European Research Studies Journal
Volume XXIV, Issue 4, 2021

pp. 75-84

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

Submitted 12/09/21, 1st revision 01/10/21, 2nd revision 19/10/21, accepted 15/11/21

Justyna Patals-Maliszewska[1], Hanna Łosyk[1]

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 determinate 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.*
Paper Type: *Research Paper.*

Acknowledgment: *This research was funded by the program of the Minister of Science and Higher Education under the name: "Regional Initiative of Excellence" in 2019–2022 project number 003/RID/2018/19; funding amount 11.936.596.10 PLN.*

[1]*Institute 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

Pirola *et al.*, 2019	TOPSIS; Pugh; EVA	to support Product-Service Systems	YES	NO
Mzougui and Felsoufi, 2019	AHP; FMEA; AFD	to improve reliability of product	NO	NO
Balusa and Gorai, 2019	AHP; FAHP	No - selection of underground metal mining method	NO	NO
Hamdan and Cheaitou, 2017	F-TOPSIS; AHP	Supply Chain Management; green supplier selection; optimization	NO	YES
This paper	F-TOPSIS, IFWA operator	Evaluation and control of SD; recommending actions related to the implementation of SD	YES	YES

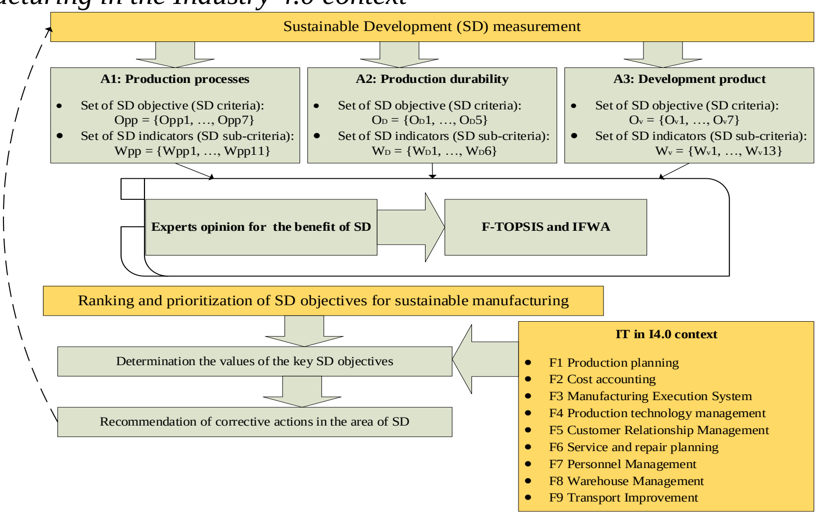
Source: *Own creation.*

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 (Moldavska *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*., 2019; 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).

Table 2. *SD Selected criteria and sub-criteria*

Area	**SD objective = Criteria**	**SD indicators = Sub-criteria**
Production processes (A1)	Reduced energy consumption ($O_{pp}1$)	$W_{pp}1$-Energy consumption
	Reduced environmental pollution ($O_{pp}2$)	W_{pp2} - Total air emissions* turing material extrusion W_{pp3} -Total air emissions* the suppliers W_{pp4} - Total air emissions* during production W_{pp5} -Total air emissions* during distribution W_{pp6} - Total air emissions* during usage
	Improved quality of the process ($O_{pp}3$)	W_{pp7}: Number of complaints
	Effective use of resources ($O_{pp}4$)	W_{pp8} -Resources productivity
	Reduced production costs ($O_{pp}5$)	W_{pp9} -Organisation's income
	Increasing innovation ($O_{pp}6$)	W_{pp10} -Technological Progress
	Reduction in generating loss ($O_{pp}7$)	W_{pp11} -Level of waste recycling
Production durability (A2)	High quality of product compared to competitors (O_D1)	W_{D1} -Quality of product compared to competitors' quality W_{D2} -Number of defective products
	Reliability process (O_D2)	W_{D3} -Downtime
	Reduction of production losses (O_D3)	W_{D4} -Re-utilisation of waste
	Reduction of the failure rate of the product (O_D4)	W_{D5} -Failure rate of product in use
	Maximising product/service effectiveness (O_D5)	W_{D6} -Repair rate of product
Development product (A3)	Customer and employee satisfaction (O_V1)	W_{V1} -Customer satisfaction W_{V2} - Client retention W_{V3} -Employee satisfaction and safety
	Worker benefits (O_V2)	W_{V4} -Range of worker benefits
	Accident reduction *per* process (O_V3)	W_{V5} -Safety incidents
	Ensuring competitiveness of the product and running competition fairly (O_V4)	W_{V6} -Cost of product compared to similar products W_{V7} -Suppliers' price/Market price
	Repairability / service (O_V5)	W_{V8} -Completing the order on time W_{V9} -Number of complaints and returns
	Reduced use of hazardous materials and educational activities relating to the safety (O_V6)	W_{V10} -Hours of safety training *per* employee W_{V11} -Hazardous chemicals used in production W_{V12} -Hazardous chemicals in products

	Minimisation of pollution *vis-à-vis* the climate (Ov7)	W_{V13} -Risk management related to the climate

Source: *Own creation.*

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.

References:

Balusa, B.C., Gorai A.K. 2019. Sensitivity analysis of fuzzy-analytic hierarchical process (FAHP) decision-making model in selection of underground metal mining method. Journal of Sustainable Mining, 18(1), 8-17.

Barletta, I., Despeisse, M., Hoffenson, S., Johansson, B. 2021. Organisational sustainability readiness: A model and assessment tool for manufacturing companies. Journal of Cleaner Production, 284.

Beier, G., Niehoff, S., Ziems, T., Xue, B. 2017. Sustainability aspects of a digitalized industry: a comparative study from China and Germany. International Journal of Precision Engineering and Manufacturing - Green Technology, 4(2), 227-234.

Chang, A., Cheng, Y. 2019. Analysis model of the sustainability development of manufacturing small and medium- sized enterprises in Taiwan. Journal of Cleaner Production, 207, 458-473.

Gonçalves Machado, C., Despeisse, M., Winroth, M., Dener Ribeiro da Silva, E. 2019. Additive manufacturing from the sustainability perspective: proposal for a self-assessment tool. Procedia CIRP, 482-487.

GRI. 2016. G4 Reporting Guidelines. https://www2.globalreporting.org/standards/g4/Pages/default.aspx.

Haddara, M., Hetlevik, T. 2016. Investigating the Effectiveness of Traditional Support Structures & Self-organizing Entities within the ERP Shakedown Phase. Procedia Computer Science, 100, 507-516.

Hamdan, S., Cheaitou, A. 2017. Supplier selection and order allocation with green criteria: An MCDM and multi-objective optimization approach. Computers & Operations Research, 82, 282-304.

https://www.gsa.gov/real-estate/design-construction/design-excellence/sustainability/sustainable-design.

Jasiulewicz-Kaczmarek, M., Żywica, P., Gola, A. 2021. Fuzzy set theory driven maintenance sustainability performance model: a multiple criteria approach. Journal of Intelligent Manufacturing, 32, 1497-1515.

Kaganski, S., Majak, J., Karjust, K. 2018. Fuzzy AHP as a tool for prioritization of key performance indicators. Procedia CIRP, 72, 1227-1232.

Kaldas, O., Shihata, L.A., Kiefer, J. 2020. An index-based sustainability assessment framework for manufacturing organizations. Procedia CIRP, 97, 235-240.

Kamble, S.S., Gunasekaran, A., Gawankar, S.A. 2018. Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives. Process Safety and Environmental Protection, 17, 408-425.

Khan, I.S., Ahmad, M.O., Majava, J. 2021. Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. Journal of Cleaner Production, 297.

Ligus, M., Peternek, P. 2018. Determination of most suitable low-emission energy Technologies development in Poland using integrated fuzzy AHP-TOPSIS method. Energy Procedia, 153, 101-106.

Ma, A., Nassehi, A., Snider, C. 2019. Balancing multiple objectives with anarchic manufacturing. Procedia Manufacturing, 38,1453-1460.

Machado, C., Depeisse, M., Winroth, M., Silva, E.H. 2019. Additive manufacturing from the sustainability perspective: proposal for a self-assessment tool. Procedia CIRP, 81, 482-487.

Manager. Retrieved from: http://manageronline.pl/optymalizacja-i-doskonaleni-kluczowych-procesow-w-przedsiebiorstwach/.

Memari, A., Dargi, A., Jokar, M., Ahmad, R., Rahim, A. 2019. Sustainable supplier selection: A multi-criteria intuitionistic fuzzy TOPSIS method. Journal of Manufacturing Systems, 50, 9-24.

Moldavska, A., Martinsen, K. 2018. Defining sustainable manufacturing using a concept of attractor as a metaphor. Procedia CIRP, 67, 93-97.

Moldavska, A., Welo, T. 2016. Development of manufacturing sustainability assessment using systems thinking. Sustainability, 8.

Moldavska, A., Welo, T. 2019. A Holistic approach to corporate sustainability assessment: Incorporating sustainable development goals into sustainable manufacturing performance Evaluation. Journal of Manufacturing Systems, 50, 53-68.

Mzougui, I., Felsoufi, Z. 2019. Proposition of a modified FMEA to improve reliability of product. Procedia CIRP, 84, 1003-1009.

Nagarajan, H.P.N., Raman, A.S., Haapala, K.R. 2018. A Sustainability Assessment Framework for Dynamic Cloud-based Distributed Manufacturing. Procedia CIRP, 69, 136-141.

Pangestu, P., Pujiyanto, E., Rosyidi, C.N. 2021. Multi-objective cutting parameter optimization model of multi-pass turning in CNC machines for sustainable manufacturing. Heliyon, 7, 2.

Patalas-Maliszewska, J., Łosyk, H., Jasiulewicz-Kaczmarek, M. 2020. A Sustainable Development Evaluation Card for a Manufacturing Company. IFAC PapersOnline, 52(2), 10468-10473.

Pirola, F., Pezzotta, G., Rondini, A. 2019. Early-stage assessment of PSS concepts: a case study in automation industry. Procedia CIRP, 83, 236-241.

Piwowarski, M., Miłaszewicz, D., Łatuszyńska, M., Borawski, M., Nermend, K. 2018. TOPSIS and VIKOR methods in study of sustainable development in the EU countries. Procedia Computer Science, 126, 1683-1692.

Rajak, S., Vinodh, S. 2015. Application of fuzzy logic for social sustainability performance evaluation: A case study of an Indian automotive component manufacturing organization. Journal of Cleaner Production,108-119.

Saad, S.M., Khamkhan, M.A. 2018. Development of an Integrated Quality Management Conceptual Framework for Manufacturing Organisations. Procedia Manufacturing, 17, 587-594.

Sangwan, K.S., Bhakar, V., Digalwar, A.K. 2018. Sustainability assessment in manufacturing organizations: Development of assessment models, Benchmarking: An International Journal, 25(3).

SDG. Small business big impact SME sustainability reporting from vision to action.

Shibin, K.T. 2016. Enablers of Sustainable Manufacturing Overview. Strategic Management of Sustainable Manufacturing Operations. IGI Global. India, 22.

Singh, M., Tatsuki, O., Rajiv, A. 2016. Green and Sustainable Manufacturing of Advanced Material. Elsevier Inc.

Sustainable development in the European Union Monitoring report on progress towards the SDGs in an EU context, edition 2019.

Waas, T., Hugé, J., Block, T., Wright, T., Benitez-Capistros, F., Verbruggen, A. 2014. Sustainability Assessment and Indicators: Tools in a Decision-Making Strategy for Sustainable Development. Sustainability, 6, 5512-5534.

Wolnowska, A., Konicki, W. 2019. Multi-criterial analysis of oversize cargo transport through the city, using the AHP method. Transportation Research Procedia, 39, 614-623.