Improving the Level of Sustainable Development in Industry 4.0 Context: A New Approach

Justyna Patals-Maliszewska¹, Hanna Łosyk¹

Abstract:

Purpose: Sustainable manufacturing models are currently being sought, the implications of which in manufacturing companies will be an integral part of their functioning in the Industry 4.0 (I4.0) concept. This paper aims to review the application of Multi-Criteria Decision-Making methods (MCDM) to assess the Sustainable Development (SD) level in industries and build a new approach to maintain and increase SD in a company.

Design/Methodology/Approach: The research methodology is based on the detailed literature studies of SD in manufacturing, applying MCDM methods and the use of an Information Technology (IT) in the I4.0 within a manufacturing company.

Findings: The overview of the related works allowed for the identification of the novel approach to SD assessment and measurement in manufacturing enterprises, which integrates the SD level assessment and an IT in the I4.0 and allows to determine the essential SD objectives for evaluation and monitoring within an enterprise using the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) method and Intuitionistic Fuzzy Weighted Averaging (IFWA) operator.

Practical Implications: The functional significance of this work was determined in the form of a framework, the implementation of which will allow managers to assess and constantly monitor the implementation process of SD strategy. At the same time, the application of IT in I4.0 ensures the ability to control them.

Originality/Value: As highlighted in the state-of-the-art analysis, none of the existing works supports all the presented features of the proposed approach to improving sustainable development in manufacturing in the Industry 4.0 context using F-TOPSIS and IFWA.

Keywords: Sustainable development, manufacturing, industry 4.0, assessment of sustainable development, Multi-Criteria Decision-Making (MCDM) methods.

JEL Classification: O1, O2.

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¹Institute of Mechanical Engineering, University of Zielona Góra, Zielona Góra, Poland, J.Patalas-Maliszewska@iim.uz.zgora.pl;
1. Introduction

Manufacturing constitutes a vast segment of the world economy; thus, it is fair to say that current industrial practices and innovation in material and manufacturing technologies must coordinate ecosystems’ natural capacity (Singh et al., 2016). A new trend is to follow the concept of Industry 4.0 (I4.0), where manufacturing solutions are driven by information technology (IT) and achieving a sustainable society (Kamble et al., 2018). I4.0 has unlimited potential to build sustainable industrial value in environmental, economic, and social dimensions. Literature indicates (Khan et al., 2021) that sustainability in the I4.0 context modifies approaches to problem-solving more systemic ways of addressing change.

Production is one of the largest consumers of natural resources, creating discussion and solutions for sustainable production processes. Manufacturing plays a significant role in society's economic and social development, yet this often comes at a high environmental cost (Barletta et al., 2021). The challenges are complex for the production companies to bear the economic burden.

Therefore, the production needs to arrange low-carbon manufacturing without increasing costs and reducing efficiency (Pangestu et al., 2021). Sustainable Manufacturing (SM) models are currently being sought, the implications of which in manufacturing companies will be an integral part of their functioning in the I4.0 concept. Moreover, research studies should focus on building a fuzzy measure to assess the Sustainable Development (SD) level in manufacturing (Jasiulewicz-Kaczmarek et al., 2021).

So, this paper aims to review the application of Multi-Criteria Decision-Making methods (MCDM) to assess the SD level in industries and build a new approach to maintaining and increasing the level of sustainable development in a manufacturing company. The Long-Life-term severe disruptions e.g., the pandemic) have forced the companies to be self-healing and have the tools enabling continuous and automatic monitoring of the SD level and support for introducing changes in the SD area. The main contributions of the work can be summarized as follows:

- The overview of the related works is presented and discussed by pointing out benefits and weak points of the other, similar solutions.
- The novel approach to Sustainability Development (SD) assessment and measurement in Manufacturing Enterprises was established.
- The proposed model integrates SD measurement, information technology (IT) used.
2. Literature Review

SD consists of three foundations, social, economic, and environmental, forming the triple bottom line (TBL), the objective of which is to meet the resource needs of current and future generations without hampering the environment (Khan et al., 2021), achieving the SD objectives in the context of I.4.0. contributes to creating sustainable business models and building a circular economy by accomplishing benefits at the TBL level. In their work, Beier et al. (2017) assume that the digital transformation is associated with I.4.0. build a sustainable environment through resource efficiency while achieving social, technological, and sustainable development through innovative support systems and less workload. It shall also indicate (Kiel et al., 2017) that TBL-based SD must go beyond its traditional framework for creating industrial value.

Therefore, they proposed extending the SD's consideration to include three additional aspects, technical integration, data and information, and public context. Barletta et al.'s work (2021) show a novel approach for top and middle management in manufacturing companies to build capabilities for sustainable manufacturing by assessing their organizational sustainability readiness. The model is based on four readiness levels, displaying a crescendo of operations management practices on the shop floor that positively affect sustainability performance. This model evaluates capabilities representing manufacturers' potential in realizing their desired sustainability strategy. Target users are decision-makers with top and middle management positions (Barletta et al., 2021). Pangestu et al. (2021) presented the concept multi-objective multi-pass turning optimization model to determine the optimal cutting parameters, including spindle rotation speed, feed rate, depth of cut, and several roughing passes. The model is aimed at the manufacturing sector to improve the efficiency of production processes efficiency while ensuring the production of products that meet the SM criteria.

An exciting proposal for an integrated evaluation system is also presented in the (Sangwan et al., 2018) “the models are based on resources sustainability (people, money, material, energy, infrastructure, water, and air), critical factors of sustainability (product, process, and policies), sustainability dimensions (environment, economic, and social), and life cycle sustainability (integrated supply chain).” Three critical factors and essential resources have been identified for production enterprises in an integrated supply chain. The implementation of the preparedness assessment model in the organization is a tool to support the work of managers in identifying weak areas of SD. So, a comprehensive analysis of the literature on available SM models indicates that it is needed to determine a
Sustainable Manufacturing model driven by Information Technology (IT) in the I4.0 context.

IT in the I4.0 context in many industries has become a standard (Haddara and Hetlevik, 2016). Multi-modularity (i.a., sales, human resources, financial resources, production) of the ERP system ensures the integration of data in the organization, enabling complete control over its activities and building competitive advantage on the market. Therefore, it seems that the ERP system, due to its functionality, is a good and reliable tool in supporting SD implementation in manufacturing companies.

Current studies indicate (Memari et al., 2019; Kaganski et al., 2018; Wolnowska and Konicki, 2019; Ligus and Peternek, 2018; Saad and Khamkhan, 2018; Piwowarski et al., 2018; Ma et al., 2019; Pirola et al., 2019; Mzougui and Felsoufi, 2019; Balusa and Gorai, 2019; Hamdan and Cheaitou, 2017) wide application of Multi-Criteria Decision-Making methods (MCDM) in many industries (Table 1). Table 1 summarizes the main features that distinguish the proposed work from existing related jobs. It enriches the discussion with a rapid overview of the primary outcome of the presented paper concerning the analyzed state of the art. Going into more details, Table 1 reports information on the related works about a) MCDM methods used, b) analysis MCDM used in manufacturing, c) IT in the I4.0 context, and finally d) analysis MCDM used in SD. To the best of our knowledge, and as already highlighted in the state-of-the-art analysis, no existing works support all the presented features. Therefore (Table 1), the F-TOPSIS method and IFWA operator among the available MCDM methods were selected for our research to build the new approach.

Table 1. Analysis MCDM used in SD and/or in manufacturing.

| Paper                  | MCDM methods used | Applied to Manufacturing /area of application | IT in the I4.0 | SD   |
|------------------------|-------------------|-----------------------------------------------|----------------|------|
| Kumar et al., 2018     | TOPSIS            | Supply Chain Management                       | NO             | NO   |
| Memari et al., 2019    | F-TOPSIS; IFNs;   | Sustainable Supply Chain Management           | NO             | YES  |
| Kaganski et al., 2018  | AHP; SMARTER      | Prioritization of key performance indicators   | NO             | NO   |
| Wolnowska and Konicki, 2019 | AHP              | No - the transport of oversize cargo          | NO             | NO   |
| Ligus and Peternek, 2018 | F-TOPSIS; Fuzzy AHP | No - to optimize energy alternatives         | NO             | YES  |
| Saad and Khamkhan, 2018 | AHP; Six-Sigma   | Quality management                            | NO             | NO   |
| Piwowarski et al., 2018 | TOPSIS; VIKOR    | No – to study the level of SD                 | NO             | YES  |
| Ma et al., 2019        | TOPSIS            | Rate of production; manufacturing systems improvements | YES           | NO   |
| Source: Own creation. |

So, the novelty of the proposed solution is the combination of three areas: (1) SD measurement, (2) information technology used in the company in the I4.0 context (ERP system), (3) F-TOPSIS method, and IFWA operator. The proposed approach includes a holistic approach for manufacturing companies by identifying critical areas of activity (Moldavská et al., 2019), such as production processes, production durability, development product.

3. Discussion

The proposed approach (Figure 1) illustrates the application of the F-TOPSIS method and IFWA operator to key SD objectives selection on the basis of the literature review of SD and MCDM used in SD and/or in manufacturing.

Figure 1. A new approach to maintaining and improving the level of SD in a manufacturing in the Industry 4.0 context

Source: Own creation.
The selection of SD objectives and indicators adopted for analysis (Figure 1) was based on the most frequently indicated in the literature of the subject (Kaldas et al., 2020; Patalas-Maliszewska et al., 2020; Machado et al., 2019; Moldavska et al., 2018; Global Reporting Initiative (GRI); Moldavska et al., 2016; Rajak et al., 2015; Singh et al., 2016; Shibin, 2016; Wass et al., 2014; Chang et al., 2019; Goncalves et al., 2019; Nagarajan, 2018; GSA SDG, 2019; Manager). The following SD objectives and the SD indicators to achieve specific SD objectives were determined (Table 2).

| Area                     | SD objective = Criteria                      | SD indicators = Sub-criteria                                                                 |
|--------------------------|----------------------------------------------|---------------------------------------------------------------------------------------------|
| Production processes (A1)| Reducing energy consumption (Op1)            | Wpp1 - Energy consumption                                                                   |
|                          | Reduced environmental pollution (Op2)        | Wpp2 - Total air emissions’ turing material extrusion                                       |
|                          |                                              | Wpp3 - Total air emissions’ the suppliers                                                  |
|                          |                                              | Wpp4 - Total air emissions’ during production                                              |
|                          |                                              | Wpp5 - Total air emissions’ during distribution                                             |
|                          |                                              | Wpp6 - Total air emissions’ during usage                                                  |
|                          | Improved quality of the process (Op3)       | Wpp7 - Number of complaints                                                                 |
|                          | Effective use of resources (Op4)            | Wpp8 - Resources productivity                                                                |
|                          | Reduced production costs (Op5)              | Wpp9 - Organisation’s income                                                                |
|                          | Increasing innovation (Op6)                 | Wpp10 - Technological Progress                                                               |
|                          | Reduction in generating loss (Op7)          | Wpp11 - Level of waste recycling                                                            |
| Production durability (A2)| High quality of product compared to competitors (Ov1) | Wv1 - Quality of product compared to competitors’ quality                                 |
|                          | Reliability process (Ov2)                   | Wv2 - Number of defective products                                                          |
|                          | Reduction of production losses (Ov3)        | Wv3 - Downtime                                                                              |
|                          | Reduction of the failure rate of the product (Ov4) | Wv4 - Re-utilisation of waste                                                               |
|                          | Maximising product/service effectiveness (Ov5) | Wv5 - Failure rate of product in use                                                       |
| Development product (A3) | Customer and employee satisfaction (Ov1)    | Wv6 - Range of worker benefits                                                              |
|                          | Worker benefits (Ov2)                       | Wv7 - Safety incidents                                                                      |
|                          | Accident reduction per process (Ov3)        | Wv8 - Cost of product compared to similar products                                           |
|                          | Ensuring competitiveness of the product and running competition fairly (Ov4) | Wv9 - Suppliers’ price/Market price                                                        |
|                          | Repairability / service (Ov5)               | Wv10 - Completing the order on time                                                         |
|                          | Reduced use of hazardous materials and educational activities relating to the safety (Ov6) | Wv11 - Number of complaints and returns                                                    |

Table 2. SD Selected criteria and sub-criteria
The manufacturing company's activities that are supported by an ERP system and its functionality were indicated (Figure 1), namely: F1 Production planning, F2 Cost accounting, F3 Manufacturing Execution System, F4 Production technology management, F5 Customer Relationship Management, F6 Service and repair planning, F7 Personnel Management, F8 Warehouse Management, F9 Transport Improvement.

Next, to use the F-TOPSIS method and IFWA and create the aggregated intuitionistic fuzzy decision matrix, a set of alternatives and the Decision Maker's (DMs) opinions are needed. Therefore, the manufacturing companies should be researched using the survey method. The results obtained using the F-TOPSIS method and IFWA represent the critical objectives of SD in production enterprises. These objectives should be pursued first, as they form the basis for further activities carried out in the organization for the benefit of the SD in the context of I4.0. Therefore, the values of the critical SD objectives set should be determined based on the data included in IT in the I4.0 context. Next, it should be compared with their adopted reference values, which gave the possibility to recommend corrective actions in SD. Thus, it was proved that applying the F-TOPSIS method and IFWA operator allowed to recommend disciplinary actions in the examined company to raise the level of crucial SD objectives in the I4.0 context.

4. Conclusions

The issue of SD in manufacturing companies is of crucial importance on a global scale. The new approach combines the SD level assessment and an ERP system. It allows to determinate the essential SD objectives for evaluation and monitoring within an enterprise using F-TOPSIS and IFWA based on the imprecise information acquired. Thanks to the implementation of our model, it is possible:

- to evaluate the adopted criteria (SD objectives) and sub-criteria (SD indicators) by assigning IFNs,
- to rank the preferential decision-making options according to their importance in the three adopted areas of activity of manufacturing companies and in SD aspects (economic, social, and environmental),
- to obtain the values of the key SD objectives from IT in I4.0 context,
- to obtain a table comparing the values of the designated key indicators with their reference values, enabling the recommended corrective actions to be determined,
- constant monitoring of the corrective actions implemented in the company.
The application of the F-TOPSIS method and IFWA operator does not limit the selection of crucial SD indicators in a narrow range of activity. It should be noted that the selected criteria and sub-criteria for sustainable development are related to the industry concerned (manufacturing) to meet the unique needs in manufacturing 4.0.

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