Article

Industry 4.0 maturity model assessing environmental attributes of manufacturing company

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Abstract: The primary purpose of this article is to present a maturity model dealing with environmental manufacturing processes in a company. First, a theoretical approach is presented where evolution from the first industrial revolution to the present (Industry 4.0.) is outlined with a need to implement environmental initiatives. Chapter two contains a detailed literature review, which resulted in the creation of our own maturity model presented in the next chapter. According to some authors, Industry 4.0 is based on characteristics that have already been the focus of "lean and green" concepts. The practical part of the article is a case study that shows which areas of the manufacturing process have "environmental" potential. The goal was to move from resource consumption, pollutant emissions and more extensive manufacturing towards environmentally responsible manufacturing (ERM). Using environmental materials and methods reduces energy consumption, which generates cost savings and higher profits. Here, VSM (Value Stream Mapping) was applied to identify core processes with environmental potential. The final part of the article summarizes the work and presents future possibilities. This paper provides an understanding of the role of environmental manufacturing in the era of the 4th industrial revolution.

Keywords: carbon footprint; environmental manufacturing; Industry 4.0; maturity models; Value Stream Mapping (VSM)

1. Introduction

Industrial revolutions were characterized by innovations in mechanics (1st industrial revolution), electronics (2nd industrial revolution) and information technologies (3rd industrial revolution) [1]. The 4th industrial revolution combines several key technologies and enables the realization of production in which individual machines and products communicate with each other. The concept is based on the German government's high-tech strategy, which was presented at the Cebit 2013 trade fair in Hanover [2]. It is characterised by information technologies and intelligent cyber-physical systems (CPS) leading to automation of production processes, gradually replacing the human workforce and creating the need for establishing modern workplaces. Cameras, transmitters, sensors, code readers and other higher generation technological devices will help to do this, taking over not only repetitive and simple tasks and dangerous activities but also the intelligent decision-making processes that people are currently carrying out [3] . According to experts [4], this should lead to an increase in production productivity by up to one third compared to the current situation.

Industry 4.0 has arrived just in time for the most critical decade for climate action. The environmental economy concept is widely discussed in many circles due to its qualitative and quantitative aspects. The environmental economy is defined as an economy that aims at reducing environmental risks and ecological scarcities, and that aims for sustainable development without degrading the environment [5]. It is closely related to

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ecological economics, but for our purposes, the environmental aspect is presented in smart factories processes with a focus on environmental production.

The environmental aspect is critical here since it intends to reduce environmental impacts and risks and at the same time achieve organizational profit and market share objectives [6]. The environmental paradigm has its roots in environmental management [7]. Environmental supply chain management adopts environmentally friendly initiatives which can be deployed to decrease the environmental impact [8]. This can be through reduction of waste such as energy, water, air emissions, solid and hazardous waste. According to [9] environmental initiatives should be considered in the initial phase of product design and raw material acquisition, continue throughout the various manufacturing stages, the delivery and distribution of the product to the customer and disposal of the various manufacturing stages, the delivery and distribution of the product to the customer and dispose of end product. The scope of the environmental supply chain ranges from initiatives implemented through reduce, reuse and recycle, rework, return, remanufacturing and reverse logistics [10].

According to [11] there are options for environmental production chain management, for example, reduce the quantity of material used by reducing the quantity of material needed to produce. Also, alternative materials are essential, because by implementing them, we can use them to replace the original material with ones with less environmental impact. Recycling materials that make up the product and searching for alternative products which perform the same function is also a way of "going environmental". Product recycling, reuse and eliminating excessive functions such as stopping production of unused or less used product features are another way of implementing "environmental" standards into production. Digital technologies, as one of the Industry 4.0. pillars, can accelerate the reduction of global emissions by up to 15 per cent by 2030 while being responsible for only 1.4% of global emissions [12].

2. Literature review

Essential topics, such as environmental manufacturing, carbon footprint, costs aspects, industrial engineering methods and maturity models assessing the readiness of companies for Industry 4.0 are included in the proposed maturity model, with environmental aspects evaluating the production and non-production processes. Therefore, these key areas are subject to a literature review, also an overview and knowledge of each area plays an important role.

2.1 Environmental manufacturing and carbon footprint

Environmental manufacturing is primarily about changing business and manufacturing practices, as well as the mind-set of stakeholders, to mitigate the industrial impact on climate change and other environmental concerns. The 4th Industrial Revolution and industrial Internet of Things (IoT) present new opportunities to unlock process innovations to develop sustainable, environmentally-friendly materials, decarbonize energy: digital innovation for doing more with less, and extend goods life cycle within a "zero waste to landfill" framework [13]. Environmental manufacturing offers revolutionary advances in productivity and efficiency without the downsides of waste or pollution. Proper implementation into the entire industry, thus accelerating toward a low-carbon reality [14]. One of the most effective ways to "calculate" the impact of environmental manufacturing is by determining the carbon footprint.

The carbon footprint is calculated by estimating the amount of carbon dioxide and other greenhouse gases (methane, nitrous oxide, and some fluorocarbons) produced during operation and by adding waste streams from manufacturing processes themselves [15]. Corporate carbon footprint (CCF) [16] can be calculated with three scopes: 1) direct emissions, 2) indirect emissions from electricity production and other services, and 3) indirect emissions upstream and/or downstream on the production chain. However, it is possible to calculate the carbon footprint of each part of the manufacturing process. Product carbon footprint (PCF) can be calculated for specific products over their lifecycle, for

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specific applications and use paths to determine the effect products have on emissions and the environment [17].

2.2 *Environmental manufacturing*

Environmental manufacturing accents the environmental philosophy in manufacturing. Environmental manufacturing refers to production processes that pollute less and create less overall production waste. Within this the scope ranges from changing processes to use fewer resources, e.g. finding ways to use less water in specific production techniques, or producing a more durable product with replaceable parts, i.e. a product that fits into a circular economy [18].

Manufacturing in general, (without special environmental regulations) concentrates on all relevant customer needs with legislative regulations taken into account and with a target to minimise production costs. Environmental manufacturing itself, even if it represents a positive approach for the environment, leads to higher costs of manufacturing [19].

For example, European Union states (EU) are trying to accent and support the environmental philosophy with manifestos on the one side [20] and with regulations and subsidies on the other. The second factor can change the situation in costs of manufacturing in order to apply the environmental ones. It has a significant influence on the internal market, where instruments include, for example, a system of emission allowance (European Union) or electro mobility – subsidies. There are also ideas to apply individual taxes to suppliers from external markets that will not comply with environmental aspects [21].

Environmental issues play a role in industrial engineering. Industrial engineering concentrates on optimisation of production and its accompanying processes with target on costs reduction. This cost reduction is standardly primary target, but targets can also differ depending on specific needs [22]. The main subject of this paper is environmental, thus the variety of possibilities that industrial engineering offers, will be concentrated on it. The costs increased issue is considered to be solved at the governmental level that all companies will have the same environmental supporting conditions mentioned above.

Industrial engineering is linked with the lean concept, using a variety of principles and methods (Just in Time, 5S, Kaizen, TPM…). The purpose of the methods differs based on specific needs [23]. For the purpose of this paper, we need first to analyse the process to get the specific information needed to determine green status. To analyse the process, methods like Theory of Constraints (TOC), Force Field Analysis (FFA), Value Stream Mapping (VSM), Critical Path Method (CPM), Ishikawa diagram, Failure Mode and Effect Analysis (FMEA) are used. Each one differs in the specific target of the method. VSM provides the relevant information about the production, logistics with links to maintenance and IT. Other methods provide specific information that is mostly not relevant or not sufficient for the purpose of identifying the environmental status. This is the reason for choosing VSM as the source of information to identify the green status by the proposed maturity model [24].

3. Materials and methods

The concept of Industry 4.0 is at the heart of many futuristic visions of business executives, economists and politicians. We need even more information about the current state of preparation in industry and especially in engineering which is an important industry for the implementation of the Industry 4.0. concept. This chapter looks at maturity models, which are run as a tool for conceptualizing and measuring the maturity of an organization or process related to a specific target state. In principle, these are models that make it possible to identify the current state and prepare for the concept of Industry 4.0 comprehensively throughout a company or in various business areas, or to look for the potential to estimate the state of readiness for the future.

The Capability Maturity Model (CMM) is a crucial concept from which individual maturity models can be selected. The Capability Maturity Model Integration (CMMI) model has been prepared [25]. CMMI is a model that aims to help an organization to plan, define, implement, develop, evaluate, and improve processes. It is not a methodology, but determines the goals that an entrepreneur has and does not have precise prescribed procedures [26].

CMMI models come in various modifications. However, they have the same internal organizational and evaluation principles, which define five levels of maturities. The model is proposed for companies naturally developing the quality of possible processes according to levels. The levels are from the lowest (1st level) Initial, through Managed, Defined, Quantitatively managed up to the highest fifth level Optimization [27].

The individual models of maturity for Industry 4.0 are primarily based on the same, albeit main principles, as CMMI models, so it is important to mention them. The analysed areas (dimensions) are always defined. For large models, dimensions are further extended to sub-dimensions. Also, the method of evaluation is important. The similarity of models in an extensive evaluation is given by a high degree of maturity in given areas (dimensions). There are four to six levels of readiness. They are arranged logically from lowest to highest. They have names and custom characteristics that relate to meeting the scale within the area (dimension). The maturity of a company is expressed in various samples quantitatively in the form of a maturity index.

3.1. Division of maturity models and their main attributes

The primary division of models for evaluation is according to the level of scope. The models are at the macro level, where evaluations are performed concerning countries and show preconditions for development and digitization of the industry in the monitored country. The priority is to improve the country's competitiveness by increasing its innovation capacity and digitization [28]. We primarily focus on micro-level models that assess a company's maturity. At the micro-level, it is not necessary to compare a large number of companies and dozens of indicators [29]. This research focuses on micro models for which there are many modifications and methodologies. The aim is to analyse individual models and their main attributes.

The scientific method in the form of analysis and comparison was used to search for these models. They are academic, but they are also models from practical associations or consulting companies. Of course, the scope and quality of the models are different. In addition to the analysis, the method of abstraction is also performed, where the potential for evaluation of green (environmental) aspects in some of the dimensions is sought.

The models were analysed according to the following main attributes:

1. Source name and origin - Models are from foreign universities, engineering associations, consulting companies, often combining academia and industry.
2. Analysed dimensions – There are different numbers and characters of dimensions. There are usually from a minimum of 3 dimensions up to 9. Some models still use partial sub-dimensions.
3. Evaluation method - Levels for evaluation are very similar for the models. Models with several levels, often from 4 to 6 levels, are used for final evaluation, and these levels are characterized.
4. Potential for evaluation of environmental aspects - Search for a dimension for the evaluation of green (environmental) aspects or perspectives in one of the dimensions.
5. In addition to these critical attributes, of course, other attributes have been analysed, such as model intent, which can be descriptive, comparative, or prescriptive.

The availability is also essential, and the model may be publicly available with an online self-assessment questionnaire or in the form of a practical study or research article with guidance on how to carry out the evaluation. The models were also categorized into groups according to design. The main categories of model implementation are roadmaps, readiness models, maturity models or a framework for assessment.

The difference between maturity and readiness models is that readiness models are used to assess readiness before involvement in the process and to check whether all necessary prerequisites and preparations for the use of technology have been met. Measuring

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technological maturity (readiness) is especially crucial for an organization with respect to its process and proposed goals. Maturity models are used to describe and capture the state of processes, systems, corporate culture and other attributes during the maturation process. Roadmaps are mainly used in technology planning and development. A specific area of technology is precisely represented and provides information on technical requirements or key numbers of technological performance [30].

3.2 Evaluation of maturity models

Thirty-five models were found and analysed, and after selection in terms of quality and suitability, only 19 models were used. Some are very complex, some are more concise. Table 1 shows all the analysed models, including the key attributes surveyed. The model name and the appropriate source are listed. Furthermore, the type of resource is indicated as academic (Acad.), Practical Association (Pract. Assoc.) and consulting companies (Cons. Co.). For the analysed dimensions, the focus of the models plays a role. Some models are designed for production areas, some for logistics or possibly in the field of information security. The number of levels with the names of the lowest and highest level has a purpose in rating method to evaluate needed attributes. Here it is important to note that models use a similar number of levels (usually six levels) with similar names and characteristics.

Table 1 The main attributes of maturity models

Title and source	Source type	Analysed dimensions	Assessing readiness method	Model intention
Impuls – Industrie 4.0 Readiness [31]	Acad Pract. Assoc	6	6 Levels from 0 (Outsider) to 5 (Top performer)	Comp Descr Prescr
SIMMI 4.0 – A Maturity Model for Classifying the Enterprise [32]	Acad	4	5 Stages from 1 (Basic digitization) to 5 (Optimized full digitization)	Descr Prescr
PwC maturity model - Industry 4.0 [33]	Cons. Co.	7	4 Levels from 1 (Digital novice) to 4 (Digital champion)	Descr
A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises [34]	Acad	9	62 criteria. Each criterion is evaluated within 5 levels of readiness.	Descr
A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies [35]	Acad Pract. Assoc	5	5 Levels from 1 (Initial) to 5 (Digital oriented)	Descr
Assessment Model for Industry 4.0: Industry 4.0-MM [36]	Acad	5	6 Levels from 0 (Incomplete) to 5 (Optimizing)	Descr Prescr
An Industry 4 Readiness Assessment Tool [37]	Acad Cons. Co.	6	4 Levels from 1 (Beginner) to 4 (Expert)	Comp Descr Prescr

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M2DDM – A Maturity Model for Data-Driven Manufacturing [38]	Acad.	6	6 Levels 0 (Nonexistent IT Integration) to 5 (Self-Optimizing Factory)	Descr
The Singapore Smart Industry Readiness Index [39].	Pract. Assoc	3	6 Levels from 0 (Undefined() to 5 (Intelligent)	Descr
Asset Performance Management Maturity Model [40].	Cons. Co.	6	5 Levels from 0 (Initial) to 4 (Excellence)	Descr
Towards a Smart Manufacturing Maturity Model [41]	Acad. Pract. Assoc	5	5 Levels from 1 (Novice) to 5 (Expert)	Descr
A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing [42]	Acad. Pract. Assoc Cons. Co.	3	4 Levels from 1 (Connected technologies) to 4 (Smart, predictable manufacturing)	Comp Descr Prescr
The Logistics 4.0 Maturity Model [43]	Acad.	3	5 Levels from 1 (Ignoring) to 5 (Integrated)	Descr
The Degree of readinnes for the implementation of Industry 4.0 [44]	Acad.	8	6 Levels from 1 (Embryonic) to 6 (Ready)	Descr
Acatech Industrie 4.0 Maturity Index [45]	Acad. Pract. Assoc	4	6 Levels from 1: (Computerization) to 6 (Adapt)	Descr .
An Overview of a Smart Manufacturing System Readiness Assessment [46]	Pract. Assoc	4	6 Levels from 1 (Not performed) to 6 (Optimizing)	Comp Descr Prescr
Maturity and Readiness Model for Industry 4.0 Strategy [47]	Acad.	3	6 Levels from 0 (Absence) to 3 (Maturity)	Comp Descr Prescr
A Smartness Assessment Framework for Smart Factories Using Analytic Network Process [48]	Acad.	4	5 Levels from 1 (Checking) to 5 (Autonomy)	Descr
Maturity levels for logistics 4.0 based on NRW'S Industry 4.0 maturity model [49]	Acad.	4	5 Levels from 1 (Unconnected analog production) to 5 (Completely networked production)	Descr

3.3 Findings

The first part of this article deals with a thorough search of the available literature on the main topics - environmental manufacturing and carbon footprint, costs aspects and industrial engineering methods and maturity models assessing the readiness of companies for Industry 4.0. Based on the review, the following summary of findings was established:

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- By implementing environmental "factors" into production (processes), we can achieve sustainable development without degrading the environment.
- Materials recycling or substitution by alternative products (with the same function) is a way of green production.
- Using digital technologies can accelerate the reduction of global emissions.
- Carbon footprint is one of the most effective ways to calculate the impact of green manufacturing,
- Product carbon footprint is used to determine the effect products have on emissions and the environment.
- Environmental manufacturing, even if it represents a positive approach for the environment, leads to higher costs. (This leads to the need for governmental support).
- Maturity models assess a company's readiness for Industry 4.0 in several dimensions, which they classify into several defined levels.
- Environmental aspects are not assessed in maturity models, and they do not occur in dimensions, sub-dimensions, or even in criteria.

The results from the state-of-the art review clearly show (which is also summarized in Table 1) that models for maturity of companies for Industry 4.0 do not include environmental aspects of production, nor the interconnection of carbon footprint (as the main indicator of environmental-friendly production). Thus, it is essential to implement this into a maturity model. Since none of the existing models meet our criteria, a proposal for a new maturity model is presented here.

4. Theory – proposal of a maturity model evaluating environmental aspects

The proposed maturity model evaluating environmental aspects is mainly based on the opinion that models evaluating readiness of companies for Industry 4.0 do not have an integrated assessment of environmental aspects in combination with Industry 4.0. This is the main result of a detailed literature search of a large number of maturity models, which have been analysed and compared, and the main reason why such a model is being newly developed. There are maturity models that assess environmental aspects across companies and use similar principles, but they are not in the context of Industry 4.0. These are, for example, models by [50 - 52]. Within the literature search, resources for Industry 4.0, main technologies, principles, etc. were also examined, which were also described in individual models. Theoretical background was an important aspect for the design of a new model and was therefore composed of maturity models and the concept of Industry 4.0.

Another suitable aspect influencing model design and form is the focus of the authors, who specialize in the field of industrial engineering. In addition to the academic area, the industrial area is also important, where professional interviews took place within the framework of cooperation and workshops.

With regard to these aspects, a maturity model with environmental aspects was gradually developed and designed in 3 main phases working with the main parameters for determining the model structure:

- The main four evaluated dimensions - production, logistics, maintenance and IT related to environmental aspects
- Levels for evaluation with characteristics
- Percentage of CO2 reduction indicator with a link to the related level

4.1 Phase 1 – Determining main dimensions, levels and indicators for evaluation

This phase contains the main steps, such as defining the main model dimensions, setting levels for evaluation and setting the percentage of CO2 reduction indicator with a link to the related level. This phase basically determines the model scope and structure. Individual dimensions are at intersections with levels and they are characterized. In

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addition, the main indicators of given dimensions are incorporated into dimensions for greater detail and coverage. Without these indicators, dimensions would be rather general and the evaluation would not be detailed. Within the characteristics, our model also works with principles of Industry 4.0 in relation to environmental aspects, as carbon footprint decreases with increasing levels of assessment.

The main dimensions are:

- Production
- Logistics
- Maintenance
- IT

There were six levels for processes evaluation in dimensions from the point of view of Industry 4.0 on the basis of analysis and synthesis. Thus, 6 levels of maturity are set for modelling the evaluation of all dimensions, including zero level with the integration of the percentage of CO2 reduction indicator.

The levels with a brief description are:

- Level 0: 0 % Carbon footprint reduction - No implementations in production processes
- Level 1: -10% Carbon footprint reduction - Very limited implementations in production processes
- Level 2: -30 % Carbon footprint reduction - Partly implemented in production processes.
- Level 3: -60 % Carbon footprint reduction - Mostly implemented in production processes
- Level 4: -80 Carbon footprint reduction – Nearly completely implemented in production processes
- Level 5: Carbon neutral company - Totally implemented in production processes.

The set levels have an upward development and from their brief definition it is clear what each level means. However, for evaluation within the model, levels are characterized in even more detail.

Table 2 Maturity model - environmental aspects indicators

Maturity model - environmental aspects indicators:	
Production	**Logistics**
1. Level of automation (I 4.0 implementation, utilization)	1. Level of automation
2. Energy sources - production equipment	2. Packaging management and environment
3. Environmental aspects of production system	3. Environmental aspects of warehouse system
Maintenance	**IT**
1. MRO processes	1. Human resources and material reduction by IT (RPA, paper)
2. Energy consumption and time efficiency	2. Energy management of the company and surrounding areas
3. Lubricants and cleaning agents	3. Use of Industry 4.0 technologies with connection to IT

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Production dimension environmental aspects indicators:

Level of automation (I 4.0 implementation, utilization) corresponds to the modern technologies used in production. It enables the production to be more effective with less waste (and less resources needed), which also leads to improving the environmental characteristics of production.

Energy sources - production equipment is linked with energy sources used by the production equipment. The important factor is the level of environmental status of the energy sources, this leads to use of alternative energy sources.

Environmental aspects of a production system represent other environmental aspects in production than the energy sources and modern technologies. For example: adaptability of the site equipment in the production system, preference of local suppliers of production equipment.

Maintenance dimension environmental aspects indicators:

MRO processes are the main indicator when dealing with the environmental aspects of maintenance in a company. Implementation of CMMS systems hand-in-hand with paperless systems and Industry 4.0 technologies are the main catalysts of environmental-friendly maintenance here.

The second very important aspect is energy consumption and time efficiency. This can be mainly influenced through equipment design (reduction of maintenance steps), pollution prevention and trying to bring resources consumption to a minimal level. At higher levels, environmentally responsible manufacturing (ERM) and environmentally conscious manufacturing (ECM) are implemented.

Lubricant s and cleaning agents are the third main indicator in our model. From not using any (or not caring for or maintaining machinery) at all, through biodegradable lubricants to the most modern synthetic lubricants derived from renewable resources. Tribology is also important here, energy efficient bearings and lubricants can effectively reduce wear, lubrication consumption and extend lubrication frequencies.

Logistics dimension environmental aspects indicators:

Manipulation processes and the level of automation within internal logistics plays a significant role. In internal logistics, where the material input point is a warehouse and the output is, for example, a production line, the goal is to transport goods, material or work-in-progress with minimal human intervention. Manipulation processes can be controlled by a person using transport technology, automated with participation of a person in different areas of the company (warehouse, production), or it is possible to fully interconnect and integrate individual technologies, processes and people into one unit. This achieves complete automation of intralogistics processes and a fully autonomous solution. Transport vehicles use different types of propulsion, while efforts towards environmental solutions include replacing diesel engines, hybrid propulsion, electric propulsion and alternative propulsion that reduces CO2, NOx and airborne particles and reduces the carbon footprint.

Packaging should be designed to allow efficient storage, followed by handling technology used by the company to make efficient use of storage and cargo space. Packaging therefore plays an important role and has important factors that influence the environmental aspects. Businesses strive for packaging with maximum service life, enabling long-lasting packaging cycles and high cyclicality and recyclability, which reduces their costs and are less harmful to the environment, unlike one-way or non-returnable packaging. The packaging is made from plant sources and can be composted at the end of its life cycle. Part of the ecological and labelled packaging is product synergy, to which robotic packaging adapts and creates an autonomous system.

Environmental aspects of a warehouse system apply to logistics and warehousing facilities where the intention is to build energy-efficient buildings, including environmental friendliness. Thus, the main goal is not only economic profit, but also environmental aspects. The indicator addresses energy intensity, intelligent lighting, water and waste management, use of environmentally friendly materials, energy-efficient building elements (double facade cladding, windows, doors) or a building's internal environment quality (or in the best case scenario synergy of all aspects). Warehouses corresponding to Industry 4.0 with regard to the environment have economic and ecological technologies, such as modern heating, cooling and ventilation systems, increased thermal insulation, etc. The highest levels are represented by warehouses built of materials such as wood, or the use of special concrete without CO2.

IT dimension environmental aspects indicators:

Material and human resources reduction is done here by implementing IT. From basic (paper) reduction to more complex forms, where complex systems are digitized and monitored by IT technicians through full automatization of company processes and services (which are automatized or remotely driven). The highest level is represented by complete integration of IT systems, production, logistics and maintenance through a comprehensive exchange of data and information

Energy consumption (efficient energy use) is very important when dealing with environmental manufacturing. The more environmental-friendly production processes there are, the more energy-measurement software is used. Energy consumption is optimized too, later process automation is implemented (RPA). The most advanced form of energy management is represented by the use of alternative energy sources. As a bonus, factories can support ecology by forest creation in empty areas of the plant.

Use and function of IT equipment in the company varies from simple HW and SW which is not interconnected and not used for data exchange, to advanced IT equipment with partial IS implementation. More sophisticated systems represent transfer of information across all company levels, wider use of cloud services and data sharing. Process automation (RPA) also plays a role here. The most advanced use of IT systems is driven by artificial intelligence, which is used to support or control all company functions ("lights-out factories").

4.2 Phase 2 –Application within VSM tool and evaluation

The second phase is focused on use of a maturity model for the evaluation of processes in the main dimensions. The key issue of the whole model and its usability is the application of the model within the VSM tool.

VSM is a tool for identifying waste and shortcomings across business processes (production, logistics processes). VSM focuses on the efficiency of processes, evaluating them in terms of the ratio between their added and non-added value. VSM serves either as a descriptive tool, where it works with the total time sum of activities that add and do not add value or as an improvement tool, where we propose a new procedure for implementing activities and eliminating shortcomings in any area and any process [53].

Within VSM, main production, logistics processes and their main attributes are mapped. The information flow is linked to them and the IT area is therefore covered. Maintenance processes are captured as part of production processes mapping. A questionnaire and a structured interview with company employees are created for the mapping and the model. This is a very important part, as evaluation results depend to a large extent on the quality of the implementation of connectivity with the VSM tool and combines the evaluators.

Table 3 An example of a question for evaluating the production dimension

Production dimension		
Indicator: Energy sources - production equipment		
Question: To what extent does your production equipment uses energy sources in relation to an environmental approach?		
Level 0	No usage in relation to environmental aspects	☐

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Level 1	Measurement of energy consumption, basic waste (water) management in production	☐
Level 2	Advanced waste management in production	☐
Level 3	Alternative energy sources used in production (solar, wind etc.)	☐
Level 4	Green production building using energy recovery. CO2 emissions report for installations.	☐
Level 5	Wide support of negative emissions technologies (Ocean fertilization, enhanced weathering etc.)	☐

Table 4 An example of a question for evaluating the maintenance dimension

Maintenance dimension		
Indicator: Use of lubricants and cleaning agents		
Question: What type of lubricants/cleaning agents are used when dealing with machinery maintenance?		
Level 0	No lubricants are needed (for example because of no leakage through joints and seals; no ground water contamination)/ nor used in the company	☐
Level 1	Tribo-materials, energy efficient bearings and long-life lubricants	☐
Level 2	Use of degradable, and less eco-toxic lubricants	☐
Level 3	Synthetic lubricants, particularly synthetic ether lubricants, derived from renewable resources	☐
Level 4	Tribo-compatible materials with self-lubricating property	☐
Level 5	No lubricants are needed (for example because of no leakage through joints and seals; no ground water contamination)/ nor used in the company	☐

Table 5 An example of a question for evaluating the logistics dimension

Logistics dimension		
Indicator: degree of automation and controllability		
Question: What manipulation technology is used in the company in terms of controllability and automation?		
Level 0	Mechanized manipulation equipment (diesel engines) only human-controlled	☐

Level 1	Manipulation technology for hybrid propulsion units replacing human-controlled diesel engines (CNG) and shortening routes by using, for example, picking systems in the warehouse	☐
Level 2	Manipulation technology driven by electric units and their partial automation, human-controlled, routes reduction and shortening with connection to partial automation of warehouse systems	☐
Level 3	Manipulation technology driven by electric units and their majority automated with collaborative human cooperation. Optimized transport routes and mainly connected to automated warehousing systems	☐
Level 4	Implemented fully autonomous and robotic handling equipment driven by electricity (AGV, drones) adaptable to products. Optimized transport routes and full connection to automated warehousing systems	☐
Level 5	Manipulation technology fueled by alternative energy sources fully adaptable to products and full connection to complex autonomous storage systems	☐

Table 6 An example of a question for evaluating the IT dimension

IT dimension		
Indicator: use of process automation		
Question: What level of process automation is used in your company?		
Level 0	Zero digitization (paper reduction), no implementation in business processes.	☐
Level 1	More complex digitization (paper reduction). Minimal cloud use.	☐
Level 2	Advanced digitalization, data and information largely managed by humans. Optimization of energy consumption for IT products and services.	☐
Level 3	More improved digitalization. Alternative energy sources used for IT. Implemented IS across the company with basic automation (RPA).	☐
Level 4	Minimal human participation. Most of processes automatized or remotely driven.) Environmentally-oriented cloud computing and services.	☐
Level 5	Complete integration of IT systems through all company sectors, comprehensive exchange of data and information. Artificial intelligence systems widely implemented.	☐

4.3 Phase 3 – Final level evaluation in given dimensions

The third phase is the final evaluation of levels in individual dimensions using a combination of the VSM tool and maturity model. The result of the VSM application is a map of the current state and a capture of the key attributes and VA index. However, based on the model application, it is possible to further determine levels in individual

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dimensions and the characteristics of the main indicators of the dimension. The company will find the areas where the level of maturity should be improved and increased.

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Table 7 Production dimension

Level	Main indicators	0	1	2	3	4	5
CF reduction		0 % carbon footprint reduction	-10% carbon footprint reduction	-30 % carbon footprint reduction	-60 % carbon footprint reduction	-80 % carbon footprint reduction	Carbon neutral company
Production	Level of automation (Industry 4.0 implementation, utilization)	No implementations in production processes	Partial interconnection of production equipment (machines, lines…) with IS – basic digitization	Level 1 + Basic automation of production processes with employee participation	Level 2 + Automated machines and production lines with human collaboration, Communication is conducted online.	Level 3 + Implementation of robots replacing workers – supervision of the process still needed, Machines and production lines autonomously connected	Level 4 + Highest form of autonomous manufacturing company - fully robotic and autonomous machinery; implementation of "lights-out factory"
	Energy sources - production equipment	No implementations in production processes	Basic water and waste machinery management – basic reduction of energy needed + basic utilization of waste, Measurement of energy consumption	Level 1 + Advanced water and waste management in production, Paperless production management system	Level 2 + Alternative energy sources used for production energy supply (solar, wind, smart lighting…)	Level 3 + Green production building using energy recovery, CO2 emissions report for installations, Implementation of artificial Intelligence (AI) to manage energy sources	Level 4 + Production fully use of alternative energy sources, Eliminating all waste streams associated with production
	Green aspects of production system	No implementations in production processes	Basic adaptability of production workplaces to the equipment - lighting, ventilation	L1 + Preference of local suppliers of production needs (equipment, etc.), Adapted workplace for equipment (with waste usage)	L2 + Heat insulation of production plant building, Production space built of green materials (wood)	L3 + Empty areas of plant (roof, etc.) environmentally used - (vegetation, etc.), Support of forest creation to balance CO2 creation in production	L4 + Wide support of negative emissions technologies (ocean fertilization, etc.) to outweigh CO2 creation in production

Table 8 Maintenance dimension

Level	Main indicators	0	1	2	3	4	5
CF reduction		0 % carbon footprint reduction	-10% carbon footprint reduction	-30 % carbon footprint reduction	-60 % carbon footprint reduction	-80 % carbon footprint reduction	Carbon neutral company
Maintenance	MRO processses	No implementations in MRO (maintenance, repairs and operations)	Basic monitoring.. Minimizing unnecessary travel and easy to transport. Proper (also use of natural) lightning and ventilation.	Level 1 + Small implementation of CMMS, maintenance processes focused on functionality. Paperless maintenance management system.	Level 2 + Implemented in MRO. Mainly by application of CMMS, other business information systems.	Level 3 + Implementation of artificial Intelligence (AI) On-line sensors, dashboards, etc. means minimal number of physical workers in MRO..	Level 4 + totally implemented in MRO.. Big data and predictive maintenance as catalysts for improving food efficiencies.
	Energy consumption and time efficiency	Energy consumption is not monitored, nor optimized	Reduction of paperwork by for example using easy IS for maintenance. Equipment design to reduce maintenance steps.	Responsibility of plant protection. Pollution prevention.	No use of paper, communication human/human, human/machine, machine/machine is conducted online. Environmentally compatible plant layout and design.	Practice of environmental guidelines/standards, waste disposal programmes. Minimum resource consumption, minimum transportation requirements.	Eliminating all waste streams associated with maintenance. Auditing the impact of maintenance on environment
	Lubricants and cleaning agents	Machine itself not maintained nor cared about at all.	Using bio-degradable lubricants and cleaning agents	Energy efficient bearings and lubricants based on effective tribological practices in order to reduce wear, extend lubrication frequencies and	Use of environmentally compatible lubricants or cleaning agents	Use of synthetic lubricants derived from renewable resources.	. Use of cleaning agents in accordance with environmentally responsible manufacturing (ERM) and environmentally conscious

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				reduce lubrication consumption.			manufacturing (ECM) principles

Table 9 Logistics dimension 1

Level	Main indicators	0	1	2	3	4	5
CF reduction		0 % carbon footprint reduction	-10% carbon footprint reduction	-30 % carbon footprint reduction	-60 % carbon footprint reduction	-80 % carbon footprint reduction	Carbon neutral company
Logistics	Level of automation and drive	Mechanized handling technology controlled only by human, non-ecological diesel engines used.	Implementation of hybrid propulsion units reducing CO2, NOx and airborne particles replacing diesel engines (CNG).	Level 1 + Implementation of electric drive units and their partial automation. Reduction of transport routes.	Level 2 + Implementation of electric power units and their majority automation with collaborative human cooperation. Optimization of transport routes.	Level 3 + Implementation of fully autonomous handling equipment for renewable electric drives (AGV) adaptable to products	Level 4 + Handling technology for alternative energy sources
	Packaging management and environment	The company is not engaged in packaging management. Packaging is not recyclable, non-ecological, there is no multiple use.	Basic packaging management, waste sorting, possible packaging recycling. Multiple packaging, low packaging reusability.	The company is engaged in packaging management. Recyclable packaging with possible multiple uses.	The company uses specialists in packaging management. Recyclable shared packaging, multiple use.	Own department for packaging management. Special recyclable packaging for multiple uses (biodegradable, plant origin)	Own department for packaging management. Use of packaging waste, use of natural materials for packaging production - composting possibility.

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	Environmental aspects of warehouse system	Warehouses without economic and ecological technologies. Unsustainable energy consumption.	Vertical storage system for picking with limited handling equipment in the warehouse, with intelligent lighting according to motion detection.	Partial automation of warehouse systems with the installation of energy-efficient systems ((LED) with detection, air recycling, ventilation, airtight windows).	Comprehensive autonomous warehouse solution with energy-efficient systems (heating, cooling, airtight construction). Use of data for energy consumption management.	Fully automated autonomous green storage areas (intelligent lighting, solar panels, thermal insulation, airtight construction). Smart communication technologies for CO2 emissions reporting.	Fully automated green storage areas (intelligent lighting, solar panels, rainwater harvesting) with climate protection elements, built of green materials (wood, CO2-free concrete).

Table 10 IT dimension

Level	Main indicators	0	1	2	3	4	5
CF reduction		0 % carbon footprint reduction	-10% carbon footprint reduction	-30 % carbon footprint reduction	-60 % carbon footprint reduction	-80 % carbon footprint reduction	Carbon neutral company
Information technologies	Human resources and material reduction by IT (RPA, paper)	Basic digitization (paper reduction), zero implementation in business processes	More complex digitization (paper reduction) and more complex IT equipment, but without IS and data exchange.	Level 1 + Advanced digitalization (advanced paper reduction). Data and information across various functions are largely managed by humans.	Level 2 + More improved digitalization. Minimal paper use.	Level 3 + Minimal human participation. Most of processes automatized or remotely driven	Level 4 + Complete integration of IT systems, production, logistics and maintenance through and comprehensive exchange of data and information.

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	Energy management - plant and dedicated areas	Energy consumption is neither monitored, nor measured.	Basic SW measurement of energy consumption for IT products and services.	More advanced SW measurement and especially optimization of energy consumption for IT products and services.	Isolation of IT plant areas (Significant reduction of heat), Alternative energy sources used for IT energy supply (solar, wind, etc.).	Widely IT process automation implemented (RPA) green oriented cloud computing and services which used the alternative energy sources (solar, wind, etc.).	Empty areas of plant used for vegetation, (trees, etc.), support of forest creation.
	IT equipment	Basic IT equipment without IS and data exchange	Minimal cloud use. Computer hardware built from environmentally-friendly materials	Advanced IT equipment with partial IS according to the department and basic management of business processes.	Implemented IS across the company. Transfer of information across all company levels. Wider use of cloud services and data sharing. Basic IT process automation (RPA).	Basic use of artificial intelligence systems. Exchange of data and information using advanced IT systems across the company and IS manages business processes.	Artificial intelligence systems widely implemented - AI is used for support of control related all company functions.

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5. Case study

In this part, a case study will be presented to illustrate the use of the application of the proposed maturity model evaluating the environmental aspects of a company. The case study mainly contains an analytical phase, which is divided into several main steps.

The analytical phase maps the current state of processes in the company, and the proposed maturity model is used in combination with the VSM tool.

Mapping the current situation in manufacturing and non-manufacturing sectors reveals possible losses, bottlenecks, shortcomings and reasons for inefficient flows in workplace processes, in the production system or warehouses. The next part of the analytical phase is the evaluation of the current state. The state of environmental aspects in individual dimensions will also be evaluated using the model. The result of the analytical phase is the input for the implementation phase, which deals with the design of corrective measures aimed at improving the situation in identified areas. Finally, the evaluation and outputs of the case study are performed.

It is important to mention that the proposed readiness model is mainly of a diagnostic nature and thus is only presented in principle in this case study. The main task is the analytical phase and evaluation of the current state of company maturity.

Aim of the case study:

Mapping the current state of processes in the company concerning green (environmental) aspects and finding potential in production, non-production and logistics areas. Application of the newly designed maturity model is the crucial issue in combination with the VSM tool.

5.1 Analytical phase – mapping the current state

The analysis of the current state was performed in a company that focuses on development, design, manufacture and installation of electromechanical components for the automotive industry. The company selected one product – an electronic aesthetic facet made of polycarbonate because the company is interested in finding out the particular state of production and non-production processes. The main attributes of the company are listed in Table 11.

Table 11 Main attributes of the company

Attribute	Assumption and Constraints
Business size	Medium-sized business
Business branch	Automotive
Production repeatability	High
Data availability	From information systems, monitoring, measurement
Complexity of non-manufacturing processes	Standard logistics equipment (warehousing and handling technology)
Complexity of production processes	Standard production equipment, production lines

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In this analytical phase a tool - Value Stream Mapping (VSM) was applied. In the maturity model we work with four main dimensions - production, logistics, maintenance and information technology. Thanks to this tool, we are also able to obtain detailed information about environmental aspects with corresponding dimensions. The maturity model is incorporated into the mapping. The versatility of the VSM tool is therefore essential.

We use this tool to map production process and information about them in detail. We find out machine attributes, the principle of production, machine controllability, production times, conversion times, tools and accessories, number of manufactured pieces, availability and workplace ergonomics.

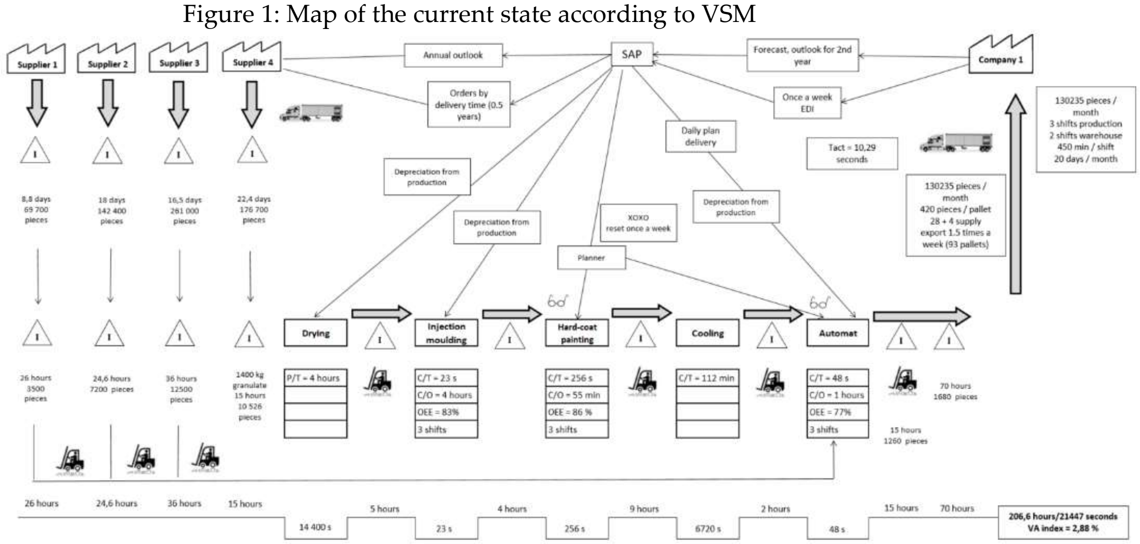
VSM has a wide range of applications in the field of internal logistics processes, such as handling, packaging, supply or storage. On this basis, we obtain information about material flows of a given product, which are later carried out throughout the company. The main parameters of material flows are the distances between workplaces, transport time, type of transport equipment, controllability of equipment, fleet equipment, handling units, types of packaging.

The use of VSM is marginal in maintenance management. However, it can be used to describe, for example, maintenance processes on monitored machines and this is the basis for describing (standardizing) the required condition. This can be helped by reports on machine maintenance, set plans for check-ups, maintenance tools used, etc.

We also use the tool to evaluate information flow. Information flows in the manufacturing plant are recorded. These include manual information transfer, electronic information transfer, material recalls, weekly scheduling, and so on.

Figure 1 shows a map of the current state according to the principles of VSM in the company. The production processes with the main measured parameters are shown graphically. The main processes include drying, injection moulding, hard coat painting, cooling and automat. Logistic processes were also recorded for manipulation between production processes with the main parameters, i.e. how long the material is stored in "intermediate warehouses" and in what quantity. The ratio of times adding the value to times not adding creates the resulting VA index.

Figure 1: Map of the current state according to VSM



During the mapping of the current state according to the VSM tool, structured interviews and a questionnaire are used to assess readiness according to the maturity model. The questions are designed so that the answers correspond to given levels. They always apply to each dimension and the relevant indicator, which are presented in Table 2.

After obtaining the relevant information about the initial conditions and the levels of particular dimensions in the maturity model, the green aspects have to be determined. To determine the levels, the current situation of the plant has to be evaluated. To evaluate the

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situation of the plant, specific "environmental" aspect indicators relevant to the maturity model, are used.

5.2 Analytical phase - evaluation

The results of individual dimensions are further characterized according to the maturity model. The following steps were completed during the previous part of the analytical phase: current state mapping, the questionnaire and structured interviews with relevant plant employees (mainly specialists, different levels of management) of the departments related to the dimensions of the maturity model. Based on the results from the questionnaire and structured interviews the individual dimensions of the maturity model were evaluated and the current levels of the dimensions were determined. Examples of the questions in the questionnaire are given in tables 3 to 6. Together with the VSM, the questionnaire is the basic tool for maturity model evaluation.

The current situation of the "environmental" aspects in the production company is shown in the maturity model classification in the table below (spider diagram).

Table 12 Evaluation and classification of dimensions into levels

Maturity model - environmental aspects current situation					
Production			**Logistics**		
Level of automation (I 4.0 implementation, utilization)	Energy sources - production equipment	Environmental aspects of production system	Level of automation	Packaging management and environment	Environmental aspects of warehouse system
1	**0**	**1**	**1**	**1**	**1**
Maintenance			**IT**		
MRO processes	Energy consumption and time efficiency	Lubricants and cleaning agents	Human resources and material reduction by IT (RPA, paper)	Energy management of the company and surrounding areas	Use of Industry 4.0 technologies with connection to IT
2	**0**	**1**	**2**	**0**	**1**

The table consists of 4 main dimensions in the manufacturing company: Production, Logistics, Maintenance and IT. Each area has 3 main indicators described in tables 7 to 10. Based on the questionnaires we determined levels for each indicator resulting in the final spider diagram below.

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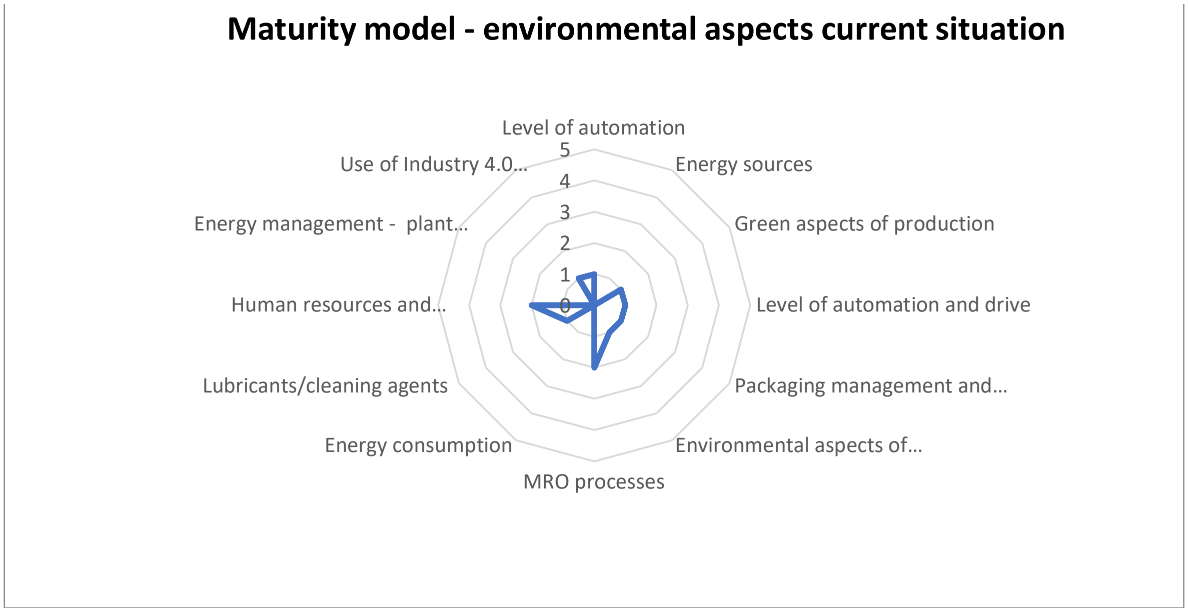

Figure 1. Maturity model - environmental aspects current situation.

6 Results

The overall level of each selected dimension depends on the evaluation of the specific indicators defined in Table 2. The evaluation was based on the questionnaire (see example questions in tables 3 to 6)

6.1 Production dimension

a. Level of automation (Industry 4.0 implementation, utilization) is the main environmental indicator, when dealing with production. Many technologies offer the potential to reduce emissions. Implementing can reduce the need for factory floor space. Using (collaborative) robots in the factory not only raises the level of efficiency, but also reduces the number of human workers, cost for heating and lighting (transition to "lights-out factories"), which is considered as the highest form of an autonomous manufacturing company.

b. Energy sources - production equipment indicator is in this case related to the previous one. Adjusting energy loads on machines can reduce energy use hand in hand with reducing carbon footprint. Another form of energy reduction is lowering heating requirements. Lowering cycle times also tends to a lower final energy output. Electric motors drain the greatest amount of power. Manufacturers use these motors in factories to act as generators and provide mechanical or hydraulic capabilities. Consumption and production increase the total demand for electricity and can easily raise greenhouse gas emissions, depending on the carbon footprints of the power sources used.

c. The environmental aspects of the production system indicator are mainly linked to factory pollution. These are mainly related to air pollution, emissions, toxic waste disposal or contamination of water. Consumption of non-recyclable resources and rapid population growth is also important here. Environmental impacts can be divided into local, regional or global. The bigger the impact is, the bigger threat it represents.

6.2 Logistics dimension

d. The indicator relates to handling technology used in internal logistics in production and storage facilities. Based on a structured interview and visual inspection and observation of use of handling equipment, companies use forklifts, low lift trucks, picking trucks, pallet trucks and conventional trucks. This technology uses several types of power units. Basic diesel engines are gradually being replaced by LPG engines. Companies are also using and testing electric trucks in the warehouse for picking goods. The warehouse technology is connected to the information system and material flow is optimized according to material call actions. All technology is human controlled. Traffic routes and their reduction are optimized.

e. There is basic packaging management in companies, which deals with individual packaging and subsequent recycling (ecological use). There are several types of packaging of different sizes. The minimum packaging is disposable. Reusable packaging has multiple circulation options (up to 20, 20-50 and over 50 circuits). Most packaging is recyclable (plastic packaging) and is environmentally friendly. The company sorts waste, possibly uses packaging secondarily for other products, has a set percentage of packaging waste.

f. The indicator emphasizes the energy aspects of storage space for material storage and work in progress. There is a minimum of economic and ecological technologies in the storage space. Some rooms are designed so that only part of a room where movement of people and machines is detected is illuminated. It is possible to light up the storage space completely independently. No modern heating or ventilation systems, thermal insulation, thermally insulated bridges are used here. The warehouse has a vertical elevator warehouse stacker for storing and picking material. This corresponds with the first indicator (level of automation) and technology, however the stacker is static in nature.

6.3 Maintenance dimension – it must be said that the environmental aspect plays only a small role in maintenance, repairs and operations (MRO) dimensions, however, we still succeeded in defining three main indicators here.

g. MRO processes are very important. Machinery maintenance itself has a long history beginning after World War II. Since then, all forms of maintenance from "no maintenance" (where operators did not care at all, once machinery was broken, it was just changed) through preventive and predictive maintenance to most advanced types of maintenance using Industry 4.0 technologies (implementation of Artificial Intelligence (AI), use of on-line sensors, dashboards, etc. in order to reduce the number of physical workers in MRO). Also, computerized maintenance management systems (CMMS) are a step in the right direction towards environmentally responsible manufacturing (ERM). Right (also use of natural) lighting and ventilation combined with paperless maintenance management systems also support this system.

h. Energy consumption is directly related to environmentally-oriented maintenance. You can reduce the amount of paper by implementing easy IS for maintenance (CMMS mentioned above). Also, with proper equipment design (which is reflected in the decline of resource consumption and transportation requirements) you can reduce maintenance steps. Pollution prevention (also eliminating waste streams) and environmentally compatible plant layout and design is also related to proper energy management.

i. By using bio-degradable lubricants and cleaning agents, you can effectively reduce wear, extend lubrication intervals and reduce lubrication consumption. Use of environmentally compatible lubricants or cleaning agents, synthetic lubricants derived from renewable resources is in accordance with environmentally responsible manufacturing (ERM) and environmentally conscious manufacturing (ECM) principles

6.4 IT dimension

j. Human resources and material reduction by IT (mostly done by implementing RPA). Digitization in companies can fulfil the basic function (paper reduction) from zero implementation in business processes to more complex, where data and information across various functions are largely managed by humans to complete integration of

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IT systems (and other dimensions of production, logistics and maintenance) through comprehensive exchange of data and information.

k. Energy management does not play such a big role, as for example in the production or maintenance dimensions, but it is necessary to mention it. Basic software measurement of energy consumption for IT products and services is often optimized for less energy consumption. Also, alternative energy sources are used for IT energy supply (solar, wind, etc.). The highest level is represented by wide IT process automation implemented (RPA) with green oriented cloud computing and services. Empty company areas are used for forest creation.

l. IT equipment is directly linked to transfer of information across all company levels, use of cloud services and data sharing and IT processes automation (RPA). Artificial intelligence systems are implemented and have a supporting function in implementing environmental principles in all company functions.

The subsequent implementation is structured into three basic phases. The first phase is focused on processing outputs from the analytical part, evaluation and classification of individual dimensions into levels and determination of the most critical areas (indicators). The second phase begins with the decision of whether it is necessary to optimize the whole dimension or only a partial indicator, which is then selected and partial measures are determined for it. The third phase is defining ways to achieve improvements in each of the key areas. The procedures are processed, including determination of the necessary methods and tools.

7. Discussion

Industry 4.0 presents challenges and opportunities for environmental protection. This paper argues that integration among concepts and technologies of Industry 4.0 would unlock the potential for environmentally responsible manufacturing (ERM) and environmentally conscious manufacturing (ECM). Four main dimensions (production, logistics, maintenance and IT) were presented. The importance of the model is shown not purely in improving production factors, but also the involvement of other important parts (logistics, maintenance and IT). These implementations need to be done in order to increase the level of potential for environmental production. We proposed a few solutions described in more detail in part 4.3.

Every level of each specific model dimension is connected to the approximation of carbon footprint reduction that represents a measure of the environmental level related to a particular sector (industry, companies, automobiles, etc.). The levels of the aspects were created with a focus on the practical examples of what technology (equipment, etc.) has to be implemented to reach the specific level, and this makes the evaluation part performed with the model easier. This also simplifies the proposals about what (technologies) to concentrate on to reach a better level (and carbon footprint reduction) in specific aspects.

Further developments assume adding more dimensions to the existing maturity model. In the proposed model we calculated only with four main dimensions (production, logistics, maintenance and IT) in order to increase their environmental potential. These dimensions were selected as the "most important". Further research will add other new dimensions (controlling, quality management, etc.) or subdimensions of the existing ones (divide logistics into internal and external logistics, divide maintenance into corrective, preventive, predictive, etc.).

Since globalisation and internationalisation is an ongoing trend in manufacturing processes, adding PEST (external) factors to the model seems a viable option. Also, questionnaires and structured interviews created for mapping the model (part 4.2.) can be modified (as more experience is gained with the model) in order to get better structured results. Finally, our initial model was operating with only 3 indicators for each dimension. Future work assumes implementation of more indicators for each factor to get a more detailed maturity model of the environmental aspects in all levels of company production processes.

8. Conclusions

The ongoing 4th industrial revolution is now a major trend in production systems, merging modern technologies (IoT, big data, cyber-physical systems, robots, drones, smart manufacturing, etc.) in order to achieve the highest possible level of automation with very few or no workers at all (lights-out factories). A comprehensive literature review of models from universities, engineering associations and consulting companies was made. This model combined academic and industrial approaches. From an initial thirty-five models only 19 models were used and presented in Table 1. The results clearly show that almost none of the available Industry 4.0 related models include environmental aspects of manufacturing (or related processes) in the company, nor their interconnection with the carbon footprint (as the main indicator of environmental-friendly production).

This was the main reason for creating the environmentally related maturity model in the context of Industry 4.0 technologies used in companies. The addition of "environment aspect" to the maturity model respecting Industry 4.0 technologies is in general the most significant result of the work.

The proposed maturity model can be used in two ways:

- as a diagnostic tool (only analytical parts of the model), or it is possible to use
- part of a phase of implementation, when proposed measures are applied as a part of a comprehensive methodology.

Within the case study presented in the article, the analytical part and evaluation of the current state are described. The potential for using the maturity model is in combination with the VSM tool as is shown in the case study. The results of this part of the article serve as input data for the execution part (Part 5 – Case study onwards). The implementation phase deals with the design of corrective measures aimed at improving specified dimensions (production, manufacturing, logistics and information technologies) in a way to reduce carbon footprint (as mentioned, this is the main measurable indicator) according to the maturity model. The potential for using the maturity model is in combination with the VSM tool.

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