Identification of maintenance factors influencing the development of sustainable production processes – a pilot study

M Jasiulewicz-Kaczmarek
Poznan University of Technology, Faculty of Engineering Management, Strzelecka St. 11, 60-965, Poznan, Poland
E-mail: malgorzata.jasiulewicz-kaczmarek@put.poznan.pl

Abstract. From the sustainable production perspective, the concept of sustainable management of the maintenance system covers activities/processes implemented at all levels of management (strategic, tactical and operational), including all the factors (TBL) and functions enabling achievement of goals and providing ability to create value in the long-term horizon. Considering the fact that sustainable development is a concept that assumes long-term sustainable results, sustainable maintenance management should refer to all levels of management, including strategic, tactical and operational. Therefore, considering maintenance from the perspective of sustainable development requires knowledge, measurement and assessment of economic, ecological and social effects of maintenance processes realization. Hence, it is necessary to develop a new approach to maintenance assessment that complements the conventional – and so far in most cases economic only - aspects. Based on the analysis of the literature on sustainable production and maintenance, factors which can significantly contribute to effective dealing with challenges of sustainable production by implementation of maintenance activities have been identified.

1. Introduction
About thirty years ago, sustainable development was defined as a ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’. This definition was quickly interpreted in terms of the necessity to balance economic growth and environmental degradation in a world with limited resources and a fast growing population. Sustainable manufacturing (SM) is one of the main contributors to sustainable development. Consequently, in the last few years, research is focusing on this new paradigm, which aims to develop sustainable production processes, innovative technologies, and new tools for evaluating economic, environmental, and social impacts of industrial assets. In this context, maintenance process, necessary to ensure availability, reliability, and safety of industrial assets, could become one of the main pillars for sustainable manufacturing [16]
Over the years, along with the production process, maintenance has evolved from the reactive function, through preventive, lean (Lean Maintenance), green (Green Maintenance), to the modern approach in which it is considered a process that should be managed in a sustainable perspective (figure 1) In the literature, the role of maintenance in the implementation of sustainable production goals is emphasized many times, e.g. [18, 38, 50], however, there is still no comprehensive theoretical and empirical research in this area.
The goal of the paper is: 1) to identify, basing on literature research, maintenance factors relevant to the development of sustainable production processes, 2) to determine their rank - perception by manufacturing companies (from the perspective of managers of maintenance and production management), 3) to carry out structural analysis of these factors for modeling future directions of maintenance activities on the example of a plastics processing enterprise. This paper presents the first part of the research carried out in the years 2016 – 2017.

Figure 1. The evolution of maintenance on a time perspective [23].

2 Literature research

2.1. Sustainable manufacturing

One of the most important issues regarding sustainable development is sustainable manufacturing [18]. Realizing a sustainable production means facing all the three dimensions of sustainability at the same time (i.e., planet, profit, and people). In this context, traditional aspects such as cost reduction, productivity increase, resources efficiency, and high quality are no longer sufficient. They have to be integrated with new social items: e.g., working environment conditions, workers’ satisfaction, workers’ safety, physical and ergonomics [7].

The term 'Sustainable Production' was introduced at the UN Conference in Rio de Janeiro in 1992. It is defined in many ways, depending on the author and the direction of their research. Some authors define SM as a strategy or approach, while others as a paradigm or a system. Moreover, analysis of the literature on the subject has led to the conclusion that the definitions of SM not always cover all three dimensions of sustainable development. The lack of an unambiguous definition of sustainable manufacturing and consequences of that fact for enterprises are emphasized in the literature among others by [17, 26, 40, 65]. Moldavska [40] suggest that the use of complexity theory’s ideas to study sustainable manufacturing may help to overcome the shortcoming of the current approaches to analyze and reach sustainable manufacturing. “The focal point of the complexity theory is not to study complexity, but to understand the behavior of complex systems, such as manufacturing organization” [40]. According [42], ‘system has a sustainable development if that development enables it to maintain its wholeness as an integral system, whilst also maintaining its role as part of a larger system on which it depends’. The production organization should therefore be considered as a subsystem that does not focus solely on its own results but also contributes to global sustainability. Based on this assumption, [40] defines sustainable manufacturing as a ‘system that contributes to the sustainability of the large system while maintaining its own sustainability. Justifying the definition of SM, she introduced the term ‘attractor’ by defining it according to Antonelli’s approach [4] as ‘a set of values in the phase space to which a system migrates over time’, where the phase space is an abstract space that represents a system’s behavior that has as many dimensions as the variables of the system. Sustainable manufacturing organization is one of the elements of the world system and has its own attractor, i.e. sustainability. Manufacturing organization tends to maintain its own sustainability, as well as contribute to the sustainability of the world. But, manufacturing organization is also a complex system.
consisting of different interconnected sub-systems. One of the sub-systems is a production department, which has its own set of sustainability values, and which contributes to the sustainability of the larger system, i.e. manufacturing organization. The definition of sustainable manufacturing introduced above and its consequences, according to the author, have a significant impact on building a framework and models of assessment not only of sustainable production, but also of other subsystems of the enterprise, including, for example, maintenance.

The objective of sustainable manufacturing is to achieve balance between the environmental, social and economic dimensions of the processes implemented so as to meet the requirements of stakeholders and achieve competitive advantage. Implementation of such a goal requires developing adequate strategies, introducing them to the company's everyday practices and measuring the results of their effectiveness. Analyzing the literature on the SM paradigm, one can indicate four pillars important from the point of view of developing sustainable production strategy: the idea of TBL, the life cycle of the product, stakeholders (there are lots of stakeholders during asset lifecycle, for example: owner of asset, production and maintenance departments, external agents (maintenance service provider), end users, regulators related to health and safety [47] and supply chain management [20]. Corporate strategies based on these pillars were the impulse for developing numerous practices and projects undertaken by companies. Alayón et al [3] defined SM practices as “the actions, initiatives and techniques that positively affect the environmental, social or economic performance of a firm; helping to control or mitigate the impacts of the firm's operations in the triple bottom line”. The majority of studies on sustainability practices have tackled mainly environmental practices. The most common environmental sustainability practices among large companies were eco-design, renewable energy usage, energy and material optimization, recycling, product life cycle and end of life-cycle management, and waste minimization. Regarding social sustainability the most often implemented practices, specifically about workers are: internal safety inspections, external work environment audits, employee training on hazardous risks, health and safety management systems, training plans, career development programs, and employee rotation. With regard to economic sustainability the most often implemented by manufacturing organization practices are e.g. financial KPI measurement, monitoring and assessing the business objectives, and technology investment prioritization. Generally, development of sustainable manufacturing practices, as well as their efficiency assessment systems is observed at three levels: products, processes and systems (figure 2).

At the product level, the traditional 3R concept (Reduce, Reuse, Recycle) has been transformed into a more balanced approach of 6R (Reduce, Reuse, Recycle, Redesign, Remanufacture), resulting in a
paradigm shift from a single product life cycle to many life cycles [27]. At the process level, actions were taken to optimize technological processes [28, 31] and to plan production processes better in order to reduce resource consumption, waste generation and threats related to the work environment and the work itself [18, 34, 45]. However, at the level of the operating system, actions evolve towards supply chain management [19], better cooperation between the company and clients, etc.

According to literature, the last few years have seen an increase in research focusing on the new paradigm of sustainable manufacturing. After [18], SM research should be conducted in five areas: sustainable technologies, resource management, sustainable product life cycle and production system, sustainable product and production, and sustainable business. The aim of the research is to develop sustainable production processes, support innovative technologies and provide new tools for assessing the economic, environmental and social impact of production processes. In this context, according to 14, 18, 22, 24, 38, 48], maintenance processes necessary to ensure the availability, reliability of machinery and equipment and the safety of processes, their implementers and the environment, can become one of the main pillars for the development of SM. Sustainability goals must be within conventional maintenance processes with the aim of eliminating breakdown and sources of energy waste, ensuring safety of people and processes, reducing internal and external costs [22, 24]. Pires et al. [22] argued that new researches are necessary for more substantially discuss the impacts of industrial maintenance on organizational sustainability and vice-versa. According [22] maintenance as a part of the circular economy can be considered first as an enabling system to sustain the artifact throughout its life cycle, then as a key tool to keep the regeneration potential of this artifact, and finally, as a target system that must be sustainable as well.

2.2. Identification of maintenance factors influencing sustainable production

According to the EN 13306: 2010 standard maintenance is ‘the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function’. From the company's perspective, this means that maintenance's activities should be aimed at, among other things, ensuring the required level of reliability and availability of machines and devices and their efficiency, optimal use of invested capital, ensuring the required level of safety for users and maintenance personnel, monitoring the environmental aspects of machine operation and technical service processes, modernizations ensuring the economic efficiency of operated facilities, cooperation with machine suppliers, spare parts and services, systematic improvement of competence of technical service employees, etc.

Maintaining in an enterprise depends on the context of the enterprise, its objectives, structure, internal constraints and external conditions. From these dependencies, among other things, the maintenance function is defined in the enterprise. The components of the maintenance functions are the result of, inter alia:

- subject of activities; this applies to specific assemblies, subsystems or machine systems that should be serviced (e.g. by inspection, maintenance, repair),

- company status in relation to the environment in which it operates; it depends on environmental requirements such as product structure, delivery times, related supply chains, quality requirements, necessary production processes, equipment, safety requirements and required skill levels of employees,

- the objectives of the enterprise; this component may include the company's market share, product productivity and product quality. The goals ultimately reflect the strategic importance of maintenance in the enterprise,

- profile of maintenance tasks; it covers various tasks or maintenance activities, such as fault diagnosis, lubrication, inventory of spare parts, etc.,

- the maintenance system itself; defined by formal and informal elements in which formal elements include management systems and methods, organizational structures and technologies necessary to implement objectives and the resulting maintenance tasks within the enterprise, while informal elements include key participants in maintenance processes, engineers, operators and managers,
results achieved by maintenance in relation to the expected value constituting the basis for introducing improvement actions.

As a consequence, the importance of management aspects in maintenance is emphasized in the literature. Generally, they can be divided into three groups: technical issues (engineering, technology, etc.); management issues (from different perspectives - manufacturer, customer, service technician); commercial issues (economic, legal, marketing, etc.). Such a wide range of issues means that maintenance decisions should be taken from the strategic perspective of the company, taking into account the requirements of currently applicable management paradigms of an increasing number of maintenance stakeholders [11].

The literature review of the aspects of SM presented in chapter 2.1 shows that maintenance can have a significant impact on the efficiency of sustainable production. Considering the above, a synthesis of various literature sources in the area of sustainable manufacturing and maintenance was carried out and 10 maintenance factors were identified, which, according to the author, have a significant impact on the development of sustainable production processes.

**A1 Spare parts and consumables management.** During operation all equipment need spare part to replace its damage element to maintain equipment availability. Maintenance relies on the availability of spare parts in order to reduce failure downtime and costs. It is clear that maintenance and spare parts management are strongly interconnected and should both be considered simultaneously when optimizing a company’s operations. In enterprises, the subjects of optimization in this area are usually: reduction of storage costs (risk of missing parts and costs of frozen capital), reduction of the probability of missing parts, linking stock levels with equipment criticality, forecasting needs and stock levels, managing replacements [41]. In addition to the purely financial aspects of spare parts management and the security of production processes [13], companies increasingly pay attention to other aspects of sustainable development [2, 10, 16, 39].

Another important element from the point of view of ensuring proper operation of the machines is lubrication economy. The use of appropriate or recommended lubricant either by manufacturer or maintenance experts plays a vital role in machinery sustenance. The choice of right lubricant will not only reduce wear from the machine but also convey off wear debris from the component parts if and when it occurs. The lubrication management includes both technical and organizational measures to ensure the most optimal lubrication conditions for machines and devices at the lowest possible cost, taking into account environmental impact and safety. Thus, the concept of lubrication service is an extremely extensive issue that concerns not only lubricants change, but also a range of other lubrication processes, including, among others: monitoring the status of oils and lubricants and possible refilling, nurturing used oils, analyzing lubricating properties of used oils, planning and implementing preventive and corrective actions in the field of lubrication, testing the condition of machines based on oil analysis, oil supply and its in-house logistics, management of used oils, preparation of oil service instructions.

**A2 Cooperation with manufacturers / suppliers of machinery and equipment.** Equipment builders and suppliers are important stakeholders as they are a fundamental source of knowledge and information for manufacturing companies. New ICT technologies introduce changes for machine manufacturers. Manufacturers and suppliers of machines complement their offer with software and data analysis services. According to data from the German Association of Machine and Equipment Manufacturers (VDMA), between 1970 and 2010, the amount of software supplied with machines increased by 45% [21]. From this perspective, in the near future machine manufacturers using eg IoT and Big Data will be able to create added value through virtual networks in the cloud, which will continuously accumulate, aggregate and model data, then predict failures and introduce actions to limit their impact [57, 58, 59].

**A3 Cooperation with services providers** Their role can be even extended, and then exploited, in the current manufacturing environment by the provision of maintenance related services as a result of a servitization strategy: technical services have been proofed to induce positive impacts on innovation in manufacturing and, among technical services, maintenance services are key to improve after-sales
services to support manufacturing assets. Necessity to cooperate with services suppliers is stressed among others by [15, 36].

**A4 Cooperation with the research and development department.** Maintenance is an essential element of a machine's life cycle. At the early stage of the life of the asset - design, construction, and commissioning - the desired condition is to get to closer cooperation among the various functions such as design, purchasing, and maintenance [44]. The importance of cooperation between maintenance and the research and development department applies to all dimensions of sustainable development, and the goal is not only to provide comfort to users but also to those who carry out reviews, maintenance and repairs [41, 60]. Another important element in the introduction of a new product is the proper preparation of machinery, tools and instrumentation necessary to ensure the correct course of the production process and, as a consequence, the production of a product in accordance with the requirements of the customer.

**A5 Cooperation with production and quality departments.** Production and maintenance are the two most functionally related areas of the production enterprise. While production is interested in achieving the highest level of machine utilization and delivery goals, maintenance is aimed at achieving the highest level of long-term machine readiness. Therefore, proper communication and coordination of activities between these areas is important [11, 44, 51, 55, 56]. Practitioners and academicians recognized that there is a strong relationship between product quality and equipment maintenance and the integration of these two aspects is beneficial to organizations. Deloux et al.’s [9] outline of a predictive maintenance policy based on combining statistical process control and condition-based maintenance, Duffuaa et al.’s [12] proposed conceptual simulation model for maintenance systems, Choudhary et al.’s [8] work on data mining in manufacturing, Lindström et al. [37] suggest that combining and integrating online predictive maintenance and continuous quality control can lead towards intelligent and sustainable production within the manufacturing industry.

**A6 Cooperation with the department of health and safety and the environment.** An important prerequisite is the safety of people, environment and assets. Regarding maintenance, the issue of safety is particularly important [24, 32, 53]. According to a survey of the European Agency of Health and Safety at Work 10-15 percent of fatal accidents and 15-20 percent of all accidents were associated with maintenance work. Thus, maintenance is usually regarded as important to operators. They are extra exposed to the variety of hazards with potential harm to their health. Therefore, one of the principal works of the maintenance department office ought to be to make a safe working environment with most extreme significance of safety in the manufacturing plant. Cooperation with the Department of Health and Safety and the Environment allows not only to reduce the risk in relation to people. Good cooperation also means building knowledge and awareness, complying with legal requirements and helping in improving activities [1, 32, 46, 52].

**A7 Competence of maintenance workers.** Effective working of maintenance department requires that the managers and employees have the appropriate knowledge, skills and expertise [29, 33, 60]. This is especially important in relation to challenges related to the Industry 4.0 concept. There are three factors to have a large influence on the maintenance staff and fundamentally change in a factory of the future [25]: (1) tools and technologies - which refer to all kinds of tools and technologies that the maintenance staff uses and by which the maintenance staff is affected; (2) organization and structure - which includes the organizational setting in which the maintenance staff performs their work; (3) working environment - which considers the physical environment that directly affects the maintenance staff because they perform their work within the working environment. The work performed by the maintenance staff on the shop floor, by maintenance managers in a factory of the future will differ significantly from the situation in today’s factories. Consequently, the qualifications and skills of the maintenance staff and maintenance managers, which are required to fulfil the tasks occurring in a factory of the future, will differ as well. The qualifications and skills of future maintenance staff should be divided into two groups: technical and personal qualifications and skills (Q&S). Qualifications and technical skills are the natural requirements as long as the technical department’s staff is concerned.
However, additionally to technical skills, soft skills such as social and communication skills as well as team working and self-management abilities become very important for the skilled labor.

**A8 Implementation of preventive and prognostic service strategies.** The essence and importance of using preventive and prognostic maintenance strategies in the context of environmental impact, safety and costs is relatively frequent in the literature. Also from the perspective of future challenges in modern manufacturing maintenance strategies are increasingly shifting from traditional preventive maintenance (PM) based approaches to more efficient and sustainable prognostic maintenance approaches. Prognostic maintenance strategies are the tools meant to predict the future performance of components by assessing the extent of deviation or degradation of a system from its expected normal operating conditions. Its principle is based on the analysis of failure modes, detection of early signs of wear and ageing and fault conditions. The concept in general aids in the estimation of remaining useful life (RUL) of the machine [35]. But making prognostic will not be only limited to the calculation of a conventional RUL, but will also include the estimation of time before which a studied item cannot be regenerated by a decomposer. Whereas [64] have proposed a methodology to choose a remanufacturing process according to the system’s RUL. Jung and Levrat, [2] propose to use the prognostic to study flows properties, and thus securing the respect of sustainability requirements. The application of prognostic service strategies requires reliable and reliable data and information as well as systems for their processing and management [30].

**A9 Implementation of collection and processing of operating data schemes.** Maintenance effectiveness depends on the quality, timeliness, accuracy and completeness of information related to machine degradation state. Sensors and various measurement instruments are deployed on equipment, leading to the generation of high-speed maintenance data streams. Equipment anomalies indicated by those data streams should be addressed promptly, to prevent financial losses, eliminate or limit potential / real threats to the safety of people and the environment. The amount and complexity of maintenance data means that without a proper system of both data collection and processing, decisions made by managers would be very risky. Hence, the number of enterprises using various forms of IT support for activities related to maintenance management ranging from support of technical reactive and preventive strategies to predictive strategies in which various corporate IT resources can be integrated is growing year by year. Information and Communication Technologies are transforming the way systems are maintained, they provide the support to generate more systems behavior knowledge and to introduce new tools and processes for a more proactive maintenance [61, 62, 63].

**A10 Modernization of machines and devices.** The manufacturing equipment in factories often is a capital good with a long use phase of up to 20 or more years. Modernizations are therefore a natural process carried out in enterprises, and their aim is to increase the efficiency of use in both financial and environmental aspects. Retrofitting enables an easy and cost-efficient way of upgrading existing manufacturing equipment with sensor and actuator systems as well as with the related control logics in order to overcome the heterogeneity of equipment in factories [49, 50, 60].

The factors presented above (A1 to A10) indicate that by building the internal potential of maintenance processes, enterprises create conditions for the implementation of obligations resulting from the paradigm of sustainable production. The identification of these factors and the determination of their validity is one of the steps to build a model for assessing the value provided by maintenance for sustainable production. Such a model will enable managers to shape the maintenance system in a conscious way and optimize their activities in line with the sustainable development policy adopted in the company. While many models, methods and evaluation guidelines have been developed for the design of products and processes and their implementation, taking into account the requirements of sustainable production, there is currently no such movement for systematic studies on the part of science or practice.

### 3. Method

#### 3.1. Examination of the importance of maintenance factors supporting SM
Research on the perception of the importance of maintenance factors supporting the implementation of sustainable production was carried out at the turn of 2016/2017 in 58 medium-sized and large production companies of various industries selected for research purposely (figure 3). The key criteria for selecting enterprises for research were: declaration of the company's implementation of the sustainable development strategy and the use of lean management tools in the area of production and maintenance.

The survey was conducted using the interview method with the managers of maintenance departments and production managers. A questionnaire was developed to collect information. The first part of the survey included questions about the company, while the second part concerned actual research. The heads of maintenance departments and production managers were asked to determine the degree of importance of the 10 factors presented in section 2.3 on a scale of 1 to 5, where 1 meant - very small while 5 very important. The data set obtained from enterprises was subjected to statistical assessment and the most-least-important factors were ranked (table 1).

The conducted research shows that the factors that can support the implementation of sustainable production processes to the greatest extent from the point of view of maintenance department managers are the use of preventive and prognostic service strategies and the use of data collection and processing systems (figure 4). In the opinion of production managers, the most important factors are the use of preventive and prognostic service strategies and competences of maintenance employees (figure 5). Significant differences between these two groups of experts can be noticed for two factors:

| Factor | Maintenance average assessment | Standard deviation | Rank by the importance | Production average assessment | Standard deviation | Rank by the importance |
|--------|--------------------------------|--------------------|------------------------|-----------------------------|--------------------|------------------------|
| A1     | 4,36                           | 0,609              | 6                      | 3,97                        | 0,524              | 8                      |
| A2     | 3,86                           | 0,629              | 9                      | 3,983                       | 0,524              | 10                     |
| A3     | 4,61                           | 0,525              | 5                      | 4,59322                     | 0,495              | 5                      |
| A4     | 2,78                           | 0,852              | 10                     | 3,95                        | 0,570              | 9                      |
| A5     | 4,64                           | 0,482              | 3                      | 4,678                       | 0,4713             | 4                      |
| A6     | 4,34                           | 0,63               | 7                      | 4,41                        | 0,56               | 6                      |
| A7     | 4,63                           | 0,61               | 4                      | 4,81                        | 0,4                | 2                      |
| A8     | 4,86                           | 0,345              | 1                      | 4,831                       | 0,378              | 1                      |
| A9     | 4,81                           | 0,434              | 2                      | 4,746                       | 0,477              | 3                      |
| A10    | 3,93                           | 0,61               | 8                      | 4,17                        | 0,53               | 7                      |
spare parts and consumables management (A1), and cooperation with the design and development department (A4).

However, in order to form general judgments on the basis of the research conducted, it is necessary to ensure compliance of the assessments issued by experts at a sufficiently high level. In a situation where there are more than two ranks, the most frequently used measure of compliance of preferences is the Kendall’s W concordance coefficient, called the coefficient of compliance of multiple orders [6]. The order obtained in the study is of a weak order type. This is due to the fact that experts were asked to evaluate 10 factors on a scale from 1 to 5, and therefore it was natural to associate some of the factors with the same rank. Considering the above, in measuring the compliance with the concordance coefficient, it is necessary to apply the average ranking method. Testing the statistical significance of the concordance coefficient consists in defining the null hypothesis H0: the convergence of expert opinions is accidental (the ranked ranks are not interrelated) and the H1 hypothesis: the convergence of opinions is not accidental, and the experts are competent. The null hypothesis is rejected when the calculated value is equal to or higher than the value read from the chi-square distribution tables for degrees of freedom at a given level of significance \( \alpha \). The results of the statistical analysis on the convergence of expert opinions are presented in the table 2.

**Table 2. Results of statistical analysis on consistency of experts opinions.**

|                | Number of factors | Number of experts | Kendall’s W coefficient | Value \( \chi^2 \) | Number of degrees of freedom | Importance level \( \alpha \) | Value \( \chi^2 \) |
|----------------|-------------------|-------------------|-------------------------|-------------------|-----------------------------|-------------------------------|------------------|
| Maintenance    | 10                | 58                | 0.865                   | 24,7177           | 9                           | 0.05                          | 16,9190          |
| Production     | 10                | 58                | 0.823                   | 22,7415           | 9                           | 0.05                          | 16,9190          |

The results obtained, ratio \( W = 0.865 \) and \( \chi^2 > 16,9190 \) indicate that the consistency between the maintenance managers' opinions is very good (0.81 \( \leq W \leq 0.95 \)) and not accidental. This consistency also occurs between the opinions of production managers. Thus, a general assessment of factors and
their weights can be made, further analysis carried out and used to build models supporting decision-making regarding future directions of maintenance development in the enterprise.

3.2. Structural analysis of factors - a case study

The next element of the research was identification of relations between factors identified in chapter 2.2. The research was conducted in the company operating in plastics processing industry. It specializes in manufacturing of various advertisement materials, as well as products for personalization and visual identification. It is also a manufacturer of devices for laboratory use. The company employs about 120 people. It operates in three shifts system. Its organizational structure includes maintenance department that is supervised directly by The CEO of the company. The maintenance department employs 14 people, and that includes 4 mechanics, 9 adjusters and a manager of the department. The methodology implemented for the analysis was the Interpretive Structural Modeling (ISM developed by [54]. The ISM analysis required answering the following two questions:
- Which factors are interrelated?
- Which activities have the greatest influence? Which are the key issues, and which are of the lesser importance?

For developing contextual relationships among variables, the opinion of total four experts, three from industry and one from academia have been taken. For expressing the relationship between different critical factors, four symbols have been used to denote the direction of relationship between the parameters i and j (here i, j):
- \( V \) is used for the relation from enabler i to enabler j (i.e. if enabler i influences or reaches to enabler j);
- \( A \) is used for the relation from enabler j to enabler i (i.e. if enabler j reaches to enabler i);
- \( X \) is used for both direction relations (i.e. if enablers i and j reach to each other);
- \( O \) is used for no relation between two enablers (i.e. if enablers i and j are unrelated).

Based on this contextual relationship, the SSIM has been developed. To obtain consensus, the SSIM was discussed in a group of factory experts and based on their responses, SSIM has been finalized and is presented in figure 6. The SSIM is transformed into a reachability matrix format by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix. The substitution of 1s and 0s are as per the following rules:
- If the \((i, j)\) entry in the SSIM is \( V \), the \((i, j)\) entry in the reachability matrix becomes 1 and the \((j, i)\) entry becomes 0;
- If the \((i, j)\) entry in the SSIM is \( A \), the \((i, j)\) entry in the reachability matrix becomes 0 and the \((j, i)\) entry becomes 1;
- If the \((i, j)\) entry in the SSIM is \( X \), the \((i, j)\) entry in the reachability matrix becomes 1 and the \((j, i)\) entry also becomes 1;
- If the \((i, j)\) entry in the SSIM is \( O \), the \((i, j)\) entry in the reachability matrix becomes 0 and the \((j, i)\) entry also becomes 0.

Following the above rules, the initial reachability matrix is prepared and is shown in figure 7. After incorporating the transitivity concept, the final reachability matrix is obtained.

The next step was analysis of relations between factors conducted with MICMAC. Matrice d'Impacts croises-multiplication appliquée anclassment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The purpose of MICMAC analysis is to analyze the drive power and dependence power of enablers. MICMAC principle is based on multiplication properties of matrices. It is done to identify the key enablers that drive the system in various categories. Based on their drive power and dependence power, the enablers, have been classified into four categories as follows: (1) Autonomous enablers: These enablers have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong; (2) Linkage enablers: These enablers have strong drive power as well as strong dependence power. They enablers are unstable in the fact that any action on these enablers will have
an effect on others and also a feedback effect on themselves; (3) Dependent enablers: These enablers have weak drive power but strong dependence power (4) Independent enablers: These enablers have strong drive power but weak dependence power. An enabler with a very strong drive power, called the ‘key enabler’ falls into the category of independent or linkage enablers. The drive power - dependence power diagram is drawn as shown in figure 8 and 9.

![Figure 6. Structural self-interaction matrix.](image1)

![Figure 7. Reachability Matrix](image2)

![Figure 8. Direct influence map.](image3)

![Figure 9. MICMAC Direct influence / dependence map.](image4)

Figure 9 has been divided into four clusters. First cluster includes ‘autonomous enablers’, second cluster includes ‘dependent enablers’, third cluster includes ‘linkage enablers’ and fourth cluster contains ‘independent enablers’:

- **Autonomous enablers.** These enablers have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong. From the MICMAC analysis, it has been found that none of the element falls under autonomous element category, which means all elements found from the literature review are necessary and organizations have to give attention to all.

- **Linkage enablers.** These enablers have strong drive power as well as strong dependence power. They enablers are unstable in the fact that any action on these enablers will have an effect on others.
and also a feedback effect on themselves. One factor can be found there – A8 ‘Implementation of preventive and prognostic service strategies’.

- Dependent enablers. These enablers have weak drive power but strong dependence power. Any action on them will have an effect on others and also feedback effect on themselves. In this section, there are three factors: A1 – ‘Spare parts and consumables management’; A7 – ‘Competence of maintenance workers’; A10 – ‘Modernization of machines and devices’

- Independent enabler. These enablers have strong drive power but weak dependence power. An enabler with a very strong drive power, called the ‘key enabler’ falls into the category of independent or linkage enablers. In this section, there are three factors: A2 – ‘Cooperation with manufacturers / suppliers of machinery and equipment’, A6 – ‘Cooperation with the department of health and safety and the environment’, A9 – ‘Implementation of collection and processing of operating data schemes’.

The ISM model developed in this paper acts as a tool for top management to understand/identify the key enablers of factors influencing sustainable development of manufacturing processes in an enterprise. This model has been developed on the basis of consensus of experts from industry and author of this paper.

4 Conclusions

The article provides a detailed literature analysis of maintenance factors affecting the development of sustainable production. Ten key factors were selected on the basis of the considerations and were characterized (chapter 2.2). Research was carried out among fifty eight enterprises in Poland. Based on the results obtained from maintenance managers and production managers, the validity of the presented factors was determined. Both groups stress the importance of implementation of preventive and prognostic maintenance strategies, necessity to employ IT to retrieve and process data, and importance of competences of maintenance staff. These three factors are interrelated. New technologies require new competences and bring new opportunities concerning maintaining production equipment. Hence, investment in the area is direction that should be followed by companies striving for economic success based on respect for environment and social standards.

Identifying the factors and defining their importance is one of the important steps to build a model for assessing the value provided by maintaining a sustainable production movement, which will enable managers to shape the maintenance system in a conscious manner and optimize their operations in line with the company’s sustainable development policy.

Then, a study was carried out on the relationship between factors in the plastics processing company. The ISM method (figure 6 and 7) and the MICMAC program were used for the study (figure 9). The research shows that all identified factors are important for the development of sustainable production processes in the enterprise (no autonomous factors). Three factors are key for the company: A2 - "Cooperation with manufacturers / suppliers of machinery and equipment", A6 - "Cooperation with the department of health & safety and the environment", A9 - "Implementation of collection and processing of operating data schemes". Interpretation of the results obtained in the enterprise has drawn attention to the A6 factor. So far, cooperation between maintenance and health & safety and environment department has not been perceived as important. The analysis proved that this area needs to be regarded as the element potentially strengthening competences of maintenance department, and as a result improving its performance.

In order for the general conclusions to be formulated on the basis of the ISM analysis carried out, further research involving more than one enterprise is necessary. What is more, in the author's opinion, these studies should be focused on a specific industry and the type of processes implemented, eg in relation to discrete or continuous production processes.

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