packaging area. He manages work and print labels even for the other operator. The operator prints and attach the label to the box (Figure 30) then starts the product picking and packing. The products flow on the conveyor belt and the operator has to select correct size and pairs to fill the box, according to the label information. During this operation, there is a visual quality control related to the painting as shown in Figure 31.

Figure 28. Boxes wall preparation (onsite photo)

Figure 29. Packaging area with box stands, VDT and foils dispenser (onsite photo)

In fact, few problems related to the painting should occur. Soles flow on the conveyor belt after an automatic painting and drying system. Visual control of the operator is the final check of the quality of that process before the packaging. Each box has to be completely filled before the closure. Soles has to be packed in layers divided by separating foil as in Figure 32. As shown in Figure 29 there is a stack of sheets that the operator has to separate then put in the boxes in order to ensure that the soles do not ruin during transport to the customer. During the packaging, operator has to count the soles before closing the box. When count is finished, box has to be transferred manually to a boxes stack were a forklift will act when the job related to a certain product is complete. The operator manages the stack with a total count and update the work report paper (Figure 34). It has to be noted that the OPL_1 update the wok paper according to the operation executed both from himself and the shift colleague, that is an operator that performs the same operation from number 3 to number 9 of the previous activity list. When the complete task list is performed it starts again the working procedure cycle from point 1 to 11 of the tasks list.

Figure 30. Box labelling (onsite photo)

After four hours there is a break time with a duration of 20 minutes.

This test had the duration of 5 hour to cover most of the working activities including the break. Even during the break, the operator was monitored in order to understand differences in terms of mental load and vital signs. At the end of the test all the tools were removed, but the environmental monitor, in order to continue the environmental assessment during the next working hours. This should permit to identify trends of environmental parameters in different day hours. The operators confirmed that its work wasn't affected by the tools that even didn't remember was still wearing.

The second test on the same operator, as shown in Table 8, was conducted on the assessment day two. This second test deserved to identify difference in terms of performances according to the different day time. This second test had the same duration of the first test.

During the data acquisition phases, few annotation and consideration were developed that will be verified and discussed in the results paragraph.

Figure 31. Product selection and quality control (onsite photo)

Figure 32. Soles packing (with separating foils, onsite photo)

Figure 33. Box transport (onsite photo)

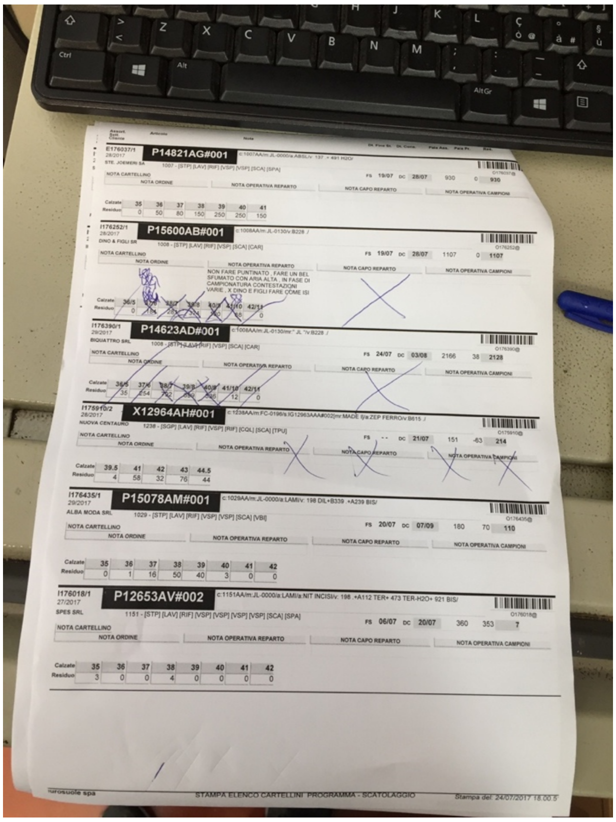

Figure 34. Work report paper (onsite photo)

<u>Carousel packaging assessment</u>

The second department where the assessment was conducted is the Carousel packaging area. Shifts in this case are different because there is a single shift from 6 am to 14.15 pm. The first data acquisition campaign in that department was conducted on day two according to Table 8. In that day focus was on the environment and the OPC_1 operator. It is a female operator with 26 years of experience in the same operation. OPC_1 parameters are collected in Table 10. For this test, the area monitored is the one in Figure 35. From the latter figure, it is possible to identify the green carousel, that rotates clockwise, the box stands, the pallets where complete boxes are temporary stored and the VDT column (in grey) where label are printed. In this area, there are two operators that performs same operations.

According to the shift in that day operations started at 5.30am to check the IoT network. The environmental sensor was put on the VDT shelf in order to check environmental condition on the area. The router was put on the shelf itself. While the tools were powered on a preliminary discussion with the OPC_1 occurs. As usual the operator was talked about the tests and potential positive relapses on its future working condition. Smart band and glasses were put on the operator then the working shift begun at 6 am. The observation was done outside the area in order not to affect movements and working phases of the operator. Moreover, it was important as previously, to stay few steps behind the area in order to avoid the "control sensation" the operator should have. As in the other area, the test also deserved to understand each specific task that the operator performs.

Tasks here are similar to the Painting Line Packaging. There are two main differences in respect of that area:

- Operator walks to the carousel to pick the shoes
- Three boxes are managed contemporary

The Figure 36 shows the OPC_1 moving from the carousel where he picks the product to the associated box. As written he manages three different boxes that should mean three different product or sizes. The test had a duration of 2,5 hours. This choice, that will be discussed later, has been done according to a consideration following the previous test. At the end of the measurement all the tools were removed but the environmental sensor (as done previously). This permitted to monitor remotely the environmental data.

On day three of the data acquisition campaign the OPC_2 has been monitored. It performs the same action already described for OPC_1. The parameters of this operator are reported in Table 11.

Table 10 – Carousel operator 1 profile

Carousel Operator 1 [OPC_1]		
	Gender	F
	Height	171 cm
	Weight	60kg
	BMI	20.52 kg/m^2(normal)
	Birth	01/08/71
	Experience in the same operation	26 years

Table 11 – Carousel operator 2 profile

Carousel Operator 2 [OPC_2]		
	Gender	F
	Height	172 cm
	Weight	52kg
	BMI	17.58 kg/m^2(Underweight)
	Birth	02/10/79
	Experience in the same operation	10 years

Figure 35. Carousel Painting packaging area (onsite photo)

Figure 36. OPC_1 moving from carousel to the box (onsite photo)

4.2.6. Data Analysis

The approach to manage the Big Data related to the test was the following:

1. Data download
2. Data classification
3. Data cleaning
4. Peaks analysis
5. Data correlations

The first step concerned the download of data from each tool: steps monitor, environmental sensors, smart glasses, smart band. Each sensor produces a csv file. Data were classified in 4 different worksheets, one for each test. Figure 47 shows how a real-time acquisition was done during the measurement campaign. All the parameters were monitored real time and few considerations were defined during test. Those consideration simplifies the off-line data classification process. During data classification, all the data flows were deeply studied and, to avoid calculating error all data were "cleaned". This task consisted in removing all data related to acquisition errors due missing signals. During test in fact, has occurred sometimes data error, especially for the cognitive data flow. Those error occurred when the operator walked away from the working area, far from the IoT environment, for special reasons (e.g. quality discussions with the area manager, collection of new boxes, etc.).

Dealing with all this data, from different sources, means managing a big set of data then a unique method of interpretation was selected. The analysis method was the Peak analysis that should permit to identify limit values for each data flow. Those limit values were interpolated with the video file in order to understand which operation was ongoing during a certain peak. The last step of the interpretation was the data correlation. This part has been proposed in order to put in relation certain parameters (e.g. temperature with heart beats). This was another hard part of the study and poor results emerged at the moment. The Data correlation is the next step of the present study and it is out of scope of the present analysis. Correlation results are expected for the end of 2018. At this moment, in fact, are ongoing few experimentations on the topic of data analytics. Bases for a data matching algorithm have been laid. In this very first study on that topic, for each data flow results and considerations will be developed according to the goal of the analysis.

It is to note that during data analysis, when dealing with the step monitor data, few problems were encountered during data download. This issue depends on the Withings acquisition made by NOKIA. This transition brought to the definition of a new device data management platform. This platform has few limits when dealing with older devices (as the one exploited in the analysis). In conclusion data acquired from the smart step monitor were not accurate. It was taken the decision to neglect those data. This choice didn't affect the analysis according to the accuracy and aim of the whole IoT environment.

Figure 37. Real time EOG report sample (onsite photo)

4.2.7. Results and observations

According to the goal of the analysis are now provided and discussed few results in relation with data interpretation phase. Results will be arranged according to different focus. Since the two assessed area are similar in terms of operations they will be discussed together most of the following sections.

<u>Test duration choice</u>

As discussed, the test was performed on five hours on the morning shift in order to cover most of the activities performed. The second test, on the same operator, in the evening shift had the same duration. A general consideration permits to re-consider the data acquisition duration on the second area, is that after 1,5 hours there is a consistent change in terms of cognitive workload according to data from the smart glasses. In fact, after 1,5 hours there are continuous peaks, meaning blinks in the EOG graph.

There is a consistent change in curve trends passing from Figure 38 and Figure 39. Those two figure represents EOG values for 15 sec of measurement before and after 1,5h. It is clear that after 1,5 hour there is a high mental load, according to the number and intensity of blinks. Moreover, after 1,5 hour it is quite difficult to identify clearly peaks according to Figure 63 then it is very complex to correctly associate peaks to operation then understand related impact. This is a first result of the assessment: after 1,5 hours, there is a high mental load on the painting line. Even after the 20-min pause (after 4 hours) the EOG trend wasn't affected. This means that with an organizational redesign of the area, pause should be re-scheduled after 1,5 hours from the shift start.

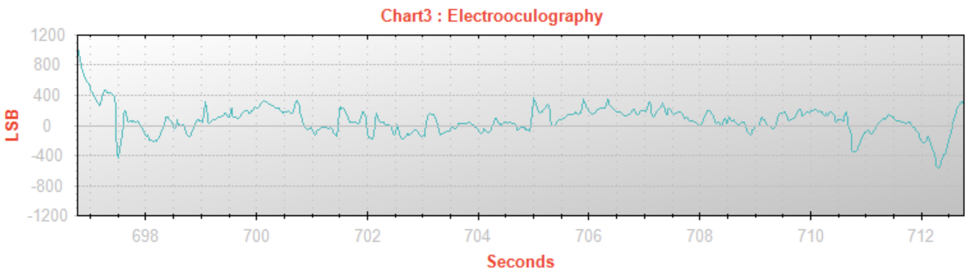

Figure 38. EOG values before 1,5h

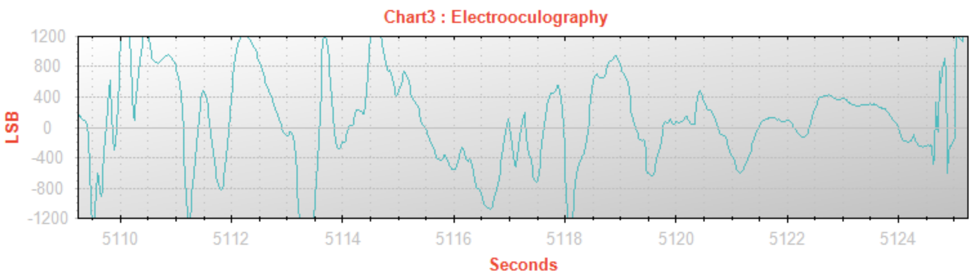

Figure 39. EOG values after 1,5h

Painting line Packaging - Shift dependency

According to the goal it was identified if there is a shift dependency in terms of operator activity. The goal was set to identify if the operator performance during same operations, should be affected by day time. To understand if dependency occurs, HR for the two shifts on OPL_1 were compared. In Figure 40 is reported the graph that compares HR in both cases.

As shown, trends are very similar. It is to note that in the Morning shift there is a medium HR of 95 BPM, in the afternoon shift, the medium HR is 104 BPM. In Figure 41there is a comparison of the temperature for the painting line, produced during the test. The latter figure has progressive time on x axis and temperature scale [°C] on y axes. It is to note that the medium temperature is 27,8°C during morning shift and 30,3°C during afternoon shift. Temperature was affected by outside conditions (Italy, Summer 2017). Then, the little difference in terms of heart rate should be explained by the temperature difference as confirmed by the work of Davies, 2009. The activity difference was also confirmed by the VMU data that defines a medium of 0,13g for the morning shift and 0,15g for the afternoon shift.

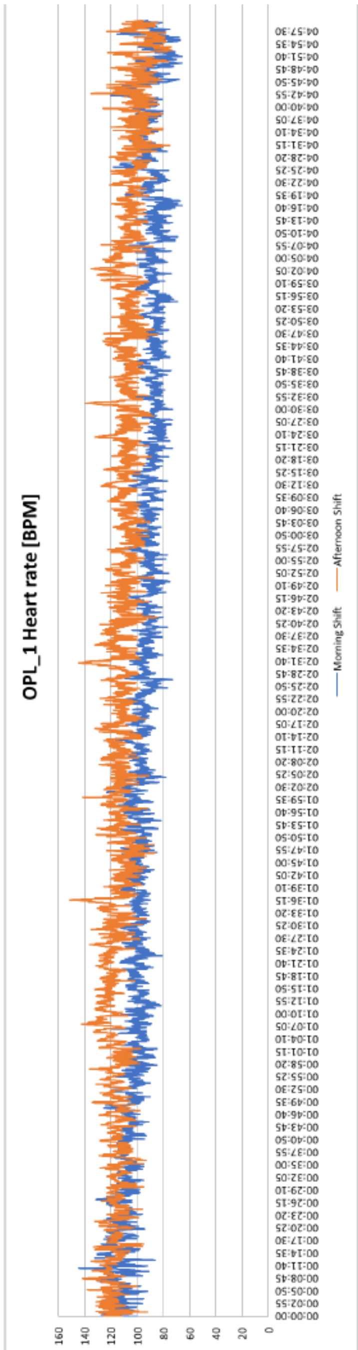

Figure 40. OPL_1 Heart rate graph

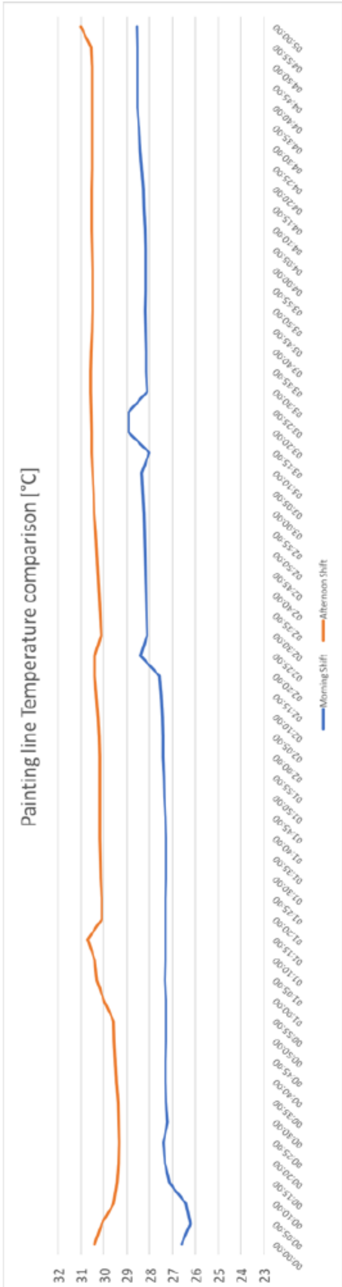

Figure 41. Painting line Temperature graph during shifts

However, there is another variable in the system that is the product. In fact, during the two shifts there were different soles to manage. Weight and shape of soles affect the performance of the operator. Bigger soles (e.g. with hells) are more difficult to pick and verify in respect of thinner ones.

After the data correlation, it was asked the operator if he noted the difference in terms of performance from the two shifts and she confirmed a (slight) difference in terms of activity. This interpolation suggests the importance of data flow management and a proper data acquisition system.

Concluding, the morning shift defines the same productivity of the afternoon shift. Temperature and products should be mitigated in order to reach best performances.

Shift dependency was not measured on the carousel line because the latter consists in a single shift

VDT user experience

It has been noted via the smart glasses data interpretation that this phase was never an impacting phase. In Figure 42 it is possible to isolate sec 1120 to sec 1130 that corresponds to the time the OPL_1 interact with the VDT aimed at printing labels (Figure 43). As shown the mental load has no peaks and the saccades has a little Delta (1120, 1130) meaning a safe mental work load. With reference to the Carousel, Figure 44 represent the OPC_1 mental load during VDT interaction (sec 692 to sec 700) and Figure 45 represents the same for OPC_2 (sec 168 to sec 178). The operation for this area is shown in Figure 46. Even in the second area the VDT interaction means a low mental workload for operators. This confirms that the user interface and the methodology to print label it was well studied and implemented within the production system.

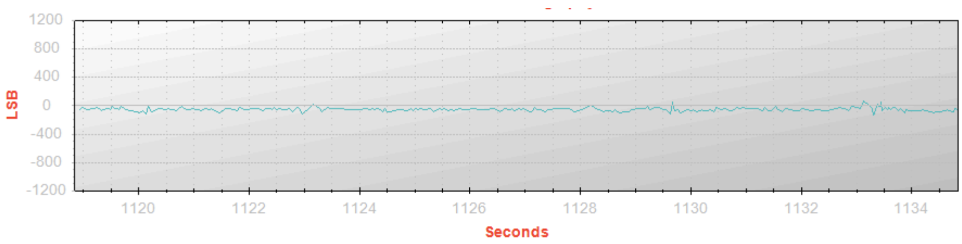

Figure 42. OPL_1 mental load during VDT use

Figure 43. VDT use phase (onsite photo)

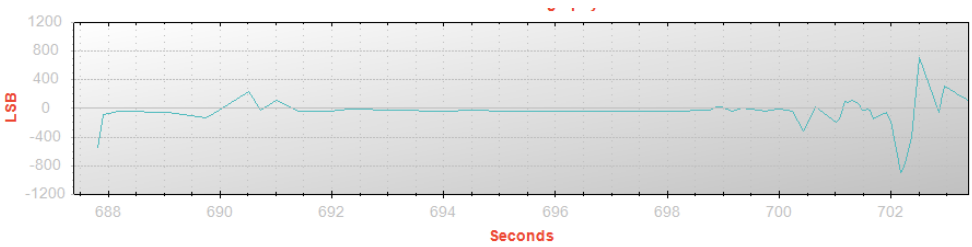

Figure 44. OPC_1 VDT use phase mental workload

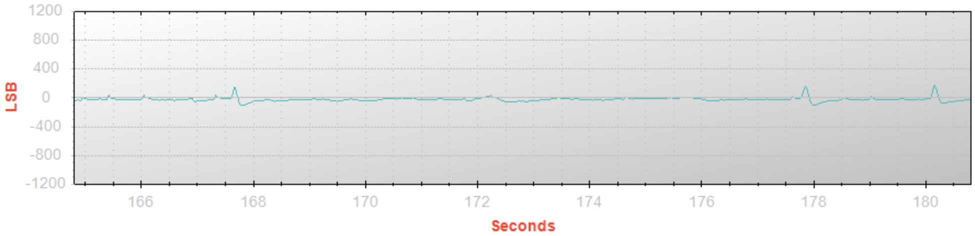

Figure 45. OPC_2 VDT use phase mental workload

Figure 46. OPC_1 VDT use phase (onsite photo)

<u>Foils separation</u>

According to the mental load analysis this sub-task is one of the most impacting on the operators. It is to be noted that there is an important difference between the two areas. In line, operator doesn't wear gloves, in carousel all operators have gloves. Below are reported graphs of mental load during the foil separation (Figure 47, Figure 48, Figure 49). OPL_1 has a big concentrated peak (sec 2409-2410). OPC_1 has few peaks (sec 1017-1020) as the OPC_2 (sec 1498-1501). This firstly demonstrates that the foil separating action tends to be mental impacting and will impact more time when performed with gloves. This operation has a similar impact during the whole working time. It is mental impacting because the small thickness of foils. Operator are not able to simply separate foils each other while taking them from the sheet stacks. Figure 50, Figure 51 and Figure 52 permits to see the operators in action.

Figure 47. OPL_1 Foil separation EOG report

Figure 48. OPC_1 Foil separation EOG report 1

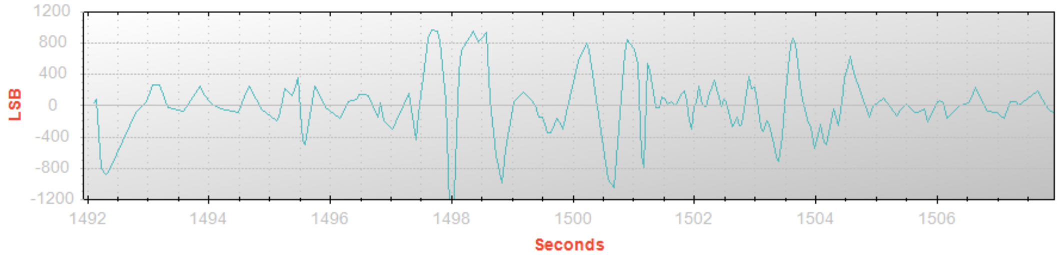

Figure 49. OPC_2 Foil separation EOG report 2

Figure 50. OPL_1 separating foils (onsite photo)

Figure 51. OPC_1 separating foils (onsite photo)

Figure 52. OPC_2 separating foils (onsite photo)

Posture and movements - Physical Workload

In this paragraph are reported results related to the posture during the operations. The Table 12 sums up the posture analysis for what concerns OPL_1 during the morning shift. After data cleaning, 20202 measurements were considered valid. Data cleaning involved all the data acquired during the band installation. In relation with ISO 11226:2000, three different range were identified. Each range concerns the inclination degree of the low back posture. In general, during the operations the low back posture is correct for OPL_1; 94,88% of measurements verified the safe conditions (low back inclination is no more than 20° with respect to vertical axis). The unsafe conditions (0,06%) are only a few but it has to be noted that are mainly registered during the box placement on the lower pallet level (Figure 53). It could be compared the latter figure with Figure 54. It is clear how the level of box placement affects the posture of the operator. For completeness in Table 13 are reported the result of the posture analysis of OPL_1 during the afternoon shift. Results are comparable.

Focusing on the Carousel area posture analysis, in Table 14 and Table 15 are reported results of the posture analysis for OPC_1 and OPC_2. It should be noted that the OPC_1 had worse results in comparison with OPC_2. If bad postures are comparable in terms of occurrences there are more warning conditions recurring for the OPC_1. For both operators, the bad occurrences are mainly related to the box placement on the 1st floor of the pallet. This was verified by aligning the EOG data to the video recording.

It is then confirmed that the lower level of pallet is a problem even in the Carousel box placement (Figure 55). When operators approach this level, it is registered every time a bad posture condition.

Table 12 – OPL_1 posture analysis (morning shift)

OPL_ 1 (morning) LOW BACK POSTURE (ISO 11226:2000) Total valid measurements: 20202		
X<20°	20°<X<60°	x >°60
19168	1021	13
94,88%	5,05%	0,06%

Table 13 – OPL_1 posture analysis (afternoon shift)

OPL_ 1 (afternoon) LOW BACK POSTURE (ISO 11226:2000) Total valid measurements: 19771		
X<20°	20°<X<60°	x >°60
18962	769	40
95,91%	3,89%	0,20%

Table 14 – OPC_1 posture analysis

OPC_ 1 LOW BACK POSTURE (ISO 11226:2000) Total valid measurements: 9295		
X<20°	20°<X<60°	x >°60
7431	1771	93
79,95%	19,05%	1,00%

Table 15 – OPC_2 posture analysis

OPC_ 2 LOW BACK POSTURE (ISO 11226:2000) Total valid measurements: 9188		
X<20°	20°<X<60°	x >°60
8459	713	63
92,07%	7,76%	0,69%

Figure 53. OPL_1 box placement on 1st pallet level (onsite photo)

Figure 54. OPL_1 box placement on upper level of pallet (onsite photo)

Figure 55. OPC_1 box placement on 1st level of pallet (onsite photo)

It should be noted that there is a difference in terms of posture between the two areas. If in both shifts OPL_1 had a bad posture in less than 1% of measurements, in Carousel areas the OPC_1 achieved the 1% of the same. OPC_2 is under the 1% but had 63 measurements in bad position, more than the OPL_1. These results depend on different factors. In the Carousel area in fact, there is more space but it is full of boxes and tools. If in the Line area there is space to prepare boxes on the stand in advance, storing them on stacks (Figure 56), in Carousel area there is not such space and operators sometimes are obliged to prepare and pick boxes with bad posture condition as in Figure 57 and Figure 58.These are little features of the operations but toward a complete improvement it is necessary to understand those characteristics to improve them.

The difference between bad postures between operators OPC_1 and OPC_2 should be also explained considering Figure 59 and Figure 60. These images refer to the labelling operation, needed for each box processed. OPC_2 performs this operation in upright position. OPC_1 perform the same operation in bent position. The latter position affects the posture analysis and defines worst conditions for the same operator.

Figure 56. OPC_2 pre-folded box picking (onsite photo)

Figure 57. OPC_2 box preparation (onsite photo)

Figure 58. OPC_2 unfolded box picking (onsite photo)

Figure 59. OPC_2 box labelling (onsite photo)

Figure 60. OPC_1 box labelling (onsite photo)

Finally, operator has defined a procedure for a correct sole picking from the carousel. They decided to let the higher operators pick soles from higher level of the carousel in order to distribute in a better way fatigue. This is an example of correct procedure that had not been imposed them but with this trick they increased productivity and their health.

Figure 61. Carousel picking (onsite photo)

<u>OPC_1 vs OPC_2 activity comparison</u>

For the carousel, a comparison between the two operators is proposed. The aim of this comparison is to understand, considering the same operations, for which operator is more socially sustainable the whole process. A consideration on productivity will be proposed.

In Appendix B there is the graph related to the comparison in terms of Heart rate between the two operators (Figure 69). As shown the OPL_2 has higher heart rate values during the whole 2,5 hours. If for OPC_1 the medium is 89 BPM, for Opc_2 is 117 BPM. It is to note that OPC_2 has a lower BMI in respect of the OPC_1. Considering the operations contour conditions, the BMI is the most important factor for this issue. The comparison was done to understand differences between data and, considering the novelty of the case study, it was analysed in order to understand if interesting conclusion should be acquired by those parameters only.

However, this result does not depend on activity; from Figure 70 in Appendix C, it is possible to understand that VMU is quite the same for both operators. The total sum of VMU for the OPC_1 is 1827,55 and for the OPC_2 is 1565,32. Value are very similar; the little difference in terms of VMU should be also assigned to the posture difference previously argued. In fact, to assume a certain posture, an acceleration is required. It is to remember that, as discussed, the OPC_1 has more bad postures than OPC_2.

The OPC_2 is productive as the OPC_1 but with more effort.

Box Movement and counting

For what concerns box movement (Figure 33) it has to be noted that this operation affects not only the physical fatigue (it was noted that BPM increases during transport) but even the mental workload of the operator (Figure 62). In the latter figure, it is possible to see from sec 2664 to sec 2668 the peaks the EOG graph shows during the transport phase. Transport need high concentration as the counting procedure. In fact, from sec 2668 to 2670 the operator counts the boxes and takes on his mind the box already completed in order to register the job already completed.

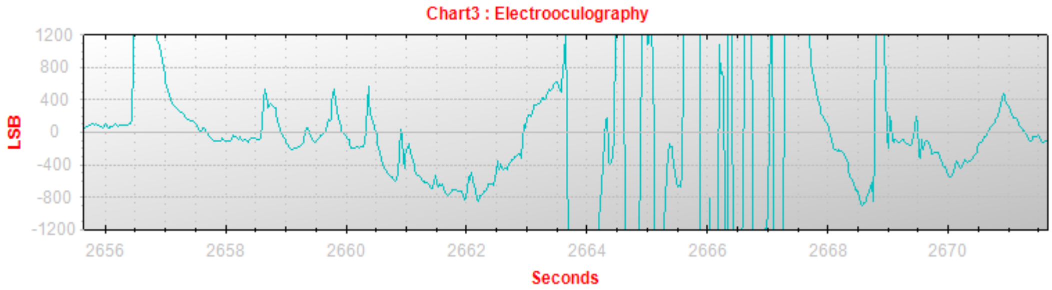

Figure 62. OPL_1 box movement EOG report

Box Stands

With reference of the box stands are here reported few observations that should be confirmed by accurate measurements.

The main problem of box stand is that they are not authentic box stands. They are obtained by stacking few plastic boxes. This means they are not adjustable depending on the operator. As shown, the posture has a crucial role in regards of social impacts.

Moreover, focusing on the Painting line packaging phase, it is shown by Figure 63 how close the box stand is to the conveyor belt motor. This should produce multiple negative effects. The first is that during the box closing, as in Figure 64, the operator should be obstructed by the motor. The second is that, the heat generated by the motor could influence the temperature perceived by the operator or, moreover, high temperatures could cause burns to the latter in case of accidental touch.

Figure 63. conveyor motor over the box stand (onsite photo)

Figure 64. Packaging closing and potential danger (onsite photo)

Painting emission

In the carousel line, there were some issues in terms of air quality. The air sensor in fact has stored many peaks in terms of carbon dioxide emissions. Even during test, it was possible to breathe a heavy air. The reason of this issue is the design of the packaging area. In fact, the carousel itself is the only separation between packaging operators and the painting zone. Moreover, packaging operators do not use masks, because their area should be safe from particulate emission. Unfortunately, this is not true, due the design of the area; the latter is in fact affected by the manual painting stations from the next area. As it is possible to see in Figure 65, there is basically no division between painting zone and packaging one. Painting stations are just over the green carousel (in Figure 65 it is possible to see the head of an operator just over the carousel, during manual painting phase). On the same picture, it is possible to see a green panel that tends to separate those areas but it can't due its little sizes. Finally, in Figure 66, it is reported the carbon dioxide emission diagram during the eight hours in both the assessed areas of packaging. It is possible to understand the difference in terms of emission and if in painting line there is a medium of 637ppm CO_2 with a peak of 1333, in the carousel there is a medium of 1264ppm CO_2 with a peak of 2512 of the same. In both cases values are under the limit of OSHA but improvement actions in the carousel area are suggested.

Figure 65. wide view of the packaging area (onsite photo)

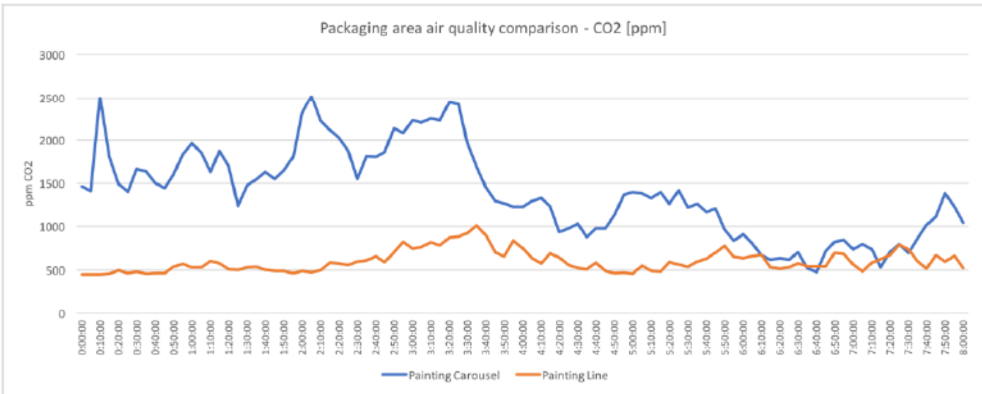

Figure 66. CO2 ppm comparison graph

Proactive operators

The IoT network produced an interesting side effect. It puts the focus on the environmental sensor. As already argued, the IoT embedded a sensor to assess air quality. This was put in both the area assessed according to the test scheduling. It is to note that the sensor was installed and remained active 24h for few days even when the operator test wasn't running. During the last day of test on the Carousel area, it has been noted that an operator working on the same area but not involved in packaging operations, occasionally raised the shutter that permits the external exit (Figure 67). It was noted that the operator opened the shutter every time the data indicates a high concentration of CO_2 in the air. That was possible because the sensor shows a red light while in air poor quality conditions. After the test was asked the operator why he occasionally activated the shutter and confirmed that he used to take a look at the sensor and when he saw red light he tried to improve the air quality enabling a better air circulation, enlarging the air exchange surface by regulating the door near the area. He confirmed to perform this actions during all the previous days while the sensor was installed. The red-blue light of the sensor was explained only to OPC_1 and OPC_2; they had probably involved all the other operators within the test. This is an example of manufacturing development participation.

This is a very interesting point in terms of CPS integration. Without a command in the sense of air regulation operators independently make improvement actions that they should benefit. These simple actions have very good relapses on the plant sustainability. This confirms that 4.0 technologies should be managed in a simple way by the operators. Looking to the IoT environment configuration, it could be implemented an automatic integration between the shutter and the sensor. This is the way toward the intelligent factory.

Figure 67. Shutter in two different position (onsite photo)

4.2.8. Summary of the results

In Table 16 it is proposed the summary of results already presented. For this analysis, it is not proposed a specific score for social sustainability. The results needed to answer the general goal; that was accomplished. With the following table a designer can understand, according to different data flows the main problems recorded. The matching of parameters with social issues is driven by norms compliance. In green are highlighted non-critical issues. In yellow are highlighted potential risks for the social assessment. In red are highlighted the operation that should be improved in order to gain social sustainability in certain conditions.

Table 16 – Social Assessment results summary

	Line Packaging	Carousel Packaging
General mental workload	high mental stress after 1,5 working hours	
Shift dependency	Same performances in both shifts	n/a
VDT interaction	sustainable for operators (low cognitive load)	
Foils separation	not sustainable for operators (high cognitive load)	
Carousel operations social impact	n/a	Operations are more sustainable for OPC_1; OPC_2 high BPM
Posture analysis	Posture matches standard requirements in general	
	load on 1st pallet layer is not sustainable	
	the packaging is obstructed by dangerous items (machine engine)	no labelling or box preparation procedure standard
Air quality	sustainable	poor in particular condition
Box stands	Lacks in terms of physical ergonomics	

4.2.9. Improvement Actions

According to the results are now proposed few improvement opportunities for the process to increase social sustainability of the same.

The following action emerged by the case study. However, it is proposed to build an improvement actions repository according to future case study. These and future actions will emerge in next case studies will be the knowledge base of an automatic tool will be developed for a faster factory development. When many case studies will be conducted a clustering by typology will be possible (e.g.

organizational actions, manufacturing improvements, etc.). This information will help a designer for faster and better choices for same problems in different context.

Considering the present case study, as discussed there is a huge difference in terms of mental workload after the first 1,5 hours from the shift start. There is the opportunity to reschedule the break during the working hours. Revising break scheduling should boost the productivity of operators that, with a proper cognitive workload balance, should be more productive during their job.

Considering the mental workload, the foils separation is the most critical task with the counting procedure. The production manager could consider two improvements that requires different economic investments. The fist solution, the cheaper one, is related to the foil delivery mode. In fact, should be installed a foils dispenser in each packaging place, in order to simply pull foils that are ripped by a thin cutting blade. This simple solution requires very cheap investments (no more 100€/pcs) resulting huge improvements in terms of social relapses.

The second solution, considering the mental workload, is an automatic counting system. This solution should permit a simplification of the operator jobs. The solution consists in a bar code scanner that automatically recognizes the content of each box updating automatically the work report. The operator needs only to scan the box after placing on the pallet. This is the first step toward the digitalization of the process. In this way, the forklift could act automatically when the system recognizes all the boxes are correctly stored. This investment simplifies not only the workload of the operator but the whole extended working process. Moreover, introducing the box stands improvements, a load cell could boost dramatically all the operations.

In fact, another problem emerged is the box stand configuration. Proper box stands could be introduced in packaging places. Those stands should have two important features: modularity and load cells. Modularity permits to regulate them according to the operator height and the load cell permits to limit the box weight according to the norms. This opportunity could improve the social sustainability of the packaging job phase. If these actions are introduced, with a digital perspective, the box stand could be regulated automatically according to the shift as the load cell. In fact, each operator has its own height and ability. The system should recognise the operator and auto adjust the stand height and regulate the cell according to the maximum load it can transport. This regulation permits to:

- avoid the operator counting phase
- avoid physical overload of the operator
- avoid wrong postures of the operator
- recognize automatically when the box is complete.

The last point of the list opens to the digitalization of data. In fact, if each product is mapped in terms of unit weight, the system according to the box weight, dependent to the operator, automatically recognizes how many pairs have been inserted in the box.

A redesign of the box buffer area is required. The movement of boxes on the first layer by the operator is not sustainable from a social perspective. This should be solved by an investment for a better pallet height management system. The pallet should be installed on adjustable benches that moves down after each layer is completed. This permits to manage boxes with a correct posture. A schematization of the solution is proposed in Figure 68. The buffer area should receive data from the system and regulate the bench height according to the operator characteristics (height and force). This will define a standard and correct posture for box movement and placement.

Figure 68. Adjustable benches (mockup)

Focusing on the carousel, a redesign of insulation of the area is required. A first approach should pass through the extension of the insulating wall between carousel and manual painting places.

Finally, it is required the development of the internal job procedures. This permits that all the operator performs actions in the same way in order to avoid incorrect postures during activities (e.g. labelling with incorrect postures).

It has been highlighted the effort provided by the OPC_2 to perform the same work of OPC_1. There are few possibilities to improve social sustainability for the OPC_2. The first is to redesign the shift of the same in order to increase its pauses. In this way he can manage its physical fatigue. The second opportunity is to move the operator to another area in order to improve his healthy condition. It is to note that the BMI of the operator is under the threshold considering its characteristics. Further improvements should be provided but concerns more the pure social sphere (eg: proper diet plan). This situation should remember that not only the operator has duties towards the company but this too has the opposite. The company should help its operators in conducting a healthy life not only inside the factory.

The improvement actions proposed act on different levels: operation level, organization level, technologies level.

The assessed areas are only a part of the whole factory. It should be projected the same study on the whole plant in order to understand how many improvement actions should be included only considering the social perspective.

4.2.10. Results discussion

According to the case study few considerations emerged. First of all the present case study covers few aspects related to ergonomic and social sustainability but not the whole of them. This was the very first case study in the context of a research at its early stage. With a deeper analysis with the same approach better results should be obtained considering different sensors covering more aspects. For example, with an ergonomic point of view, aspect such as leg and arm movements are not considered in this study. The improvement actions proposed are only the beginning toward a complete social sustainability manufacturing environment. This explain the loop approach of the method. If the company wants to go in deep with certain aspects, then analysis, the IoT infrastructure should be renewed exploiting different and more accurate technologies. Moreover, technologies should be upgraded in times. It has been planned, after the implementation of the action proposed to reply the method, then the analysis, with different and more accurate tools. This very first case study permitted the company to understand the opportunity to perform such kind of social analysis and related impacts on company productivity.

5. Discussion and concluding remarks

In the present work, it has been shown the importance of the sustainable perspective for connected factories. Manufacturing system should take into account the three sustainability pillars even during this 4.0 transition. A proper mix of sustainability and technologies opens up new scenarios in terms of company productivity and competencies development.

The work has focused on the social pillar and proposed two methods to take into account the social theme during the design phase of a product and a factory.

In the first part, it was argued about an improved S-LCA inventory technique permitting to understand social relapses of products from a life cycle perspective. A simplified S-LCA was proposed. It is a social analysis that permits to define measurable score of social impact considering the whole lifecycle of a product and related stakeholders. The method was exploited within a EU project in order to give social scores to the product. Method has permitted to identify general social relapses of a product by a brand-new procedure but its limits emerged. The S-LCA required a lot of efforts in terms of time without effective results in terms of criticalities. A designer through the method should understand general inefficiencies of the product development but specific actions to improve the product design does not emerge.

The application of the method has allowed to understand from a lifecycle perspective which is the stage where social sustainability should be handled in the most appropriate way from a company: the production site. In fact, considering the stakeholders, the most accurate information have been collected by surveys to company employees. Moreover, surveys for the same stakeholder were the most numerous and accurate permitting a deeper analysis.

From this starting point, it has been developed a method to boost sustainability for new production systems. The method promotes manufacturing sustainability, and embeds a procedure to implement an IoT network in the factory.

IoT related opportunities are huge for a factory but these should be achieved only by adopting a structured method. The method focused on overall sustainability; it has come into detail with the social aspect by the case study. The method permits also to understand all the data flows needed to be monitored within a production site. Here IoT was thought as the key enabler of new factory technologies; the network permits to monitor the plant in order to understand criticalities should be improved by technological innovations. Without a clear view of the actual limits, a company can't proceed toward the Industry 4.0.

In that work, the IoT was exploited to assess plant social relapses on operators, understanding criticalities of the process from a social point of view.

In the proposed case study were identified manufacturing criticalities from a social point of view. By designing and installing an IoT infrastructure it was possible to monitor operators and environment toward a social plant optimization. In this specific case study, two manufacturing area were assessed by the IoT portable framework. Data permitted to highlight social criticalities of the processes. During the assessment, each task the operator performed was analysed in order to understand (through an interpretation of sensors signals) the criticalities in respect of human capabilities. The assessment permitted to understand many criticalities that should be improved by new technologies, better organizational choices and better process management. The improvement of the manufacturing system from the social point of view should have positive relapses on operators' health and company productivity both. Without the IoT framework, where few data had linked each other, the same assessment was not possible. The method tends to underline that IoT environments is a way to industry 4.0 but not the only one. By IoT environments proper data framework should be guaranteed. As data are the baseline of the improvements, IoT are fundamental tools in connected factories.

The effectiveness of the method has been validated through the case study. The company where the case study was developed is actually analysing the improvement actions here proposed and is planning other social assessment for different areas.

With a broader view, the connected network permits to understand if a CPS is well integrated within the plant or, if manual operations should be boosted by technological implementations (e.g. Industry 4.0 techniques). In that perspective, the Factory of the future should integrate this kind of IoT environment in order to understand real effectiveness of innovation and technologies implementation on the plant. If a technology is not sustainable from humans there is a limit in the production system. The new collaboration scenario between human and machine in connected factories requires deep studies, in order to take care of human development and company productivity both. A company is not competitive if CPS has sustainability limits.

The assessment had an important limit: data acquisition phase and related interpretation required a big effort in terms of time. The classification of different kind of data with different acquisition time steps was really time consuming. The analysis should be simpler in the future if a single tool is exploited to convey all data. From this perspective, it was developed the mock-up of a software tool driven by a computational intelligence that permits a decision maker to interpret and assess the social sustainability of the plant in a faster way. The tool is shown in Appendix D. The Figure 71 represent the empty user interface. The real-time data monitoring software should consist in simplified data conveyor system that easily permit to visualize social data in a standard manner. Figure 72 represent the tool in action. The interface permits to simply identify critical condition for parameters related to the social assessment of the production plant. A deeper study and development of the tool it is proposed for a post-doc work.

Considering the IoT framework exploited, it is possible to extend and improve the social assessment by associating a IPS (internal positioning systems) to the network. This permits to track accurately the operators within the plant. This will permit to identify their movements in order to optimize each department from a design point of view.

Data acquired by the IoT can be exploited for other analysis and in compliance with standards (e.g. ISO 50001, risk assessments, etc.). On the other hand, anticipating critical issues means savings and advantages. For instance, professional diseases has a medium cost of 30k€ per person year for a company. The opportunity to monitor operators permits to anticipate diseases and improve work places reaching a win-win situation for both operators and company.

Moreover, a connected factory, from a social perspective have positive relapses on operators. In the future, data from a plant could be shared externally and match medical information of the workers. This vision is an extension of the actual smart cities where each system contributes with its data to the human development. It is clear that privacy standards and accurate laws has to be developed to prepare society to this future vision.

IoT environments should be an opportunity to improve process sustainability by implementing automatic actions toward a thinking factory. The exploitation of IoT as a connected network to favour the sustainability could improve also productivity. Connected factories open to deeper data acquisition for faster improvement actions implementation.

Thanks to the positive results of this research are actually ongoing different studies to develop IoT framework for other companies with other sustainability drivers (resource efficiency and energy monitoring).

In conclusion, the 4.0 industrial transition has not a single way. A company should adopt proper technologies with structured innovation plan, in consideration with its actual strengths and limits. SMEs and large companies should have similar problems that can be solved with different techniques by Industry 4.0 technologies. Structured method as the one presented should help companies during this transition toward the sustainable factory of the future.

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Appendix A. Ergonomic Factors Classification

1.1 General	Title	Norm	Title
1.1.3	Materials and products	**EN 626-2:1996 + A1:2008**	Safety of machinery - Reduction of risk to health from hazardous substances emitted by machinery - Part 2: Methodology leading to verification procedures
		EN ISO 14123-1:2015	Safety of machinery -- Reduction of risks to health resulting from hazardous substances emitted by machinery -- Part 1: Principles and specifications for machinery manufacturers
		EN ISO 14123-2:2015	Safety of machinery -- Reduction of risks to health resulting from hazardous substances emitted by machinery -- Part 2: Methodology leading to verification procedures
1.1.4	Lighting	**EN 1837:1999+A1:2009**	Safety of machinery - Integral lighting of machines
1.1.5	Machine transport	**EN 1005-2:2003+A1:2008**	Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery
1.1.6	Ergonomics	**ISO 10075:1991**	Ergonomic principles related to mental work-load - General terms and

			definitions
		ISO 10075-2:1996	Ergonomic principles related to mental workload - Part 2: Design principles
		ISO 10075-3:2004	Ergonomic principles related to mental workload - Part 3: Principles and requirements concerning methods for measuring and assessing mental workload
		UNI EN ISO 13857:2008	Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs
		UNI EN 614-1:2006	Safety of machinery. Ergonomic design principles. Terminology and general principles
		UNI EN 614-2:2000	Ergonomic design principles - Part 2: Interactions between the design of machinery and work tasks
		EN 1005-1:2001+A1:2008	Safety of machinery - Human physical performance - Part 1: Terms and definitions
		EN 1005-3:2002+A1:2008	Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation
		EN 1005-4:2005+A1:2008	Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
		UNI EN ISO 9241-151:2008	Ergonomics of human-system interaction Guidance on World Wide Web user interfaces
		UNI EN ISO 9241-171:2008	Ergonomics of human-system interaction - Part 171: Guidance on software

			accessibility (ISO 9241-171:2008)
		UNI EN ISO 9241-410:2008	Ergonomics Of Human-system Interaction - Part 410: Design Criteria For Physical Input Devices
		EN 13861:2011	Safety of machinery - Guidance for the application of ergonomics standards in the design of machinery
		EN ISO 14738:20	Safety of machinery -- Anthropometric requirements for the design of workstations at machinery
1.1.7	Work places		
1.1.8	Seats	**UNI 10814:2004**	Work seating - Construction characteristics, requirements and test methods
1.2 Control Systems	**Title**	**Norm**	**Title**
1.2.1	Security and reliability of control systems	**EN 574:1996 + A1:2008**	Safety of machinery - Two-hand control devices - Functional aspects - Principles for design
		EN 1037:1995+A1:2008	Safety of machinery - Prevention of unexpected start-up

1.2.2	Control devices		
		UNI EN ISO 13849-1:2008	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design
		UNI EN ISO 13849-2:2008	Safety of machinery - Safety-related parts of control systems - Part 2: Validation
		EN 981:1996+A1:2008	Safety of machinery - System of auditory and visual danger and information signals
		EN ISO 7731:2008	Ergonomics - Danger signals for public and work areas - Auditory danger signals (ISO 7731:2003)
		BS EN 61310-1:2008	Safety of machinery. Indication, marking and actuation. Requirements for visual, acoustic and tactile signals
		EN 842:1996+A1:2008	Safety of machinery - Visual danger signals - General requirements, design and testing
		Cenelec EN 62061:2005/A2:2015	Safety of machinery. Functional safety of safety-related electrical, electronic and programmable electronic control systems

1.2.3	Start-up		
1.2.4	Stop	UNI EN ISO 13850:2008	Safety of machinery - Emergency stop - Principles for design
1.2.4.1	Normal stop		
1.2.4.2	Operative stop		
1.2.4.3	Emergency stop		
1.2.4.4	Machine assembly		
1.2.5	Type and command selection		
1.2.6	Emergency failure		
1.3	**Measurement to avoid mechanical dangers**	**Norm**	**Title**

1.3.1	Instability		
1.3.2	Failure during operations		
		EN ISO 4413:2010	Hydraulic fluid power - General rules and safety requirements for systems and their components
		EN 349:1993+A1:2008	Safety of machinery - Minimum gaps to avoid crushing of parts of the human body
1.3.3	Risks due to the fall or projection of objects		
1.3.4	Specific hazards due to surfaces, edges or corners		
1.3.5	Risks due to combined machines		
1.3.6	Risks related to variations in operating conditions		
1.3.7	Risks due to mobile elements		
1.3.8	Choice of protection against hazards due to mobile elements		
1.3.8.1	Transmission elements		

1.3.8.2	Moving elements that are involved in the machining		
1.3.9	Risks of uncontrolled movements		
1.4	**Requirements for repairs and protection devices**	**Norm**	**Title**
1.4.1	General requirements	Cenelec EN 61496-1:2013	Safety of machinery. Electro-sensitive protective equipment. General requirements and tests
1.4.2	Particoular requirements	UNI EN 953:2009	Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards
1.4.2.1	Fixed repairs	UNI EN 1088:2007	Safety of machinery - Interlocking devices associated with guards - Principles for design and selection
1.4.2.2	Temporary repairs	EN ISO 13856-2:2013	Safety of machinery - Pressure-sensitive protective devices - Part 2: General principles for design and testing of pressure-sensitive edges and pressure-sensitive bars
1.4.2.3	Adjustable repairs	EN ISO 13856-1:2013	Safety of machinery - Pressure-sensitive protective devices - Part 1: General principles for design and testing of pressure-sensitive mats and pressure-sensitive floors

1.5	**Other dangers**	**Norm**	**Title**
1.5.1	Electric energy	BS EN 60204-1:2006+A1:2009	Safety of machinery. Electrical equipment of machines. General requirements
1.5.2	Static Energy	**DIR/2014/30/UE**	
1.5.3	non electric energy	**EN ISO 13732-1:2008**	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 1: Hot surfaces (ISO 13732-1:2006)
1.5.4	Assembly errors	**EN ISO 13732-3:2008**	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 3: Cold surfaces (ISO 13732-3:2005)
1.5.5	Extreme temperatures	**EN 13478:2001 + A1:2008**	Plastics and rubber machines - Calenders - Safety requirements
		EN ISO 19353:2016	Safety of machinery - Fire prevention and fire protection (ISO 19353:2015)
1.5.6	Fire	**EN 1127-1:2011**	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology
		EN 15967:2011	Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours
1.5.7	Explosion	**EN ISO 3741:2010**	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for reverberation test rooms (ISO 3741:2010)

		EN ISO 3743-1:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for small movable sources in reverberant fields - Part 1: Comparison method for a hard-walled test room (ISO 3743-1:2010)
1.5.8	Noise	**EN ISO 3743-2:2009**	Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering methods for small, movable sources in reverberant fields - Part 2: Methods for special reverberation test rooms (ISO 3743-2:1994)
		EN ISO 3744:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane (ISO 3744:2010)
		EN ISO 3745:2012	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for anechoic rooms and hemi-anechoic rooms (ISO 3745:2012)
		EN ISO 3746:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting

			plane (ISO 3746:2010)
		EN ISO 3747:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering/survey methods for use in situ in a reverberant environment (ISO 3747:2010)
		EN ISO 7235:2009	Acoustics - Laboratory measurement procedures for ducted silencers and air-terminal units - Insertion loss, flow noise and total pressure loss (ISO 7235:2003)
		EN ISO 9614-1:2009	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points (ISO 9614-1:1993)
		EN ISO 9614-3:2009	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning (ISO 9614-3:2002)
		ISO 11200:2014	Acoustics -- Noise emitted by machinery and equipment -- Guidelines for the use of basic standards for the determination of emission sound pressure levels at a work station and at other specified positions
		EN ISO 11201:2010	Acoustics - Noise emitted by machinery and equipment - Determination of emission

			sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental corrections (ISO 11201:2010)
		EN ISO 11203:2009	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions from the sound power level (ISO 11203:1995)
		EN ISO 11204:2010	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions applying accurate environmental corrections (ISO 11204:2010)
		EN ISO 11205:2009	Acoustics - Noise emitted by machinery and equipment - Engineering method for the determination of emission sound pressure levels in situ at the work station and at other specified positions using sound intensity (ISO 11205:2003)
		EN ISO 11546-1:2009	Acoustics - Determination of sound insulation performances of enclosures - Part 1: Measurements under laboratory conditions (for declaration purposes) (ISO 11546-1:1995)
		EN ISO 11546-2:2009	Acoustics - Determination of sound insulation performances of enclosures -

			Part 2: Measurements in situ (for acceptance and verification purposes) (ISO 11546-2:1995)
		EN ISO 11688-1:2009	Acoustics - Recommended practice for the design of low-noise machinery and equipment - Part 1: Planning (ISO/TR 11688-1:1995)
		EN ISO 11691:2009	Acoustics - Measurement of insertion loss of ducted silencers without flow - Laboratory survey method (ISO 11691:1995)
		EN ISO 11957:2009	Acoustics - Determination of sound insulation performance of cabins - Laboratory and in situ measurements (ISO 11957:1996)
1.5.9	Vibration	**UNI EN 1032:2009**	Mechanical vibration - Testing of mobile machinery in order to determine the vibration emission value
		EN 12786:2013	Safety of machinery - Requirements for the drafting of the vibration clauses of safety standards
		EN 13490:2001+A1:2008	Mechanical vibration - Industrial trucks - Laboratory evaluation and specification of operator seat vibration
		EN ISO 13753:2008	Mechanical vibration and shock - Hand-arm vibration - Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system (ISO 13753:1998)
		EN ISO 10326-1:2016	Mechanical vibration - Laboratory method for

			evaluating vehicle seat vibration - Part 1: Basic requirements
1.5.10	Radiation	**EN 12198-1:2000+A1:2008**	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 1: General principles
		EN 12198-2:2002+A1:2008	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 2: Radiation emission measurement procedure
		EN 12198-3:2002+A1:2008	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 3: Reduction of radiation by attenuation or screening
1.5.11	External radiation	**EN ISO 11553-1**	Safety of machinery - Laser processing machines - Part 1: General safety requirements (ISO/DIS 11553-1:2016)
1.5.12	Laser radiation	**EN ISO 11553-2**	Safety of machinery - Laser processing machines - Part 2: Safety requirements for hand-held laser processing devices (ISO/DIS 11553-2:2016)
		EN 12254:2010	Screens for laser working places - Safety requirements and testing
		EN ISO 11554:2017	Optics and photonics - Lasers and laser-related equipment - Test methods for laser beam power, energy and temporal characteristics
		EN ISO 11145:2016	Optics and photonics - Lasers and laser-related equipment - Vocabulary and symbols

1.5.13	Hazardous Substances radiation	**EN 1093-2:2006 + A1:2008**	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 2: Tracer gas method for the measurement of the emission rate of a given pollutant
		EN 1093-3:2006 + A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 3: Test bench method for the measurement of the emission rate of a given pollutant
		EN 1093-4:1996 + A1:2008	Safety of machinery. Evaluation of the emission of airborne hazardous substances. Capture efficiency of an exhaust system. Tracer method
1.6	**Manteinance**	**Norm**	**Title**
1.6.1	General mantainance	**EN ISO 14159:2008**	Safety of machinery. Hygiene requirements for the design of machinery
		EN ISO 14122-1:2001	Safety of machinery -- Permanent means of access to machinery -- Part 1: Choice of fixed means and general requirements of access
1.6.2	Workplace availability	**EN ISO 14122-2:2016**	Safety of machinery -- Permanent means of access to machinery -- Part 2: Working platforms and walkways
		EN ISO 14122-3:2016	Safety of machinery -- Permanent means of access to machinery -- Part 3: Stairs, stepladders and guard-rails

		EN ISO 14122-4:2016	Safety of machinery -- Permanent means of access to machinery -- Part 4: Fixed ladders
1.7	**Information**	**Norm**	**Title**
1.7.1	General Information	**Cenelec EN 61310-2:2008**	Safety of machinery. Indication, marking and actuation. Requirements for marking
		Cenelec EN 61310-3:2008	Safety of machinery. Indication, marking and actuation. Requirements for the location and operation of actuators

Appendix B. OPC_1 vs OPC_2 Heart rate comparison

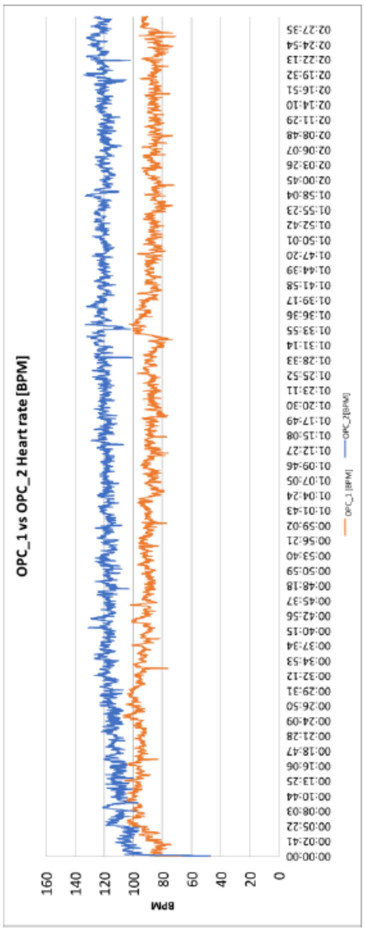

Figure 69. OPC_1 vs OPC_2 Heart rate comparison

Appendix C. OPC_1 vs OPC_2 VMU

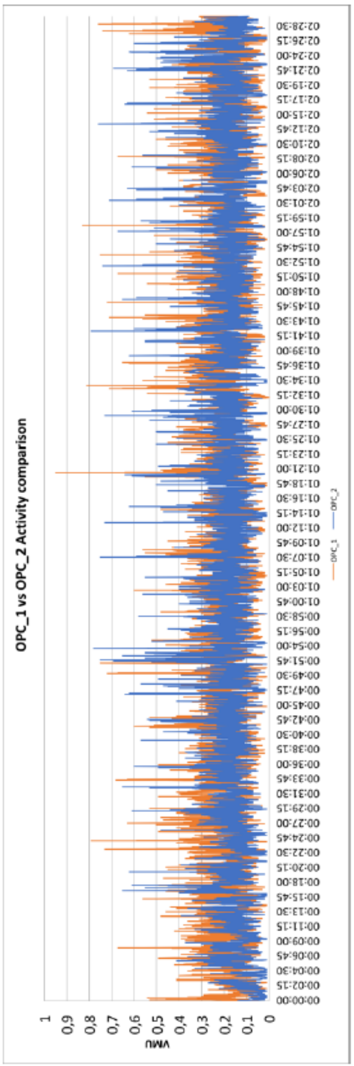

Figure 70. OPC_1 vs OPC_2 VMU comparison

Appendix D. Social assessment tool interface

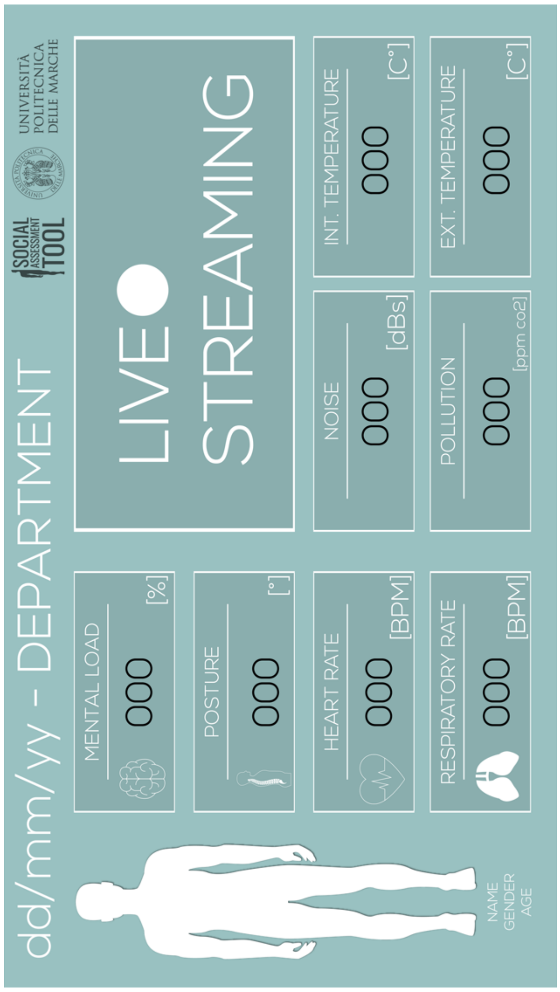

Figure 71. Social assessment tool mock-up

Figure 72. Social assessment tool working mock-up