MAESTRI

Total Resource and Energy Efficiency
Management System for Process Industries

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Technology Watch Report

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1. Executive Summary

The MAESTRI project aims to advance the sustainability of European manufacturing and process industries. This will be achieved by providing a management system in the form of a flexible and scalable platform and to guide and simplify the implementation of an innovative approach in organizations with the Total Efficiency Framework.

The overall aim of this framework is to encourage a culture of improvement within manufacturing and process industries by assisting the decision-making process, supporting the development of improvement strategies and helping to define the priorities to improve the company's environmental and economic performance.

For the key development activities of MAESTRI it is necessary to have a good and complete overview of the nowadays most relevant approaches, methods and tools, in order to create an original and wide application of the Total Efficiency Framework.

In this document and broad compilation is performed to provide a complete state-of-art for all the fundamentals topics necessary for the project, namely: Efficiency Framework, Management Systems, Industrial Symbiosis and Internet-of-things.

For each topic a description is given not only for the introduction to its subject domain, but also a complementary review for both the technological and business aspects.

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2. Introduction

Europe was the cradle of the manufacturing industry and it has traditionally led important industrial changes. Process industries represent the foremost part of the manufacturing base, around 20% of the total European manufacturing industry, which include more than 450,000 individual enterprises (EU27), employment of around 6.8 million citizens and generation of more than 1,600 billion € turnover. On other hand, process industries are largely dependent on resources imports from international markets that are hampering the industry's access to globally traded raw materials, due to the increased political instability in many regions of the globe, which is perfectly visible from a sharp increase in raw material prices during recent years. Moreover, European industry has also accounted for more than a quarter of total energy consumption in 2010 in Europe with a significant portion of that used within the process industry.

This represents both an opportunity and responsibility of this sector contribution to the sustainability challenges of European societies, being imperative to drastically reduce the environmental footprint and increase competitiveness and production systems efficiency by "doing more with less". However, to successfully implement sustainability in manufacturing and process industries, a holistic, multidimensional and systematic approach is required.

With this in mind, the MAESTRI project aims to advance the sustainability of European manufacturing and process industries by providing a management system in the form of a flexible and scalable platform to promote and simplify the implementation of an innovative approach, the Total Efficiency Framework. Based on a holistic approach, which combines different assessment methods and tools, the overall purpose of the Framework is to generate improvement on a continuous basis and increase eco-competitiveness by fostering sustainability in routine operations.

In order to develop more resource and energy efficient processes, utilize waste streams and improve recycling in a sustainable manner, modelling and assessing all the interacting value chains is a must. However, despite the environmental, economic and social improvement potentials by sharing resources (e.g. energy, water, residues and recycled materials), it is essential to understand and assess resource and energy efficiency in order to optimize European production systems. Moreover, the increased availability of ultra-modern technologies for process monitoring and optimization should be carefully adapted and integrated for a wider and facilitated adoption of state-of-the-art tools and methodology for efficiency and eco-efficiency. Such methodologies and tools should support wastes and cost reductions in to companies (large or small).

2.1 Main industrial needs and related R&I challenges

In order to face the challenges of increased competition, the required environmental impact reduction, as well as the retention of high-quality process industries and jobs in Europe, a systems approach will be necessary. Maximum value must be generated from energy and resource streams by using them for the most resource efficient purpose. The vision of the next generation, highly efficient process industry is zero-waste and has a competitive advantage in producing materials and products in the most sustainable way.

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The industrial needs and the related research and innovation challenges should go beyond the state-of-the-art, and focus the following main sub-domains and related priority areas:

1. Feed: Increased energy and resource efficiency through optimal valorisation and smarter use and management of existing, alternative and renewable feedstock;

2. Process: Solutions for more efficient processing and energy systems for the process industry, including industrial symbiosis;

3. Applications: New processes to produce materials for market applications that boost energy and resource efficiency up and down the value chain;

4. Waste 2 Resource: Avoidance, valorisation and re-use of waste streams within and across sectors, including recycling of post-consumer waste streams and new business models for eco-innovation;

5. Horizontal: Underpinning the accelerated deployment of the R&D&I opportunities identified within SPIRE through sustainability evaluation tools and skills and education programmes as well as enhancing the sharing of knowledge, best practices and cross-sectorial technology transfer;

6. Outreach: Reach out to the process industry, policy makers and citizens to support the realisation of impact through awareness, stimulating societal responsible behaviour.

Besides the actual needs for European process industries, and focusing on the Process priority area (Solutions for more efficient processing and energy systems for the process industry, including industrial symbiosis), some major gaps and challenges arise and are responsible for the major sustainability issues that industries have to cope with current. On the other hand opportunities emerge in order to address the gaps and challenges.

Gaps:

a) Technical/Technological Gaps
    - Lack of flexible, scalable and holistic tools to support decision making process regarding resource and energy efficiency;
    - Lack of simple and integrated tools to assess and optimize resource and energy efficiency, crossing the different environmental and economic operational aspects;
    - Deficient knowledge to identify the potential use of wastes as resources (energy, resources, man-power, etc.);

b) Management Gaps

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- Non-incorporation of sustainability aspects in company strategy and objectives;
- Non-implementation of structured management systems targeting resource consumption and energy efficiency;
- Dispersion of process efficiency relevant data and information across different departments of the company;
- Difficulty on the definition of clear and consistent KPIs, and their follow-up;

c) Organisational Gaps

- Poor means for sharing resources (e.g. plants, energy, water, residues and recycled materials) through the integration of multiple production units of a single company or multiple companies on a single industrial production site;
- Difficulty to collect and share information about all process flows (resource and energy inputs as well as waste and pollutant outputs).

Challenges:

- Implement sustainable manufacturing approaches as a given in process industries focusing on general cross-sectorial interaction for a major positive impact within the process industry and.
- Poor understanding of each other's processes is hindering the development of technical and non-technical interactions and exchanges, which are necessary for industry to properly face the challenges and consequently enhance sustainability.

Opportunities:

- Enable the implementation of a broad variety of technologies, encompassing a wide range of disciplines, such as fundamental science, and plant engineering and management. The integration into a single management system of all these environmental, energy and economic factors is key for the improvement in efficiency of the process industries.
- Analysis and optimization tools for flexible energy use and material flow integration should be developed, aiming at a holistic approach for resource management in process industries, suitable both for small and large scale in a flexible approach. To facilitate a proper dissemination and use, it is expected that standards-based software for measuring critical footprint issues and relevant data used into the daily routine of the plants/clusters will be developed.
- Topic: Rapid transfer from lab-scale and conceptual design into testing at demonstration sites, using realistic industrial streams and process conditions. Pilot tests should focus on integrated solutions and tools adapted to the specific conditions in real production units. This will facilitate future industrial symbiosis between different sectors, by integrating energy and material flows within existing industrial parks.
- Topic: New approaches that perform cost-saving optimization of energy and resources supply and demand, in order to reduce the residues and costs in

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intensive industries, taking into consideration both economical and sustainability constraints.

2.2 Overview – Sustainable Manufacturing

Manufacturing is the process of transforming inputs like material, personnel and energy into valuable outputs (products) often together with undesirable outputs like different forms of waste and other emissions. While starting from handcraft scale, within the last two centuries industrial revolutions lead to manufacturing in factories with higher manufacturing volumes and productivity. With economic aspects being clearly in focus, factories are - certainly not without reason - associated with diverse negative environmental and social impacts. Just within the last decades more and more work has been done in order to minimize these impacts. However, most activities focus on the strategy of efficiency ("doing the things right") (HERRMANN 2015). Yet, people are becoming more and more conscious about the deterioration of today's global environment. Some buzz words, such as global warming, pollution, shortage of oil, extinction of species, have frequently been used in the news headlines and major subjects of political disputations (BI, 2001).

Sustainability of economy, society and environment has been recognized as priorities in fundamental engineering research. In the area of manufacturing, many new terminologies related to sustainability, such as Environmentally Conscious Manufacturing, Sustainable Manufacturing, Green Manufacturing, and Reverse manufacturing, have been proposed. Although these studies are limited to some general discussions on new requirements of next-generation manufacturing systems (BI, 2001).

According to Bi (2001), customers' requirements on products has gradually expanded. Today, people are very conscious about the global environment and the predictable shortage of natural resources in near future. Hence, manufacturing companies have been forced to change their system paradigms to accommodate the new needs of sustainability. Figure 1 shows the evolution of manufacturing system paradigms divided into six phases: mass production, lean manufacturing, mass customization, reconfigurable manufacturing, and 'sustainable manufacturing'.

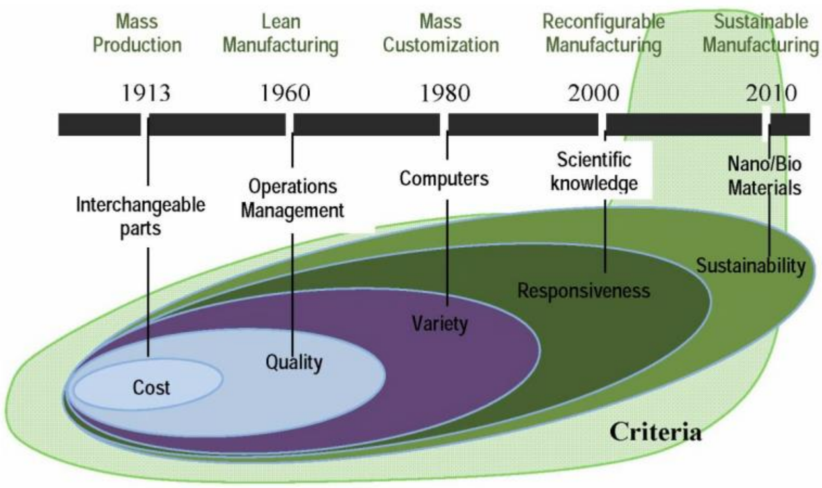

Figure 1: Evolution of manufacturing

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Regarding the sustainability assessment, according to SINGH (2009) there are two distinct methodologies that can be found for Sustainability Assessment.

- "Mainstream economists use monetary aggregation method, whereas scientists and researchers in other disciplines prefer to use physical indicators. Economic approaches include greening the GDP, resource accounting based on their functions, sustainable growth modelling, and defining weak and strong sustainability conditions. Mainstream economists assume sustainable growth to be a part of sustainable development of the economy".

In neo-classical models, natural environment is valued for its functions and economic welfare is measured in terms of the level of consumption. Therefore, sustainable growth models from this paradigm seek to find a non-declining per capita consumption path over an infinite time horizon through optimal use of resources and technology including discounted benefits from environmental functions and non-renewable natural resources. Substitution possibility between different types of capital is assumed in different forms (SINGH, 2009).

2.2.1 Environmental Concerns & Tools

Concerns for the environmental impact and depletion of resources as a result of unlimited economic growth, have stimulated engineers, for many years, to reduce the impact of product lifecycles.

According to Ehrenfeld (2005), eco-efficiency has assumed a key role, as its "practical and theoretical importance lies in its ability to combine performance along two of the three axes of sustainable development, environment and economics".

One of the most used and useful tools for assessing the environmental burden is Life Cycle Assessment (LCA). According to ISO 14040, LCA consists of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation (ISO, 2006; Lozano et al., 2011). LCA is an analytical tool, used to assess the environmental impacts and resources used within a product's life cycle (Finnveden and Moberg, 2005; ISO, 2006).

While LCA is an established method to assess environmental performance in an eco-efficiency assessment, no established method exists for assessing value performance (Product or Service Value) (Michelsen et al., 2006). The economic value of a product or service may be determined by many methods. Namely via LCC (Life Cycle Costing) method, which aims to identify and estimate all costs within the life cycle of a product or process (Czaplicka-Kolarz et al., 2010). On the other hand, the WBCSD recommends using monetary indicators that are easy to understand (Michelsen et al., 2006). For instance, the value performance in a segment of eco-efficiency is measured as net sales (value of sales minus the cost of all inputs purchased). This gives a measure of the costs added to the product due to unit processes costs (Michelsen et al., 2006). ISO 14045 makes reference to the product value or service through functional value, i.e. the luminous flux (lumens) or durability (years) can be used as a functional value (ISO, 2011).

The identification of Key Environmental Performance Indicators (KEPI) has been widely studied. For instance Michelsen et al. (2006) used eco-efficiency to assess extended supply chains, their goal was to identify performance indicators for individual companies that would be easily understood by non-specialists. Wursthorn et al. (2011) mention that disaggregated indicator should consider eco-efficiency's main goal, in order to link the activities of

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individual companies and macroeconomic level. Jasch (2000) defines environmental indicators as comprehensive and concise key data set. They provide decision makers with an overview of relevant progress and highlight problematic areas. Consequently, the environmental indicators depict a set of environmental targets, which are supported with measurable data. Furthermore, environmental indicators remain connected to well-known traditional indicators, enabling the identification of potential monetary benefits. Moreover, this type of indicators give the opportunity to identify potential improvements.

The WBCSD suggests methods for identifying KEPI. For example the ISO 14031 standard proposes a list of environmental indicators, divided into three types: operational performance; environmental management and environmental condition (IPQ, 2005). Besides ISO 14031, the WBCSD also mentions the Global Reporting Initiative indicators, which are based on the quantification of the environmental dimension that reflect the concerns of sustainability and the environmental impact of organizations on natural systems (GRI, 2006). The indicators defined by OECD, are also recommended by the WBCSD, these consist in a small set of environmental indicators that are approved by the Environment Ministers of OECD countries for systematic use in communication and political work of the OECD (OECD, 2003).

Regarding eco-efficiency assessments, several evaluations have taken place for various industries and with various approaches. For instance BASF performed an eco-efficiency assessment to quantify the sustainability of products and processes and support decision making (Kicherer et al., 2007; Saling et al., 2002). Côté et al. (2006)assessed the eco-efficiency performance of several SME using a self-developed eco-efficiency checklist. The author concluded that the existing eco-efficiency tools are not suitable for SME, therefore it is important to develop new ones. Kharel and Charmondusit (2008) evaluated the eco-efficiency of an iron road industry, using an empirical assessment that considers energy, material and water consumption and emissions, as the environmental aspects. The production values were defined as the net sales. Since Kharel's study only considers five environmental aspects, this could lead to some limitations in terms of overall environmental assessment.

Eco-efficiency and environmental performance assessment of industrial processes are powerful tools for achieving sustainability, especially when considering the decompiling of the economic performance from environmental burdens (Despeisse et al., 2012), i.e. maintain economic growth and reduce environmental impacts (Verfaillie and Bidwell, 2000). This paradigm is directly applied to eco-efficiency, although according to Huppes and Ishikawa (2005a), within the common eco-efficiency framework, economic growth overshadows the improvements per unit of consumption. Due to this reason eco-efficiency assessments can be left behind and consequently encourage the use of effectiveness assessments in a more direct way, as it has been done in the past. However, by assessing effectiveness and "descanting" eco-efficiency, it doesn't mean that environmental and economic improvements will not be achieved. For example Despeisse et al. (2012), states that efficient and effective material and energy use can reduce natural resource inputs and waste or pollutant outputs. But on the other hand one can effectively use materials, energy or resources and not take into account the related environmental impact, and consequently never look for alternatives and improvements that can enhance economic and environmental performance.

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2.3 Overview of the proposed approach

Coherently, and due to the gaps and challenges, MAESTRI intends to develop an innovative and integrated platform combining holistic efficiency assessment tools, a novel management system and an innovative approach for industrial symbioses implementation.

The main concept of the MAESTRI project consists of the development of a flexible and holistic integrated Framework to foster manufacturing sustainability in process industry, the "Total Efficiency Framework". The overall aim of the Total Efficiency Framework is to promote improvement culture within process industries by assisting decision-making process, supporting the development of improvement strategies and helping on the definition of priorities to improve the companies' environmental and economic performance. The Total Efficiency Framework will be based on four main pillars to overcome the current barriers and promote sustainable improvements:

- An effective Management System targeted for process and continuous improvement;
- Efficiency assessment tools to define improvement and optimization strategies and support decision making process;
- Integration with Industrial Symbiosis concept focusing material and energy exchange;
- An IoT Platform to simplify the concept implementation and ensure an integrated control of improvement process;

a) Management System

The management system embraces the development of management tools that encompass LEAN strategies related to sustainable continuous improvements (from environmental, social and economic point of view). Apart from the definition of specific procedures, as commonly applied for any other Management System, continuous improvement will be promoted by the implementation of efficiency assessment tools. Its flexible and holistic approach will allow the definition and monitoring of relevant KPIs, on an appropriate time scale, aiming for the identification of potential improvement initiatives and decision support making process. Integration with strategy, management system and managers' behaviours will ensure the proper motivation and people engagement on every level of the company. Synergies with other Legal (e.g. REACH, IPPC, E-PRTR, etc.) Management (e.g. ISO standards 9001, 14001 and 50001) and Communication (e.g. GRI, ETS, Ecolabel, etc.) instruments, will be also evaluated and taken into account, in order to support decision and stimulate competitiveness.

Motivation strategies, people engagement schemes and Cultural Behaviour Analysis, will be assessed and used with the intention of improving total efficiency and supporting continuous improvement process.

The possibility of adapting low cost eco improvement methods to the specific conditions of manufacturing and process industries will be investigated with the intention of improving total efficiency and supporting continuous improvement.

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b) Efficiency Assessment

For efficiency assessment, optimization and support decision making, the MAESTRI project proposes the integration of two innovative methodologies: Multi-layer Stream Mapping (MSM), to assess overall efficiency performance, and Eco-Efficiency Integrated Methodology for Production Systems (ecoPROSYS) , to assess and evaluate eco-efficiency performance. This integration enables an overall efficiency performance assessment both from environment, including energy efficiency, and value and cost perspectives. Such integration encompasses Environmental Performance Evaluation with Environmental Influence and Cost/Value assessment models through a life cycle perspective. Its aim is to optimize all process elementary flows via cost-saving optimization by clearly assessing resource and energy usage (valuable / wasteful), and each flow efficiency. Decision support model will be composed by: (a) simulation models for assessing scenarios, (b) predictive models to identify consumption patterns and emission projections, and (c) optimization models for energy and resources efficiency.

c) Industrial Symbiosis

Industrial Symbiosis, within the scope of sustainable manufacturing for process industries, fosters the sharing of resources (energy, water, residues and recycled materials etc.) within the different processes of a single company or between multiple companies. This association enables companies to reduce raw material and energy consumption, and waste disposal costs, promoting the efficient use of resources.

In order to develop industrial symbioses, it is fundamental to identify the waste (energy or material) sources, demands and potential synergies. It is necessary to understand the success factors associated with implementations and attempted implementations of industrial symbiosis in order to establish the principles for the toolkit development and its integration with the Total Efficiency Framework and Management System into the IoT platform. The examples collected to build the library of case studies will be analysed to extract key success factors which will provide the foundation for the toolkit development. In addition, the library of case studies will be used to initially populate the waste database by providing example of wastes which have been converted into resources. This will serve as a basis to define the database structure and operational design. Through the development of a database architecture – an open platform for value-laden wastes available to companies across the EU – increased availability of information will be enabled and potentially provide inspiration for companies to identify reuse opportunities for their own waste. This is essential to expand the uptake of industrial symbiosis practice across the EU.

With an understanding of the success factors and challenges (technical, organizational, behavioural and regulatory) associated with implementations of industrial symbiosis, 'how-to' guides will support the process of learning how symbiosis might be best applied to one's own circumstances, catalysing the search for internal and external opportunities. The toolkit and database developed in the MAESTRI project will encourage a greater appreciation and retention of the value embedded in waste streams as well as encourage collaboration and exchange between processes, sites, companies and across industrial sectors. Furthermore

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the knowledge and insights from new understanding of industrial symbiosis application will be developed to provide a user guide supporting the toolkit and platform.

d) IoT Platform

For the purpose of MAESTRI project, to assess and improve the overall efficiency and eco-efficiency performance of process industry in an innovative way, (i.e. monitor process data, most of it in continuum, for energy and resource efficiency, eco-efficiency, optimization and for parameters currently not taken into account for plant engineering, process monitoring and to connect to the value chain information with a life-cycle approach), an "open source" platform will be developed. The platform should promote and support the Total Efficiency Framework implementation, encompassing the three above mentioned modules. This will allow better support management decisions within companies (both Large and SME) for improvement actions and also to capital investment on new efficient technologies.

These vectors of the platform will be developed in order to ensure a scalable and flexible scope of application, namely into three main perspectives:

- Single companies – supporting decision making in order to improve the efficiency of any product, process, or service system.

- Multi-companies – promoting cross-sectorial interactions by identifying residues/ wastes sources, demands and potential synergies.

- Following a value chain approach – promoting an integrated overall resource and energy management system to facilitate information flow among the participating companies (both in material supply chains and equipment supply chains). This will assure a complete overview of the mutually tightly connected stages in a product production chain.

Moreover, the integration of the platform with IoT concept will enable an effective control of process efficiency by measuring, mostly in near real time, the most significant flows/aspects related with resource and energy efficiency as well as its major environmental and economic effects.

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3. Efficiency framework

A growing global population with growing affluence may well lead to reduced environmental quality and a diminishing quality of nature, ultimately jeopardizing the quality of human life and even human life itself. The challenge we face is to reduce the environmental consequences of our actions so as to reduce environmental risks and to retain the quality of the environment not only as is necessary for survival but also reflecting higher order values on nature and human life, as for example reflected in the concept of sustainability (HUPPES, 2007).

Sustainability refers to reconciling environmental, economic and social concerns both from a current point of view and long term intergenerational perspective. The way to go to sustainability is through decoupling the resources used and pollutant emissions from economic development (LEHNI, 2000). In other words, the decoupling process can be described as the separation made between environmental impacts and the production of wealth. These topics embrace a wide range of aspects that are hard to evaluate. Following this need, the concept of eco-efficiency emerged playing an important role on the rising of sustainable development. Eco-efficiency is then a relatively new concept in environmental management which integrates it with economic analysis to improve products, systems and technologies.

This concept is increasingly becoming used for different applications. Consequently, the use of this idea has been shifting from specific, to larger and more embracing systems, enabling the overall economic and environmental improvements (ISO, 2012).

A wide variety of terminology referring to eco-efficiency has been developing, differing depending on application, on the background of the researchers, and possibly even on views on how to treat negative signs (HUPPES, 2007). The term eco-efficiency, that first established the link between environmental performance and economic benefits was first introduced in 1990 by two Swiss researchers, Schaltegger and Sturm and was adopted and presented by the World Business Council for Sustainable Development (WBCSD) in 1991. The World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as "the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity".

Another definition, according to ISO 14045:2012 (ISO, 2012), says "eco-efficiency is a quantitative management tool that enables the consideration of life cycle environmental impacts of a product system alongside its product system value to a stakeholder". On the other hand, the European Environment Agency (EEA) defines eco-efficiency as "a concept and strategy that enables the separation of the "use of nature" from economic activity needed to meet human needs (welfare) to allow it to remain within carrying capacities and to permit equitable access and use of the environment by current and future generations" (EEA, 2008).

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Eco-efficiency measures the relationship between economic growth and environmental pressure, and is generally expressed by the ratio between economic value and environmental influence, represented by equation 1 (LEHNI, 2000).

Eco-efficiency = Production or Service Value/Environmental Influence (1)

Eco-efficiency therefore aims creating more value with the less environmental impact.

The eco-efficiency concept initially focused on issues within companies, and then its use was extended to help assess policy strategies and their possible macroeconomic outcomes (WURSTHORN et al., 2011). Eco-efficiency is progressively becoming more common and widely used for different purposes. Consequently, eco-efficiency purposes have been shifting from site-specific to larger systems, subsequently enabling overall economic and environmental improvements (CZAPLICKA-KOLARZ et al., 2010; MICHELSEN et al., 2006; Van CANEGHEM et al., 2010).

3.1 Technological aspects

This section addresses the application of eco-efficiency namely the tools that are used to put in practice by companies and industries.

3.1.1 Performance Measure and Indicators

Economic development and environmental protection together are now being considered by industrial leaders as the basis for competitive advantage, thanks to the double impact that resource efficiency can have both on operating costs and on company brand image. The motivations for corporations to pursue sustainability have been extensively researched (SEARCY, 2012).

According to a McKinsey report (McKinsey, 2012), positive effects on Return on Capital of manufacturing companies might come from i) marketing resource efficiency attributes, ii) improving product value propositions with low environmental impacts, iii) reducing operating costs through improved internal resources management (energy, waste, water, hazardous substances).

In this context, therefore, European manufacturers have to fundamentally change their approach to competition: they need to deliver high quality and increasingly customized products and services, with minimum cost and environmental impact. Production systems requirements therefore entail improving energy and resource efficiency, reducing waste and emissions, while pursuing all the other manufacturing performances (GARETTI et al., 2012). Enterprises need methods and guidelines to support decision making to design, operate, manage and "fine tune" their manufacturing systems, aiming at economic and environmental objectives to achieve the so called eco-economy with their future factories, the eco-factories.

Therefore, there is the need for evaluation of sustainable manufacturing performance (see for instance AMRINA et al., 2011). Development of appropriate metrics is critical to enable designers, engineers and managers to orientate their decision processes, from the factory planning, to operations, management and control.

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Eco-efficiency indicators rose from the need to measure and quantify eco-efficiency, and are used worldwide as a management tool to assess a company's progress on a certain requirement. As such, an indicator provides important qualitative and quantitative information for decision making and can be defined as a parameter or a reference value of a parameter.

The WBCSD suggests the indicators should:

i. "Be relevant and meaningful with respect to protecting the environment and human health and/or improving the quality of life"
ii. "Inform decision making to improve the performance of the organization"
iii. "Recognize the inherent diversity of business"
iv. "Support benchmarking and monitoring over time"
v. "Be clearly defined, measurable, transparent and verifiable"
vi. "Be understandable and meaningful to identified stakeholders"
vii. "Be based on an overall evaluation of a company's operations, products and services, especially focusing on all those areas that are of direct management control" and
viii. "Recognize relevant and meaningful issues related to upstream (e.g. suppliers) and downstream (e.g. product use) aspects of a company's activities".

The ultimate goal of these eight principles is to ensure the indicators are scientifically supported and environmentally relevant, relating to issues where there is a clear need for improvement, accurate and useful for all businesses, considering the indicators for different products or processes must be defined in the same way so that comparisons are made regarding the same units, and must be designed to minimize the influence of extraneous factors in order to avoid "false" changes in eco-efficiency, allowing to improve the performance of businesses and monitoring that performance with transparent and verifiable measures, clearly defined by estimation methodologies, and limitations with individual indicators clearly understood. These indicators must also be meaningful to both internal and external members of a company, such as business managers and stakeholders respectively, mainly focusing on all areas of a business's operations, products or services but also recognizing the relevance of issues upstream and downstream of a company's activities (VERFAILLIE et al., 2000).

The Eco-efficiency indicators can be classified as Generally Applicable indicators, used by any business, relating to a global environmental concern or business value, with measuring methods accepted globally, using available metrics such as Eco-Indicator 99 or ReCiPe for environmental impact measurement, or Business-Specific indicators which are defined from one business, or sector, to another, not being necessarily less important than the first group. For the later, the WBCSD recommends the use of the ISO 14031 standard (ISO 2013) as a guide for the selection of relevant indicators (VERFAILLIE et al., 2000; LOURENÇO, 2012).

"A company's Eco-efficiency profile will include both types of indicators" (MADDEN, 2006) where the WBCSD recommends the use of a limited number of Generally Applicable Indicators and a set of Business Specific Indicators in order to keep the company's Eco-efficiency profile as clear as possible (VERFAILLIE et al., 2000).

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Table 1: Generally applicable indicators (VERFAILLIE et al., 2000)

	Indicators	Units
Product/service value	Quantity of goods/services produced or provided to customers	Number or mass (kg, ton, etc.)
	Net sale	€, £, $, etc.
Environmental influence in product/service creation	Energy consumption	GJ, kW.h, etc.
	Material consumption	kg, ton, etc.
	Water consumption	m3
	Greenhouse gas (GHG) emissions	CFC11 equivalent/ton
	Ozone depleting substance (ODS) emissions	CO2/ton

An important sub-group of Business Specific Indicators are the KEPI (Key Environmental Performance Indicators), which are useful to demonstrate the impacts in a measurable level, meaning in relation to the functional unit defined by the company, so the results are presented in the form of a metric, in accordance to the objectives of the company (LOURENÇO, 2012). The purpose of this functional unit is to provide a reference to which results with different units can be related. However, for the same study, the company needs to guarantee the use of the same functional unit in all results. These indicators are usually generated from the Operational Performance Indicators of ISO 14031(ISO 2013), since they are mostly quantitative, or from results obtained by the Global Initiative Report (GRI), in accordance to recommendations of the WBCSD, but are not usually included in the company´s eco-efficiency profile, being mainly for internal evaluation and measurement (VERFAILLIE et al., 2000).

The transition toward resource efficient production and consumption patterns is currently one of the main challenges in engineering, environmental science and especially in governmental policies. This transition has led to a proliferation of meanings related to the resource efficiency concept, resulting in a wide variety of indicators. Huysman et al. (2015) proposed a **systematized framework** in which resource efficiency indicators can be structured and comprehensively positioned. The aim was to provide a proper understanding of the scope and limitations of particular existing resource efficiency indicators in order to assist policy makers and the scientific community in the application and further development of indicators. This framework covers all different resource use-related aspects evaluated in existing approaches, including simple accounting of resource extraction and use; environmental impact assessment due to resource extraction and use; accounting and environmental impact assessment of specific processes and of full supply chains; analyses at micro-scale and macro-scale; and analysis of both natural resources versus waste-as-

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resources. To illustrate the potential application of the framework, a set of currently used indicators was selected, whereupon these indicators were structured and evaluated within the framework.

The proposed systematized framework in which resource efficiency indicators can be classified is presented in Table 2. This table also includes some general examples to illustrate each family of indicators (HUYSMAN et al., 2015).

Table 2: Systematized framework with some general examples (HUYSMAN et al., 2015)

		Level 1		Level 2 (Eco-efficiency		
Fields of study: environmental science and engineering or environmental policy		**Resource efficiency at flow level (RE-FL)** Benefits over resource flows (natural, waste or industrial)	**Emission efficiency at flow level (EM-FL)** Benefits over emissions flows (often the reciprocal is used)	**Resource efficiency at impact level (RE-IMP)** Benefits over impacts derived from the resource flows	**Emission efficiency at impact level (EM-IMP)** Benefits over impacts derived from the emission flows	**Overall efficiency at impact level (OE-IMP)** Benefits over impacts from both resource and emission flows
Micro-scale ↓ Macro-scale	**Gate-to-gate perspective**	*Benefits over (kg) resources*	*Benefits over (kg) emissions*	*Benefits over (ADP) impact*	*Benefits over (GWP) impact*	*Benefits over single score impact*
	Life cycle perspective	*Benefits over (kg) resources in life cycle*	*Benefits over (kg) emissions in life cycle*	*Benefits over (ADP) impact in life cycle*	*Benefits over (GWP) impact in life cycle*	*Benefits over single score impact in life cycle*
	Domestic perspective	*GDP over (kg) domestic extracted resources*	*GDP over (kg) domestic emissions*	*GDP over domestic (ADP) impact*	*GDP over domestic (GWP) impact*	*GDP over domestic (single score impact*
	Global perspective	*GDP over (kg) global extracted resources*	*GDP over (kg) global emissions*	*GDP over Global (ADP) impact*	*GDP over Global (GWP) impact*	*GDP over global single score impact*

GDP = gross domestic product, ADP = abiotic depletion potential, GWP = global warming potential. The white columns (RE-FL, RE-IMP) are 'resource efficiency indicators in sensu stricto', the column (OE-IMP) are 'resource efficiency indicators in sensu lato', the grey columns (EM-FL, EM-IMP) are in this study not considered as resource efficiency indicators. For the sake of completeness, they are also presented to clearly accentuate the difference with the other efficiencies (HUYSMAN et al., 2015).

The proposed systematized framework makes it possible to structure and critically analyse resource efficiency indicators, providing insights in what exactly one likes to indicate: progress in terms of resource flows or in terms of environmental impacts; natural resources or industrial resources; a global or domestic perspective; etc. These insights can assist governmental policies and the scientific community in effective implementation and further development of indicators for quantitative assessment of resource efficiency and eco-efficiency. The framework could for example be used as a basis for decision-making models, making it possible to select relevant indicators for specific needs. Such models could take additional aspects into account, e.g. the calculation time, budget, data availability, etc. (HUYSMAN et al., 2015).

3.1.2 Eco-efficiency analysis methods and tools

Production systems are the elementary systems of industrial processes that are responsible for the production of all kind of equipment, products and goods that are placed in the market. Thereby it is of great importance to assess the eco-efficiency of production systems to

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enable an informed decision making regarding economic and environmental performance and, consequently to increase energy and resource efficiency (BAPTISTA et al., 2014).

The eco-efficiency approach has been embraced by a large number of companies as a way of improving their economic and environmental performance. One such example is the chemical company BASF, which has developed an **Eco-Efficiency Analysis method** (SHONNARD et al., 2003). This method considers the economic and environmental effects of a product giving these equal weighting. Thus, in addition to its relevance to the environment, the costs of a product go into the analysis in equal proportions. BASF established this holistic method in 1996 and was one of the first companies in the chemical industry to do so. The Eco-Efficiency Analysis follows ISO 14040:2006 and 14044:2006 for environmental life cycle assessments. The assessment of life cycle costs and aggregation to an overall Eco-Efficiency is based on ISO 14045:2012. BASF's method for Eco-Efficiency Analysis is validated by the German Association for Technical Inspection (TÜV Rheinland). The most recent validation has been conducted in 2015 by the American NSF (National Sanitation Foundation).

Every eco-efficiency analysis passes through several key stages. This ensures consistent quality and the comparability of different studies. Environmental impacts are determined by the method of life cycle assessment (LCA), and economic data are calculated using the usual business or, in some instances, national economic models. The basic preconditions in the BASF eco-efficiency analysis are as follows (SHONNARD et al., 2003):

- Products or processes studied have to meet the same defined customer benefit. The specific *customer benefit* always lies at the centre of eco-efficiency analysis.
- The entire life cycle is considered
- Both an environmental and an economic assessment are carried out

The eco-efficiency analysis is worked out by following specific and defined ways of calculations:

- Calculation of total cost from the customer viewpoint
- Preparation of a specific life cycle analysis for all investigated products or processes according to the rules of ISO 14040
- Determination of impacts on the health, safety, and risks to people
- Assessing use of area over the whole life cycle
- Calculation of relevance and calculation factors for specific weighting
- Weighting of life cycle analysis factors with societal factors
- Determination of relative importance of ecology versus economy
- Creation of an eco-efficiency portfolio
- Analyses of weaknesses, scenarios, sensitivities, and business options
- Optionally: inclusion of social aspects

The analysis allows for a holistic view of chemical products and processes that combines assessment of life cycle environmental impacts with economic performance in equal measure to achieve a greater level of sustainability. The relevance of the eco-efficiency analysis on internal strategic decisions is very high within BASF, and most analyses are presented to upper management. Over 180 eco-efficiency analyses have been conducted

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at BASF, and their results have been used to support strategic decision-making, marketing, research and development, and communication with external parties.

Baptista (BAPTISTA et al., 2014) proposed an **eco-efficiency framework** named **ecoPROSYS** as a decision support tool aiming to maximize product/processes value creation and minimize environmental burdens, i.e. decouple economic growth from environmental burden. The proposed framework fosters informed and sustainable decision making processes by the use of an organized set of indicators which are easy to understand/analyse. The approach is based on four main steps:

1) Data inventory;
2) Environmental performance evaluation;
3) Environmental impact assessment;
4) Cost models.

The developed framework can be applied to any industry or production system, where all the unit processes involved are identified and the inputs/outputs of each unit system quantified and easily perceived. Key Environmental Performance Indicators and Eco-efficiency ratios related to the principles of eco-efficiency arise as outcomes of this approach. The results can be used to evaluate the production system's performance and can help to understand which unit processes or aspects play a key role in terms of economic value and/or environmental burden, so improvement actions can be applied in order to enhance the overall performance, eco-efficiency and value increase for organizations.

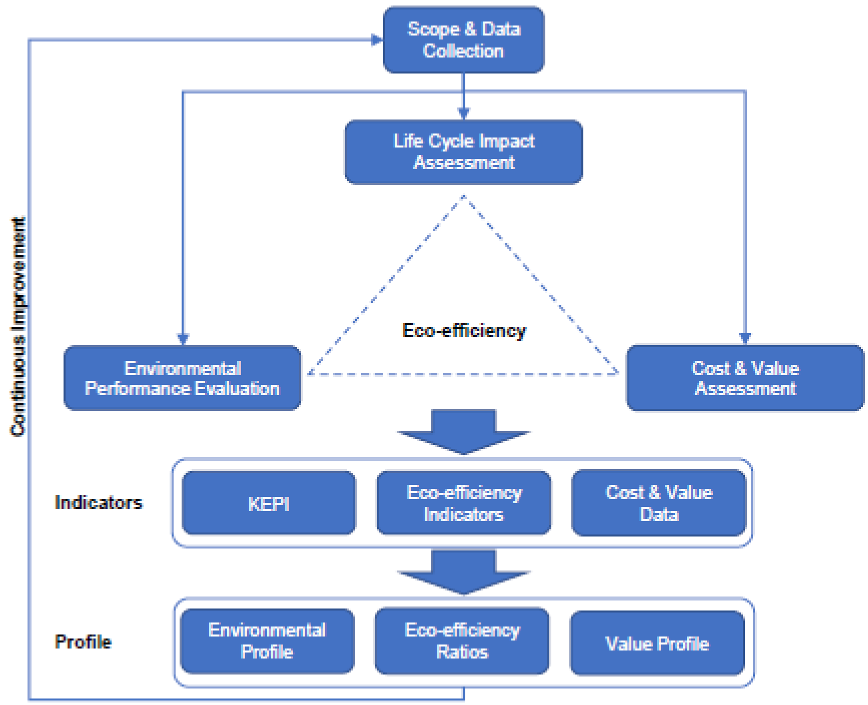

Figure 2: Eco-efficiency framework (BAPTISTA et al., 2014)

To comply with increased requirements from customers and authorities, it is necessary for companies to be aware of the performance of their products throughout their life cycle. One possibility is to measure eco-efficiency in the extended supply chains (ESC). Michelsen

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et al. (2006) have demonstrated how this approach can be used to compare different products in terms of environmental performance and costs over the life cycle of the products.

When products are analysed to reveal possible eco-efficiency improvements, the extended supply chain should be included. Christopher (1998) defines a supply chain as 'the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hand of the ultimate consumer.' An extended supply chain also includes the use and disposal of the products. The term extended supply chain encompasses both the companies involved and the life cycle perspective. Clift and Wright (2000) and Clift (2003) found significant differences in the ratio between environmental impact and added value in different segments of manufacturing processes. Michelsen et al. (2006) have shown the same for furniture, and revealed that a major part of the environmental impact of the products originated not from the end producer but elsewhere in the ESC. Management of the ESC goes beyond what is normally recognised as supply chain management, as it also includes end-of-life treatment. The ESC is, in principle, infinite, and criteria must be defined for the selection of boundaries.

Companies must be able to identify where improvements are possible in the ESC and what impacts these will have on environmental and economic performance. Michelsen et al. (2006) have shown how this could be done by using eco-efficiency.

Over the last years the sustainability issue has grown exponentially and it has involved several engineering areas, starting with the product sustainability, then to the factory sustainability, up to reach the entire Value Chain sustainability. The sustainability assessment along the Value Chain is a study that requires a high degree of detail. Unlike the product sustainability assessment, here the focus is to define and evaluate the relations among the factories involved in the specific Value Chain in terms of material, information, resources and energy flows. Due to the continuous increasing of complex relations among factories, suppliers, and customers, a new method for investigating the entire Value Chain, considering its key partners, their requirements in terms of materials usage and energy consumption, and how these requirements influence the Value Chain sustainability was proposed (LUZI et al. 2015). In fact the aim of this new assessment method is to create several synergies within the network, able to improve the product EoL strategies, reduce and/or reuse the scraps, decrease the transport impacts, improve the processes performance in terms of materials and energy used, etc.

The proposed method is able to identify the existing relations among the different factories involved in a tailored Value Chain, their main criticalities and also the new possible synergies hidden till now, through the comparison of the Value Chain companies requirements. To achieve these purposes, the method is developed in three main steps:

1) **Mapping of each Value Chain factory**. The factory model is conducted in terms of inputs needed, outputs produced, waste generated and process or factory constrains;
2) **Value Chain factories relations recognition**. The goal is to detect all the existing relations among the factories involved in the analysis. This representation allows to discover also other synergies, hidden inside the Value Chain;

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3) **Requirements analysis**. This phase is the core of the proposed methodology. It provides how to collect requirements for each factory involved in the sustainable analysis, and then tries to create a correlation between the factories according to the shared requirements. The considered requirements in this work are the business requirements, in order to assess the economic convenience to apply a certain actions or policy, and the sustainable requirements that are focalized on the factory's capacity to obtain energy, a material or other resources efficiency.

This model aim companies to define the criticalities inside the Value Chain relations and to develop possible improved scenarios.

Manufacturing industry is the largest end-users of energy around the world. Continuous improvement of energy efficiency is seen as a key approach to reduce energy consumption, lower greenhouse gas emissions, and achieve eco-efficiency. Energy efficiency benchmarking is a technique to identify best practices to serve as possible benchmarks for measurement and management of energy efficiency improvement. However, it is a challenging task to identify the best practices and quantify the energy saving potentials in manufacturing environment, particularly when the operation is high-mix low-volume (HMLV). Y.S. Tan (TAN et al., 2015) presented an **Energy Efficiency Benchmarking Methodology** (E2BM), which can be applied for both mass and HMLV production environments. This methodology allows the quantification of energy efficiency gaps between manufacturing operations and the corresponding best practices, and hence reveals the potentials for achievable energy savings.

The E2BM has been developed for manufacturing industry to benchmark energy efficiency in different levels of hierarchy, i.e. plant, production line and machine levels. At each level, benchmarking can be performed internally within a company or externally with other companies in an industrial sector.

The method consists of five steps and takes three levels of hierarchy (i.e. plant, production line and machine) into consideration Figure 3).

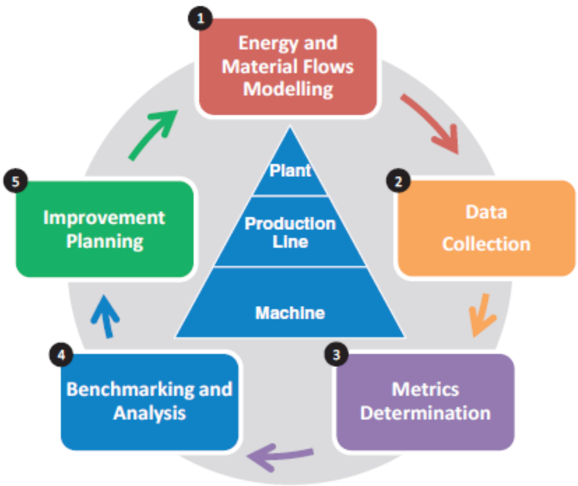

Figure 3: Five steps of the E2BM (TAN et al., 2015)

The methods have been tested in some examples. Based on the studies, the energy efficiency benchmarking has resulted in valuable benefits to the participation plants (TAN et al., 2015), namely:

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- determination of achievable energy reduction targets,
- establishment of energy efficiency baseline and best practice within the company and last,
- identification of best in class in the industry sector.

3.1.3 Eco-efficiency reporting

During the last decade, several methods were reported, with indicators for reporting and measuring eco-efficiency of companies and industrial regions (VERFAILLIE et al., 2000; STURM et al., 2003). The main objective of these methods is to provide information on environmental performance vis-à-vis economic performance in a comprehensive, systematic and consistent manner over periods of time (STURM et al., 2003). A **methodology for eco-efficiency reporting** with eco-efficiency indicators for climate change, acidification, photo-oxidant formation, human toxicity, freshwater aquatic ecotoxicity, eutrophication, energy consumption and waste generation has been proposed by some authors (CANEGHEM et al., 2010). The method was applied to emission, consumption and production data of the Flemish industry provided by the Flemish environmental agency for the period 1995–2006. For climate change, acidification, photo-oxidant formation, human toxicity, freshwater aquatic ecotoxicity and eutrophication, the eco-efficiency improved by 39, 55, 41, 58, 72 and 53%, respectively. For each of these impact categories, the total environmental impact decreased despite an increase in production, indicating absolute decoupling of environmental impact from economic growth. The eco-efficiency indicator for energy consumption and waste generation improved by 16 and 14%, respectively. However, due to the increase in production, the total energy consumption and the amount of waste generated increased: for these two environmental themes decoupling from economic growth was relative. Despite the improved eco-efficiency, industry remains one of the main polluters in Flanders. The application of the method to emission, energy consumption and production data of the Flemish industry resulted in a comprehensive and correct source of information for the general public and the government. Moreover, it can serve as a basis for economically and environmentally sound decisions and for the evaluation of the impact of former decisions.

3.1.4 Efficiency analysis methods and tools

In addition to eco-efficiency assessment, several tools and decision support approaches addressing global environmental and economic sustainability issues are currently used. Examples include Material and Energy Flow Analysis (MEFA), Life Cycle Assessment approaches, and other tools more directed towards the ecological branch of sustainability (i.e. Carbon footprint, Design for the Environment, etc.). These tools and approaches aim at maintaining or increasing production while reducing costs, materials and energy consumption as well as all emissions, i.e. aiming to underpin overall efficiency (Hauschild et al., 2005; Kunz et al., 2013). Sometimes, these existing tools and methods are not always directly applicable to any product and/or production system, and are often addressed as "isolated stage analysis". Therefore, in most cases, the positive outcomes from the use of these tools can be easily ignored and can be seen as a burden.

Recently new tools and approaches are being developed and used in order to assess/measure sustainability of the plant/company sectors/production systems/unit process focusing on overall efficiency. For instance, Paju et al. (2010) presents the Sustainable

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Manufacturing Mapping approach that focuses on the application of a Value Stream Mapping (VSM) based assessment as an integrated visualization and monitoring method for environmental impacts and production control. The approach considers sustainability indicators and is based on VSM, LCA, and Discrete Event Simulation. The goal is to create a map which is suitable for communication between the production floor and the management level, as well as support continuous improvement through the Plan-Do-Check-Act cycle. Li et al. (2012) presents an eco-efficiency approach to evaluate energy as well as resource efficiency of manufacturing processes. The author presents a case study of a grinding process, in which the eco-efficiency performance of unit processes is addressed as well as quality performance and environmental impacts. Both approaches lack the assessment of efficiency performance of unit processes and of the overall system, and do not identity KEPI. The approach presented by Paju et al. (2010) does not present a transparent relationship between the process parameters and the related environmental impacts. On the other hand, Li et al. (2012) takes into account such relationship, but lacks the evaluation of costs within the unit process. All in all, neither of the approaches measure the efficiency of production systems in a clear and simple manner, which is a must in order to archive today's sustainability targets.

3.1.4.1 MSM Approach

The MSM -Multi-Layer Stream Mapping, framework starts from the classic bathtub curve of Value Stream Mapping (VSM) and focuses on the dichotomy between value-waste in a given production system. VSM is a practical and useful tool to identify actions that do not add value to the final product and to identify inefficiency and wasteful situations. According to Shook and Rother (1999), a value stream consists in the collection of all actions that are required to bring a product or a group of products through the main flows, starting with material and ending with the customer (SHOOK and ROTHER 1999, ARBULU, D.TOMMELEIN et al. 2003, ABDULMALEK and RAJGOPALB 2007). In the MSM approach, the idea is to simultaneously assess the unit process efficiency and eco-efficiency performance. This is accomplished by using a VSM bathtub curve for each environmental and financial aspect, or any kind of variable, i.e. Value Stream Layers (VSL) that can be used to quantify in detail the efficiency of: costs, emissions, energy consumption, resource and material consumption, waste generated, etc., for all unit processes. Consequently, a Multi-Layer Stream Mapping emerges, and overall performance of a system is then possible to be quantified. In other words, the MSM consists in the addition of multiple layers, called VSL, which embrace environmental and economic aspects or other key variable in order to assess efficiency and eco-efficiency performance.

The Process Stream Analysis (Figure 4) determines the usage efficiency results for the variables under study (horizontal analysis). This result is called Flow Efficiency (FE) and quantifies the useful percentage of material, energy or any other variable. The FE is calculated by the ratio between the added value portion of the variable and its total. This same method of calculation is used to determine the efficiency (Defined as % - Efficiency in Figure 1) of variables within a specific unit process.

On the other hand, it is also possible to quantify the unit process efficiency (defined as PE - Process Efficiency in Figure 4), this is by following the MSM direction (vertical analysis) and

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taking into account the average efficiency results of all variables that are used to carry out the unit process (LOURENÇO, BAPTISTA et al., 2013).

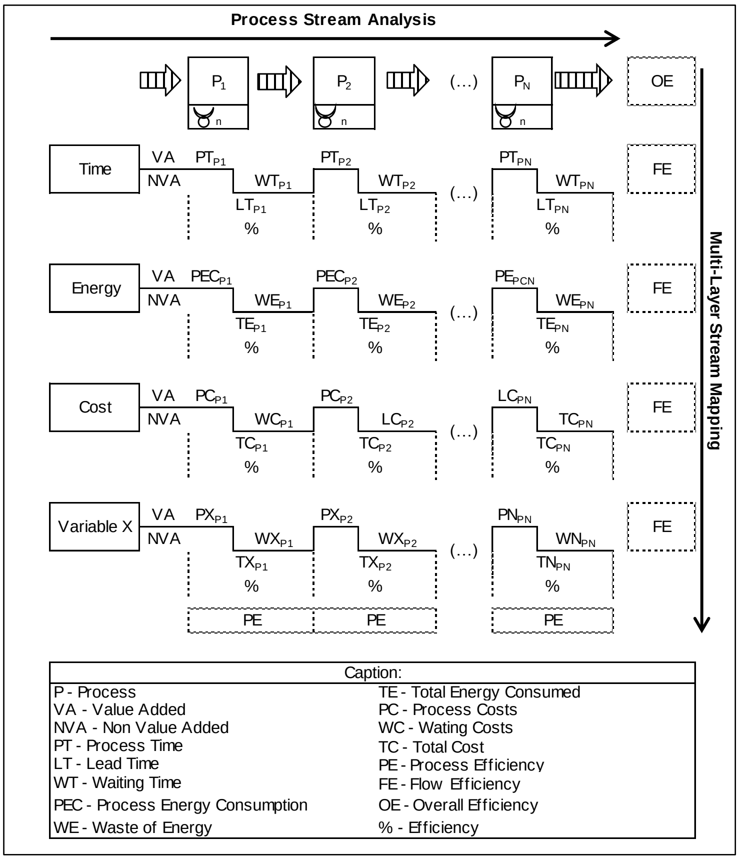

Figure 4: MSM schematic approach (LOURENÇO et al., 2013)

The main goal of the MSM approach is to be a practical and useful approach for:

- Identifying inefficiencies in a very direct and visual way
- Assessing eco-efficiency performance for overall production system and unit processes
- Assessing efficiency performance for overall production system and unit processes
- Identifying the most critical aspects and variables
- Identifying Key Environmental Performance Indicators
- Supporting decision making
- Defining priorities for improvement measures

MSM Objectives

Develop a multi-variable combined use of the Value Stream Mapping (VSM) Lean Tool and demonstrate its suitability to assess environmental and energy performance of unit processes and production systems in a fast and flexible manner. This by mapping the unit processes inputs and outputs and assessing their efficiency.

Demonstrate the importance of presenting environmental issues and efficiency performance in a simple manner through visual management maps and layouts, in order to simplify top/middle management understanding of the Key Environmental Performance Indicators (KEPI's), and the Key Performance Indicators (KPI's), as well as their suitability for decision making and overall awareness.

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Create an approach that is able to assess productivity and the efficiency and eco-efficiency of a production system, since the tools and methods are not always directly applicable to every product and/or production system, and often addressed as "isolated stage analysis".

Create a very easily understandable assessment (for all level collaborators) based in fast visual management attributes in most methods and tools used for eco-efficiency assessments.

The four main pillars of the MSM approach

a) Pillar 1: Assess Value Addition versus not adding value

A value stream mapping consists basically in the collection of all actions (actions that add value and actions that do not add value) that are required to bring a product or a group of products through the main flow, starting with the customer and ending with the raw-material (upstream).

The primary goal of this tool is to identify all types of waste in the value stream flow and processes in order to take actions to try and eliminate these, by analysing the Value Stream Map.

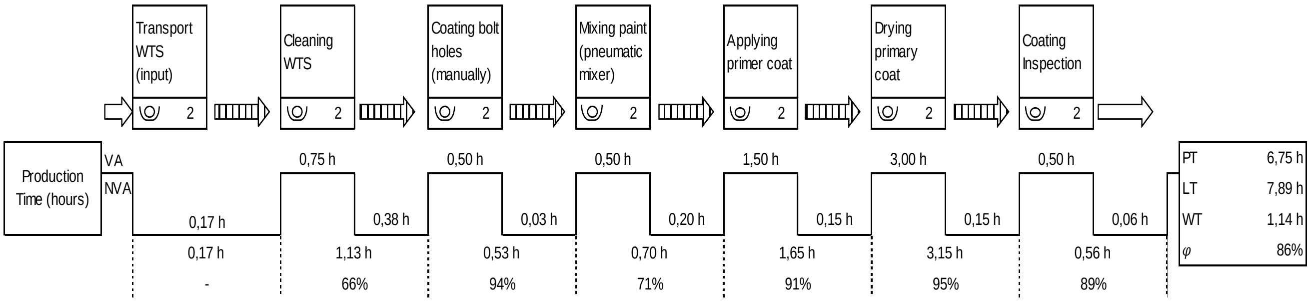

Figure 5: Example of a common VSM of a Metalworking Industry

The MSM framework combines Value Stream Layers evaluated by the waste elimination / value creation mind-set, identifying the variable part that adds value from the one that does not add value, with detailed unit process inventory and visual management attributes

The VSM root transforms, in the MSM concept, the understanding of eco-efficiency into something easily quantifiable, simpler, concise and directly applicable to any production system, in a process sequence or even in compartmented units

To assess the environmental, financial and global performance of a production system (by the composition analysis of its subparts), and identifying and quantifying the inefficiencies or misuses, the MSM concept starts from the classic bathtub curve of Value Stream Mapping

The combined use of Value Stream Layers of a Value Stream Map emerges in order to "see beyond" the global environmental and financial performance of a production system in a simpler manner and enable the understanding of the overall efficiency assessment, and at the same time simplify the identification and quantification of specific inefficiency situations

b) Pillar 2: Systematically evaluate variables (and KPIs) through efficiency ratios

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Several environmental aspects can take place as variables, for instance energy, material and fuel consumption, the amount of emissions and waste treated and routed appropriately. It's important to notice that all variables should be addressed in order to maximize performance (increased efficiency). The dimensionless character of the ratios of variables allows them to be combined and aggregated in order to compute a global efficiency for a part or for all the system (Figure 6). Since the MSM approach considers dimensionless ratios (actual variable divided by the maximum of the same variable, on the same process step), so the higher the result for the ratio, the better the performance of the energy, mass or time flow or other key variable of a process or system.

$$\Phi = \frac{\text{“Value added” fraction}}{\text{“Value added” fraction} + \text{“Non-value added” fraction}}$$

Figure 6: MSM ratio calculation

Alternatively, one can indirectly measure eco-efficiency performance by analysing the results of the MSM approach, i.e. evaluate the efficiency results over time. For instance, if efficiency performance is increasing this could mean that the eco-efficiency performance is also improving (considering that the economic variables are constant and the same materials and resources are being used), since the same value is being added to the product but more efficiently, and therefore fulfilling the main goal of eco-efficiency, which is, "doing more with less", by:

- Identifying all the variables that influence the stages of the value chain
- Creating/Identifying Key Performance Indicators (KPI) for the variables in the form of ratios
- Values of the ratios should be always within the range [0-100%]
- KPI always created in order to be always maximized

The MSM consists in replicating part of the approach used for Value Stream Mapping, but allowing the addition of multiple layers (stream flows for each process variable) that embrace environmental and economic aspects, or other variable, to assess eco-efficiency (Figure 7).

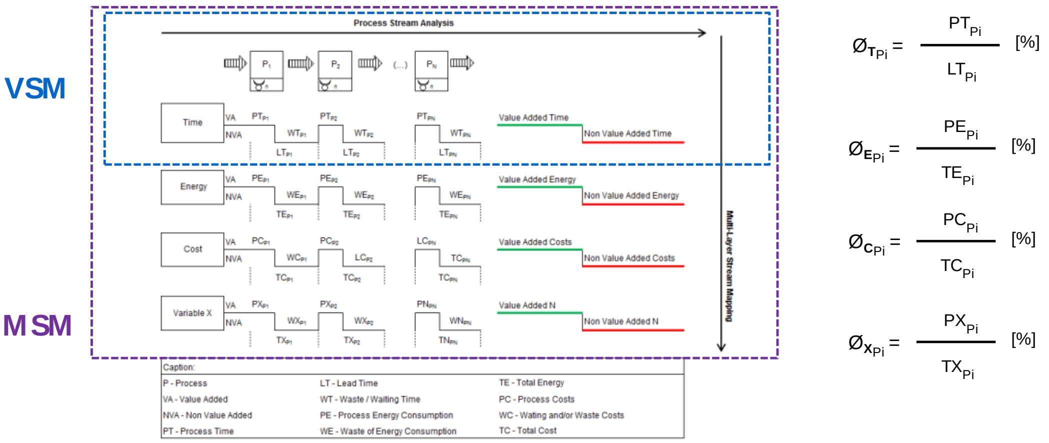

Figure 7: MSM vs. VSM

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The process variables, must be assigned consistently to be maximized. The analysis of variables with the MSM is almost unlimited, for instance, the following environmental aspects can take place as assessing variables:

- Electrical energy
- Raw Material
- Fuel
- CO2 Emissions reduction
- Waste elimination
- Toxic materials reduction

Beside environmental aspects, other specific cost flows can be added, i.e. cost flow lines to assess the costs of energy consumption only, or raw material only, thus allowing to assess specific eco-efficiency indicators (since product value and environmental influence are specific).

c) Pillar 3: Apply simple methodologies of Visual Management

For a faster assessment of the efficiency, it was added visual management attributes by relating a very common key of 4 colours (red, orange, yellow, green) in the positive direction of efficiency, from 0% to 100% (Figure 8).

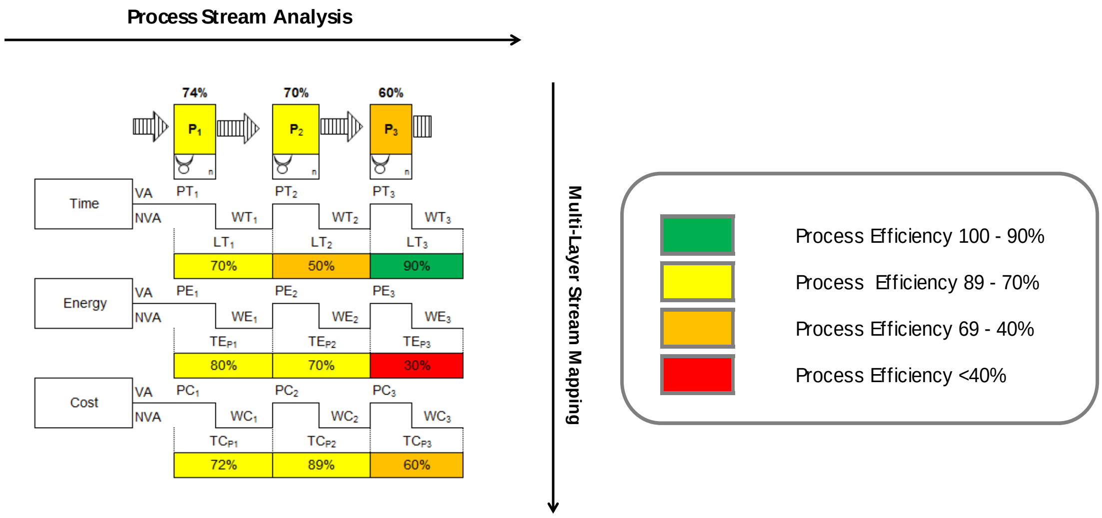

Figure 8: MSM Visual Management

d) 4th Pillar: Aggregate efficiency of unit processes (columns) and the variables (lines)

The production system's overall performance is shown in the MSM scorecard (Figure 9). This layout quantifies the global and unit process efficiency for each processes variable. The data shown in Figure 9 is of great importance, and useful for assessing efficiency as well as for quantifying and allocating losses. The outcomes of the MSM approach are presented as a dashboard which includes the global production's system efficiency, the flow efficiency and the unit process efficiency. Alongside the MSM "Snapshot" presents a simple efficiency dashboard, which includes visual management attributes, i.e. colour labels.

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MSM® efficiency card — Efficiency Process Stream Analysis

	Cleaning WPTS	Coating bolt holes	Mixing paint	Applying primer	Drying	Inspection	Global efficiency
Unit Process Efficiency	**79%**	**83%**	**70%**	**69%**	**85%**	**90%**	**79%**
Production Time (hours)	67%	94%	70%	90%	90%	80%	82%
Electrical Energy Consumption	69%	65%	70%	65%	80%	95%	74%
Diesel Consumption (kg)	-	-	-	85%	85%	-	85%
Paint & Curing agent & Diluent Consumption (kg)	-	90%	-	35%	-	-	63%
Auxiliary Material Consumption (kg)	100%	-	-	-	-	-	100%
Proper Waste Disposal (kg)	-	-	-	-	-	95%	95%

MSM (resource efficiency)

Key: Process Efficiency 100 - 90% (green); Process Efficiency 89 - 70% (yellow); Process Efficiency 69 - 40% (orange); Process Efficiency <40% (red)

Figure 9: MSM efficiency scorecard

Applicability and Strengths

The MSM approach, like the traditional VSM, can be used to identify which processes and/or streams are less efficient, thus contributing for decision support and allowing continuous improvement to environmental and financial key performance indicators.

This approach can also be used for process reengineering evaluation, since in some cases the unit processes, or even the whole production system of a factory, have good operational results, but the efficiency is not as high as it could be. Therefore, using this approach to scrutinize "how", "where", and "how much" can a unit process and/or a production system improve its financial, environmental and performance aspects, is of great importance for decision-making.

A drilldown approach of the MSM can be executed (Figure 10), in order to, for instance, assess and identify inefficiencies and misuses that occur along a production system, at a unit process or in one particular stage of a production system.

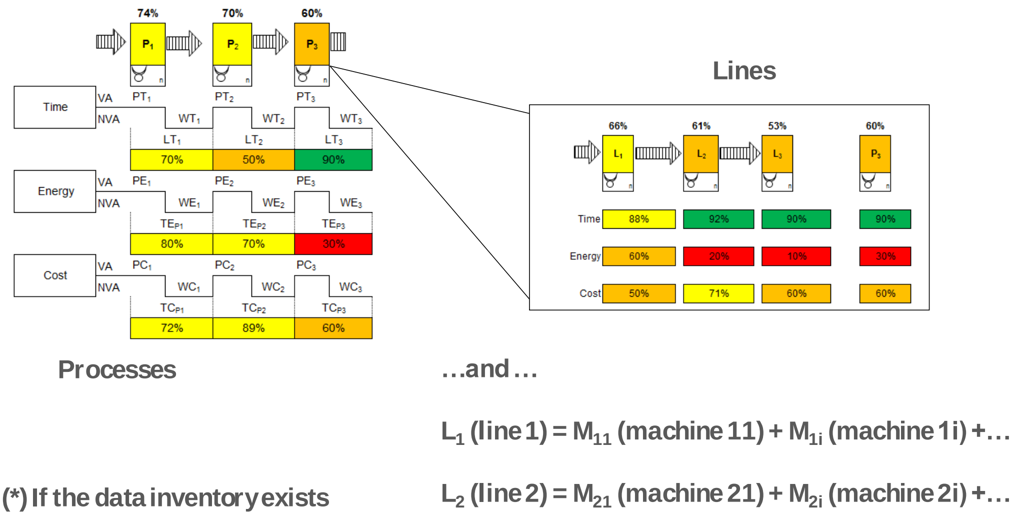

Figure 10: Multi-Layer Stream Mapping Drilldown

One other strong point in this approach is related to the versatility of the outcomes. In Table 3 it is noticeable that the outcome features of this approach are suitable for presenting the data in a dashboard or scorecard format, since its purpose, users, updates, data and display features are very widespread. This results from the MSM construction simplicity, that is

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supported by applying a lean tool (VSM) and a lean thinking approach that highlights the value (for any kind of process variable) in a process sequence or system.

Table 3: Features of Dashboards and Scorecards compared with Multi-Layer Stream Mapping approach

Feature	Dashboard	Scorecard	MSM outcomes
Purpose	Measures performance	Charts progress	Measures performance and Charts progress
Users	Supervisors, specialists	Executives, managers, and staff	Supervisors, specialists, executives, managers, and staff
Updates	Right-time feeds	Periodic snapshots	Periodic snapshots
Data	Events	Summaries	Events and Summaries
Display	Visual graphs, raw data	Visual graphs, comments	Visual graphs, raw data and comments

Moreover, the target users for the MSM diagrams analysis can be simultaneously the top and middle managers, or even the production line workers, since its mathematical concepts and visual attributes are straightforwardly understandable. The outcome and results are a diagrammatical and intuitive representation of managerial concepts, and can be very practical and useful for:

- Top management decision support
- Defining priorities
- Identifying inefficiencies in an easy manner
- Identifying Key Environmental Performance Indicators (KEPI)
- Assessing eco-efficiency performance
- Identifying improvement actions needs
- Informing all level of collaborators of the efficiency of the production cell or unit

Its simplicity is one great advantage, since it allows a very fast and visual assess of multi-variable efficiency and its integration (for instance by heighted average), simultaneously for top management or even workers.

3.2 Business aspects

This section will focus on the business aspects of eco-efficiency implementation. It presents an overview of eco-efficiency implementation, business models enablers of eco-efficiency as well as some examples of eco-efficiency actions taken by companies.

3.2.1 Eco-efficiency implementation

Implementation of the eco-efficiency concept not only fosters the creativity and eco-innovations within organizational practices but also increases eco-efficiency of the company outside operational borders by covering supply chain enhancement as well as the effective use of products and goods. According to the WBCSD (2000) eco-efficiency focuses on three main objectives:

1) reducing the consumption of resources (minimization of energy, material, water and land use; an increase of recyclability and durability of goods),
2) reducing the impact on nature (minimization of air emission, waste disposal, water discharges as well as promotion the consumption of renewable resources),

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3) increasing product or service value (greater benefits for customers with less material and resource use, selling the service instead of selling the product).

The main eco-efficiency objectives were elaborated by the WBCSD into seven success factors that companies can use to improve their eco-efficiency:

- Reduce material intensity,
- Reduce energy intensity,
- Reduce the toxic dispersion,
- Enhance recyclability,
- Maximize the use of renewable resources,
- Extent product durability,
- Increase service intensity.

The opportunities for achieving eco-efficiency can be classified into four main groups: reengineer processes, re-design products, re-think markets and re-valorise by-products (WBCSD, 2000). The figure below represents the eco-efficient opportunities for the company.

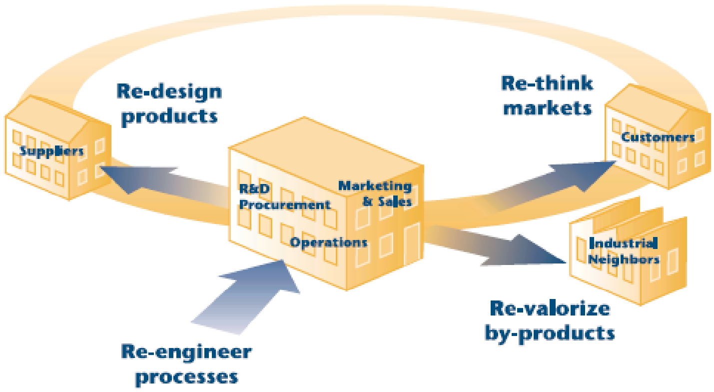

Figure 11: Navigating eco-efficient opportunities (WBCSD, 2000)

According to WBCSD, companies can start by choosing to re-engineer processes (process change) in order to lower the use of resources, minimize the pollution and eliminate risks while saving costs. The important aspect here is the necessity to involve employees into the activities of recognizing such opportunities. The changes may also include improvements in supply and delivery operations as well as distribution system, use and disposal of products.

Next, the collaboration with other companies to re-valorise by-products helps to create more value with less waste and fewer resources, to generate additional income and benefit from the synergy effect between these organizations. Another way toward eco-efficient business is through product re-design. In most cases designing the product in accordance with ecodesign recommendations allows to reduce costs of goods by making them simpler and smaller with lower material diversity. It can also lead to better functionality, durability and recyclability. Such products which provide higher value for customers with lower environmental impact are called eco-efficient products.

Finally, certain creative and innovative organizations move from selling products toward selling services. The idea is to re-think the markets and re-form the demand in order to satisfy customers' needs in less resource-intensive way. In this case, companies benefit from saving

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costs, reducing environmental impact and avoiding risks which can result in higher profitability.

The set of opportunities referred above has shown that the company can contribute to the enhancement of its eco-efficiency in different ways with the support of almost all departments. As an example, Caetano et al. (2012) proposes the use of eco-efficiency indicators for use in technology development process (TDP) in order to develop eco-efficient technologies. It would be important to study the development of a system of indicators of eco-efficiency to support R&D, and this effort should begin in specific sectors such as technology development, and then be generalized to other functional areas of business. It would also be of great value to insert "filters green" at the end of the TDP so that before the technology projects reached the stages of decision they would undergo a selection with respect to their environmental performance.

Understanding this, many organizations have decided to incorporate the principles of eco-efficiency into their corporate strategy. Eco-efficiency can be seen as a driving force for innovation and progress on both micro and macro levels (WBCSD, 1997).

Oriented on eco-efficiency, a company's business strategy can help in decoupling economic growth and use of natural resources. The below graph depicts possible decoupling channels as well as the role of policy measures determining their effectiveness. Eco-efficiency strategy promotes innovations as one of the main driving motives for company development.

Such innovations will lead to the creation of new goods and development of new skills where the former results in enhanced competitiveness of the company and a bigger market share, the latter results in increased knowledge with additional service jobs.

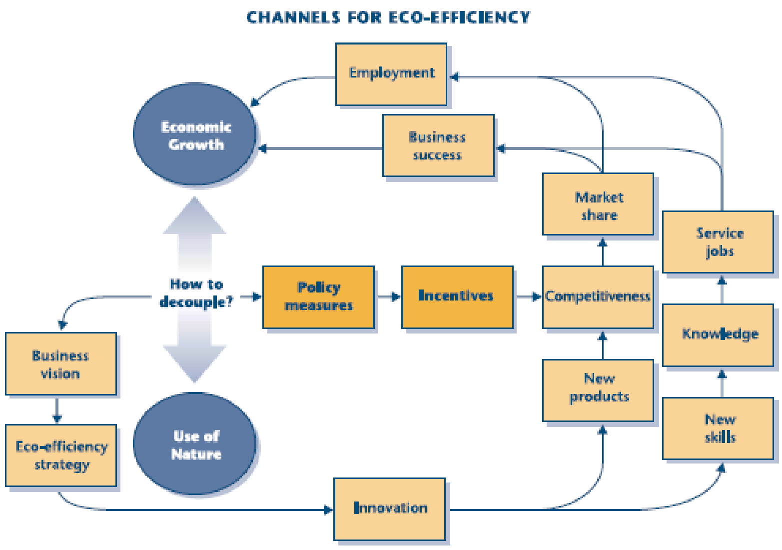

Figure 12: Channels for eco-efficiency (WBCSD, 2000)

The eco-efficiency concept significantly contributes to the development of sustainability ideas. It encourages organizations to improve efficiency of their production processes and product development while decreasing the environmental influence. Companies can

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enhance their eco-efficiency through re-designing products, re-engineering processes, re-valorising by-products and re-thinking markets.

The companies' decision to move toward sustainable development and adopt the eco-efficiency concept is driven by various factors. The main driving force is the need for environmental protection. However, public demand, industry and international trade, standards and law have gained an increasing influence on business activities and encouraged organizations to be more environmentally responsible actors. Although sustainability activities are often driven by regulatory requirements, companies can also be motivated to implement sustainability strategies by the potential payoffs of improved sustainability practices which are financial, operational, customer-related and organizational ones.

3.2.2 Eco-efficiency enabled business models

Business models combine all the core components of business strategies and operations that create and deliver value to the customers as well as to the firm. The components of business models typically include strategic decisions on customer segmentation, products and services (or value propositions) to offer, business and research partners to engage with, resources to create and channels to deliver value, as well as the underlying cost structure and revenue streams to ensure economic viability of business. Here are great expectations of the role of new business models to support resource efficiency because of the promise of a wider uptake of eco-innovations contributing to the green economy (EUROPEAN COMMISSION, 2011). Studies have highlighted the expected potential to create multi-billion euro markets in the EU and overseas and substantial environmental and economic benefits derived from a larger uptake and wider implementation of innovation in business models (COWI, 2008).

Sustainability awareness as a source of value creation is being acknowledged among business stakeholders (including shareholders). Many top executives claim that corporate sustainability is driven by a combination of public pressures, regulation and securing a competitive position in the markets. Businesses are increasingly recognizing that the greening of their own business or value chain by improving resource productivity may increase both their short-term and long-term competitiveness and new markets creation.

A growing percentage of companies are currently engaged in implementing actions for the reduction of resource use in operations, with advantages for those identified as sustainability leaders. Changes to business models are considered as an action area for companies in their strategies for increasing resource productivity and sustainable value creation

At the operational level, the re-design and implementation of green(er) business models involve a great deal of technological, organisational, behavioural, economic and institutional changes (BOCKEN et al., 2014). This is often done via the adoption of company-level measures that lead to decreased use of (natural) resources. Resource efficiency measures could be understood as the implementation of (technological and non-technological) concepts, methods, tools, techniques and technologies applied by companies in order to reduce the resources needed for the manufacturing of goods or provision of services.

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Companies have diverse approaches to changing business models in respect of resource efficiency with differentiated approaches to innovation and change. The Eurobarometer (2011) survey identified a number of changes within European companies having implemented eco-innovations to become less material intensive. Most companies report purchasing of more efficient technologies (56%), followed by developing more efficient technologies in-house (53%), recycling practices (52%), improving the material flow in the supply chain (46%), material substitution (38%) and changes to business models (27%) in order to reduce material costs (EUROBAROMETER, 2011). The results of this survey show that the ratio of material costs/total costs seem to be highly influential in company's decisions to modify their business models, with up to 32% of surveyed companies reporting that they have changed their business model as a response to material cost reduction measures when the material costs exceed 50%.

Business models that support resource efficiency are a critical component for achieving a win-win situation in the relation of business and the natural environment.

In the past decades, a transition from manufacturing to services has been notable in advanced economies. There are multiple examples of corporations in the U.S. and Europe that are growing the service aspect of their business. They are selling product functionality rather than products: flooring services instead of carpeting, document management instead of photocopiers, and clean clothes instead of washing machines. This product-service mix is commonly known as Product Service Systems (PSS). Many researchers (STAHEl, 1998; GOEDKOOP, 1999; WHITE, 1999) view this concept as having great potential to achieve economic and environmental efficiency. They claim that PSS can deliver financial benefits, while reducing the environmental impacts associated with the product's life cycle. For example, selling services may create an incentive for the manufacturer to redesign products to extend their life span, therefore reducing energy and material intensity (STAHEL, 1994).

An example of a PPS is Chemical Leasing (ChL), a new instrument to promote the sustainable management of chemicals and to close the material cycles between the suppliers and users of chemicals. In this innovative business model, chemicals are no longer just sold to the customer to render a specific service, but are made available and maintained. Consequently, the economic interest no longer lies in selling a chemical product, but in providing a chemical service. In a ChL business model, the chemical supplier is paid for the service provided by the chemicals and not for the amount of chemicals delivered. The chemical supplier becomes a service provider, and as such is interested in keeping the costs low while providing its customers with the demanded service. Reducing costs means reducing the consumption of chemicals, which in a ChL business model becomes an expense factor for the chemical supplier. The chemical supplier will therefore try to make chemical application as efficient as possible, using its know-how of the substance. Efficiency does not, however, only depend on the chemical, but also on the production process. An optimized production process, adjusted to the relevant chemicals, reduces the amount of chemicals needed while allowing additional savings like reduced energy consumption. This is in line with the chemical user's intention. Both partners are therefore motivated to find a joint solution to optimize the process.

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3.2.3 Eco-efficiency in practice

Eco-efficiency includes improving eco-efficiency in production, service and delivery. Examples are substituting old production capital with new energy efficient capital and training employees to act more resource efficient. Eco-efficiency focuses on processes within companies and finds its roots in production, service or delivery methods. Depending on the implementation in one of these areas, the precise application of eco-efficiency can be very different.

In regards to production, eco-efficiency may focus on using less input materials or replacing materials with a more resource efficient or recyclable alternative. The company *Worn Again* is an example of such eco-efficiency implementation. *Worn Again* is developing a chemical textile to textile recycling technology that will enable end of use clothes and textiles to be collected, processed and made back into new yarn, textiles and clothes again and again. Through this process they are able to recover 99.9% of the fibres without reducing the quality.

Service implementations of resource efficiency are often linked to education and training regarding resource efficient or environmentally friendly actions. This is more focused on how employees within the company act and apply the concepts to their working life. An interesting example of such service eco-efficiency can be seen in the case of *Schuco International KG*. Only here they enable their customers to be eco-efficient in their energy use. They developed a housing solution based on smart grids, which enables the owners of the building to sell their excess energy back to the network. This service promotes more eco-efficient behaviour amongst their customers.

Delivery eco-efficiency is directly related to the logistics of transporting goods in a way that requires less resource use. For example, in freight carrying via ships *Maersk Line* has developed the process of 'slow steaming' which exchanges a slower travel time for more efficient delivery (better punctuality) as well as lowered CO_2 emissions and fuel costs. Through this new shipping process they are able to be more resource efficient.

Several examples of the successful application of eco-efficiency initiatives exist. Enough time has passed from such early efforts to identify the significant benefits achieved:

- In 1999, *DuPont* executives pledged to reduce the company's greenhouse gas emissions by 65% below 1990 levels by 2010. Their plan, in part, involved diversifying their product line by focusing on materials that reduce greenhouse gases. By 2007, DuPont had cut emissions 72% below 1991 levels, reduced its global energy use by 7%, and saved $3 billion.
- *Interface Inc.* is one of the world's largest manufacturers of modular carpet for industrial and residential applications. Starting in 1994, *Interface* started focusing on environmental sustainability issues and reducing the amount of petroleum it used to produce its products. Between 1995 and 2007 the changes made across different processes resulted in a $372 million reduction in cumulative waste costs, kept more than 100 million pounds of materials from landfills, and reduced overall greenhouse gas emissions by more than 30%. Since 1996, water intake per unit of production is down 75% and the energy intensity of its products has been reduced by 45%.

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- *STMicroelectronics* is a Swiss-based semiconductor company – the largest semiconductor supplier in Europe. In 1994 it set a goal of zero net greenhouse gas emissions by 2010 while also increasing production 40-fold. By 2008, it had decreased energy consumption per unit of production by 52% and water use by 73%. It accomplished this in part using cogeneration sources to supply 55% of its electricity and renewable energy sources supplying another 15%. During the 1990s, its energy efficiency projects averaged a two-year payback – nearly a 71% after tax rate of return. Such innovative changes enabled ST to move from the twelfth to the fifth largest chipmaker globally in 2005. By the time it achieved its goals in 2010, it saved nearly $1 billion.
- In addition to CO_2 released by the combustion of fossil fuel and leading to climate change, large steelworks emit pollutants that have other environmental impacts. ArcelorMittal Gent, an integrated steelwork producing ca. $5x10^6$ tons of steel per year, not only decreased its specific energy consumption and CO2 emissions, but also reduced the environmental impact of its other emissions (CANEGHEM et al., 2010). This is illustrated by means of the evolution of 6 partial eco-efficiency indicators for the impact categories acidification, photo-oxidant formation, human toxicity, freshwater aquatic ecotoxicity, eutrophication and water use. The partial eco-efficiency indicators are eco-intensities, defined as the environmental impact in the respective impact category, divided by the amount of liquid steel produced. In the period 1995 – 2005 these indicators decreased by 45, 4, 52, 9, 11 and 33% respectively, whereas the steel production increased by 17%. The net impact of discharges of wastewater is negligible for human toxicity and is negative (concentrations lower than in the canal water used) for freshwater aquatic toxicity and eutrophication. For acidification, human toxicity (only emissions to air) and water use, the decoupling between environmental impact and production was absolute; for photo-oxidant formation, freshwater aquatic ecotoxicity (only emissions to air) and eutrophication, it was relative.

Eco-efficiency innovations are wide reaching; finding a place in the following sectors: transportation, automotive, housing, agriculture, retail & wholesale, infrastructure, logistics, textiles and more.

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4. Management Systems

4.1 Technological aspects

Regarding technological aspects (hardware, methods, tools / software, algorithms, etc.), there is no significant technological aspects within management system. Therefore state-of-art for Management Systems will only focus on business aspects.

4.2 Business aspects

Very often ecology is not taken under consideration within strategies of manufacturing companies because top management believes that it requires investment in new technology. The research that was conducted in February and March 2015 among Polish production companies, shows that the lack of support from the government discourage them to improve ecological performance. It proves that managers think about ecological issues from cost perspective and do not treat them as an opportunity to increase profits and competitiveness. It was also noticed that the primary focus of improvement projects is on productivity, cost and quality (Figure 13).

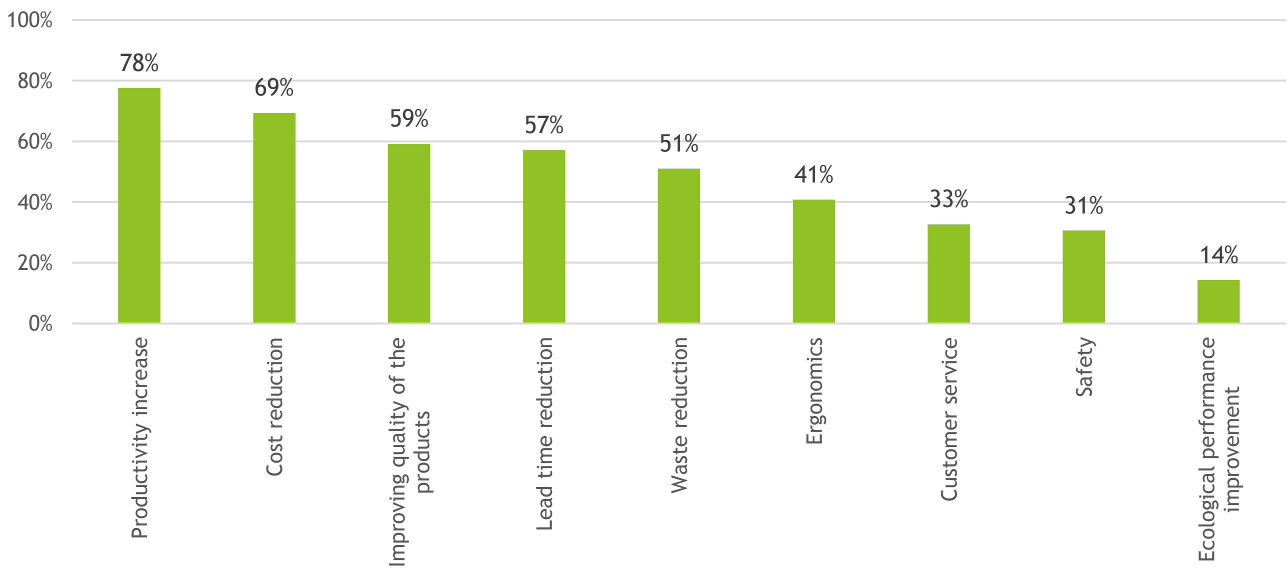

Figure 13: Main Improvement goals. Research conducted by Lean Enterprise Institute

Implementation of an environmental management system following the ISO 14001 standard obligates companies to identify environmental aspects and determine which one have significant environmental impact. Moreover the objectives and targets must be formulated as well as the program of procedures for meeting them (ISO 14001). Even though middle management and shop floor employees usually are not motivated thus not involved in continuous improvement activities in regards to the eco performance. The first step in structured improvement work contain creating motivation among the concerned people.

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Motivation mechanisms according to Lean Thinking

The question is how to start improvement cycles, how to develop and motivate people to improve their processes every day to achieve challenging targets and improve themselves as problem solvers and innovators.

According to Frederick Herzberg (2002) the role of financial motivation should be marginal in modern motivation systems (HERZBERG, 2002). On the one hand money is important. Salaries below satisfactory level might be a main reason of low retention. This minimum, expected level of reward should be ensured so employees can focus on their challenges. On the other hand money do not motivate people to higher engagement, do not trigger willingness to increased effort to improve their work organisation and manufacturing processes. To achieve that, something more is required. The work itself and its conditions should respond to ambition, satisfaction and development needs of employees.

Lean Thinking in many aspects is in line with Herzberg's findings. It requires from leaders and employees team work to achieve common improvement objectives which results also in development of their manufacturing and business competences. Cheryl Jekiel (2011) proposed several motivating factors in Lean companies (Figure 14).

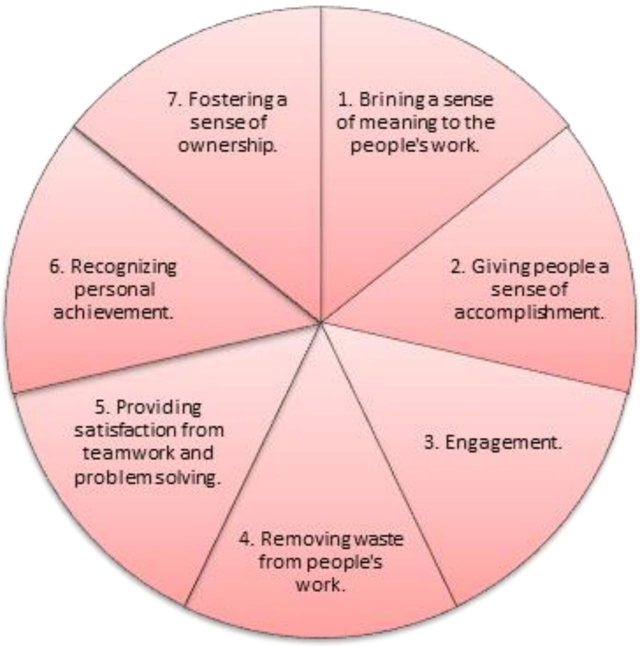

Figure 14: Seven motivating factors in Lean environment [JEKIEL, 2011]

Lean Enterprise Institute Polska concentrates in its research on motivation on middle management (area managers and department directors). This level is natural connection between strategy formulated by top management and operations, involving daily activities of operators. Middle management engagement is crucial for deploying and executing strategic plans. If a manager is motivated to undertake an action with his team, he will also try to motivate his subordinates to be involved. On the other hand if a manager is not motivated to carry on an improvement activity it is unlikely that his team members will be.

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To simplify there are two mechanism motivating leaders (Figure 15):

- Willingness. It encompasses the actions they are willing to undertake because of their internal beliefs, ambitions, sense of satisfaction.
- Importance. It encompasses the actions they think are important and have to be done.

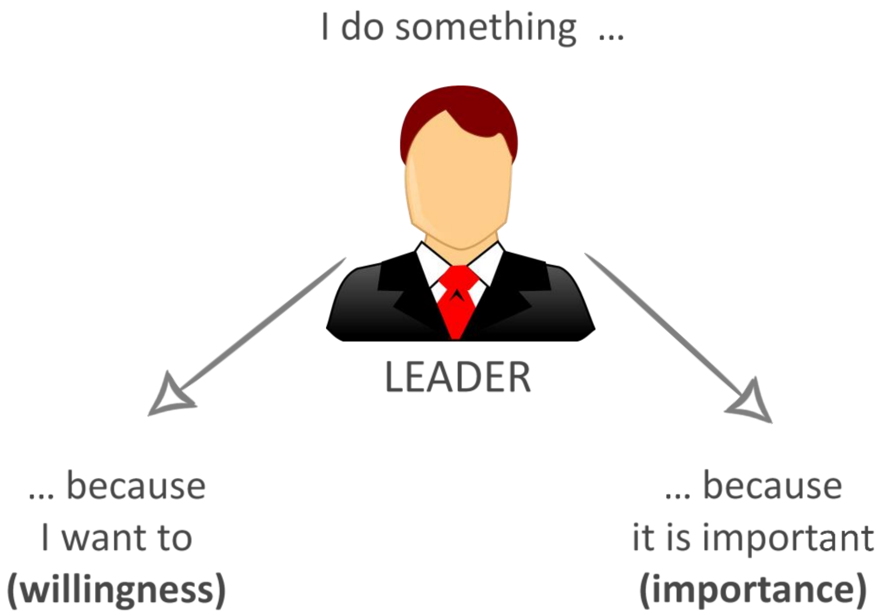

Figure 15: Simplified model of two motivation mechanisms

In Lean approach both mechanisms should work together. However in many cases it is easier to build engagement on the mechanism of importance, which can be implemented quicker and in isolated part of an organisation (in so called pilot area). Then willingness mechanism could be built on it but it is long term activity and concerns such aspects, like e.g. company culture, people development process, sense of ownership.

The importance mechanism is based on challenges and problems (Figure 16):

- Challenges are ambitious targets, which leaders feel responsible for (e.g. building a new team, training 5 new employees, reduce quality costs by 50%).
- Problems are deviations from expected, standard condition. There are two types of problems:
    - Personal perception problems (e.g. working overtime too much, too many ad-hoc tasks), which result from feelings and intuition.
    - Business problems (e.g. too many defects, too many orders delayed), which result from targets and Key Performance Indicators (KPIs).

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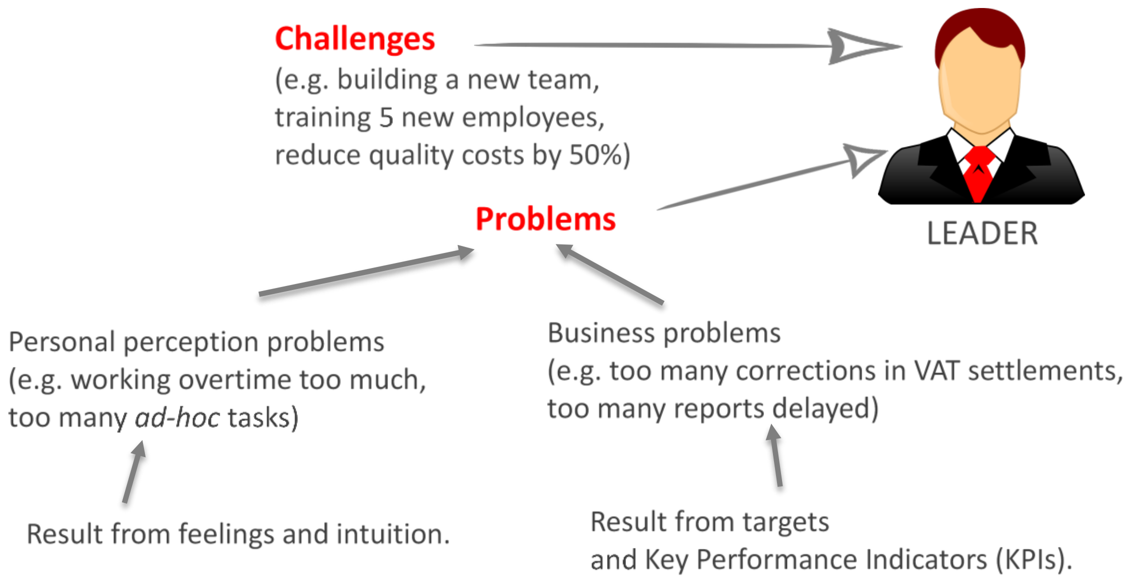

Figure 16: The elements of the mechanism of importance

To assess if importance mechanism works in a company and motivates leaders to engage in organisational improvement activities the following questions could be used.

1. Do leaders have challenges to meet and/or problems to solve, which are ambitious and impossible to achieve using simple solutions (e.g. by tense work or extra people)?
2. Do leaders have direct impact on the challenges, objectives and problems assigned to them (or maybe objectives are too general and influenced by many other departments or units) ?
3. Do improvement actions planned, address directly leaders' challenges, objectives, problems ?
4. Do leaders see for all improvement actions planned direct relation with their business challenges, objectives, problems? (the communication criterion)
5. Do leaders know what is their role in the improvement actions, do they have clearly assigned responsibilities (not for particular tasks but for particular objectives)?
6. Are the leaders also leaders of improvement actions „I organise my room myself" (or somebody else is doing it for them „someone is organising my room")?
7. Do leaders have time to carry on improvement activities?
8. Do leaders have skills and know tools to carry on improvement actions?
9. Are improvement actions important for this organisation (e.g. do we monitor weekly progress of improvement actions)?

Answering "yes" for all the above questions is crucial to engage leaders in any improvement activities. To achieve such a condition, several methods offered by Lean Management, could be used:

- Hoshin Kanri to define challenging strategic objectives and deploy them down to the level of departments, areas and teams (Denis, 2006).

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Managers' routines (e.g. daily accountability process) to build discipline in daily analysis of status of performance indicators vs. targets and solve problems, which are obstacles to achieve targets (MANN, 2014).

Improvement routines (Kaizen routines) to generate organisational innovations (HAMEL, 2012).

- Moving responsibility and authority for problem solving and improvements down to lower levels of the organisation (building ownership) (KOCH, et al).
- Lean process of people development in continuous improvement including Plan for Every Person PFEP.
- The manager-coach model (A3-coaching) (SHOOK, 2008)
- Development of leaders in organisational innovations using Kata concept (ROTHER, 2010).

In MAESTRI project the main focus will be on Hoshin Kanri as a method of defining challenging improvement objectives, however these objectives should not be only related to immediate business gains but also to sustainability (including ecological performance). The important part of Hoshin Kanri is deploying improvement objectives down to the level of departments, areas and teams and to make leaders on all the level of organisation accountable for achieving those objectives.

Hoshin Kanri

Hoshin Kanri (strategy deployment) is a management process that aligns all functions and activities within an organization with its strategic objectives (Lean Lexicon, 2014). It combines strategic management and operational management by linking the achievement of top management goals with daily management at the operational level.

It is also called strategy deployment because it requires the deployment of high level goals down to the operations level. The vision and mission of the organization are providing input for defining goals and objectives on the strategic level. The latter ones are used to define and deploy goals and objectives for one management level below. And the pattern repeats up to the level of line managers/line leaders and their operational teams. However Hoshin Kanri is not a top-down deployment process. It should be a dynamic top-down, bottom-up process of setting goals and objectives that are aligned with the strategic direction of a company and that are set with active involvement of those affected by these objectives (Figure 17). Usually companies use different dimensions of goals. The four most common target categories for Hoshin Kanri are quality, cost, delivery and education (WITCHER, 2001)

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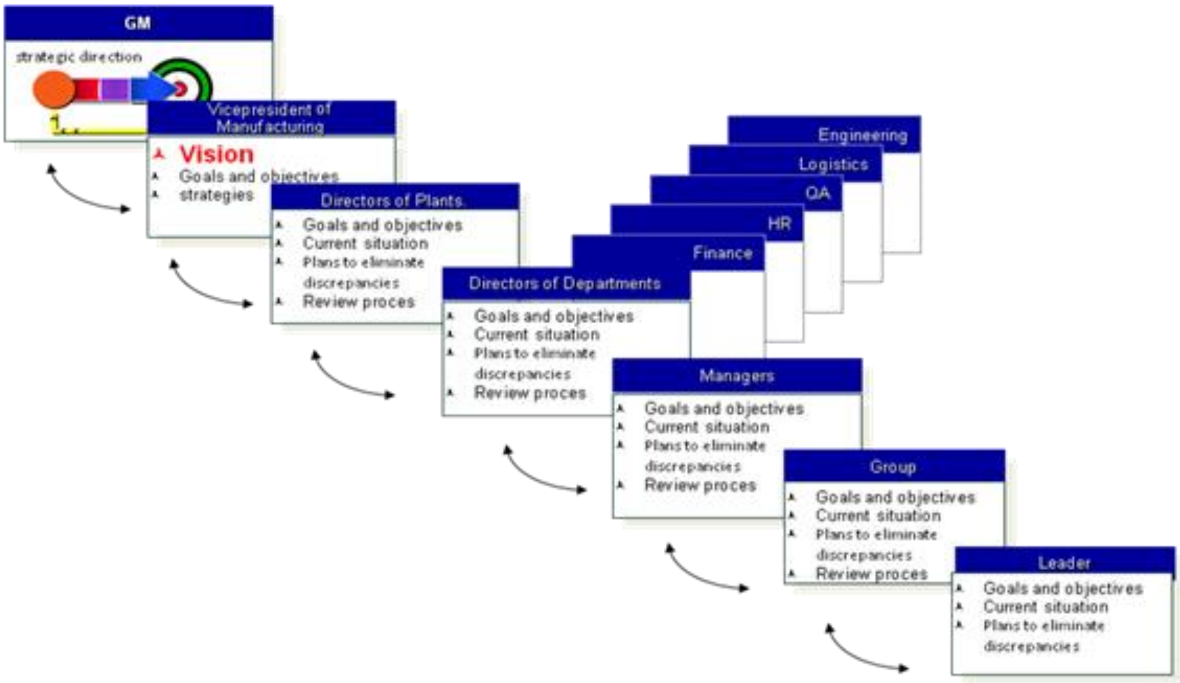

Figure 17: Goal cascading at GM corporation (KORPAK, 2011).

Hoshin Kanri is based on the Deming's cycle (Plan-Do-Check-Act). It's first step is related to "Plan". However it is not a typical strategic planning where the goals are deployed top-down. In *Hoshin Kanri* the first step of the process is called *catchball* and it is engaging many employees in defining their targets (JACKSON, 2006). It is practiced at the deployment stage of *Hoshin Kanri* process. *Catchball* is a process of formal and informal meetings by which people translate a policy objective into agreed annual targets. In *catchball*, the policy proposals for the company are repeatedly reviewed, starting at the highest management level and, in principle, going down to lower levels. Meanwhile, cross-functional policy proposals at the top management level (for quality, profit etc.) are discussed by all relevant divisions. Feedback from all these discussions is provided to the top management. Only then, taking into account this feedback the forthcoming year's policy for the entire company is decided.

In order for *catchball* to be successful it needs to be conducted in line with the Japanese conepct of *nemawashi*. It is an informal process of consensus building to develop understanding about what seems to be the right course of action for a particular policy before any formal steps are taken. *Nemawashi* minimizes the risk of public conflicts and increases understanding about agreements and compromises (WITCHER, 2001)
The *catchball* process is time consuming. It may last for several weeks. However it makes all the people engaged in it understand the company policy and how their targets influence the company's strategic goals. Through this stage of *Hoshin Kanri* process companies hope to switch from a top-down way of setting mandatory targets to a participative way where targets are set voluntarily and bottom-up (KONDO, 1998). This is a way of motivating people to achieve their targets.

After agreeing on the targets for each of the different functions and management levels a set of methods for achieving each of the targets and a way of measuring whether one meets the target or not (metrics) is being developed. In relation to methods are certain

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actions that need to be done to achieve targets – they are also written down next to the methods and metrics. All these items also require on agreeing how often they will be evaluated. All this is first part of the *Hoshin Kanri* – "Plan" (Figure 18)

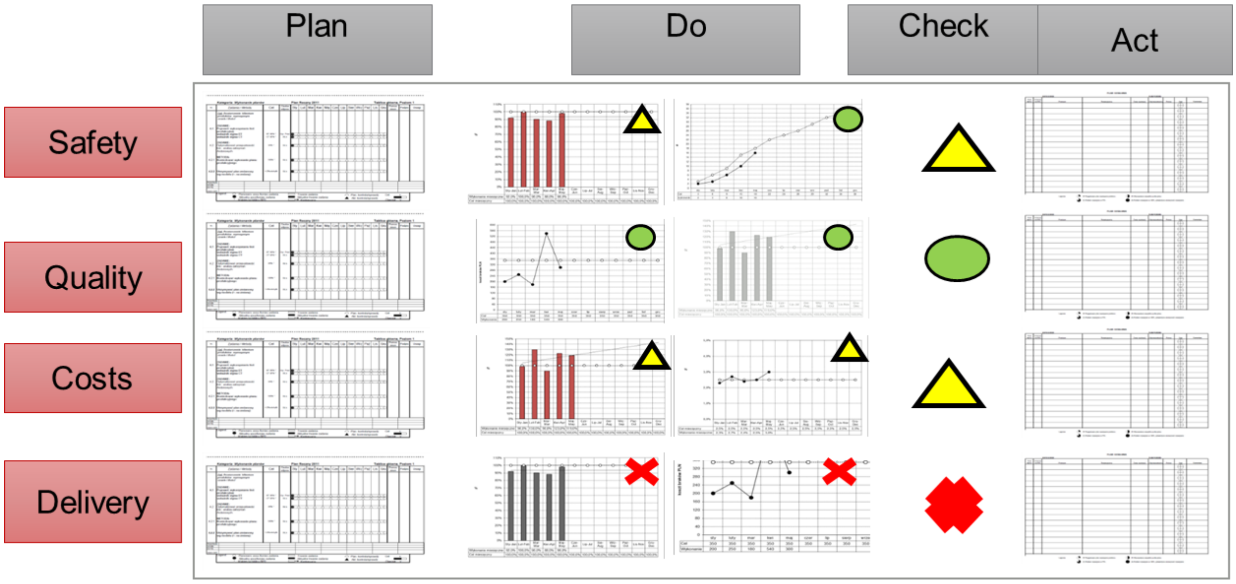

Figure 18: Example of Hoshin Kanri board.

After deciding on the objectives, methods how to reach the targets set and metrics to measure the status and after starting work on putting these methods into life ("Do") the team must conduct regular reviews in order to check the status of actions ("Check") and if necessary undertake actions, implement countermeasures and check the effectiveness of these corrective actions ("Act"). These meetings may be weekly, bi-weekly or monthly. It is important not to cancel them as they guide the actions of the team in alignment with other functions within the organization.

A supervisor of a team who reviews their Hoshin Kanri board should also participate in Hoshin Kanri board review for one level higher than his team. Than if difficult problems occur that his team cannot cope with by themselves the supervisor can and should escalate the problem one management level up. It should trigger the support of higher level management in finding a solution to the problem.

The whole Hoshin Kanri process is usually done in an annual cycle. So the strategy deployment (and the catchball driven by nemawashi) takes place every year. And in between the annual strategy sessions the regular Hoshin Kanri board review meetings take place.

Hoshin Kanri may look at first glance like a typical top-down approach to planning and implementation supported by MBO (Management By Objectives-a process of defining objectives within an organization). However, thanks to the Nemawashi, it has a much more participative form than MBO especially during the catchball but also during the daily management of objectives. In Hoshin Kanri the stress is on management out of the objectives (and not management by objectives). Therefore, Hoshin Kanri strongly supports the engagement of all the people in the organization in improving the business accordingly.

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In the Figure 19 the relation between Key Performance Indicators KPIs (including targets derived from strategic objectives) and leaders' motivation has been depicted.

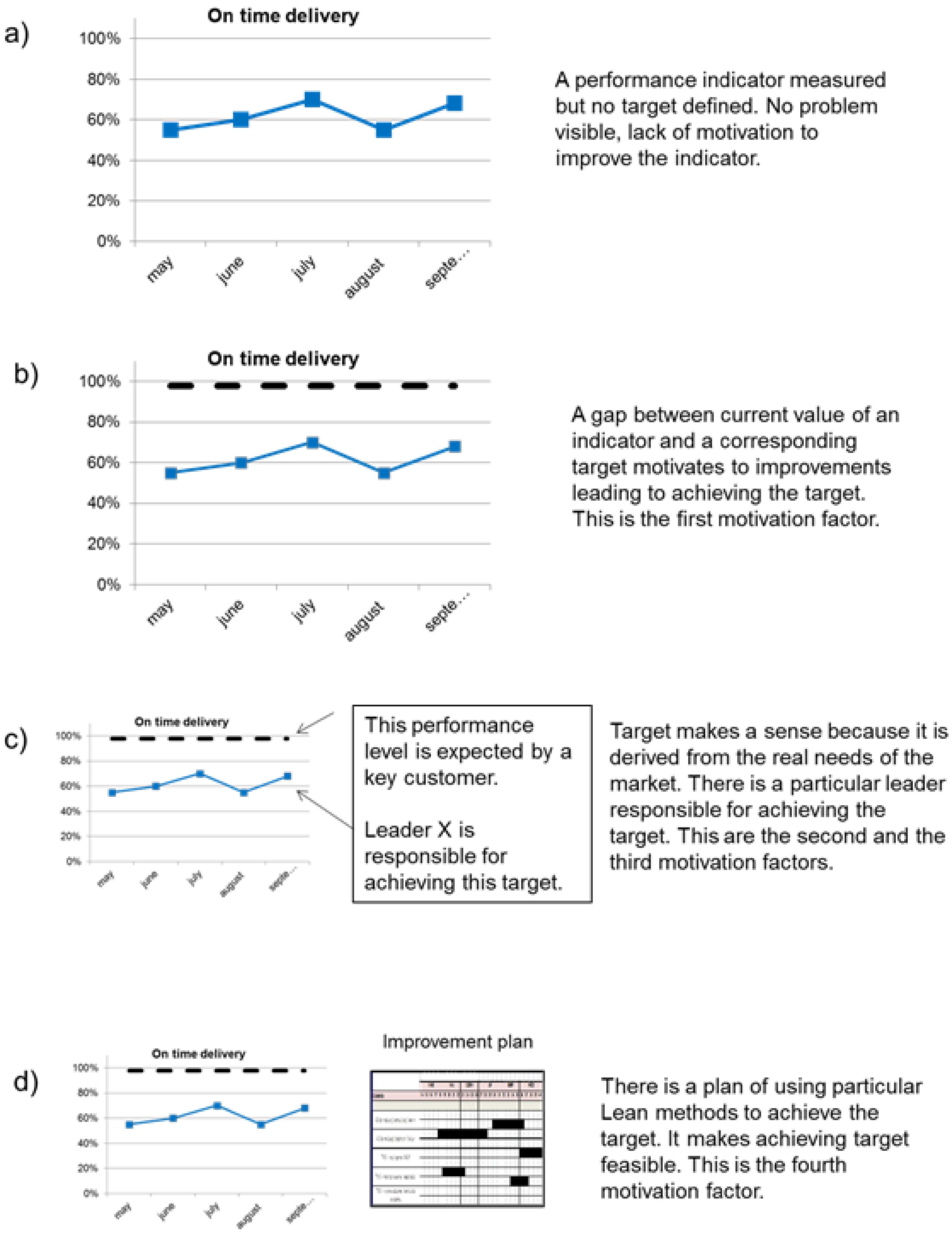

Figure 19: The logic of Hoshin Kanri and 4 motivation

Manager's Routine as an element of Lean Management System

Lean production has been proved to be a successful way to organize production operation, however very often a critical element needed to sustain it, is overlooked. This element is a lean management system which contains the discipline, daily practices, and tools needed to establish and maintain focus on process. (MANN, 2014).

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According to D. Mann (2010) a lean management system contains four principal elements:

1. Leader standard work – daily checklists for line production leaders, team leaders, supervisors, and value stream manager, that shows expectations for what it means to focus on the process.
2. Visual controls – tracking charts and other visual tools that present authentic performance output compared with planed performance.
3. Daily accountability process – brief, structured, tiered meetings focused on performance with visual action assignments and follow up to close gaps between actual results vs. expected performance.
4. Leadership discipline – leaders themselves consistently following and following up on others' adherence to the process that define the first three elements.

Leader Standard Work

Standard work for leaders is the first principal element which provide a structure and routine that allow leaders shift from focus on result to focus on process plus results. Very often the management system depends on person. Leader standard work eliminates that as specifies what the leader should do and moreover identifies what they should not be doing It is kind of an equivalent of the standardized work of the operators, whereas it does not include physical activities, but daily, repetitious activities based on the managers' responsibilities. In the Figure 20 the crucial elements of the standardized work of the managers at various levels have been presented.

Foreman	Supervisor	Department's principal	Factory manager
Team meeting 5 min.	Administ. shift handover - coordination	Administration	Trends and indicators review
The start of production review	The start of production review	Walk though the department	Visual boards check and signing
Supervisor – foremen meeting 10 min.		Leading the improvement meeting 10 – 20 min.	Improvement actions review in selected department
Supervisor is auditing the process with a selected foreman		Process audit with a selected supervisor	Verification of the principals' standardized work
Supervisor – foremen meeting 10 min.		Formal audit of the department	Master's and foreman's audit in the department
Every 20 min. – hourly production boards review	Reaction to the problems, reviewing the situation at the line	Factory manager leads the weekly meeting with departments' principals regarding the reactions to the problems	
Planning the next day	Hourly boards check and signature	Factory manager conducts and audit with selected department's principal	

Figure 20: Elements of principals' standardized work, See (MANN, 2014).

An example of a standardized master's work has been presented in the Figure 21. Please not that this will obviously vary depending on the company's organizational structure, duties scope, process specifics, etc.

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Daily standardized work plan	
Time	Task
5^{55}-6^{05} am	Security, efficiency and quality problems discussion with the previous shift master.
6^{30}-7^{00} am	Walk through the factory floor, meetings with foremen at the hourly boards, discussing the problems and ways of reaction, discussing the defects analysis.
6^{45}-8^{00} am	Auditing operators' standarized work at the the selected workplace together with the foreman.
8^{00}-8^{15} am	Leading a meeting at the area information center with manager, foremen, mechanist and process engineer; causes analysis of the difficult problems; responsibilities assignment to remediation and corrective actions and/or building problem teams.
1^{00}-1^{30} pm	Walk through the factory floor, meetings with foremen at the hourly boards, discussing the problems and ways of reaction.
1^{00}-2^{30} pm	Results reporting and shift handover.
Weekly stanradized workplan	
Mon	9^{00}-10^{15} am: meeting at the department information center with the manager, discussing the main indicators, problems and improvement projects.
Tue	9^{15}-10^{45} am: meetings with selected foremen regarding their improvement projects.
Wed	9^{00}-10^{15} am: meeting with the menager regarding onw improvement project. 10^{00}-11^{00} am: working on own improvement project.
Thu	9^{00}-11^{00} am: working on own improvement project.
Fr	9^{00}-9^{30} am: 5S audit of the whole area.

Figure 21: Example of a standardized work plan for supervisors.

Visual Controls

In lean management the status of every process should be visible. Within workstation usually we ca see many different requirements, specifications, procedures what make it very difficult to remember all of these. The aim for visual control is to focus on the process and show a comparison of the actual vs. expected performance. So when the process is not performing as expected, people can easily see that and suggestions for improvement might be required. Visual control helps to transform the concept of lean management into directly observable data. It is essential that leaders understand why they track performance and commit to take an action in response to any deviation from the plan (MANN, 2014). There are very different tools used to visually monitor processes. One of the most commonly used are performance tracking charts, such as hour-by-hour production-tracking charts. This tool shows expected vs. actual production in number of units every hour (or more frequently if required) during the day (Figure 22). When these numbers are different from each other the operator provide a reason of this variation.

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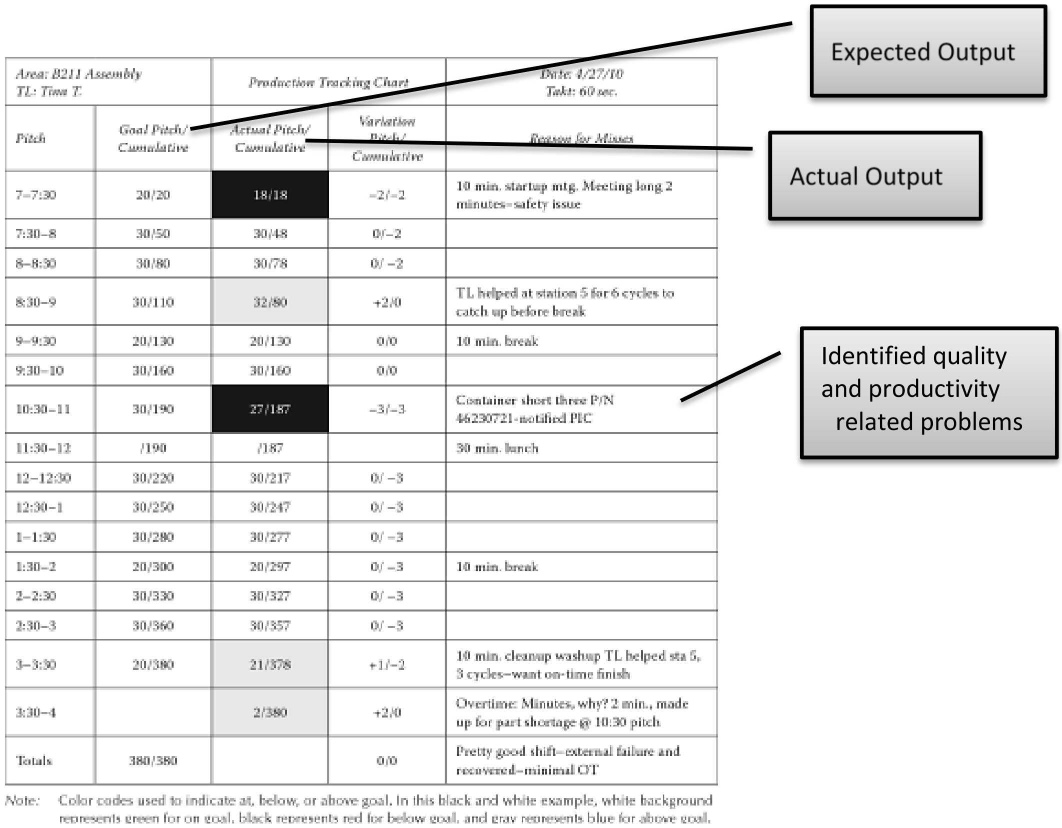

Area: B211 Assembly TL: Tim T.		Production Tracking Chart		Date: 4/27/10 Takt: 60 sec.
Pitch	Goal Pitch/ Cumulative	Actual Pitch/ Cumulative	Variation Pitch/ Cumulative	Reason for Misses
7–7:30	20/20	18/18	–2/–2	10 min. startup mtg. Meeting long 2 minutes–safety issue
7:30–8	30/50	30/48	0/–2	
8–8:30	30/80	30/78	0/ –2	
8:30–9	30/110	32/80	+2/0	TL helped at station 5 for 6 cycles to catch up before break
9–9:30	20/130	20/130	0/0	10 min. break
9:30–10	30/160	30/160	0/0	
10:30–11	30/190	27/187	–3/–3	Container short three P/N 46230721-notified PIC
11:30–12	/190	/187		30 min. lunch
12–12:30	30/220	30/217	0/ –3	
12:30–1	30/250	30/247	0/ –3	
1–1:30	30/280	30/277	0/ –3	
1:30–2	20/300	20/297	0/ –3	10 min. break
2–2:30	30/330	30/327	0/ –3	
2:30–3	30/360	30/357	0/ –3	
3–3:30	20/380	21/378	+1/–2	10 min. cleanup washup TL helped sta 5, 3 cycles–want on-time finish
3:30–4		2/380	+2/0	Overtime: Minutes, why? 2 min., made up for part shortage @ 10:30 pitch
Totals	380/380		0/0	Pretty good shift–external failure and recovered–minimal OT

Note: Color codes used to indicate at, below, or above goal. In this black and white example, white background represents green for on goal, black represents red for below goal, and gray represents blue for above goal.

Figure 22: Production pitch-tracking chart (MANN, 2014).

In result:

- the operators identify the problems which were treated as a part of standard before,
- the leaders are informed about all the problems,
- the problems noted down on the hourly production sheets are discussed during production meeting every shift,
- the opportunity to improve the process is identified.

<u>Daily accountability process</u>

Daily accountability guarantee that focus on process leads to action to improve it. The structure contain a series of three brief meetings that review what happened yesterday and allocate action for improvement. The observation of recorded data on the visual control translate them into improvement actions and follow up activities to verify are completed (MANN, 2014).

In summary '*the data on the visual control, when brought to accountability meeting, results in the process change. The follow up through leader standard work provides the mechanism to systematically sustain the change*' *(*Figure 23*)* (MANN, 2014)

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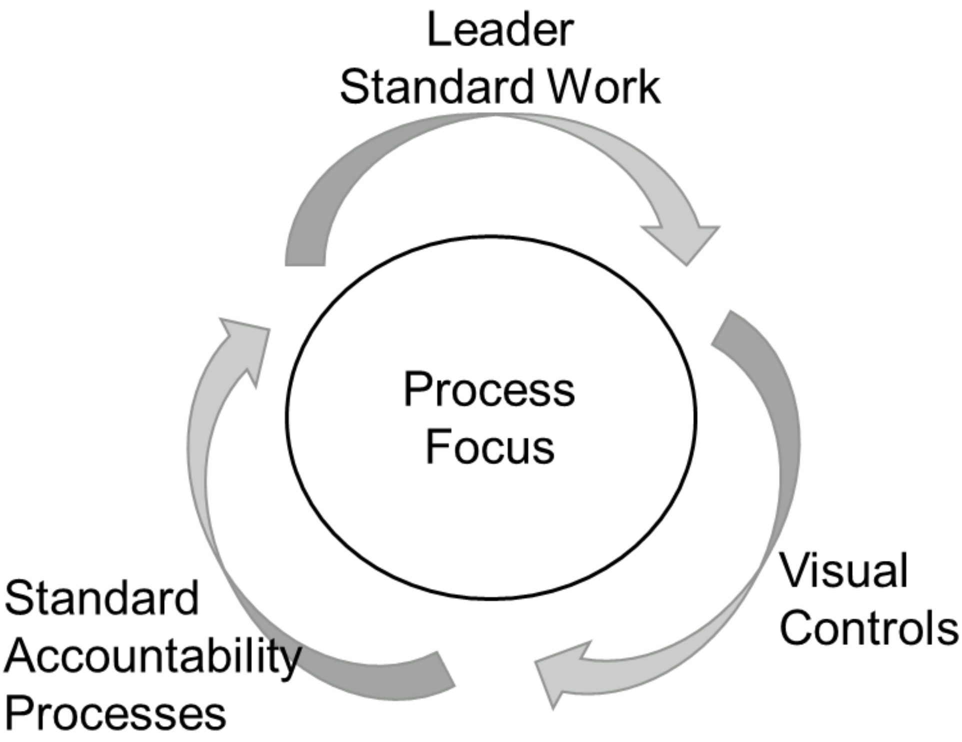

Figure 23: Lean management as a closed loop system produces focus and process improvement (MANN, 2014).

Continuous Improvement

Except four principal elements lean management system consist of a root cause orientation to problem solving, a rapid response system and a progressive approach to process improvement. All improvements, should be based on a defined need for them.

According to James Franz Lean Thinking is an approach to involve all the people in the company (from operators to senior managers) into continuous innovation process based on daily problem solving and organisational improvements (*kaizens*)(FRANZ, 2013). The objective of MAETSRI is to use *kaizens* to improve also ecological performance of companies. Franz defines Lean company as "a company that utilizes PDCA (Plan-Do-Check-Act cycle) continually at all levels of the organisation and all functions to achieve challenging targets". Such the approach creates special requirements for people development. Franz stated that "The development of people takes canter stage in any companies' thinking as it strives to implement and maintain and improve continuous improvement culture. These activities, often called *kaizen*, are aimed at both improving the processes that deliver the product or services as well as improving capability of the people using the process or delivering the services".

The relationship between ecology and economy

The problem MAESTRI consortium has to tackle is the practice in many companies to focus on business goals, and not sustainability goals, within the process of defining business objectives. Even in companies, that applied norm ISO 14001, and are obliged to define environmental goals, do it often outside of their existing performance measurement system. In this way environmental goals are perceived by middle management as less important and

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much less or no efforts are undertaken to improve ecological performance within the framework of organisational innovations.

This is why Lean Enterprise Institute Polska developed a method of Eco Orbit View to show clear relations between business and sustainability goals to reconfigure strategic objectives of companies so they will be more focused on improving ecological performance (Figure 24)

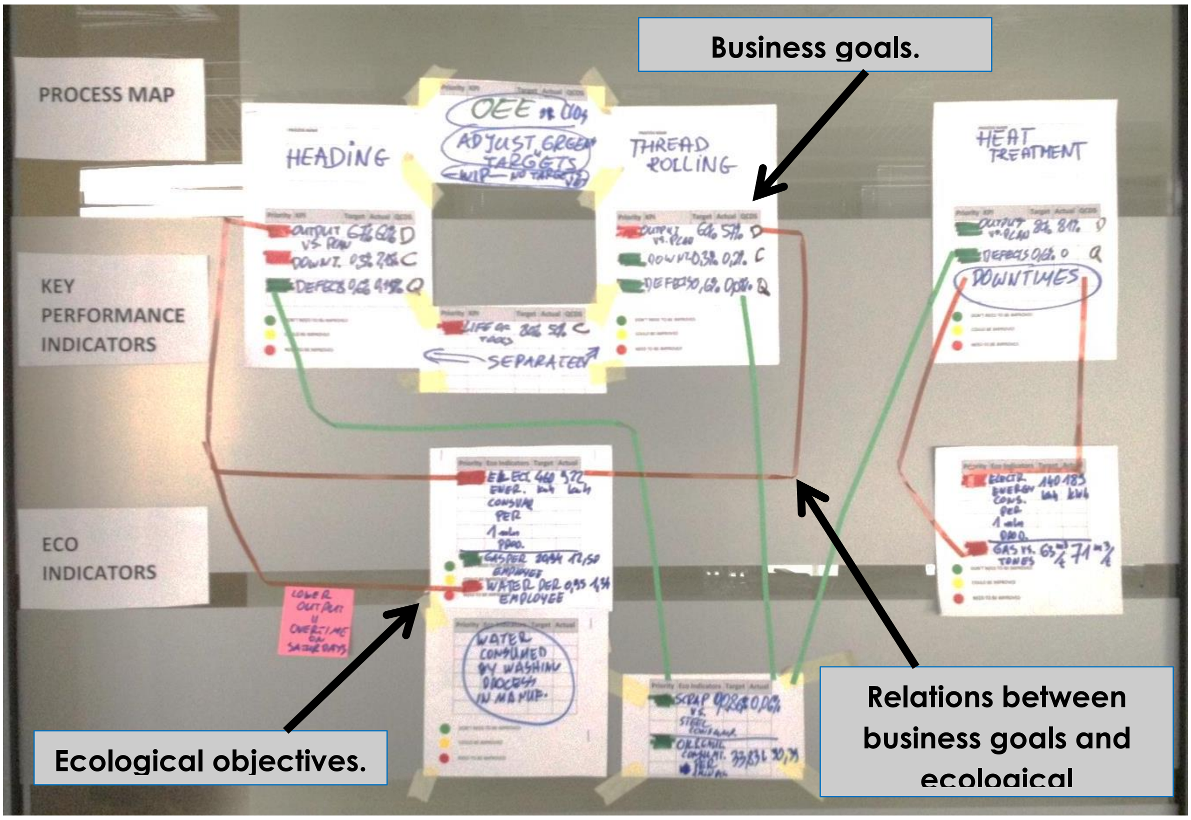

Figure 24: Identifying relations between business goals and ecological objectives using Eco Orbit View.

Eco Orbit View shows clear direct and positive impact of improved ecological performance on business goals. For example reduction of extra shipments will let to reduce the fuel consumption and CO_2 emission but also will result in decreased logistics costs (see example in the Figure 25).

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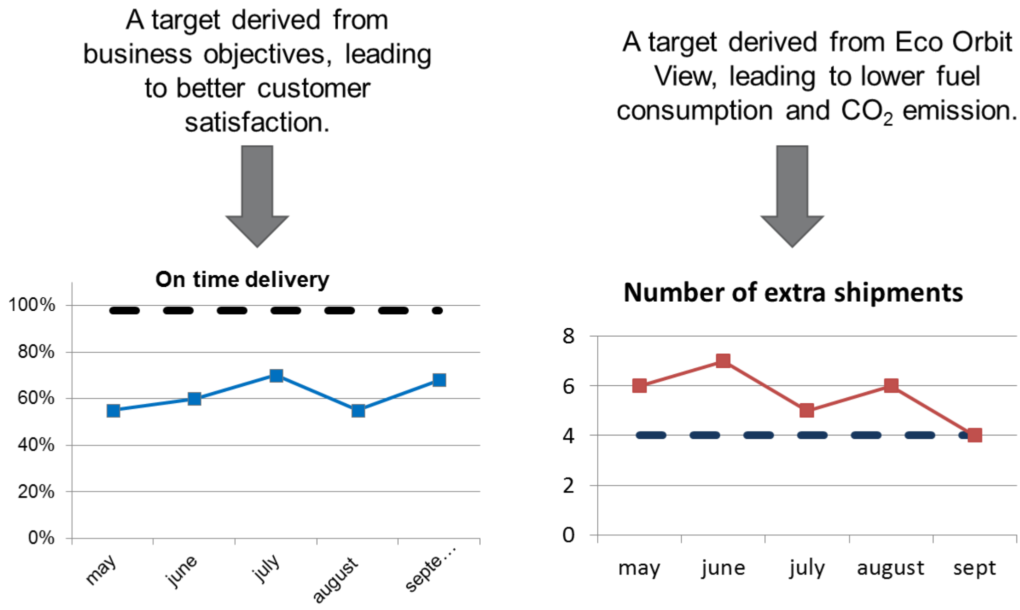

Figure 25: Adding eco-friendly targets to business objectives thanks to Eco Orbit View analysis.

Conclusions

Currently in the lean system the continuous improvement becomes the main duty of the managers of all levels – from the foreman to the CEO. The employees do obviously participate in the improvement processes as well, in the business in a day-to-day basis. However the improvement efforts are not often concentrate on eco performance. The MAESTRI Project will contribute to the including ecology within the company's strategy , and 'eco' strategic goals will be deployed at every level within the company. Moreover integrating ecology with management system and manager's behaviors will drive an improvement efforts from top management all the way down to the plant floor in regards to the ecology.

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5. Industrial Symbiosis

Industrial Symbiosis (IS) provides the foundation to think about possible connections of waste-producing facilities into a network that minimises the amount of waste that ends up in landfill or disposal sinks or is lost in intermediate processes (GIBBS and DEUTZ, 2007). There are different types of waste. IS refers most commonly to waste materials, wastewater, loss/dissipated heat or unused by-products of production processes. IS is materialised through exchanges of waste between a waste-producing facility and another facility where the waste can be used as an input to its production processes or in any other way. These exchanges can happen in five different ways, according to CHERTOW (2000): exchange within a factory or an organisation; exchange among companies located in the same industrial area; exchange among companies not located in the same industrial area; exchange among companies across a broader region. Thus, IS covers both, the cases in which IS opportunities are realised by a single company itself alone and those realised in partnership with other companies.

The factors influencing IS development and its operational characteristics are related to multiple aspects, such as technical, political, economic and financial, informational, organisational and motivational (MIRATA, 2004). It has been recognised that a balance between different organisational capabilities, regarding the aspects mentioned before, is seen as a success factor in the implementation of IS (SAKR et al., 2011). For example, BEHERA et al. (2012) suggest that converting current industrial areas into Eco-Industrial Parks, based on IS principles, could be realised if all these factors are put in place:

- an economic principle to reduce cost and generate enlarged revenue among businesses;
- environmental policy that can be streamlined to increase the resource flows and transactions for industrial symbiosis;
- new or existing technology that are available or can be developed to make the industrial symbiosis successful;
- the enhanced economic performance of participating businesses is closely related to making relationship to communities through business attraction and improved quality of life;
- EIP development will increase their environmental benefits across a community such as improved community health and reduced GHG emission.

The above list of factors highlight the potential environmental benefits of IS and positive impact on the communities. They also point out to technological and economic feasibility as necessary conditions for IS to happen. Next sub-sections will expand on these two aspects. The following section (5.1) explores the technical aspects of IS while next section (5.2) regards the business aspects.

5.1 Technological aspects

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This section will focus on the technological aspects of IS implementation. An overview of the technology-oriented opportunities and challenges related to IS design, planning and implementation is given, followed by concrete examples of tools and methods applied for IS.

5.1.1 Overview of technological aspects in IS design, planning and implementation

Technological factors has been highlighted as potential enablers / barriers for IS applications. Concretely, BAAS (2008) underlines that the technical and regulatory capabilities are dominant at the initial stages of IS processes. Considering the whole path that companies may follow when implementing IS, GRANT et al. (2010) identified five development steps and reflect on the potentialities and challenges that ICT technologies bring to these steps. The five development steps are illustrated in Figure 26 and are described herein.

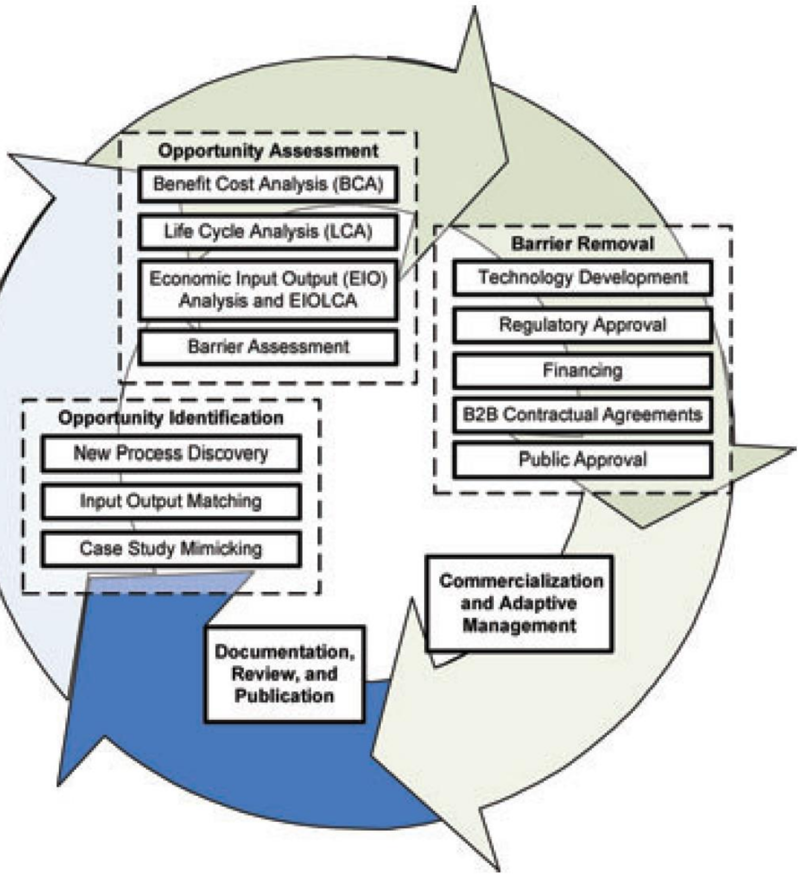

Figure 26: IS development process model (GRANT et al., 2010)

The three main mechanisms for the first step, *Opportunity Identification*, are the discovery of a new process to transform a by-product into a usable resource, the identification of links between inputs and outputs needed / produced in different organisations and the replication of successful exchanges done previously by similar organisations. The main challenge for ICT-based tools application related to input-output matching is the lack of taxonomical classifications or common language for potentially exchangeable resources. The characterisation of these resources would require a large list of attributes and tacit knowledge on substitutable resources in order to digitalise the process of resource matching. There are, on the contrary, more opportunities for ICT applications on the mimicking of existing cases in similar industries as the industries can be more easily codified / search within a database.

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In the second step, *Opportunity Assessment*, different methods can be used either based on tacit-based judgements or on explicit quantifiable information. The understanding of barriers related to market, political, social, environmental, financial and technical feasibility relies more on tacit knowledge and it would be difficult to codify. Evaluations through quantitative methods or multi-criteria objective analysis methods can be more easily supported by ICT-based tools.

The third step, *Barrier Removal*, relates to mechanisms to overcome the challenges related to IS exchanges implementation. Regulatory and public approval as the exchanges concern non-traditional resources may be necessary at this stage. Business-to-business contractual agreements and financing or procuring investment capital will also be necessary. Technology development of new processes to utilise the by-products or non-traditional resources could be also required and could include pilots and small scale demonstration

Commercialization, i.e. a full scale implementation of the IS processes, *and Adaptive Management*, i.e. feedback-based continuous improvement of the IS processes, would potentially use technologies and methods as third and first steps, respectively.

Documentation, Review and Publication concerns the communication stage of the process and it is seen as critical to establish a knowledge database on successful IS exchanges and processes. The information regarding the successful cases could be coded and made searchable within an opportunity identification tool.

In general, they found that most ICT-based tools focus on opportunity identification, specifically on relationship mimicking and input-output matching algorithms. They also identified attempts to codify tacit knowledge, for example, based on an extensive rule-based expert system

5.1.2 Tools and methods for IS

IS embeds within the broader concept of Industrial Ecology (IE). One of the core elements of IE is the use of tools such as Materials Flow Analysis (MFA), Life Cycle Analysis (LCA) and Design for Environment (DfE) to measure the environmental impact of current or potential industrial processes (BOONS and HOWARD-GREENVILLE, 2009). These tools has been often found in IS literature either as stand-alone tools or combined with each other or with other tools.

SENDRA et al. (2007) has adapted the MFA methodology to apply it to a whole industrial park and the companies located within it, in the northeast part of Spain. They provide an example (Figure 27) on how the boundaries of an MFA would vary for a theoretical system compound by three industries, when applied to each single company (A) before the IS exchanges or to the whole system after the IS exchanges (C). The IS exchanges are also illustrated (B) as well as the "black box" of the system when applying MFA at system level (D).

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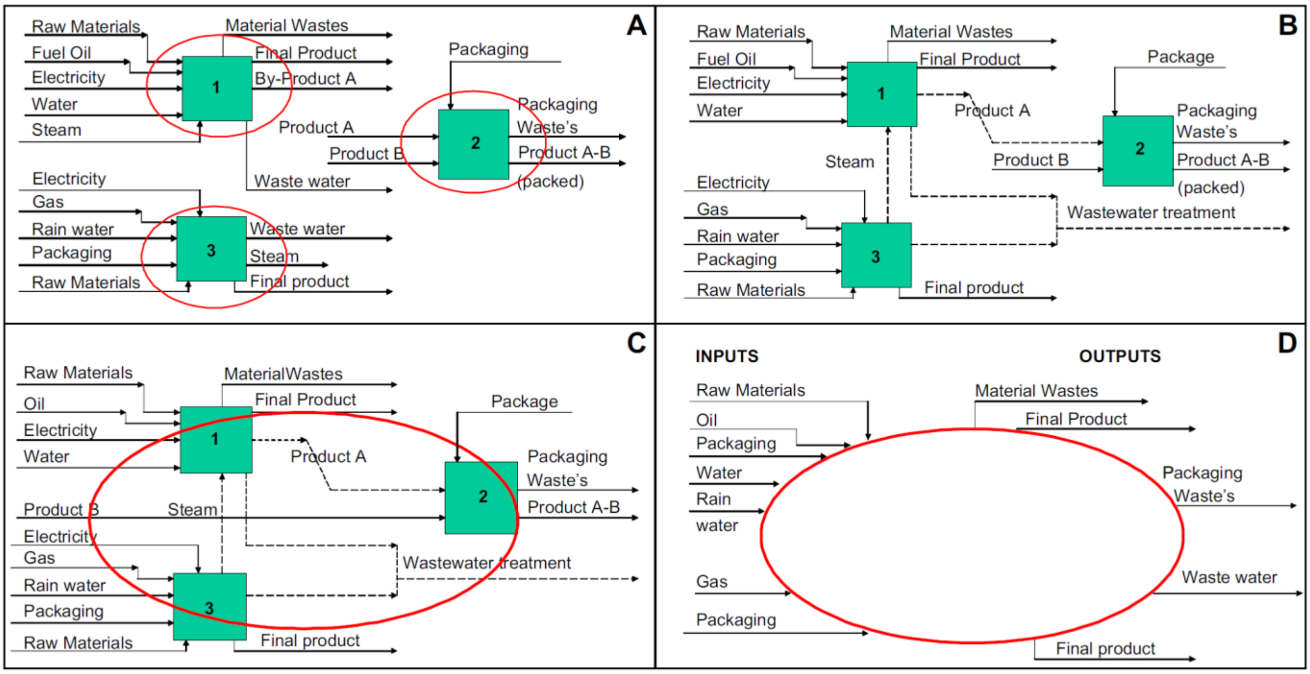

Figure 27: Boundaries of an MFA analysis when applied to different units of analysis (SENDRA et al., 2007)

LCA is a well-known tool for environmental impact assessment and has been extendedly used for comparison of different scenarios. Related to IS processes, it has been applied in several ways. LIU et al. (2011) used LCA to analyse different scenarios of application of a planned IS in Jinqiao EIP, China. The scenarios were defined according to different types and ratios of fuel (fossil fuels or waste derived fuels) for supplying 1TJ-steam. Another application of LCA to compare different scenarios was done by SOKKA et al. (2011). In this application, the current IS scenario is compared to two hypothetical reference scenario in which there is no IS exchanges, thus, the participants work on their own.

Several variations of LCA has been applied to IS contexts. Combined LCA with Emergy Synthesis was proposed by ULGIATI et al. (2007) and applied to the case of two power plants. Environmentally extended input-output (EEIO) was used by MATTILA et al. (2012) to provide input data on the estimated sector average reference case for a variety of products when giving recommendations for applying LCA in an IS context. A simplified LCA model ("cradle to gate") was applied to the cement industry to perform a quantitative analysis of the CO2 emissions from different cement production systems and products, both existing and hypothetical (AMMENBERG et al., 2015).

Extending this list of tools, CHERTOW (2000) examined 12 IS projects and categorised the tools observed to realise those projects into three types: input-output matching, stakeholder processes, materials budgeting. The three types are described briefly herein:

- *Input-Output Matching* tools collect data regarding inputs and outputs of various entities systematically to make links across industries or providing profiles of typical inputs/outputs for a specific type of facility. Examples of these tools are Triangle J, FaST (Facility Synergy Tool), DIET (Designing Industrial Ecosystems Tool) and REaLiTy (Regulatory, Economic and Logistics Tool).
- *Stakeholder Processes* tools consider a broad array of community involvement techniques and methods to reach agreement and consensus between the

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stakeholders involved in the projects. Design charrettes to create a shared vision of how the EIP should look like or to define guiding principles, such as Cape Charles Principles, are examples of this type.

- *Materials Budgeting* tools can be used to map material and energy flows through a certain system, indicating reservoirs, fluxes, sources and sinks of materials and energy. Tracking material flows can provide an overview of the whole network, as exemplified in the case of Styria, Austria.

More recently developed matching tools are using different means to collect data for opportunity identification. For example, the Looplocal tool, developed by AID et al. (2015) estimates the material and energy flows in a region and provides potential IS connections by referring to IS potential datasets based on both IS data and industry data. The IS data was collected from case studies as well as knowledge possessed by the recycling industry and information held by experts in related fields. The main datasets used to collect industry data are LCI, waste, and industry attribute datasets.

Furthermore, GRANT et al. (2010) reviewed 17 ICT tools built explicitly for IS-related purposes that they fit into the steps proposed in Figure 1. However, they suggest that other ICT tools, not related to IS initially, could also be helpful to support IS implementation processes such as GIS, water quality and energy software, collaborative project management or document technologies.

5.2 Business aspects

This section will focus on the business aspects of IS implementation and commercialisation. It presents an overview of barriers and opportunities related to IS opportunities as well as examples of IS enabled business models in literature.

5.2.1 Overview of commercialisation barriers and opportunities for IS

It seems that IS design, planning and implementation is very frequently an ad hoc process built up for each specific context. GRANT at el. (2010) reflect on this and suggest that one way of providing a common practice for IS realisation is by bridging the gap between opportunity identification and commercialisation (See Figure 26). To narrow this gap, it is crucial to know which barriers companies will face when implementing business opportunities based on IS exchanges. In this sense, usual business barriers could affect IS projects such as risk, finance, capital mobility and availability of higher pay-back options elsewhere, as well as specific IS barriers related to the lack of large, continuous waste streams that could make the project attractive (CHERTOW, 2000). Other explicit barriers of IS applications could be related to government regulations and public approval of the IS project, difficulties in the definition of contractual agreements or in the application of new technology specifically to enable the IS exchange or process (GRANT et al., 2010). IS applications will have also challenges related to the network level, as exchanges can be performed between different companies. SAKR et al. (2010) propose the following limiting factors related to symbiotic business relationships in EIPs:

- To think that ‘physical’ energy, water, materials and by-product exchanges are the most important features of EIP development;
- Lack of company interest in IS exchanges or in the formation of new business networks;

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- Collaboration and cooperation between companies cannot be mandated by the government;
- Lack of stakeholders' involvement and participation;
- Absence of a champion functioning as a communication platform between the companies involved;
- Absence of trust in new dependency links or in competences of others and lack of means to build trust between companies.

The high degree of interconnectedness between the companies engaging in the IS exchange is leading research on the mutual dependencies between them (WELLS, 2013). Moreover, cooperation and trust seems to be an important element to address when creating IS connections, as it was highlighted in well-known IS case studies such as kalundborg (JACOBSEN, 2006) or EIPs in US and Europe (GIBBS and DEUTZ, 2007). A mixture between industrial ties and social ties has been observed in IS networks (BASS, 2008). Figure 28 presents some results on the investigation of social ties in IS networks done by DOMÉNECH and DAVIES (2011).

	Mechanisms/conditions	Outcomes
Trust	• Size of the network • Past-history and shared experience • Common goals and values • General reciprocity • Emotional contractual ties • Frequent interaction	• Reduce the risk associated with transactions, by preventing opportunistic behaviour • Reduce access barriers and learning costs • Promotes willingness to collaborate
Fine-grained information transfer	• Learning by doing and close interaction facilitates deep understanding of the organizations dynamics • Generation of tacit knowledge	• Flexibility and rapid response and adaptability • Reduces the risks and costs and increases the effectiveness of coordination
Joint problem solving	• Routines of negotiation and communication • Development of a 'common language'	• Rapid identification of problems, due to implicit feedback mechanisms • Cooperative approach
Multiplexity	• Diversity of roles that a pair of nodes can represent • Embedded ties are a combination of business relation, friendship and other social/cultural attachments	• Multiplexity promotes trust and willingness to cooperate • Minimize opportunistic behaviour • It confers stability and flexibility to the connections

Figure 28: Main features of embedded ties and networks, their mechanisms / conditions and outcomes in IS networks (DOMÉNECH and DAVIES, 2011)

On the other side, IS are bringing many opportunities into the business arena that make worthwhile the attempts to overcome the previously discussed barriers. Their potential environmental and economic benefits has been extensively stated (CHERTOW, 2007). Related to the environmental benefits, IS has been recognised as a means to increase the efficiency of manufacturing processes and comply with new environmental regulations on waste materials. Moreover, economic constraints such as economic downturns and government regulations can be seen also as a main driver to engage in IS programmes and increase value for the business (PAQUIN et al., 2015). Economic benefits to companies will come from the generation of new revenues, savings on waste treatment expenses or landfill-taxes and the more efficient use of resources (MANUFACTURING COMMISSION REPORT, 2015).

Nevertheless, these benefits represent incremental innovations of current business activities or enlarged business activities by selling directly by-products. They represent initial steps into

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more sustainable operations but as TENNANT (2013) points out "incremental eco-efficiency is a necessary precursor to more radical innovation". The application of IE principles, being IS a key concept within IE, could be source for radical innovations in business models (WELLS, 2013). IS enables the development of new processes that reuse the waste materials from production facilities, thus, being a contributor to more circular material loops rather than linear loops, which end up with product disposal or waste sent to landfill. In this regard, it can be a driver for new business models that create value in all triple bottom line aspects, economic, environmental and social. Indeed, closing material loops is recognised as one of the characteristics of sustainable business models (STUBBS and COCKLIN, 2008). Different concepts cover these new strategies to create more sustainable business models by closing loops of materials and products, such as "cradle-to-cradle" (BRAUNGART and MCDONOUGH, 2010) or "circular economy" (ELLEN MACARTHUR FOUNDATION, 2013). This is further explored in next subsection.

5.2.2 Business models based on IS opportunities

IS prompts companies to think on their waste as a potential valuable input to other companies (WELLS, 2013). Its application to manufacturing industry encourages manufacturing companies to think on new ways to create value from their waste. This new mind-set will then create opportunities for business model innovations in manufacturing companies. A recent book by LACY and RUTQVIST (2015) explores how companies can create advantage within the circular economy by "creating value from waste"[1]. They identify five types of business models within the circular economy perspective:

- *Circular Supply Chain*, which uses fully renewable, recyclable or biodegradable materials that can be used in consecutive lifecycles;
- *Recovery and Recycling*, in which everything that used to be considered as waste is revived for other uses;
- *Product Life Extension*, by maintaining and improving products through repairs, upgrades, remanufacturing or remarketing;
- *Sharing Platform*, which enables the rental, share, swap or lend of idle assets;
- *Product as a Service*, which consider leasing or pay-per-use of manufactured products.

Recovery and Recycling is the type that relates more directly to IS. This model refers to the recovery of end-of-life products as well as the recovery of waste and by-products. Among the benefits of the *Recovery and Recycling* business model type, manufacturing companies will see positive impacts on the following aspects:

- Reduced costs of compliance and waste management
- Increased revenue from selling unwanted products
- Diminished environmental impact with lower demand for virgin resources and energy
- A lower material bill when switching from primary to secondary resources (not for all material types, though)

[1] They consider an extended definition of "waste" that considers wasted resources, wasted products, wasted capacity and wasted embedded values in components, materials and energy.

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Reported cases by LACY and RUTSQVIST (2015) of companies engaging in a zero waste program are Procter & Gamble, where all manufacturing waste in 45 production sites is recycled, repurposed or converted into energy, and General Motors, where 90% of manufacturing waste is recycled and owns 102 landfill-free facilities.

TENNANT (2013) refers to two examples of closed-loop business models of manufacturing companies: Adnams and AB Sugar. Adnams[2] is a UK brewer that has partnered with a local business to bring an anaerobic digestion plant to their facilities in order to convert brewery and local food waste into fertilizer and biogas. AB Sugar[3] is a large sugar producer that reuses all its by-products, including low-grade heat, to manufacture a large range of additional products ranging from animal feed and bio-ethanol to tomatoes.

TSVETKOVA and GUSTAFSSON (2012) investigated modularity in business models as a means to solve challenges related to complexity and adjustment to local conditions. They studied the particular case of a biogas producer under three different possible configurations of the IS network. These configurations are shown in Figure 29. Their findings indicate that modularity in the value proposition gives the biogas producer the advantage to be flexible and adaptive to potentially changing local conditions.

Elements of the business model	Configuration 1. Biogas for transportation (see Fig. 1)	Configuration 2. Biogas for heat and power production (see Fig. 3)	Configuration 3. Liquefied biogas (see Fig. 4)
Value proposition	1. Waste management 2. Transport fuel 3. Organic fertiliser	1. Heat and power 2. Organic food	1. Liquid fuel for various purposes 2. Waste management
Revenue model	1. Gate fees for waste treatment 2. Sales of biogas 3. Sales of organic fertiliser	1. Sales of heat and power 2. Sales of organically grown food	1. Sales of liquefied biogas 2. Gate fees for waste treatment
Customer	1. Municipality 2. Transportation companies, individuals, municipal units 3. Farmers	1. Local communities and industrial enterprises 2. Individuals and companies	1. Various consumers: ship operating companies, energy producers, etc. 2. Municipality
Capabilities	1. Ability to process waste 2. Ability to produce biogas of proper quality to be utilised as vehicle fuel 3. Ability to produce organic fertiliser of acceptable quality	1. Ability to provide energy according to the contract with the customer 2. Ability to produce organic fertiliser of acceptable quality	1. Ability to produce liquefied biogas of proper quality 2. Ability to process waste

Figure 29: Differences in business models under three different configurations

KABONGO and BOIRAL (2011) studied how companies can create value from waste, considering different ways for material waste reclamation. They identified six dimensions within the recovery and reclamation of materials:

1) *Reclaiming goal*, related to whether the reclaimed materials will be used for their transformation into products to be sold to consumers or for alterations and improvements of the internal manufacturing processes as new input materials.
2) *Reclaiming scope*, which could be integrality, i.e. recovery done at the level of manufacturing processes and coincides with the mission and purpose of the company, or fractionality, i.e. recovery limited to certain company's activities.
3) *Awareness*, regards the level of awareness while designing and implementing reclaiming activities. They define two levels: market sensibility, when focusing on

[2] More information in Adnams' website: http://adnams.co.uk/about/
[3] More information on how the factories operate is available here: http://www.britishsugarlearningzone.com/how-our-factory-operates/

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maximise economic opportunities and stakeholder demands, when aiming at meeting environmental demands from several stakeholders.

4) *Manufacturing processes*, related to whether residual reclamation processes are based on formalised technical processes or non-standardised processes.
5) *Environmental management*, related to whether the efforts for material reclamation were done based on compliance or proactivity approach to reduce environmental impacts of the activities.
6) *Material variety*, refers to whether recovery and transformation were done for a single type of waste or for a broad range of waste materials.

Their findings show the importance of addressing materials reclamation and recovery in early stages in order to effectively plan the choice of materials to be reused and the recovery and technology-related initiatives to implement for those materials. These are all dimensions that would be needed to take into consideration when designing new IS related business models.

As mentioned above "creating value from waste" is considered a driver for new business models, where undesirable outputs of a manufacturing process are turned into valuable inputs for other processes, either within the same organization or between different organisations. In this regard, BOCKEN et al. (2014) emphasize the sustainability aspects of this driver by describing it as one archetype for the creation of sustainable business models. The archetypes are explanations of groupings of mechanisms and solutions that may contribute to building up the business model for sustainability. The archetype "Create value from waste" is presented in Figure 30, giving a high-level description of the value proposition, the value creation & delivery and the value capture of the business models included in this archetype.

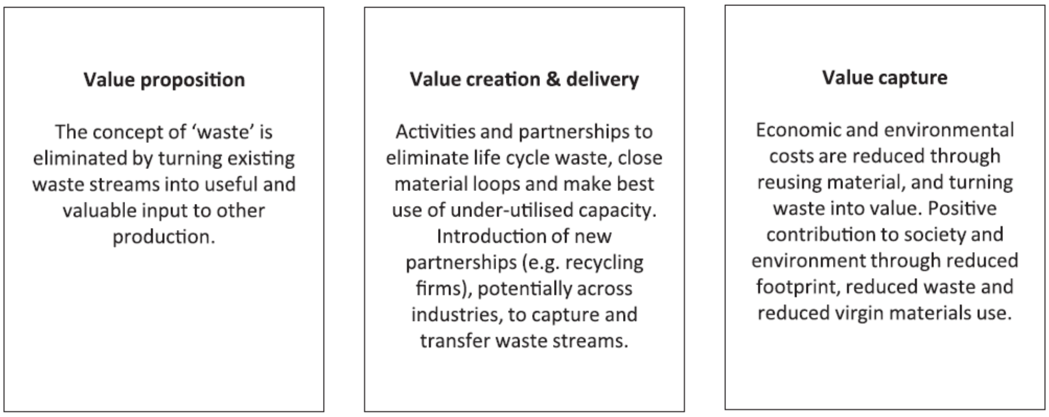

Figure 30: Description of archetype "Create value from waste" (BOCKEN et al., 2014)

In a long term, the creation of sustainable business models can bring opportunities related to materials efficiency and resilience as well as high-quality jobs and positive effects for society at large, however, the economic viability and scalability needs to be demonstrated, in a world of constraint resources (MANUFACTURING COMMISSION, 2015). In the context of IS, the feasibility study would include an assessment of the potential uses of by-products, an assessment of the techno-economics and environmental feasibilities, and a conceptual design for the particular network type (BEHERA et al., 2012).

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6. Internet-of-Things

The Internet of Things (IoT) has leveraged during years to many definitions: many authors, even if referring to the same ideal concept, provided their own interpretation. The ITU (International Telecommunications Union) definition is exhaustive, describing the IoT as:

> *"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."*

This definition sounds today much more concrete than few years ago since IoT vision and IoT awareness, including research activities and product development, is constantly growing and IoT applications are innovating the way of life and work, having a potential societal benefits recognized as "unlimited". Indeed, from a broader perspective, the IoT can be perceived as a vision with relevant technological and societal implications (VERMESAN, O., 2011). IERC (European Research Cluster on the Internet of Things) states that IoT is

> *"A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network".*

Finally, a recent definition of IoT is provided by (IEEE, 2015):

> *"IoT refers to any systems of interconnected people, physical objects, and IT platforms, as well as any technology to better build, operate, and manage the physical world via pervasive data collection, smart networking, predictive analytics, and deep optimization."*

ITU also provide a definition of Thing, as:

> *"An object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks",*

Accordingly, everything can be a "thing", like an industrial machine which sends information about its operation to a sever (BAHGA, A., 2014). Generally speaking, the number of IoT devices has grown rapidly, with a recent estimate suggesting that there were 12.5 billion internet attached devices in 2010 and a prediction of 50 billion devices by 2020 (EVANS, D. 2011).

6.1 IoT and Smart Industry

The evolution of technologies used in the industrial ecosystems has usually followed the advancements of Information and Communication Technology (ICT) systems. Many aspects of ICTs are involved in this evolution, like environmental sensing, data communication technologies, data mining, data storage, and so on. In recent years, specific fields like application logic and decision-making are features where modern ICTs support and maintain the progress of manufacturing systems. Furthermore, the computing technology ecosystem is today facing with the Internet of Things (IoT) innovation, driven by both

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technological and methodological changes, which include communications paradigms among devices as well as instruments to enable the creation of value added services on top of them. As consequence, the accelerating growth of miniaturized embedded systems and the constantly increasing interest within ubiquitous computing is showing the direction for the next-generation industry, since it already leverages on modern microelectronics and wireless data communication.

Thanks to the growth of such technology services, today's production environment is living a new era of innovations and changes that have the potential to bring higher efficiency, flexibility and interoperability among industries, even if belonging to different production ecosystems. The IoT introduction into the industrial applications enables to enrich the value of the information traversing specific application, thereby supporting the development of actual intelligent environments, even in industrial and energy intensive ecosystems where this has been never considered. Furthermore, an elevated level of flexibility is needed into these environments, and today this is achievable thanks to the IoT framework available combined with high level of pervasiveness and ubiquitous computing. Integrated with intelligence, pervasiveness and flexibility, industrial applications can enjoy improved service quality, achieve better efficiency and accelerate the business innovation (UCKELMANN, D, 2014).

A vast number of IoT development already exist in the industry fields, namely for oil and gas level monitoring, automated stock calculation, explosive and hazardous gases detection, machine auto-diagnosis and assets control, etc.

The main characteristic of these developments is that are vertically designed, since mainly leveraging on specific technologies to handle specific problems. In addition, other systems, SCADA, MES, ERP and EAI, provide limited vision on the status and performance of the production systems from both the economic and environmental perspective.

6.1.1 IoT and process optimizations

The Internet of things, the natural extension of the Internet, added the key concept of connecting things, sensors, actuators, and many other smart technologies apart the sole computers: the vision of having an immediate access to information about physical objects is now fully related with the possibility to provide innovative services with high efficiency and productivity. Indeed, the fact that the industrial scenario can take several advantages from the introduction of the IoT paradigm has been widely ruled by a number of publications. For example, BI, Z. (2014) states that IoT has is crucial technology that will definitely affect the industry and will have a great impact on the economy. BI, Z. (2014) also underline that an IoT system is well aligned with the architecture of an industry, since an enterprise can be modelled as a set of components and a set of interactions among them. From those premises is it possible to underline that the IoT match the industry on two main side: in one side, the IoT represents all the new technologies and communication protocols that enable the flexible, efficient and effective sensing and data acquisition in the production environment. On the other side, the IoT meet the industry in the orchestration, aggregation and federation of logical component, systems and subsystems.

Furthermore, modern industries face a challenge raised from the increasingly complexity and dynamicity of the production environments. The IoT and the pervasive computing has enabled companies continuously adapting to these changes. Within (EU COMMISSION, 2016)

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is evident how European research strategy today specifically addresses this need while stating that future shop floors have to endorse flexibility and define networks in which a tight collaboration between humans, machines and robots is key for performance e.g. maintenance operations and changes in product set-up. These will be reality enabling machinery and robots to collaborate and adapt their behaviour in order to give a response to unforeseen changes, situations or problem.

Finally, modern industry also faces with the worker's well-being under working conditions, as a crucial part of manufacturing element. Human factors indeed need to be considered in order to achieve sustainable and efficient organizational. For example, the advances in the area of wearable sensors, useful for sensing human parameters, make it possible to enable a wide range of user-factory' value added services. As stated by NEUBAUER, M. (2015), sensing human conditions, such as the level of comfort or stress, allows for continuous adaptation of the manufacturing process behaviour on the top of randomly changing human needs.

6.1.2 The Maestri's IoT vision

Within the business environment, vertical and horizontal integration is the key condition for seamless information flows from different business units as well as between business partners. Unfortunately, there is still a huge gap to achieve this integration: the MAESTRI project propose a vision for filling this gap. Specifically, The integration of IoT topic is not of course centred in development of ICT specific components, but rather to get the best capabilities and functionalities of this powerful technology in order that processing industries are aligned and benefited with these high-level technologies application and usefulness.

The proposed approach advantages on the deeper integration, in the production environment, of the Internet of Things paradigm, envisioning a seamless interconnection of heterogeneous devices, systems and subsystems in order to achieve higher degree of interactions between the shop floor, the legacy management systems and the end users, supporting end-to-end business optimizations addressed by MAESTRI. The full integration of the Internet of Things allows managing assets, optimizing performance, and developing new business models, paving the way to the hyper-connected factory, which improve energy efficiency and optimize resource management and savings.

This chapter aims at provide a state of art overview of the IoT approaches, technologies and already existing platform, from both the technological and practical point of view, also considering business aspect related with this new vision.

6.2 Technological aspects

This section summarizes the key elements related with the state of art IoT technologies, mainly focusing on the industrial scenario, considering the publicly available scientific publications, the actual IoT technologies as well as results of EU funded project completed or ongoing.

From a technological point of view, it is possible to identify three layer of IoT related technologies, architectures and standards:

1. Hardware: smart heterogeneous devices provided by disparate vendors typically used to gather information from the shop floor and afterwards processed.

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2. Communication technologies: choose the right one among the available on the market depends on the specific IoT application deployed (amount of shared data per second, sensors capillarity required, power constraints, physical constraints, etc.).
3. Middleware platforms and cloud services: software component which retrieves data from smart devices, through common and standardized interfaces, also providing a uniform and transparent view of heterogeneous services and resources. The cloud component is in the edge of the networks, enabling composition and coordination of services into long-running transactions and collaborative business processes, also allowing to build large-scale systems including thousands of users. For example, FIWARE (FIWARE, 2015), (SOFIA2, 2015) are such typo of platforms funded by EU projects. Many other platforms are available from private vendors such as Cisco, Thingworx, Microsoft, etc.

From a different perspective, DA XU, L. (2014) provides an extensive recap of IoT in the industry scenario, also defining the "FOUR-LAYERED ARCHITECTURE FOR IOT", composed by 1) Sensing, 2) Networking, 3) Service and 4) Interface Layer.

6.2.1 IoT technologies for the industry

Apart from process related optimizations mentioned in previous sections, the IoT bring a relevant advantage in terms of sensing technologies and communications networks. AIOTI WG11, (2015) clearly and simply underlines that:

> *"Sensors are the eyes and ears of the smart factory, and as such they will be everywhere. Besides conserving power, embedded sensing systems must be small, inexpensive and rugged"*

Sensors need to be connected, and connectivity (wired or wireless), as well as computational power and energy requirements, are crucial factors for automated manufacturing. Industrial devices will communicate through low power (even leveraging on energy harvesting), will be highly integrated and will offer high flexibility. Increased bandwidth will also be important, especially for wired communications, pointing to greater use of Gigabit Industrial Ethernet (AIOTI WG11, (2015).

Focusing on wireless technology, KARIMI, K. (2013) recap into the following table, the major non-exhaustive relevant details about the largely available wireless communications.

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	NFC	RFID	Blue-tooth®	Blue-tooth® LE	ANT	Proprietery (Sub-GHz & 2.4 GHz)	Wi-Fi®	ZigBee®	Z-wave	KNX	Wireless HART	6LoWPAN	WiMAX	2.5–3.5 G
Network	PAN	PAN	PAN	PAN	PAN	LAN	LAN	LAN	LAN	LAN	LAN	LAN	MAN	WAN
Topology	P2P	P2P	Star	Star	P2P, Star, Tree Mesh	Star, Mesh	Star	Mesh, Star, Tree	Mesh	Mesh, Star, Tree	Mesh, Star	Mesh, Star	Mesh	Mesh
Power	Very Low	Very Low	Low	Very Low	Very Low	Very Low to Low	Low-High	Very Low	Very Low	Very Low	Very Low	Very Low	High	High
Speed	400 Kbs	400 Kbs	700 kbs	1 Mbs	1 Mbs	250 kbs	11-100 Mbs	250 kbs	40 Kbs	1.2 Kbps	250 kbs	250 Kbs	11-100 Mbs	1.8-7.2 Mbs
Range	<10 cm	<3 m	<30 m	5-10 m	1-30 m	10-70 m	4-20 m	10-300 m	30 m	800 m	200 m	800 m (Sub-GHz)	50 km	Cellular network
Application	Pay, get access, share, initiate service, easy setup	Item tracking	Network for data exchange, headset	Health and fitness	Sports and fitness	Point to point connectivity	Internet, multimedia	Sensor networks, building and industrial automation	Residential lighting and automation	Building automation	Industrial sensing networks	Senor networks, building and industrial automation	Metro area broadband Internet connectivity	Cellular phones and telemetry
Cost Adder	Low	Low	Low	Low	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium	High	High

Figure 31: Wireless communication technologies with potential IoT applicability

Modern industrial sites should be able to integrate & reconfigure sensors without the need of difficult & costly hardware reconfigurations & repairs. Some technologies like ZigBee or &LowPAN are inline with these objectives, fully leveraging on the Wireless Sensor Networks (WSNs) communication paradigm. They are increasingly being adopted in various applications due to their potential to provide flexibility for monitoring and control of industrial processes, and perform local computations by providing energy efficient short-range wireless connectivity. According to the most general definition, a WSN consists of a large number of densely deployed nodes equipped with one or more sensing units, capable of communicating with each other through a wireless medium, for the purpose of collaboration, coordination and information exchange. Additionally, a wireless sensor network possesses self-organizing capability so that little or no network setup is required. Ideally, individual nodes are battery powered with a long lifetime and should cost very little. Wireless sensor networks have witnessed a tremendous growth in the recent years, thanks to the technology progresses in device miniaturization, embedded computing, and networking. Many applications in the fields of defense, wildlife and environment monitoring have been proposed or realized; however, so far practical most deployment s have taken place in so-called benign operative environments (e.g., houses, office buildings, greenhouses) for the purpose of monitoring and control of slowly varying phenomena (e.g., temperature, humidity, light). So far, deployment of wireless sensor networks in adverse or harsh operating conditions has been less popular, due to the technical challenges such environments pose to a technology that, after all, is still quite young. The question of whether the technology available is good enough to meet the challenging performance requirements set by industrial applications is thus very relevant indeed. Recently has been also introduced the concept of Wireless Sensor and Actuator Networks (WSANs), a set of wireless devices that can operate in a cooperative manner in order to accomplish more complex tasks, can perform actual actions and can execute self-configuration and self-organization mechanisms. As a result WSAN based industrial systems carry the potential to enhance the currently existing wired solutions (GUNGOR, V.C., 2009), (PAAVOLA, M., 2010)).WSAN technologies are still under development, since the current research is mainly focused on the

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definition of flexible WSN infrastructure which takes care of communication factors such as latency, redundancy, scalability, duty cycle, re-configurability.

The Radio Frequency Identification (RFID) is a technologies fully related with the IoT and the industry (KRIPLEAN, T., 2007). RFID is considered the basis of the modern IoT concept, and today is also a key enabling technology to optimize various factory automation procedures, from the inbound-outbound management to the automatic identification of items, instruments and apparatus (as well as humans sometimes). Thousands of scientific report and actual applications have demonstrated during years the value of RFID technologies in industry (PAYNE, T., 2009), which is impossible to mention exhaustively. Furthermore, RFID implementations do not have a "one size fits all" solution and different industrial sectors are reached different levels of adoption and RFID maturity (ZELBST, P.J. 2010). For example, the retail industry is the one which is today mainly benefitting of this technologies, adopting the RFID for transversal applications (from warehouse logistic, to product anti-counterfeiting and anti-theft systems in retails). In addition, the big production, as the automotive one, today is using the RFIDs for disparate purposes (logistic, PLM, automation). Recent researches developments are focused on the so called "Item-level tagging", which enables information visibility that reduces uncertainty all along the supply chain and this increased certainty can improve supply chain coordination, reduce inventory lacks, increase product availability, provides better management of perishable items and returns, among others (ZHOU, W. 2009).

Another promising technology is the so called Ultra-Wide-Band which, although not very mature yet from the commercial point of view, promises to mitigate most of the issues affecting radio wave propagation in typical industrial environments characterized by rich, time-varying multi-path and electromagnetic interference, induced by coexisting radio systems or industrial processes. UWB is a communication technology for short-range wireless indoor communication based on short time-domain impulse. UWB technology is quite recent and many technical issues still need to be addressed but it is very promising for the industrial application for its interference resistance, which is achieved pushing to an extreme limit the concept of frequency diversity. UWB radio signals, in fact, spread the radiated energy over a wide radio frequency spectrum thus limiting the negative effects of interferers. This is especially true for IR-UWB signals whose RF spectrum, ranging from 3.1 GHz to 10.6 GHz, does not overlap with the frequency spectrum of other wireless technologies sometimes overcrowding the unlicensed 2.4 GHz band (e.g., WLAN, Bluetooth), as described in (LEUNE, T., 2012).

Finally, it is necessary to mention the Bluetooth Low Energy (BLE) technology. BLE is a lightweight version of the worldwide spread Bluetooth and was introduced as part of the Bluetooth 4.0 core specification. Even if there is some overlap with classic Bluetooth, BLE actually has a completely different lineage is today officially recognized. The big advantage of BLE is that it represents the easiest way to implement a communication between an IoT device (like a sensor) and any modern mobile platform on the market (iOS, Android, Windows, BlackBerry, etc.). For this reasons, BLE have a huge potential in the industrial scenario, but some limitation still need to be addressed (like the limitation in the topology of the networks that can be deployed).

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6.2.2 IoT Middleware Platform and industrial applications

Information coordination among business planning systems such as ERP, MES, and other shop-floor equipment controllers is relevant for manufacturers. Furthermore, production information systems are often vertically designed and consequently a large amount of effort is needed to implement connection functions corresponding to combine different subsystems or systems from multiple vendors. The so-called middleware aims at overcomes those needs, providing internet-based large-scale systems which gather, manage, process and exchange data from heterogeneous IoT objects to support pervasive context-aware services. A middleware allows developers in the production environment to incorporate heterogeneous physical devices into their applications by offering easy-to-use interfaces (e.g. web service) for controlling any type of physical device irrespective of its network technology (Bluetooth, RF, ZigBee, RFID, Wi-Fi, etc.). In the paper of (BANDYOPADHYAY, S., 2011) is provided, as a general vision, a functional blocks representation of an IoT middleware.

During years a plethora of different approach has been presented. In the paper (FREMANTLE, P., 2015) the authors provide a synthetic recap of the available development, which is reported in the following figure:

Middleware	Defined Security Model	Tangible Security Architecture	SOAP/WS-*	REST	Event Driven	Semantic	IoT-specific Protocol Support	Integrity and Confidentiality	Access Control	User-centric access control	Policy-based security	Authentication	Federated Identity	Attestation	Summarisation and Filtering	Privacy By Design	Context-based security/Reputation
ASPIRE	N	N	Y	N	N	N	N	-	-	-	-	-	-	-	-	-	-
CBCPM	N	N	N	Y	Y	N	N	-	-	-	-	-	-	-	-	-	-
Dioptase	N	N	N	N	Y	Y	N	-	-	-	-	-	-	-	Y	-	-
DREMS	Y	Y	N	N	Y	N	Y	Y	Y	N	N	Y	N	N	N	N	N
EDSOA	N	N	Y	N	Y	N	N	-	-	-	-	-	-	-	-	-	-
GSN	N	N	N	N	Y	N	N	-	-	-	-	-	-	-	Y	-	-
Hydra/Linksmart	Y	Y	Y	N	N	Y	N	Y	Y	N	N	Y	N	N	N	N	N
ISMB/VIRTUS	Y	Y	N	N	Y	N	N	Y	Y	N	N	Y	Y	N	N	N	N
MOSDEN	N	N	N	N	Y	N	N	-	-	-	-	-	-	-	Y	-	-
NAPS	Y	N	-	-	Y	N	Y	-	-	-	-	-	-	-	-	-	-
OpenIoT	N	N	-	-	-	Y	N	-	-	-	-	-	-	-	Y	-	-
SBIOTCM	N	N	Y	N	N	N	N	-	-	-	-	-	-	-	-	-	-
SIRENA	Y	Y	Y	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N
SMEPP	Y	Y	-	-	Y	-	N	Y	Y	N	N	Y	N	N	N	N	N
SOCRADES	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	N	N	N	N	N
Thingsonomy	N	N	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-
UBIROAD	N	N	Y	N	N	Y	N	-	-	-	-	-	-	-	-	-	-
UBISOAP	N	N	Y	N	N	N	N	-	-	-	-	-	-	-	-	-	-
UBIWARE	Y	N	-	-	-	Y	N	-	-	-	Y	-	-	-	-	-	-
WEBINOS	Y	Y	N	Y	N	N	N	Y	Y	N	Y	Y	Y	Y	N	N	N
WHEREX	N	N	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Figure 32: Middleware systems and major properties reviewd by (FREMANTLE, P.,2015)

Among the listed ones, it is possible to underline DE SOUZA, L. M. S., (2008), as well as LinkSmart (originally named Hydra (EISENHAUER, M., 2010), (KOSTELNIK, P., 2011)), which are middleware designed for manufacturing shop floors and other industrial environments. LinkSmart is an open source framework, based on a service-oriented architecture, working as a service infrastructure for the creation of distributed IoT applications. LinkSmart incorporates semantic Web Services, secure peer-to-peer (P2P) networking, device/service discovery and developer tools, while addressing the need of an interoperable platform that facilitates the creation of cost-effective, high-performance cyber-physical systems. Furthermore, the feasibility of IoT application creation through LinkSmart and its subcomponent has been

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widely demonstrated, as described by KHALEEL, H. (2015). The MAESTRI project will advance LinkSmart, addressing the resource sharing and the interoperability of available services.

As studied by CHAQFEH, M., (2012), the main issues that drive IoT middleware development are interoperability, scalability, abstraction provision, spontaneous interaction management, unfixed infrastructure, multiplicity, security and privacy. On the top those objectives is it possible to underline some major challenges:

- IoT Resources Adaptation and Abstraction: the solutions to integrate, to discover and to annotate (semantically) heterogeneous devices, in order to turn them into Internet resources (e.g. REST Services, Event Flows, etc.).
- Definition of IoT models and architectures: this includes standards and middleware tools to support operations of large-scale IoT systems
- Actual IoT data exploitation: the value added services leveraging on data processing and machine learning techniques applied to IoT data streams, which aims to extract useful information (also in real-time scenarios) and so create the value on top of them.

6.2.3 Relevant Projects

The increasing complexity of manufacturing systems and processes creates the need for workers to be supported by appropriate tools providing them with assistance for operations along the entire production chain in factories and further development of their competences and abilities to enable the optimization of processes. Appropriate user interfaces (e.g. visual, audio, etc.) and assistance tools for communication will assist workers while performing manufacturing operations, including assembly, operation of machines, maintenance activities, ramp up procedures, troubleshooting and remote guidance.

The following research projects are relevant to MAESTRI with respect to IoT and the ongoing projects will be monitored closely in order to potentially incorporate results into the project work. Consortium partners are key members in some of the following mentioned projects and this will ensure the proper integration and continuous development of results that will benefit the achievements within the work packages.

6.2.3.1 ebbits

The ebbits project (involved partners were ISMB and FIT) provides a semantic approach to IoT and introduced an innovative bridge between backend enterprise applications, people, services and the physical world, using information generated by tags, sensors, and other devices performing actions in the real world. The resulting architecture, technologies and processes allow businesses to semantically integrate IoT into backend enterprise applications and support interoperable end-to-end business applications. Useful information generated from sensors and context awareness devices applied to machinery and subsystems can be distributed to mainstream backend information systems, human professional users in technical supports and other business environments.

- ebbits: http://www.ebbits-project.eu/ [Accessed: 20-Nov-2015].

The ebbits project features a platform enabling the semantic interoperability between heterogeneous physical world technologies and enterprise systems with scalable network architectures and featuring opportunistic communication paradigms.

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Communication between entities is established locally and across stakeholders is enabled by innovative Data and Event Management, through a P2P (peer-to-peer) Event Management Architecture, which leverages on the publish/subscribe communication paradigm to handle rule-based service orchestration.

Semantic Knowledge Infrastructure, connecting many conventional data sources to semantic models, with support of hybrid querying and real-time reasoning forms the basis for Centralized and Distributed Intelligence which allows the usage of various data fusion frameworks and the implementation and usage of individual data-fusion algorithms.

The ebbits project advanced the LinkSmart middleware, the main result of an EU project called Hydra and also one of the major components in MAESTRI for the integration of data coming from devices on the shop floor. LinkSmart combines a service-oriented architecture, peer-to-peer networking technologies and semantic Web Services, bridging the heterogeneity of devices and protocols solving interoperability issues (BRIZZI, P., 2013).

6.2.3.2 LifeSaver

The LifeSaver project (involved partners were ATB, JWO and OAS) focused on a system for optimising energy performance of industrial operations by providing specifically tailored ICT tools and a platform for context aware process monitoring and optimisation.

- http://www.lifesaver-fp7.eu/ [Accessed: 20-Nov-2015]

LifeSaver followed an approach of applying also parameters that are usually not directly related to the energy management, to enable decision support for the optimisation of industrial operations regarding their energy efficiency. Within MAESTRI, this approach will support recording the total efficiency of the system.

The LifeSaver project provides decision-making support in different time-frame situations. For short-term routine decisions the goal was to maximise energy savings in daily use of equipment while in the medium term enabling the energy-efficient configuration of processes in manufacturing companies. Ultimately support for long-term decisions aiming at managing cumulative emissions and supporting emissions trading among companies were explored.

6.2.3.3 Impress

The IMPReSS project (involved partners are ISMB and FIT) is a joint EU-Brazil project that aims to provide a System Development Platform which enables rapid and cost effective development of mixed criticality complex systems involving Internet of Things and Services (IoTS) and at the same time facilitates the interplay with users and external systems.

- [Impress website, http://impressproject.eu [Accessed: 20-Nov-2015]

The IMPReSS project aims at solving the complexity of IOT system development by providing a holistic platform that is applicable across different sectors, addresses the heterogeneity of the Internet of Things and their networks and supports the management of large amounts of data.

The IMPReSS development platform consists of a set of technologies that help building general-purpose applications accessing a multitude of sources, such as information from the

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physical world, analysing and fusing relevant data and perform monitoring and control operations on complex systems. MAESTRI will reuse the experience and knowledge gained regarding the approach to reduce complexity of system development through middleware components and appropriate development tools.

- IMPReSS, D2.1.1 Initial Requirement Report, 2013

6.2.3.4 Satisfactory

SatisFactory (involved partners are ISMB and FIT) aims to enhance and enrich the manufacturing working environment towards attractive factories of the future that encompass key enabling technologies such as augmented reality, wearable and ubiquitous computing.

- http://www.satisfactory-project.eu/ [Accessed: 20-Nov-2015]

The goal for factory environments is to design and implement a semantically enriched knowledge modelling framework and proper data analytics techniques leveraging a model-based approach. Analytics techniques for the shop floor activities intend to support the integration with heterogeneous business systems (like ERP or MES) and semantic orchestration of existing unstructured and complex data.

The fundamental component of the proposed system will be the assessment and storage of the explicit and tacit knowledge created on the shop floor by aggregating a set of heterogeneous smart devices and sensors and extracting context-aware information based on their measurements.

- [SatisFactory D1.1.1] SatisFactory consortium, "User group definitions, end-user needs, requirement analysis and deployment guidelines", April 2015.

Satisfactory plans to develop ubiquitous user interfaces to support all employees seamlessly in real time and on the move with modern wearable devices that will allow the interaction of workers with the system without disrupting their workflow. These developments are especially interesting to the implementation of MAESTRI user interfaces in the pilot sites.

6.2.3.5 Finesce

Finesce – Future INternEt Smart Utility ServiCEs – addresses efficient energy usage in residential and industrial buildings. Development of a new prosumer energy marketplace and building a cross-border private virtual power plant enabling energy providers to move from reactive to pro-active energy network management through Future Internet ICT is one of the major goals. The trials, organized and run in seven European countries should prove the practical applicability of Future Internet technologies and the FI-WARE Generic Enablers to the challenges of the energy sector.

- http://www.finesce.eu/ [Accessed: 20-Nov-2015]

MAESTRI will leverage on the FINESCE derived expertise especially regarding enabling instruments for energy optimization by combining solutions which utilise energy generation from renewable energy sources and the optimization of energy usage efficiency through a Smart Energy Platform (SEP).

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The developments within Finesce are planned to be Open-Source which allows for the possibility to integrate components into the MAESTRI platform and in addition to that a cloud-platform should be established to provide Finesce services. Those cloud-services can be easily integrated where applicable because of the use of a service-oriented architecture approach.

6.2.3.6 LinkedDesign

The LINKEDDESIGN project aims to solve the missing integrated and holistic view on data across the full product lifecycle for the current ICT landscape for manufacturing. The design and engineering of products and manufacturing processes is currently decoupled from the actual process execution. The project targets a tight integration of all tools used throughout the full product lifecycle and implementing the holistic view on data through new design methodologies and novel integration tools.

LinkedDesign intends to boost the productivity of today's engineers by using the Linked Engineering and Manufacturing Platform (LEAP), capable of providing an integrated, holistic view on data, persons and processes across the product lifecycle as a vital resource for the outstanding competitive design of novel products and manufacturing processes.

- [LinkedDesign, 2012) P. LinkedDesign, "Linkeddesign Project Overview." pp. 1–7, 2012.

Besides the unified access to the integrated information, specific knowledge exploitation solutions such as design decision support systems to analyse the integrated information are explored while offering tight feedback mechanisms to existing engineering tools in order to push back formalised knowledge to enable automated design of elementary product components.

Interesting to MAESTRI should be the development of algorithms that could be considered as machine learning to automatically recognize complex patterns and supporting intelligent decisions based on the given data. However, LinkedDesign scenarios involve engineers, manufacturers or other users as essential stakeholders and therefore pure machine learning algorithms based on artificial intelligence are not the main focus but supporting decision making through the generation of a set of high-quality solutions for the tasks at hand.

6.3 Business aspects

After the technological aspects were presented above, this section addresses business aspects regarding IoT. When looking at existing publications regarding Iot, up to now they largely focus either on the "big picture" and visions on how the IoT will change the (business) world, or on technological topics. In comparison, rather few sources address concrete business results of IoT application like concrete figures regarding efficiency improvement potentials or return on investment. However, several sources can be found about IoT related business aspects, for example FLEISCH (2010), who addresses the questions of what is new in IoT and what it means from an economical perspective. WESTERLUND et al (2014) present an initial concept for a business model design tool focusing on the IoT ecosystem, while CHAN (2015) proposes a business model framework, which is also validated in several concrete IoT case studies, each including several collaborating partners.

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According to WESTERLUND et al (2014), there are currently two major trends regarding business perspectives on the IoT topic: i) viewing IoT not just as a technology platform, but also as a business ecosystem; and ii) designing ecosystem business models rather than just focusing on the business model of a single firm.

This section is structured as follows: at first a short overview about the IoT market and application fields will be given. Then several business aspects are addressed, ordered in a "bottom-up" style: starting from preconditions for IoT business like digitalization and virtualization of equipment, processes, products and services, through related business models and application scenarios in industry, up to opportunities in business ecosystems based on IoT. The section will close with an overview of open issues and challenges that companies are facing right now when trying to make business and monetize the IoT.

6.3.1 Overview of the IoT market and ecosystem

According to IEEE (2015), the IoT market is currently rather fragmented: Early players are implementing proprietary solutions in case they see a market potential, and some of these proprietary solutions may possibly evolve into de facto standards. The aim of companies developing and deploying IoT solutions is, on the one hand, to provide and use existing goods and services more efficiently and, on the other hand, to create new goods and services that will drive new revenue streams. Connecting things and allowing data to move is expected to open new markets, just as the Internet did (IEEE, 2015).

Several analysts made promising statistics and predictions for IoT related business aspects. According to Cisco, up to now only 10 billion things are connected, which is just a very small part of the estimated 1.5 trillion things that exist globally and could be connected to the Internet (PIRAS, 2014). According to METERING & SMART ENERGY (2013), global cumulative smart meter deployment increased by 500% between 2008 and 2012, from 46 million to 285 million meters installed, with a further increase to almost one billion installations projected before the end of 2018. According to MORGAN (2014), Gartner expects that there will be 26 billion connected devices by 2020. Cisco expects there will be 50 billion, while Intel expects that there will be 200 billion, and the IDC estimates 212 billion. Looking at industrial players, based on a survey from June 2012 asking large companies about their IoT plans, BUSINESS INSIDER (2014) expected that 82% of companies will have IoT applications implemented into their business in some way by 2017. These huge numbers will have a big impact also regarding financial aspects. GE economists estimate that the wave of innovation unleashed by the industrial Internet could boost global gross domestic product by as much as $10 trillion to $15 trillion over the next 20 years (OVERFELT, 2014) and Gartner estimates that the incremental revenue generated by the Internet of Things suppliers will generate $309 billion by 2020 (BINGHAM, 2014). Another estimation is given by IDC who predict that the worldwide IoT market will grow to $7.1 trillion by 2020, compared to $1.9 trillion in 2013 (PREMRAJAN, 2015). In any case, these are all really big numbers and promise a huge impact in many areas.

Several classes of players will play significant roles in the growing IoT market according to IEEE (2015): Commercial players in the "off-line" world, i.e. manufacturers of the "things" that will form the IoT; Commercial players in the "on-line" world, i.e. providers of IoT-enabling services; Research and academia, developing theories and products to support IoT, but also educating the people who will work in the IoT market in the future; Governments and utilities,

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who are creating smart cities and smart grids, but also shaping technology through funding and settings regulatory frameworks and policies; Entrepreneurs, creating new products and markets; Consumers, who will influence the market by their purchase decisions; Regulatory agencies, who will have an impact regarding aspects of privacy, health, wireless technology, etc.

Very important players from the business point of view will also be standardization bodies, whose work should enable interoperability between devices of different manufacturers. As IoT is a global paradigm, standardisation issues have to be addressed in the global view (GUILLEMIN et al, 2015). IEEE (2015) provides a list of organisations and activities related to IoT standardization, although it is emphasized that due to the fast growth of IoT such a list cannot be complete. An elaborate overview of the IoT standardisation landscape is given in GUILLEMIN et al (2015).

The IoT has also become a priority for the European Commission since the past decade. In the previous RTD Framework Programme (FP7), 27 projects were funded from 2006 to 2013 (see http://cordis.europa.eu/fp7/ict/enet/projects_en.html), creating an active community of large and small companies, universities and research centres that has led to the creation of the European Research Cluster for the Internet of Things (IERC, 2015). These projects triggered several research issues (management, scalability and heterogeneity of devices and users - humans but also machines -; networked, context-aware knowledge; or privacy, security and trust) that are today's bigger challenges for the definitive breakthrough of IoT. The current Horizon 2020 programme is not only focused on solving these issues, but also on driving these technologies to the market, promoting the creation of a European market of devices, applications, and services that compete globally.

Another initiative launched by the European Commission and various key IoT players is the Alliance for the Internet of Things (AIOTI, 2015), whose purpose is to establish a dialogue among all the actors in the IoT ecosystem and to build bridges between research and business. Also remarkable is the support that the European Commission is providing to accelerate the uptake of the so called FIWARE technology, which was developed as part of the FIWARE initiative, which is aiming to build an open sustainable ecosystem around public software platform standards that aim to ease the development of smart Internet applications in multiple sectors (FIWARE, 2015). In this field several acceleration initiatives can be found that support the creation of vertical markets ruled by startups and SMEs that make use of FIWARE technology, many of them in the field of IoT.

There are a big variety of of application fields and therefore market segments that are expected to drive the IoT growth. ATZORI et al (2010) describe several application scenarios from the transportation and logistics domain, the healthcare domain, smart environment domain (home, office, plant) as well as the personal and social domain. CHUI et al (2010) describe several application scenarios in the areas of information and analysis (tracking behaviour, enhanced situational awareness, sensor-driven decision analytics) as well as automation and control (process optimization, optimized resource consumption, complex autonomous systems). HOSAIN (2015) describes a number of consumer as well as enterprise IoT applications already in use today.

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In any case, the mentioned application fields should just be seen as some examples, because eventually applications can be imagined nearly everywhere. Summarized from a business point of view: as essentially every business process in every industry is embedded in the physical world, the IoT is potentially relevant for every step in every value chain (FLEISCH 2010).

While according to IEEE (2015) consumer goods and eHealth will probably be the two primary market segments to initially account for growth in the field of IoT sensors and devices, the following sections will focus mainly on industrial applications of IoT as well as on energy and resource efficiency aspects, as the aim of the MAESTRI project is to improve resource and energy efficiency in industries. However, this does not preclude that other application fields and business models are indicated in some places to get a broader view on the topic.

6.3.2 Digitalization and virtualization of equipment, processes, products and services

The digitalization and virtualization of equipment, processes, products and services is a fundamental base for industries to start with IoT related businesses. *Digitalization* means to equip physical equipment, processes or products with technology (from RFID tags up to (embedded) computers) that enables the connection of physical things to an IoT network, enabling communication possibilities between so called "things". *Virtualization* of a digitalized physical thing means to create a virtual representation of that thing, as a virtualized object, accessible over the IoT. Related to a specific use case it could be necessary to know just the unique identifier (UID)[4] and the location of a thing, but it could also be necessary to get a virtual representation with much more details (ambient conditions, status, actor positions, connections with other things, etc.). To get a more realistic virtual representation of a physical thing, it could become necessary to equip it with further sensors and smart embedded computers to offer, besides classical features like information provision, monitoring and control also extended services and intelligent features (e.g. maintenance or security).

Beyond simple digitalization and virtualization of physical static objects, it is also possible to digitalize and virtualize physical ((electro-) mechanical) systems, which is then often recognized under the term "Cyber-physical System" (CPS): Physical devices/systems are getting their "cyber shadow" and become reachable through a unified network technology, providing their classical features (like monitoring and control) but also advanced features (like the provision of (pre-calculated) (maintenance-, ambient-, etc.) information or analysis/maintenance/etc. features) inside of a cloud, so that such CPS can be seen as things inside of an IoT in case that they rely to the IoT-enabled architecture (ELSEVIER, 2015). But not all things in the IoT need to have a physical nature as described by ESPADA et al (2011). Pure virtual things could be virtual objects which are representing e.g. a new engineered concept for a future product or could be smart objects, which are executing tasks similar to software services or agents. This digitalization and virtualization of equipment, processes, products and services into "things" and the provision of them into an industrial IoT (IIoT) network is in each business domain a fundamental basis for IoT-based business.

[4] A thing inside of an IoT can have more than one identifier, but it requires at least one unique identifier within any domain through which it can be accessed, like an Uniform Resource Identifier (URI) in the classical Web (I. Friese (2015)).

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FLEISCH (2010) took a list of about a hundred existing and emerging applications that leverage the IoT concept. As IoT can in theory applied nearly everywhere, FLEISCH (2010) did not group IoT applications based on application fields, but rather had a look at how IoT applications provide value. He recognized that every investigated application includes one or more of the following seven main value drivers (MVD) that are described in (FLEISCH, 2010):

1. Simplified manual proximity trigger – Means that a thing can communicate their UID when the thing is manually moved into the roaming space of a proximity sensor, where the UID will be scanned to know the location of the thing.
2. Automatic proximity trigger – Adds to MVD 1 the feature to trigger a transaction automatically when the physical distance of two things drops below a threshold.
3. Automatic sensors trigger – Adds to MVD 2 the feature to provide, besides the UID, also additional data that a sensor (which was added to the thing) could collect (including combined or aggregated data).
4. Automatic product security – Means that things often needs to be protected by security features related to proof-of-origin, anti-counterfeiting, product pedigree, and/or access control. The thing to be secured can be equipped with a minicomputer that provides some security features such as cryptography. The space or user confronted with such a smart thing can then check the validity of it by walking through the implemented method, for example, a challenge-response operation.
5. Simple direct user feedback – Means that things provide feedback to events in form of human perceptible signals, e.g. an audio signal or a flashing LED as feedback in case that a manual (MVD 1) or automatic proximity trigger (MVD 2) was activated.
6. Extensive user feedback – Extends MVD 5 by complex event processing features, which means that a simple event as mentioned in MVD 5 triggers a service which can provide more comprehensive user feedback based on knowledge available in the IoT.
7. Mind changing feedback – Means that things have the power to change minds (or the behaviour) of users in case that they will get a feedback about deviation from aimed goals. An illustrative example for this MVD from the FP7 project LifeSaver is described by SUCIC et al (2013): in an industrial business case, production control operators got feedback about their energy consumption and related emissions in comparison to benchmark values, leading to a change in their attitude about energy use in daily operational practices and routines.

Based on the digitalization and virtualization and these IoT value drivers, two practical examples of a "thing" are explained in the following:

(1) An example of a very simple thing could be a product in the assembly process, which is equipped with one RFID tag (digitalization) to provide its UID in case that it reaches an assembly cell (virtualization with MVD 1).

(2) An example of a more complex thing could be a pump equipped with sensors, a drive control device and an embedded device to connect the thing to the IoT network (digitalization). For the virtualization sensors provide information about actor positions, pump speed, motor temperature, ambient temperature, humidity and location (MVD 3); the drive control device provides actor control features; the embedded computer provides pump information as UID (MVD 1), classical monitoring features (sensor data provision and pump specification provision (MVD 3)) and control features (access to the drive control device); and extended features as maintenance

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(MVD 2&6) and security (MVD 4), which also allows communication with other things and users inside of an IoT.

The digitalization and virtualization of (physical) objects (things), which are providing their (extended) features to the IoT, enable the possibility of uni- or bidirectional communication between things and (human) users, and opens the possibility of a reactive or pro-active behaviour of things based on environmental events or cooperation and collaboration with other things and (human) users inside of an IoT network, which is the base for several industrial IoT application opportunities for business as described in the following.

6.3.3 IoT based application opportunities for business improvements in industry

Although automation and software suppliers have been working already for a long time on connecting industrial systems to provide operators and managers with actionable information, these efforts have not always been entirely successful, mainly due to poor interoperability between operational technology and information technology (HILL 2015). Today, due to the emerging IoT, the cost of connectivity is dropping, as automation suppliers and industry can use a wide variety of lower cost, commercial technologies within their industrial connectivity solutions. IoT is increasing automation and providing more flexibility and efficiency to the production process, also allowing localization of individual products in the production lines and the automatic selection of the required production steps. Furthermore, remote and predictive maintenance are improving the efficient operation of entire factories (IEEE 2015).

The industrial IoT will impact industrial companies through the digitalization and virtualization of equipment, processes, products and services because more sensor data will be available, more data in general, more analytics possibilities for a continuous improvement of production processes and a better visibility of production processes. This will create more software and "Manufacturing Execution System (MES)", "Supervisory Control and Data Acquisition (SCADA)", "Human Machine Interface (HMI)" requirements; new product requirements; new production equipment capabilities (software defined, autonomous, intelligent, etc.); new architectures and new service requirements. All these impacts will generate new business possibilities, which will also have an impact on B2B Relationships (GORBACH 2014).

Especially for industrial sectors it can be expected that the visibility of their products and productions processes will be improved, suitable to improve KPIs as productivity or energy efficiency, and to generate future innovations for (collaborative engineered) products, services and business models (GORBACH 2014).

According to HOSAIN (2015), most industrial uses of IoT up to now have been for preventive maintenance, i.e. specific parameters of a machine are monitored to detect conditions that signal that they might need maintenance. But such an IoT usage for preventative maintenance is just a start, as it does not use the possibilities of network-connected devices that can talk to each other, allowing them to work together (HOSAIN 2015). New potential business model possibilities in the manufacturing domain enabled through IoT are locatable in several other areas as e.g. monitoring of KPIs through collected and analysed data of things, energy management, waste management, material flow traceability systems, resource management, marketing through extended product information provision (e.g.

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consumed energy, used materials, etc.), developing business models in ubiquitous computing environments, real time remote diagnosis and resolution of manufacturing problems, improve performance through predictive maintenance, easily share info and collaboration with suppliers, decreasing asset lifecycle costs through remote monitoring, fixes and updates, etc.

Looking at IoT application scenarios in industry and/or regarding energy efficiency aspects, the following scenarios from the literature are suitable examples to show IoT application possibilities related to MAESTRI project objectives.

ATZORI et al (2010), based on SPIESS et al (2009), describe an industrial application scenario, where smart environments help in improving automation in industrial plants with a massive deployment of RFID tags associated to the production parts. In a generic scenario, as production parts reach the processing point, the tag is read by the RFID reader. An event is generated by the reader with all the necessary data, such as the RFID number, and stored on the network. The machine/robot gets notified by this event (as it has subscribed to the service) and picks up the production part. By matching data from the enterprise system and the RFID tag, it knows how to further process the part.

MAZHELIS et al (2012) describe a possible business model regarding IoT-adapted manufacturing processes (with situation-aware smart machines and robots), where manufacturing lines can customize products during the production process. This is cheaper, more flexible, and there is less need for human interaction. Situations can be analysed in real- time by gathering data from sensors. This also facilitates decentralization of business processes to decrease the complexity of supply-chain processes. Application areas are production lines, warehouses, automated storage facilities, or similar. Systems need to be set up by B2B partners, so B2B channels are used to reach customers. The business model is locally set up and can be globally applied for different kinds of production lines. The model is very scalable, adaptable, and fairly easy to copy. Sensors, actuators, sensor networks, robots, and data warehouses are among the technologies used. Focal actors in this business model would be the producers of smart supply chains and robots or machines for supply chains. The supply network would comprise manufacturers of equipment for smart objects, producers of industrial robots and supply chains, data warehouse providers, and companies delivering the needed materials. The network would be open for all companies, but most likely not affordable for small companies. Critical success factors in this business model include the interoperability of production line elements with existing IT environment: IoT-adapted production lines must be adaptable considerably faster compared to traditional ones.

CHUI et al (2010) explain several approaches for automation and process optimization in industries. One example is that industries like chemical production could increase the monitoring granularity by additional sensors. Data from these sensors are automatically analysed to generate control signals to actuators that adjust processes. In chemical production, examples would be modifying ingredient mixtures, temperatures, or pressures. In assembly lines such an approach could be used to change the position of a physical object as it moves down the line, ensuring that it arrives at machine tools in an optimum position, avoiding small deviations that could lead to jams or even damage machine tools. Such IoT based improved process supervision and control allows for major reductions in waste, energy costs, and human intervention.

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A concrete application scenario from the pulp and paper industry is explained by CHUI et al (2010), where the need for frequent manual temperature adjustments by human operators was mitigated using embedded temperature sensors whose data is used to automatically adjust a the kiln flame. The production could be raised by 5 percent, also improving the product quality by reducing temperature variance to near zero.

Another example presented by CHUI et al (2010) is not related to industrial production, but to energy efficiency in data centers – a fast growing segment of global energy demand – which are starting to adopt power-management techniques tied to information feedback. Energy consumption patterns can be rather complex, as the energy usage of servers varies heavily depending on workloads. Therefore sensors have been developed that monitor each server's power use, employing software that balances computing loads and eliminates the need for underused servers and storage devices. Such technologies could become standard features of data centres in the future.

Regarding the future IoT application in industry, CHUI et al (2010) recommend that companies should start using the new technologies to optimize business processes in which traditional approaches have not brought satisfactory returns. Energy consumption efficiency and process optimization are mentioned as good early target areas.

6.3.4 Opportunities in business ecosystems based on IoT

Traditional business models are designed based on a company-centric view and are therefore seen as not adequate for IoT business due to the nature of the IoT ecosystem, in which firms have to collaborate with competitors and across industries. Moreover, fast changing market environments in technology-related industries imply that companies have to quickly adjust to market challenges if they want to succeed (CHAN 2015). Also WESTERLUND et al (2014) suggest that companies should change their focus towards an ecosystem approach of doing business, to overcome current challenges like the huge diversity of IoT objects as well as the immaturity of current IoT solutions. Business model design tools should consider the ecosystem nature of the IoT rather than emphasize an individual company's self-centered objectives.

IoT is expected have an impact on both Business to Business (B2B) and Business to Customer (B2C) relationships. Through a network across companies and consumers where every*thing* is theoretically reachable new business perspectives will be opened, e.g. for IoT based supply chains, IoT based product support and IoT based product feedback. One challenge for entrepreneurs is to open minds for new IoT business possibilities, considering that IoT is an ecosystem where things of business partners and consumers are reachable: consumer products becoming reachable for product manufacturers/other consumers/other business partners; intermediates in the B2B supply chain become reachable; etc. IoT will enable new data mining possibilities, B2B/B2C collaboration possibilities, feedback loops and could automate B2B/B2C processes along the value chain supported by (automated) decision support.

According to HOSAIN (2015), successful industries are seeing potentials for supply chain management based on the data about their own manufacturing processes, collected by IoT systems. Real-time analysis of this information along the supply chain could bring a competitive advantage, as it helps streamlining manufacturing, lowering down, tracking

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goods and improving customer satisfaction. Transferring this view to MAESTRI projects objectives, IoT could support industries to improve resource efficiency through improved IoT based data collection/generation, which could be published along the supply chain. This would e.g. enable suppliers to improve their production planning, based on better information from their customers, thereby saving resources/energy in the overall chain.

Another business opportunity in an IoT based ecosystem is described by CHUI et al 2010: resource consumption could be optimized based on networked sensors and automated feedback mechanisms, which can change the usage patterns for scarce resources, including energy and water, by enabling more dynamic pricing. Utilities are deploying "smart" meters that provide (industrial) customers with visual displays showing energy usage and the real-time costs of providing it at that time of the day. Based on time-of-use pricing and better information customers can shift energy-intensive processes and production away from high-priced periods of peak energy demand to low-priced off-peak hours.

6.3.5 IoT challenges and open issues from the business point of view

The Internet of Things is very promising, but as a precondition for wide adoption, business, policy, and technical challenges have to be addressed (CHUI et al 2010). Many challenges and open issues are mentioned in the literature, which are considered as slowing down the development of the IoT from a business point of view.

One of the issues most frequently mentioned in the literature is the need for standardization. IEEE (2015) states that many IoT applications will require interoperability among devices from different manufacturers, thus requiring that widely accepted standards exist. Otherwise this could lead to fragmented markets if products from different manufacturers do not interoperate and thus can have (relatively) low market penetration and high prices. A similar view is presented by WESTERLUND et al (2014), who see a major challenge in the diversity of objects, referring to the difficulty in designing business models for the IoT due to a multitude of different types of connected objects and devices without commonly accepted or emerging standards. An overview of the standardization requirements for the IoT, based on the work of the IERC (Internet of Things European Research Cluster) is provided by GUILLEMIN et al (2013), considering the currently existing standards, analysing the gaps and providing recommendations for future standardisation activities.

Another one of the most important challenges is summarized by IEEE (2015) under the term "Quadruple trust", covering four aspects that are important for the IoT market discussion: protection, security, privacy and safety. These play a deciding role in the success of IoT-related devices and services and can dramatically affect the reputation of companies providing those products and services. Open questions to be solved according to IEEE (2015) include who provides the various elements of the quadruple trust and how the difficult trade-offs between quadruple trust and usability will be resolved. ATZORI et al (2010) emphasize that people will resist the IoT as long as there is no public confidence that it will not cause serious threats to privacy. Regarding the security aspect, they state that the IoT is extremely vulnerable to attacks because (i) often its components spend most of the time unattended, making it easy to physically attack them; (ii) most of the communications are wireless, making eavesdropping simple; (iii) many IoT components have low energy and computing resources and therefore cannot implement complex security features. BALDINI et al (2015) provide an extensive overview of the challenges identified by the IERC cluster regarding

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governance security and privacy in IoT. Solutions from cluster projects as well as a framework to address the challenges are also presented.

Another business challenge mentioned by WESTERLUND et al (2014) is what they call “immaturity of innovation”, referring to the situation that today’s IoT innovations have not yet matured into products and services that are standardized or modularized for wider usage. This leads to high efforts to couple them together and apply them in other application areas. They say that prerequisites for an emerging market are modularized objects, which have a "plug and play" character of components. IEEE (2015) mentions a related aspect: many current IoT applications start as “silos”, meaning that there are strong barriers preventing other applications from using their information. Although such silos are sometimes necessary (e.g. applications processing health-related data that has to be protected for privacy reasons), in general it is expected that IoT market growth will be slowed down by silos.

When trying to make business in the field of IoT, the unstructured ecosystems are another major challenge according to WESTERLUND et al (2014), lacking defined underlying structures and governance, stakeholder roles, and value-creating logics. Appropriate participants needed for a new business model may be missing or hard to find in an emerging ecosystem. They emphasize that it takes time and is a challenge for managers to pursue new business opportunities, as it often demands to open new relationships in new industries, or to extend existing relationships.

Some further challenges and open issues are mentioned by IEEE (2015): Usability is seen as a vital factor for the growth of all IoT devices and services. Cross-boundary collaboration of usability experts, subject-matter experts of the relevant application areas, and technology experts will be needed to optimize the usability. Another aspect is education: Users of IoT systems will need to be trained to use the system. In case training costs are too high, adoption of IoT systems may be delayed. Also the technologists who are developing IoT systems will need education, especially regarding security features, which could have a big impact if implemented wrong in IoT applications.

CHUI et al (2010) add some additional challenges, e.g. the need for legal liability frameworks for the bad decisions of automated systems. Such legal frameworks will have to be established by governments, companies, and risk analysts, together with insurers. They also mention that the cost of sensors and actuators must fall to levels that will spark widespread use.

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