**Assessment of sustainable development goals through Industry 4.0 and reconfigurable manufacturing system practices**

**Abstract**

**Purpose:** The United Nation’s Sustainable Development Goals (SDGs), introduced in 2015, connect several manufacturing strategies and promote sustainable practices in an organization. Manufacturing companies are struggling to meet changing market demands while also addressing social and biological issues. The current study aims to develop a framework that can assist practitioners and managers contribute to the attainment of the SDGs through the adoption of reconfigurable manufacturing system (RMS) practices and Industry 4.0 technologies.

**Design/Methodology/Approach:** An extensive literature review was carried out to identify RMS-Industry 4.0 practices and their interconnection, as well as their contribution to achieving the SDGs. The Stepwise Weight Assessment Ratio Analysis (SWARA) method was then used to compute the weights of the selected RMS-Industry 4.0 practices, whereas the Weighted Aggregated Sum Product Assessment (WASPAS) method was used to prioritize performance metrics. The developed framework's robustness was tested using a sensitivity analysis across five different organizations.

**Results/Findings:** The findings show that advanced technologies practices have the most importance, followed by customization and rapid adjustment of capacity and functionality practices. The sensitivity analysis revealed the robustness of the developed framework as well as its adaptability among the chosen organizations.

**Practical Implications:** This research will assist in the adoption of RMS and includes recent technologies that can help in the attainment of industrial SDGs. Managers will also be able to evaluate RMS in the context of industrial SDGs. Researchers and practitioners can now address the various RMS-Industry 4.0 practices while keeping the social and environmental aspects in mind.

**Originality Value:** No previous research has investigated the SDGs through the nexus effect of Industry 4.0 and RMS practices.

**Keywords –** Reconfigurable Manufacturing System, Industry 4.0, Sustainable Development Goals, SWARA, WASPAS, Sustainability

1. **Introduction**

The sustainable development goals (SDGs), which primarily concentrate on the 5Ps (Planet, Peace, Prosperity, People, and Partnership), emphasize the importance of the private sector and its collaboration with the public sector to achieve sustainable economic growth and reduce poverty. To achieve sustainability, every organization must focus on stakeholder engagement as well as new ways of thinking and behaving. As a result, manufacturing organizations are forced to adopt new technologies to capture new markets and stay competitive. Several studies in this area have attempted to investigate general and environmental sustainability, as well as the strategies and policies that have been implemented to meet the 2030 goal. Sustainability, according to Khezri et. al., (2020), is a critical factor for next-generation manufacturing, which includes design, manufacturing, and engineering. Khezri et. al., (2020) further suggested that the manufacturing system of the twentieth century was characterised by automation, whereas the twenty-first century is characterised by sustainability. As a result, sustainable manufacturing, which focuses on pollution, carbon footprint, and energy consumption, is increasingly becoming a design consideration.

Reconfigurable Manufacturing Systems (RMSs) provide flexibility, and other advantages assist to secure sustainability, which also leads to cost reduction, waste reduction, high responsiveness, lower power consumption, and improved health conditions (Khezri et al., 2020). Manufacturing systems are becoming more complex as a result of intense competition, globalization pressure, and changing customer demands, and are shifting from traditional to changeable systems like RMS. RMSs have the crucial attribute of changeability, which allows them to meet the above-mentioned requirements in the context of Industry 4.0 (Bortolini et. al., 2021). Intelligent manufacturing, cloud computing, agile manufacturing, collaborative engineering, and other well-known technologies are used in Industry 4.0, where rapid reconfiguration is a must. RMS, on the other hand, can provide rapid reconfiguration through hardware and software that can be quickly reconfigured to manufacture a wide range of products (Morgan et. al., 2021). Various researchers in this field have contributed by incorporating sustainability in RMSs in a variety of areas such as planning and scheduling, process plan generation, and other areas that can help improve satisfaction and prosperity, education, safety, and provide a variety of other benefits (Khezri et al., 2020). Ivanov et. al., (2020) commented that one of the major research streams in the context of Industry 4.0 is sustainability, defined Industry 4.0, as the integrity of organisational concepts for a cost-effective, sustainable, and data-driven system that can provide rapid reconfiguration of components while also being environmentally friendly. It can be seen that RMSs and Industry 4.0 help to achieve the SDGs in this way.

As previously stated, today's market is driven by global competition, the need for customized products, low costs, and many other factors. As a result, manufacturing companies are being forced to adopt modern manufacturing systems to meet these demands. Furthermore, advanced technologies such as the Internet of Things, Cloud computing, smart devices, the ability to manufacture customized products, high reconfigurability, and others are required by the Industry 4.0 revolution (Ivanov et al., 2020). RMS is one of the advanced manufacturing systems that can meet the needs of Industry 4.0. It offers reconfigurability and thus flexibility in manufacturing, as well as low product costs, customization, scalability, and many other benefits, all while being environmentally friendly (Bortolini et al., 2021). As a result, an extensive literature review is required to be carried out to identify common RMS practices that can meet Industry 4.0's technology requirements. This will allow researchers and practitioners to understand the relative importance of RMS in the context of Industry 4.0, while also assisting practitioners in selecting the most appropriate manufacturing system for their needs (Pansare et al., 2022c). Simultaneously, it is essential to understand how RMS and Industry 4.0 contribute to the achievement of the SDGs. Several researchers have attempted to develop methodologies and frameworks for achieving the SDGs (Kynčlová et. al., 2020). Some researchers have also attempted to create a framework for evaluating SDGs in the context of a specific manufacturing industry (Alawneh et. al., 2018; Johnsson et. al., 2020; Ordonez-ponce et al., 2020). However, the role of RMSs and Industry 4.0 in attaining the SDGs is still largely unexplored in the literature. Furthermore, no literature was found in which the Industry 4.0 technologies and RMS practices that can assist in the attainment of the SDGs are explored and listed at a glance. Also, there is a need to investigate the relationship between RMS practices and Industry 4.0 technologies in context of achieving SDGs. Because advanced manufacturing technologies and various approaches are capable of assisting in the achievement of the SDGs, such integration of two distinct areas would be beneficial. The authors believe it is therefore necessary to investigate general RMS practices and Industry 4.0 technologies so that researchers and practitioners in this field can make decisions in conflicting situations. This can also assist RMS designers to plan the design of the manufacturing systems from a sustainable perspective while the set of performance metrics identified in the presented work through the extensive literature review can be used to evaluate RMSs performance concerning the SDGs. Additionally, using a multi-analysis method and expert opinion to prioritize these performance metrics can help RMS practitioners determine their relative importance. This can also help practitioners and managers identify the root cause of poor RMS performance from the standpoint of the SDGs by using the proposed framework and interrelationships of practices and performance metrics. The developed framework can inspire practitioners to design and operate manufacturing systems in accordance with the SDGs, resulting in sustainable development. Based on this gap in the literature and the industrial need for the present study, the following research questions are formulated:

***RQ1 -*** *What is the nexus effect of RMSs and Industry 4.0 technologies on the SDGs?*

***RQ2 -*** *How can we identify and prioritize a set of performance metrics for assessing SDGs in the context of RMSs and Industry 4.0?*

To bridge the above-mentioned research gaps and find answers to these research questions, a simultaneous review of research articles on SDGs, Industry 4.0, and RMS retrieved from the Scopus database was carried out to determine 'how the combination of Industry 4.0 technologies and RMS practices helps to achieve the SDGs. The literature review assisted in identifying the nexus effect of RMS and Industry 4.0 practices on SDG achievement, leading to the development of a set of performance metrics that can reflect RMS and Industry 4.0's contribution to SDG achievement. Peer-reviewed articles published in English were considered for this study, in which the Industry 4.0 technologies and RMS practices that contribute to the SDGs were identified, along with performance metrics to assess their effectiveness. The overall journey of research is depicted in Figure 1.

Research objectives and scope

Literature review about RMS, industry 4.0 and SDG articles

Literature review of RMS articles

Literature review of industry 4.0 articles

Literature review of SDG articles

Identify general RMS practices

Identify industry 4.0 technologies

Categorize SDGs as Social, Industrial and Biological

Identify nexus effect of RMS and industry 4.0 practices for attainment of SDGs

Identify performance Metrics of Industrial SDGs

Develop framework to evaluate the contribution of RMS and industry 4.0 towards achieving SDG

Formation of expert panels in five industries for case analysis

Collect expert opinions for computation of weights and prioritizing the performance metrics

Prioritize performance metrics using hybrid SWARA-WASPAS technique

Conduct sensitivity analysis

Results and conclusions

**Figure 1: Research methodology**

The paper is divided into five sections including the current one; Section 2 discusses the literature review related to RMSs, Industry 4.0, and SDGs, as well as the identified gaps. This is followed by the case analysis, framework development, and multi-method analysis in Section 3. In Section 4, the study's findings and implications are discussed, whereas in Section 5 the conclusion and future scope are explained.

1. **Literature review**

The article selection was divided into two parts: one for articles concerning RMS and Industry 4.0, and the other for articles related to the SDGs. The keywords 'Reconfigurable Manufacturing System' and 'Industry 4.0' were used, and 52 peer-reviewed journal articles for Industry 4.0 from 2010 to 2021 were selected for the study, in addition to 281 articles from 1999 to 2021 that only discussed RMS. The keyword for the second part was ‘Sustainable Development Goals,' and 1190 peer-reviewed articles (only English language) from the period 2015 to 2021 were considered. The study, however, only included articles from peer-reviewed journals and reputable publishers such as Elsevier, Emerald, Taylor & Francis, Springer, and Inderscience. In addition, research articles from conferences and book chapters were excluded, ensuring that only high-quality articles were chosen.

1. ***Industry 4.0 and RMS practices***

The current section identifies Industry 4.0 technologies and RMS practices that can assist in achieving the SDGs. Additionally; literature focusing on RMS practices and/or Industry 4.0 technologies to develop sustainable manufacturing systems and thus achieve the SDGs was analyzed.

Advanced technologies can assist in achieving SDGs in several ways like better working conditions, lesser power consumption, improved quality, etc. The researchers of RMS Morgan et. al., (2021) highlighted the need for advanced technologies such as machine intelligence, smart reconfigurable machines, Machine controls, etc. while he also stated that Industry 4.0 requires several technologies such as Internet of things, cloud manufacturing, and data analytics to achieve customization, agility, and flexibility. Wang et. al., (2016) agreed with this and added the importance of supervisory control in RMSs practices. However, according to Dantas et al., (2021), the mere use of technologies may increase carbon emissions, so new technologies such as those mentioned above must be preferred to overcome this. Few more researchers have also focused on the use of new technologies such as cloud computing, Internet of Things, big data, Cyber-Physical Production Systems, and smart machines that can improve working conditions. These are required to implement advanced manufacturing systems such as RMS (Maganha et. al., 2018). Furthermore, Johnsson et al., (2020) emphasized the importance of shared value in the industrial SDGs, which can be achieved through developed services and technologies. The researchers also stated that the efficient use of resources, ethical practices, improved employee skills, collaborations, etc., in addition to the use of renewable energy, can significantly assist in the achievement of the SDGs. According to Ordonez-ponce et al., (2020), the SDG9 includes industry, innovation, and infrastructure; however, according to Morgan et al., (2021), RMS have the capability to incorporate advanced technologies, infrastructure, etc. in order to achieve such SDGs. Table 1 summarizes the RMS practices and Industry 4.0 technologies identified through the literature review.

**Table 1: RMS practices and Industry 4.0 technologies**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No.** | **RMS practices** | **Industry 4.0 technology** | **References** |
| 1 | Flexibility and Automation | Internet of things, cloud manufacturing, Data analytics, Additive Manufacturing, Augmented reality, Robots | (Ivanov et al., 2020; Pansare et al., 2021) |
| 2 | Quality and Customization | Digital factory, reconfigurability, and flexibility, Data analytics, Production planning | (Boccella et. al., 2020) |
| 3 | Flexible and Reconfigurable manufacturing, Effective collaboration | Digitization, real-time information, Intelligent manufacturing system | (Guo et al., 2020) |
| 4 | Customization and Quality products | Smart manufacturing, Digital manufacturing | (Bortolini et al., 2018) |
| 5 | Machine intelligence, Smart reconfigurable machines, Machine controls, System integration, Advanced control | Artificial intelligence, Cyber-Physical Systems (CPS), Digital Twins, Cybersecurity, Autonomous Robots, Smart and Reconfigurable capabilities  | (Morgan et al., 2021) |
|  6 | Intelligent manufacturing, Automated Storage and Retrieval system | Virtual reality, Engineering education | (Salah et al., 2019) |
| 7 | Cloud computing, Internet of Things, big data | Cyber-Physical Production Systems, smart machines | (Maganha et al., 2018) |
| 8 | Modular machines, Reconfigurable Machine tools | Advanced machines | (Moghaddam et. al., 2020) |
| 9 | Configuration design | Digital twins system for configuration | (Q. Liu et al., 2020) |
| 10 | Flexibility, mass individualization, Additive manufacturing | System intelligence, decision-making, Optimization, Additive manufacturing (AM) | (Gu & Koren, 2018) |
| 11 | Rapid adjustment of production capacity and functionality | Automation, Data exchange, Big data & Analytics | (M. Liu et. al., 2019) |
| 12 | Integration of technologies, Responsiveness, Lean Manufacturing | Internet of Things (IoT), Artificial Intelligence, Cyber-Physical System | (Prasad & Jayswal, 2019) |
| 13 | Reconfiguration flexibility, Autonomous, and intelligent system | Integrate machines and humans, Distributed manufacturing system | (da Silva et al., 2016; Pansare, Yadav, & Nagare, 2022b) |
| 14 | Smart factory, Cloud, and supervisory control | Cyber-Physical Systems, Internet of Things, Cloud control | (Wang et al., 2016) |
| 15 | Reconfigurable Machine Cells, Intelligent machine, Optimization of RMT | Mass personalization, Dynamic market demands | (Bortolini et al., 2021) |
| 16 | Reconfigurable process plan, Greenhouse gas emission optimization | - | (Touzout & Benyoucef, 2019) |

1. ***SDGs and Industrial SDG Performance Metrics***

The SDGs primarily focus on business organizations' contributions to sustainable development and provide them with guidelines for meeting long-term market demands. SDGs also help businesses represent market trends so that long-term strategies can be developed. As a result, business organizations are gradually required to implement sustainability strategies and report on them (Johnsson et al., 2020). SDGs cannot be achieved, according to Dantas et al., (2021), if required innovations are not addressed at a specific phase of evolution and market needs are not considered. Several pieces of literature addressing SDGs are reviewed here to find the nexus effect of RMSs and Industry 4.0, and a summary of the selected 1190 research articles is shown in Figure 2.



**(d): Bibliometric analysis of text data for SDG articles**

**Figure 2: Analysis of SDG articles** (Source: Author)

Several studies have shown that categorizing the 17 SDGs into appropriate groups is necessary and Industry 4.0 contributes to the achievement of SDGs 7, 8, 9, 10, and 11 (Dantas et al., 2021). The 17 SDGs were divided into three categories: social, biological, and industrial. There were five SDGs identified that deal with industrial products and their environmental consequences. At the same time, eight SDGs deal with social issues such as poverty, hunger, education, justice, gender equality, etc., and are thus classified as social SDGs. The biological SDGs provide guidelines on climate action, life on land, life underwater, and climate control. Figure 3 depicts the categorization of 17 SDGs.

**Sustainable Development Goals (SDGs)**

SDG 1 – No poverty

SDG 2 – Zero hunger

SDG 3 – Good health and well-being

SDG 4 – Quality education

SDG 5 – Gender equality

SDG 6 – Clean water and sanitation

SDG 7 – Affordable and clean energy

SDG 8 – Decent work and economic growth

SDG 9 – Industry, innovation and infrastructure

SDG 10 – Reduced inequalities

SDG 11 – Sustainable cities and communities

SDG 12 – Responsible consumption and production

SDG 13 – Climate action

SDG 14 – Life Below water

SDG 15 – Life on land

SDG 16 – Peace, justice and strong institutions

SDG 17 – Partnerships for the goals

Categorization of SDGs

**Industrial SDGs**

**Social SDGs**

**Biological SDGs**

SDG 7

SDG 8

SDG 9

SDG 12

SDG 17

SDG 1

SDG 2

SDG 3

SDG 4

SDG 5

SDG 10

SDG 11

SDG 16

SDG 6

SDG 13

SDG 14

SDG 15

**Figure 3: Categorization of SDGs**

RMS practices and Industry 4.0 technologies, according to Dantas et al., (2021), can greatly assist in the achievement of Industrial SDGs 7, 8, 9, 12, and 17. To meet these goals, technological advancements and behavioural changes in the production and consumption sectors are critical (Dantas et al., 2021).

As previously discussed, it is also necessary to evaluate the effectiveness of RMS and Industry 4.0 practices in achieving the industrial SDGs. Several researchers in this domain have discussed these practices as well as performance metrics that can be used to evaluate their contributions. This includes a study conducted by Moldavska & Welo, (2019) on sustainability assessment in manufacturing, in which the authors discussed hazardous chemicals and their impact on the environment, as well as carbon emissions during product manufacturing and use. They further expressed the importance of evaluating manufacturing organizations for the minimum wage of workers, profit earned, employee health and safety issues that can affect their availability and R & D activities carried out. This has assisted organizations in assessing the sustainability of their manufacturing processes, and Johnsson et al., (2020) agreed, stating the importance of measuring the use of renewable energy, the availability of advanced technology, product testing, quality assurance practices, and optimization practices. Fatimah et. al., (2020) also express the need to consider the number of skilled employees, employee retention rate, and overall satisfaction of employees at work when assessing waste management systems to achieve SDGs. Alawneh et al., (2018) considered working space, waste reduction, material recycling, and increased exports when assessing the SDG achievement in their study on water and energy efficiency in green buildings. Ordonez-ponce et al., (2020) developed a measuring tool in the automotive industry, taking into account infrastructure, material recycling, CSR funds contributed, and financial and technological support received from foreign countries as some of the important parameters to assess the manufacturing system for achieving SDGs. Table 2 summarizes the SDG targets addressed by the RMS-Industry 4.0 nexus and the corresponding performance metrics.

**Table 2: SDG targets addressed**

|  |  |  |  |
| --- | --- | --- | --- |
| **SDG** | **SDG targets directly affected by RMS and Industry 4.0** | **RMS-Industry 4.0 nexus effect** | **Performance Metrics** |
| SDG7 | * By 2030, ensure universal access to affordable, reliable, and modern energy services.
* Increase substantially the share of renewable energy in the global energy mix.
* Double the global rate of improvement in energy efficiency.
* Enhance international cooperation to facilitate access to clean energy research and technology.
* Expand infrastructure and upgrade technology for supplying modern and sustainable energy services
 | * Energy consumption and emissions can be monitored using RMS and maintain energy efficiency (Kurniadi & Ryu, 2020).
* Promotes the use of natural resources and reduces greenhouse gases (Kurniadi & Ryu, 2020).
* Optimizes resources and improves infrastructure (Sindhwani & Malhotra, 2018).
 | * Energy consumption (M. Liu et al., 2019)
* Usage of renewable energy (M. Liu et al., 2019)
* Usage of hazardous chemicals (Moldavska & Welo, 2019)
* Carbon emissions (Moldavska & Welo, 2019)
 |
| SDG8 | * Economic productivity through diversification, technological upgrading, and innovation.
* Global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation.
* Productive employment and decent work for all women and men.
* Promote safe and secure working environments for all workers.
 | * RMS can fulfil the social and economic needs of sustainability (Kurniadi & Ryu, 2020).
* Modularity, a pillar of RMS, supports an eco-friendly structure (Kurniadi & Ryu, 2020).
* RMS and Industry 4.0 improve organizational culture with safety (Dubey et al., 2017).
 | * Wage per worker per day (Moldavska & Welo, 2019)
* Profit percentage (Moldavska & Welo, 2019)
* Average employee availability (Moldavska & Welo, 2019)
* No. of skilled labour (Fatimah et. al., 2020)
* Employee retention rate (Fatimah et. al., 2020)
 |
| SDG9 | * Develop quality, reliable, sustainable, and resilient infrastructure.
* Promote inclusive and sustainable industrialization.
* Upgrade infrastructure and retrofit industries to make them sustainable.
 | * RMS and Industry 4.0 assist to develop sustainable infrastructure and quality (Kurniadi & Ryu, 2020).
* To fulfil the dynamic demands of the market, continuous up-gradation is required.
 | * Allocation of R & D budget (Moldavska & Welo, 2019)
* Availability of sufficient working space (Alawneh et. al., 2018)
* Availability of advanced technology for reconfigurability (Johnsson et al., 2020)
* Utilisation of machine infrastructure (Johnsson et al., 2020)
 |
| SDG12 | * Sustainable management and efficient use of natural resources.
* Reduce waste generation through prevention, reduction, recycling, and reuse.
* Strengthen their scientific and technological capacity.
 | * Promotes the use of natural resources and reduces greenhouse gases (Kurniadi & Ryu, 2020).
* RMS leads to a reduction in waste (Bi et. al., 2008).
 | * Production lead time (Gumasta et. al., 2011)
* Reduction in waste (Alawneh et al., 2018)
* Number of accidents in the organisation (Moldavska & Welo, 2019)
* Recycling of materials (Ordonez-ponce et. al., 2020)
* Product testing and Quality assurance practices (Garbie, 2014; Johnsson et al., 2020)
 |
| SDG17 | * Operationalize the technology bank and science, technology, and innovation capacity.
* Enhance capacity-building support to developing countries.
 | * The innovations are a potential strength of RMS (Kurniadi & Ryu, 2020).
* RMS can adjust the capacity as per the needs of the market.
 | * CSR budget allocation (Ordonez-ponce et al., 2020)
* Co-ordination with other industries and educational institutes (Morgan et al., 2021)
* External financial support (Ordonez-ponce et al., 2020)
* The technology received from other countries for automation (Ordonez-ponce et al., 2020)
* Increase in export (Alawneh et al., 2018)
 |

The contribution of selected practices to SDG attainment can be evaluated using these identified performance metrics. In addition, as stated in SDG 17.19, initiatives are expected to develop a system for measuring the progress of sustainable development by 2030.

1. ***Literature gaps***

The literature gaps identified during the literature review are listed below,

* During the review of RMS articles, it was observed that none of the studies adequately reflected RMS practices. Hence, there is a need to represent overall RMS practices.
* Since very few studies on Industry 4.0 have represented the common technologies used in this era, it was necessary to represent all technologies at a glance.
* The current literature lacks a generalized framework that can guide RMS practices at specific stages of its implementation. A similar observation was made about Industry 4.0 technologies.
* Very few studies have tried to present the interrelation between RMS practices and Industry 4.0 technologies. However, the nexus effect of these relations is somewhere unattended in the present articles.
* Only a few RMS research articles have addressed manufacturing system sustainability. Furthermore, current research does not address the sustainability achieved as a result of RMS practices. The assessment of RMS and Industry 4.0 contributions to achieving SDGs was not addressed during the analysis of RMS, Industry 4.0, and SDG research articles.
* No study has yet proposed a systematic procedure for the penetration of sustainability in current RMS practices.
* There is no framework that represents the nexus effect of RMS and Industry 4.0 technologies on the SDGs. Moreover, several researchers have discussed the SDGs and their targets. However, only a few studies have found that SDGs are classified based on the issues they address. Furthermore, current studies do not identify performance metrics to study the contribution of RMS and Industry 4.0.
* While some RMS studies have discussed sustainability in RMSs, these studies do not address the assessment of SDGs in actual industrial environments through case studies.

The gaps identified in this study clearly emphasize the importance of identifying general RMS practices and Industry 4.0 technologies. As discussed in Section 1, few researchers have discussed sustainability in the context of RMSs and Industry 4.0, whereas the assessment of sustainability penetration and achievement is not addressed in the current literature. According to Kurniadi & Ryu, (2020), an in-depth study of sustainability in RMS, as well as several environmental issues in the case of processes and operations, is required. As a result, the present study addresses these gaps and aims to develop a framework that can assist in assessing SDG achievement through RMS and Industry 4.0 practices. It also includes case analysis and expert opinion to ensure that the proposed framework incorporates the actual industrial environment.

1. **Case analysis**
	1. ***Industry identification and data collection***

To develop a framework that could be used to assess SDGs achieved through the adoption of Industry 4.0 and RMS practices in an industrial context, the authors decided to approach companies that could participate in the process so that practical experiences can be incorporated into the developed framework. With this goal in mind, the authors approached 25 different organizations and explained the framework development process to them. Finally, five companies, out of the 25, agreed to participate in the process and contribute to it. At the same time, while approaching these companies and selecting five of them, the most difficult task was ensuring that all selected companies were relatively similar so that the framework developed would be unbiased. As a result, the five industries chosen included manufacturers of various types of control valves with an annual turnover of 45 to 50 crore rupees. Each company employed between 90 and 100 people, including both technical and non-technical personnel. Control valves manufactured at a capacity of around 100 products per month were supplied to a variety of organizations in India as well as other countries and were primarily used in process industries as well as some other applications.

Following several brainstorming sessions with company officials, it was decided to form a panel of fifteen experts from five companies to ensure uniformity. All the experts were highly qualified and experienced in RMS and Industry 4.0, and a few were working on the long-term sustainability of their products and manufacturing systems. Three of the fifteen experts had completed their Ph. Ds., five had postgraduate degrees in various fields, and seven were undergraduate engineers. The authors attempted to maintain uniformity in the expert profiles so that the results obtained could be compared to one another. Several meetings were held with the expert panels, and the selected practices, SDGs, and performance metrics, as well as the process that would be followed, were explained to them. Following these discussions, the panel members proposed some changes to the selected practices and performance metrics of industrial SDGs. The expert panel also suggested categorizing these practices into groups based on similarity, so that framework development could be carried out more easily. Finally, all experts were asked to prepare pairwise comparisons for all selected practices, as well as performance metric prioritization. A series of brainstorming sessions were held with the expert panel, during which the process and technique used for weight computation and prioritization were explained to them. Following the collection of their opinions, the SWARA and WASPAS steps were followed, and the results were presented to them, with minor changes made based on expert recommendations, as explained in the remainder of this section.

* 1. ***Framework development***

As discussed earlier,the expert panel suggested categorizing all the selected RMS-Industry 4.0 practices using main-criteria and sub-criteria practices that would facilitate the pairwise comparison and framework development process. The suggestion was to categorise the practices based on five main criteria: advanced technologies, customization, quality, rapid adjustment of capacity and functionality, and system integration, with all practices linked to performance metrics so that the effectiveness of these practices could be evaluated, as shown in Figure 4.

Assessment of SDGs adoption by penetrating nexus practices

Advanced Technologies

(AT)

Customization

(CM)

Quality and Safety practices

(QS)

Rapid adjustment of capacity & functionality

(RA)

System integration

(SI)

Internet of things (AT1)

Cloud manufacturing (AT2)

Artificial intelligence & Machine Learning (AT3)

Cyber Physical System (AT4)

Digital Twins/Simulations (AT5)

Big data Analytics (AT6)

Virtual reality/Augmented reality (AT7)

Automation/Production planning (CM1)

Distributed manufacturing system (CM2)

Cloud control/Advanced reconfigurable controls (CM3)

Infrastructure for mass personalisation (CM4)

Autonomous Robots (CM5)

High customer responsiveness (CM6)

Employee education/training (QS1)

Decision making practices/Testing (QS2)

Optimization of layout and infrastructure (QS3)

Sustainable lean six sigma (QS4)

Ethical practices/Safety practices for employees (QS5)

Flexibility/Innovations (RA1)

Smart and Reconfigurable capabilities (RA2)

Prediction of dynamic market (RA3)

Reverse supply chain and logistics (RA4)

Reconfigurable process plan (RA5)

Additive manufacturing (RA6)

Smart factory adoption (SI1)

Real-time information/Data exchange (SI2)

Collaboration within and outside countries (SI3)

Integrate machine and humans/Interoperability (SI4)

Vertical & Horizontal integration (SI5)

Energy consumption (SPM1)

Usage of renewable energy (SPM2)

Usage of hazardous chemicals (SPM3)

Carbon emissions (SPM4)

Wage per worker per day (SPM5)

Profit percentage (SPM6)

Average employee availability (SPM7)

No. of skilled labour (SPM8)

Employee retention rate (SPM9)

Allocation of R & D budget (SPM10)

Availability of sufficient working space (SPM11)

Availability of advanced technology for reconfigurability (SPM12)

Utilisation of machine infrastructure (SPM13)

Production lead time (SPM14)

Reduction in wastes (SPM15)

Number of accidents in organisation (SPM16)

Recycling of materials (SPM17)

Product testing and Quality assurance practices (SPM18)

CSR budget allocation (SPM19)

Co-ordination with other industries and educational institutes (SPM20)

External financial support (SPM21)

Technology received from other countries for automation (SPM22)

Increase in export (SPM23)

Organisation 1

Organisation 2

Organisation 3

Organisation 4

Organisation 5

**Level 1**

**Level 2**

**Level 3**

**Level 4**

**Level 5**

**Figure 4: A developed framework for prioritizing RMS performance metrics**

* 1. ***Multi-method analysis***

The SWARA method was used to compute the weights of the selected RMS-Industry 4.0 practices, and the WASPAS method was used to prioritize the performance metrics as discussed below.

***3.3.1 Application of the SWARA approach***

Various researchers have used the SWARA technique for computing weights of selected criteria as it is simple to use and takes less time. The SWARA method, developed by the researcher Kersuliene in 2010, grades alternatives based on their relative importance, beginning with the most important and progressing to the least important (Pansare et al, 2022a). The SWARA method was used in this study because of its ability to compute the criteria weights and rank them. The method can calculate the criteria importance ratio and is a useful tool for gathering and analysing expert opinion data. In addition to the benefits listed above, the method has a few limitations, including the fact that different researchers used different steps without justification, and there is a need to rank the criteria based on their significance at the start. In addition, if there is ambiguous information, the fuzzy method must be combined with this method. The method is subjective, and inaccuracy and inadequacy of criteria information may result in inefficiency of results that accurately and conclusively consider input parameters. The following steps are followed during SWARA,

**Step 1:** The alternativesare first arranged in descending order based on their relative importance.

**Step 2:** Prepare a comparative importance scale for each value of the chosen alternative.

**Step 3:** Compute the value Kj using the relation

**Step 4:** The weights qj are computed using an equation,

**Step 5**: Compute the relative weights of alternatives using relation,

As previously stated, the expert panel of fifteen members was asked to prepare a comparative importance matrix and the same for one of the members for major criteria and sub-criteria. These are shown in Tables 3 and Appendix A1 to A5.

**Table 3: Comparative importance for major criteria**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr. No.** | **Major criteria** | **Average value (Sj)** | **Kj = (1+Sj)** | **qj = q(j-1)/Kj** | **Wj = qj/Σ (qj)** |
| 1 | AT | 0.0000 | 1.0000 | 1.0000 | 0.4508 |
| 2 | CM | 0.8500 | 1.8500 | 0.5405 | 0.2437 |
| 3 | QS | 0.9000 | 1.9000 | 0.2845 | 0.1283 |
| 4 | RA | 0.4000 | 1.4000 | 0.2032 | 0.0916 |
| 5 | SI | 0.0700 | 1.0700 | 0.1899 | 0.0856 |
|  |  |  | **Sum:-** | **2.2182** |  |

The arithmetic means of the weights obtained for the comparative importance of fifteen experts, followed by major criteria weights multiplied by sub-criteria weights to obtain global weights for all of the selected RMS and Industry 4.0 practices, as shown in Table 4.

**Table 4: Global weights for sub-criteria practices**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Major Criteria** | **Major criteria weights** | **Sub-criteria** | **Ratio weights** | **Global weights** |
| AT | 0.2358 | AT1 | 0.1528 | 0.0360 |
| AT2 | 0.1384 | 0.0326 |
| AT3 | 0.1468 | 0.0346 |
| AT4 | 0.1603 | 0.0378 |
| AT5 | 0.1389 | 0.0327 |
| AT6 | 0.1282 | 0.0302 |
| AT7 | 0.1346 | 0.0317 |
| CM | 0.2021 | CM1 | 0.1878 | 0.0379 |
| CM2 | 0.1541 | 0.0311 |
| CM3 | 0.1522 | 0.0307 |
| CM4 | 0.1638 | 0.0331 |
| CM5 | 0.1631 | 0.0329 |
| CM6 | 0.1791 | 0.0362 |
| QS | 0.1809 | QS1 | 0.2222 | 0.0402 |
| QS2 | 0.1900 | 0.0344 |
| QS3 | 0.2069 | 0.0374 |
| QS4 | 0.1808 | 0.0327 |
| QS5 | 0.2000 | 0.0362 |
| RA | 0.1915 | RA1 | 0.1540 | 0.0295 |
| RA2 | 0.1922 | 0.0368 |
| RA3 | 0.1864 | 0.0357 |
| RA4 | 0.1533 | 0.0294 |
| RA5 | 0.1654 | 0.0317 |
| RA6 | 0.1487 | 0.0285 |
| SI | 0.1897 | SI1 | 0.2398 | 0.0455 |
| SI2 | 0.1787 | 0.0339 |
| SI3 | 0.1603 | 0.0304 |
| SI4 | 0.1844 | 0.0350 |
| SI5 | 0.2369 | 0.0449 |

The calculated weights of all practices were then used during the WASPAS method to prioritize SDG performance metrics.

***3.3.2 Application of WASPAS approach***

The WASPAS method, developed by Zavadskas in 2012, is a one-of-a-kind combination effect of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), with prioritization based on the optimality criteria of these two models (Pansare et al., 2022a). The WASPAS method was used in this study due to its high efficiency and effectiveness in decision-making. Furthermore, its results are consistent and simple to calculate. Despite its many advantages, the WASPAS method has a few limitations, including the inability to handle vague, imprecise, and uncertain data which may be resolved with fuzzy numbers. It also disregards decision maker's refusal and neutral information. Many researchers ignored the WASPAS method's ranking accuracy, whereas the combination parameter of WSM and WPM is determined ad hoc and is generally taken as 0.5 for each. The following are the steps taken when applying the WASPAS method.

**Step 1:** Prepare the initial decision matrix for the selected alternatives and normalize the same using the equation,

x͂ij = ---- if beneficial criteria

 x͂ij = ----if non-beneficial criteria

**Step 2:** Calculate the total relative importance using WSM as per the following equation,

**Step 3:** Calculate the total relative importance using WPM as per the following equation,

**Step 4:** The total relative significance is computed using the following generalized equation (assuming λ = 0.5),

The initial pairwise comparison made for performance metrics is shown in Appendix A6 whereas the total relative importance tables are shown in Appendix A7 and A8. The final ranking of performance metrics obtained during WASPAS method is shown in Table 5.

**Table 5: Total relative significance**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr. No.** | **Performance metrics** |  |  | **Qi** | **Rank obtained** |
| 1 | SPM1 | 0.5844 | 0.5367 | 0.5605 | 11 |
| 2 | SPM2 | 0.5353 | 0.4602 | 0.4977 | 22 |
| 3 | SPM3 | 0.5615 | 0.5101 | 0.5358 | 17 |
| 4 | SPM4 | 0.5366 | 0.4314 | 0.4840 | 23 |
| 5 | SPM5 | 0.5877 | 0.5025 | 0.5451 | 15 |
| 6 | SPM6 | 0.6611 | 0.6139 | 0.6375 | 3 |
| 7 | SPM7 | 0.5673 | 0.5320 | 0.5496 | 14 |
| 8 | SPM8 | 0.5970 | 0.5815 | 0.5893 | 7 |
| 9 | SPM9 | 0.5737 | 0.5362 | 0.5550 | 13 |
| 10 | SPM10 | 0.6035 | 0.5155 | 0.5595 | 12 |
| 11 | SPM11 | 0.6078 | 0.5340 | 0.5709 | 9 |
| 12 | SPM12 | 0.6603 | 0.6429 | 0.6516 | 1 |
| 13 | SPM13 | 0.6530 | 0.6052 | 0.6291 | 4 |
| 14 | SPM14 | 0.6613 | 0.6331 | 0.6472 | 2 |
| 15 | SPM15 | 0.6132 | 0.5866 | 0.5999 | 6 |
| 16 | SPM16 | 0.5758 | 0.5495 | 0.5627 | 10 |
| 17 | SPM17 | 0.5627 | 0.5256 | 0.5441 | 16 |
| 18 | SPM18 | 0.6326 | 0.6070 | 0.6198 | 5 |
| 19 | SPM19 | 0.5637 | 0.4895 | 0.5266 | 19 |
| 20 | SPM20 | 0.5447 | 0.4891 | 0.5169 | 20 |
| 21 | SPM21 | 0.5245 | 0.4931 | 0.5088 | 21 |
| 22 | SPM22 | 0.5601 | 0.5071 | 0.5336 | 18 |
| 23 | SPM23 | 0.6015 | 0.5438 | 0.5726 | 8 |

The framework adoption indexes across the selected organizations were computed to rank these as shown in Table 6.

**Table 6: Framework adoption index across different organizations**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Performance Metrics** | **OG1** | **OG2** | **OG3** | **OG4** | **OG5** |
| SPM1 | 0.0388 | 0.0273 | 0.0273 | 0.0302 | 0.0273 |
| SPM2 | 0.0243 | 0.0345 | 0.0268 | 0.0243 | 0.0345 |
|

|  |
| --- |
|  SPM3 |

 | 0.0289 | 0.0316 | 0.0371 | 0.0234 | 0.0316 |
| SPM4 | 0.0335 | 0.0261 | 0.0310 | 0.0211 | 0.0335 |
| SPM5 | 0.0322 | 0.0377 | 0.0377 | 0.0154 | 0.0349 |
| SPM6 | 0.0409 | 0.0245 | 0.0376 | 0.0409 | 0.0278 |
| SPM7 | 0.0352 | 0.0296 | 0.0352 | 0.0183 | 0.0240 |
| SPM8 | 0.0257 | 0.0166 | 0.0257 | 0.0348 | 0.0166 |
| SPM9 | 0.0327 | 0.0242 | 0.0327 | 0.0356 | 0.0299 |
| SPM10 | 0.0387 | 0.0273 | 0.0301 | 0.0215 | 0.0387 |
| SPM11 | 0.0337 | 0.0366 | 0.0395 | 0.0307 | 0.0337 |
| SPM12 | 0.0418 | 0.0384 | 0.0384 | 0.0384 | 0.0418 |
| SPM13 | 0.0274 | 0.0274 | 0.0403 | 0.0371 | 0.0274 |
| SPM14 | 0.0448 | 0.0183 | 0.0382 | 0.0382 | 0.0315 |
| SPM15 | 0.0354 | 0.0323 | 0.0385 | 0.0385 | 0.0385 |
| SPM16 | 0.0188 | 0.0332 | 0.0274 | 0.0332 | 0.0390 |
| SPM17 | 0.0293 | 0.0265 | 0.0349 | 0.0349 | 0.0377 |
| SPM18 | 0.0397 | 0.0397 | 0.0429 | 0.0270 | 0.0366 |
| SPM19 | 0.0230 | 0.0257 | 0.0284 | 0.0365 | 0.0338 |
| SPM20 | 0.0331 | 0.0358 | 0.0331 | 0.0305 | 0.0278 |
| SPM21 | 0.0274 | 0.0326 | 0.0300 | 0.0326 | 0.0248 |
| SPM22 | 0.0315 | 0.0315 | 0.0287 | 0.0260 | 0.0233 |
| SPM23 | 0.0250 | 0.0338 | 0.0397 | 0.0338 | 0.0279 |
| Adoption Index | 0.7417 | 0.6912 | 0.7814 | 0.7027 | 0.7225 |
| Rank | 2 | 5 | 1 | 4 | 3 |

* 1. ***Sensitivity analysis***

In the case of framework-based studies, it is necessary to conduct sensitivity analysis tests to ensure that the framework's suitability and behaviour that could be predicted under variable conditions (Yadav et. al., 2018). The weights of selected practices were varied, and a sensitivity analysis was performed. In total, 69 experiments were run in three slots to test the robustness of the developed framework. During this process, the weight of one practice was held constant while the weights of the other practices varied for each slot. The same procedure was repeated for the 69 experiments, as shown in Appendix A9. Finally, Figure 5 depicts the results of the sensitivity analyses for various experimental conditions. During the sensitivity test, the results showed that the variations in the adoption index scores were significantly low in all five organizations. The rankings of the organizations were also obtained based on the adoption index, which may help to increase the adaptability of the developed framework.

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |
|  |
| (c) |

**Figure 5: Sensitivity analysis results across different experimental conditions**

1. **Discussion**
	1. ***Study findings***

The findings of the study primarily contribute to important knowledge regarding SDG attainment and performance evaluation through the nexus effect of RMS practices and Industry 4.0 technologies. Knowledge of several RMS practices, Industry 4.0 technologies, their relative importance, and ranked performance metrics, in particular, is useful during RMS adoption as well as SDG attainment and evaluation. In future research, the relative importance of the selected practices can be further investigated in order to prepare a detailed RMS implementation plan.

The year-on-year increase in the number of publications related to the SDGs, as shown in Figure 2 (a), demonstrates the growing importance of the SDGs in industries. Figure 2(b), which depicts the county-by-country contribution of SDGs articles, demonstrates that awareness about SDGs is limited to developed countries, whereas it has yet to be explored in developing countries. Also, Figure 2(c) shows that the majority of SDGs articles contribute to areas such as social science, environmental science, energy, and medicine, whereas areas such as engineering and others are comparatively less focused. In addition, the bibliometric analysis of articles, as shown in Figure 2 (d), indicates that articles are mainly focused on the country, health, energy, and sustainability.

The hybrid SWARA-WASPAS technique is now used to compute the weights of the chosen practices, and the results are presented and discussed in Table 7.

**Table 7: Study findings and discussion**

|  |  |  |
| --- | --- | --- |
| **Analysis particulars** | **Graphical results** | **Discussion** |
| Major criteria practice weights | **Figure 6(a): Ranking of major criteria practices** | The advanced technologies have ranked first, indicating that the most recent technologies can be extremely beneficial to SDG achievement. Dantas et al., (2021) discussed the same, mentioning that technologies can reduce pollution levels. The second place was awarded to customization practices that emphasize the importance of meeting customized customer needs on a priority basis. Morgan et. al., (2021) mentioned this during their RMS literature review and mentioned that several technologies can help with customization. As shown in Figure 6(a), the rapid adjustment of capacity and functionality, system integration, and quality and safety practices ranked third, fourth, and fifth, respectively. This can help in answering RQ1 and determining the impact of practices on SDG attainment.  |
| Global weights of practices | **Figure 6(b): Global weights of practices** | The obtained global weights, as shown in Figure 6(b), show that smart factory adoption is critical for SDG attainment. Morgan et. al., (2021) conducted a review of RMS articles with a focus on machine intelligence and smart manufacturing capabilities that back up these findings. Morgan et. al., (2021) considered vertical and horizontal system integration as a prominent machine control where sensing, actuating, management, and control are included and required for the integration to be in the second position. Employee education and training was the third most important practice as discussed by Yadav, et al., (2018). Several researchers, including Dantas et al., (2021), studied CPS and concluded that its implementation could lead to production optimization, which would assist in the attainment of the SDGs. As a result, automation/production planning was ranked fourth, while CPS was ranked fifth. |
| Ranking of performance metrics | **Figure 6(c): Ranking of the performance metrics** | As shown in Figure 6(c), the availability of advanced technologies for reconfigurability ranking first. While assessing SDGs in the construction industry, Johnsson et al., (2020) identified technology as one of the key criteria supporting the current findings. Lead time was ranked second, and the same significance was highlighted by Puik et al., (2017), who considered lead time when evaluating reconfiguration schemes. The next ranking position was for profit percentage, which emphasizes the importance of financial benefits to organizations in order to remain competitive and grow. According to Moldavska & Welo, (2019), one of the criteria for sustainable manufacturing is profitability. Machine utilisation was ranked fourth, implying that increasing machine utilization is necessary to maximize the return on investment in machine infrastructure. As a result, Goyal & Jain, (2016) attempted to optimize the flow line while taking machine utilization into account, referencing economic justification. Several researchers, including Garbie, (2014); Johnsson et al., (2020), focused on product quality and considered it a prominent parameter that supports the next position for product testing and quality assurance practices during ranking.  |
| Adoption index | **Figure 6(d): Adoption index of the case organization**  | The adoption index computed for five organizations revealed that organization 3 had the highest adoption index (0.7814). This demonstrates that the developed framework had the highest adoption rate of 78.14%, with the lowest adoption rate of 69.12% across the selected organizations, strengthening the framework's applicability. |

The analysis of the above results shows that the importance of the SDGs and their attainment is rapidly increasing, and it is necessary to instil these in developing countries. Furthermore, a greater emphasis on the engineering and industrial aspects of the SDGs is required. Industries must seek to use advanced technologies to improve performance and achieve the SDGs. To remain competitive in the marketplace, efforts must be made to meet customized needs. Smart factory adoption, in tandem with machine module integration, is the best option for this. Practitioners must also try to adopt such practices and train employees to instil multi-skills. In today's competitive environment, automation of production activities using CPSs is almost mandatory. Automation and advanced technologies can significantly reduce lead time. The proposed framework can therefore help to identify the root cause of poor lead time and improve it by implementing selected practices. For a low profit, practitioners must focus on selected practices and strive for improvement. The RMS should be designed in such a way that it maximizes machine utilization while also improving product quality.

Further, it can be also noted that the uses of renewable energy and carbon emissions have received less attention from policymakers. This could be due to the fact that these points are most important in terms of sustainability and the environment, but less in terms of economic benefit. The authors would like to suggest that there is a need for government initiatives to promote them and provide economic benefits to those who implement them for environmental benefits. The minimal variations obtained during the sensitivity analysis under variable conditions indicate that the framework developed is robust and can be used in other similar organizations too. In practice, this means that the developed framework can be applied in a variety of situations and perform with roughly the same efficiency. As a result, it can be seen that the integration of RMS practices and Industry 4.0 technologies through the developed framework can assist in achieving the SDGs and bridge the above-mentioned research gaps.

* 1. ***Theoretical implications***

This study will help to enrich the theoretical content of the topic as previously proposed frameworks for evaluating SDGs (e.g. Alawneh et. al., 2018; Johnsson et. al., 2020; Ordonez-ponce et al., 2020) have been industry specific and they have not considered the role of RMSs and Industry 4.0 in attaining them. The first section of the study focuses on a review of research articles related to RMS practices and Industry 4.0 technologies, in which previous research articles are reviewed and a list is generated. This has assisted in the preparation of theoretical understanding of the topic as well as the enrichment of knowledge among researchers and practitioners. The study also includes a review of articles on the SDGs and their analysis, as well as a bibliometric method. This has assisted in the revision of the SDGs and their targets. The categorization of SDGs, on the other hand, will help researchers to identify the relevance of SDGs and the issues that they are addressing (Dantas et al., 2021; Patyal et al., 2022). The identified performance metrics and developed framework demonstrate a novel methodology for measuring the contribution of RMS-Industry 4.0 practices to SDG achievement. The researchers may, however, use the same methodology in other areas of their research. The presented work also demonstrates the use of the SWARA-WASPAS method for calculating criteria weights and alternatives prioritization (Pansare et al, 2022a). The presented work may foster the interest of and attract more researchers to work in this domain, resulting in the achievement of SDGs within the time frame specified.

* 1. ***Managerial Implications***

The framework presented here may assist managers in evaluating and improving the performance of manufacturing industries. Managers may now be able to make quick decisions about CSR funds, employee empowerment, environmental issues, etc., which may result in the overall growth of the organization. This will also encourage managers to participate in social activities that benefit humanity. The framework developed may also help managers determine their priorities and technologies to use during RMS implementation in the context of Industry 4.0. The performance metrics chosen here may also motivate managers to improve infrastructure utilization and collaborate with other countries. This may result in increased financial and technical assistance from developed countries to developing countries.

* 1. ***Implications for researchers and practitioners***

The identified RMS-Industry 4.0 practises may help future researchers and practitioners quickly refer to them, allowing them to deepen their knowledge in the chosen domain. The researchers can investigate and model these practices further using other techniques such as optimization. Practitioners can refer to them and make the most of them during RMS implementation to improve the success of the manufacturing system. Furthermore, designers of manufacturing systems can refer to the prepared list and attempt to incorporate it to meet the needs of a changing market. The nexus effect of RMS practices and Industry 4.0 technologies on SDG achievement presented in this work can assist future researchers in determining the contribution of these two manufacturing advancements to SDG achievement. This emphasizes the road map for achieving the SDGs' targets and may entice more researchers to contribute in this domain, potentially leading to increased awareness about energy, environmental, and other critical issues. Furthermore, the work presented may entice practitioners to work toward SDG achievement while also meeting changing customer needs. The study also demonstrates how to use a hybrid SWARA-WASPAS method to calculate criteria weights and prioritize alternatives. It may be referred to and used by future researchers. Furthermore, the case study presented here illustrates the methodology for applying theoretical knowledge developed in practice to increase its utility. This can assist practitioners in implementing research developed by multiple researchers in their domain. The performance metrics identified in this work can help researchers and practitioners understand all aspects of the manufacturing system's expected outcome. This also demonstrates that simply increasing productivity and profit margins are insufficient; at this stage, social and environmental factors are equally important. Researchers from various fields may be encouraged to contribute research in their field to help achieve the SDGs. The prioritized performance metrics in this work demonstrate the relative importance of selected practices as well as the performance metrics themselves. In practice, this means that practitioners can now understand the relative importance of a particular aspect of output and take corrective action at the appropriate stage to improve it. Researchers may benefit from this in terms of new research directions and contributions to global goals such as energy crises, poverty, environmental issues, etc. The research presented here was conducted in a real-world industrial environment with the assistance of an expert panel comprised of industrial members. This means that the output takes into account actual industrial issues, which can guide future researchers and practitioners in carrying out their research and putting it into practice.

* 1. ***Implications for government and policymakers***

The presented study covers a variety of topics such as energy, the environment, sustainability, employee empowerment, etc. This may assist government officials in making decisions about the manufacturing sector. This can help both industries and government authorities by speeding up the decision-making process. As previously discussed, the various factors considered can assist government officials in issuing permits to manufacturing industries. Simultaneously, a set of performance metrics can be used to evaluate their application from the standpoint of these critical aspects. This can speed up the permissions process, which benefits both industries and government authorities. The work presented here helps to raise awareness about the aforementioned aspects and SDGs. This can assist policymakers in developing policies for allocating funds to specific areas and awarding research grants. Policymakers may also be able to make quick decisions about consulting projects and allocate funds for them as a result of this. With the assistance of the presented work, government officials and policymakers can frame several policies for manufacturing industries and make certain aspects such as energy conservation, social aspects, employee empowerment, etc. mandatory. This can also encourage industries to contribute CSR funds to participate in social benefits.

1. **Conclusions and future scope**

Because of changing environmental conditions, sustainable practices and thus attainment of SDGs in manufacturing industries are becoming increasingly important. However, the role of RMS and Industry 4.0 in this has received little attention in the literature. As a result, during this study, the hybrid SWARA-WASPAS approach was used to compute the weights of selected RMS-Industry 4.0 practices and then prioritize the industrial SDG performance metrics. The obtained results and their impact, as shown in Table 8, indicate that advanced technologies and smart factory adoption practices can significantly assist in the achievement of the SDGs. Organizations must try to incorporate them to contribute to the achievement of the SDGs.

**Table 8: Key findings and their impact**

|  |  |  |  |
| --- | --- | --- | --- |
| **Study/analysis** | **Key findings** | **Impact of study** | **Literature support** |
| Literature review | Researchers' awareness of the SDGs is growing, resulting in an increase in the number of research articles published. RMS practises, Industry 4.0 technologies, and RMS practices can all contribute significantly to achieving the SDGs. | More researchers may be inspired to contribute to research, resulting in the achievement of SDGs. It may also encourage researchers to utilize RMSs and Industry 4.0 practices to achieve the SDGs. | (Patyal et al., 2022) |
| Weights of practices | The use of Industry 4.0 technologies such as smart factories, system integration, etc. can be extremely important in achieving the SDGs. | The practitioner can adopt practices based on their importance in achieving the SDGs and improving performance. | (Dantas et al., 2021; Lerman et al., 2022; Morgan et al., 2021; Patyal et al., 2022) |
| Prioritization of performance metrics | Top evaluation parameters include the availability of advanced technologies and the manufacturing lead time.  | Managers and practitioners can use the developed framework to evaluate the RMS and diagnose poor performance. | (Dantas et al., 2021; Morgan et al., 2021; Pansare & Yadav, 2022d) |
| Sensitivity analysis | Under changing operating conditions, the variations are minimal. | The framework can be applied to other similar industries. | - |

Despite the extensive literature review, the authors agree that some critical practices and technologies may have been overlooked in the presented work. More similar studies from researchers around the world may help accelerate the process of achieving industrial and other SDGs, as well as allow organizations to evaluate themselves. Through similar studies in their respective domains, future researchers may also contribute to the achievement of social and biological SDGs. In addition, expert panel members were chosen from a specific industry and product to test the framework in that context. An expert panel comprised of members from various geographical locations and industries can be chosen to put the developed framework to the test.

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