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Research paper

Maintenance 5.0, Sustainability and Sustainable Development Goals: A Review

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Abstract

The advent of Industry 4.0 has brought about a surge in productivity using technologies such as digital twins, cloud computing, additive manufacturing, big data, sensor technologies, Internet of Things [IoT], Industrial Internet of Things [IIoT], etc,. However, it is essential that all nations need to adopt sustainable technologies due to the resolutions in the Paris Agreement [Paris Climate Accords] and global outrage. As a part of this endeavor, the industry 4.0 paradigm is transitioning to Industry. 5.0, emphasizing sustainable technologies. The activities related to maintenance in Industry 4.0 are often called as maintenance 4.0 or smart maintenance as they use predictive and prescriptive approaches. When maintenance 4.0 is augmented with sustainability aspects, then the maintenance can be called as maintenance 5.0 (M5.0).

In this paper, the state of the art and challenges associated with maintenance 4.0 have been reviewed along the three layers viz. actual sensing layer, processing layer, and application layer. In addition, it also highlighted the United Nations sustainable development goals from the perspective of triple bottom line of sustainability and which SDGs fall under which triple bottom line has been suggested.

We concluded that by developing sustainability indices for each axis of sustainability, the efficacy of Maintenance 5.0 can be evaluated, which will reveal the effectiveness of the implementation of sustainability in M 5.0.

***Keywords**: smart manufacturing, digital twins, cyber-physical system, sustainable development goals, triple bottom line*

1. Introduction

The rise of colonization and increase in consumerization in European society made it evident for the first industrial revolution in the Eighteenth Century [1760 C.E] with the help of mechanization. Here, the agrarian and the handmade production started getting replaced by the mechanized production. This change can be attributed to the advent of steam engine and its application majorly used in the textile and iron production sector. The manufacturing, which was limited to households and small workshops started shifting to bigger factories. Along with the manufacturing transition in communication sector occurred in this era, where canal ways, roadways and the railways improved [1]. The next century saw the need for mass production where the automobile sector thanks to the internal combustion engines blossomed in Europe, America, and Asia as well due to the continual scientific discoveries in the Nineteenth century [1870 CE]. After the second industrial revolution the oil and electricity became the primary source of energy. The communication sector also enhanced because of telegraphs and telephones [2]. Then came the century of information, rapid use of computers, electronics and communication along with the advent of automation making way for the third industrial revolution in the Twentieth century [1970 CE]. During this industrial revolution, the precision in manufacturing increased, wastes in manufacturing decreased because of the automation and there began change in the communication which transformed from the analog to digital[3]. Then with the end of the first decade of the twenty-first century [2011 CE] came the fourth industrial revolution, also known as Industry 4.0 [4-10]. The Industry 4.0 is based upon smart systems and internet-based solutions [9], [11-17] . Here the actual system that manufactures items, like the machinery and the process equipment are integrated with the information and communication technologies (ICT) [9], [11-13], [15-17]. There has been a tremendous push for the new technologies in Industry 4.0, where features like sensor technology, Internet of Things [IoT], Industrial Internet of Things [IIoT], big data, additive manufacturing, Cloud Computing, autonomous robots, augmented reality [AR], digital twins, etc. have now become more common [11-14], [18] . The conventional manufacturing technologies are replaced by smart manufacturing [13], [19]. These smart manufacturing methods predominantly use additive manufacturing, automated robots, AR and virtual reality [VR] [20-22].Fig 1 shows the stages of industrial revolutions from the first industrial revolution to second, third and fourth with their year of inception and the special attribute concerned with each industrial revolution.

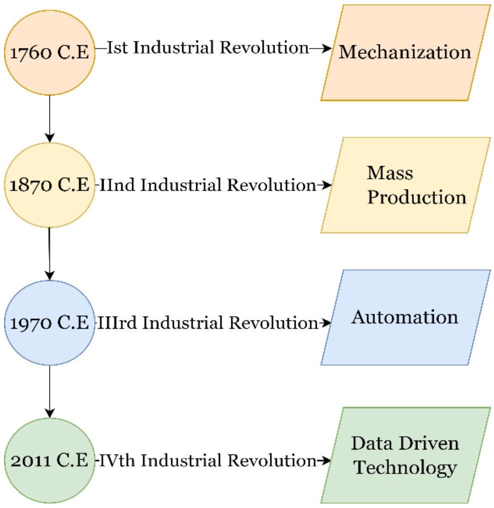

Fig 1: Evolutions of industrial revolutions

The core of Industry 4.0 is a Cyber Physical System [CPS]. The characteristics of the cyber-physical system include integration of physical and digital systems, real-time data processing, interconnected systems, autonomous decision-making, and feedback loops [23-27]. This CPS is divided into various architectural layers that consists of an actual sensing layer, a processing layer, and an application layer [10], [25], [28]. The actual sensing layer which is also called as physical layer consists of sensors and controls that help in gathering real time information from the system. The data sensed is transferred through the network devices (processing layer) to the application layer. The application layer consists of IoT based systems that help in visualizing and helping the task managers to take required actions. All these layers of Industry 4.0 (I4.0) are shown in Fig.2.

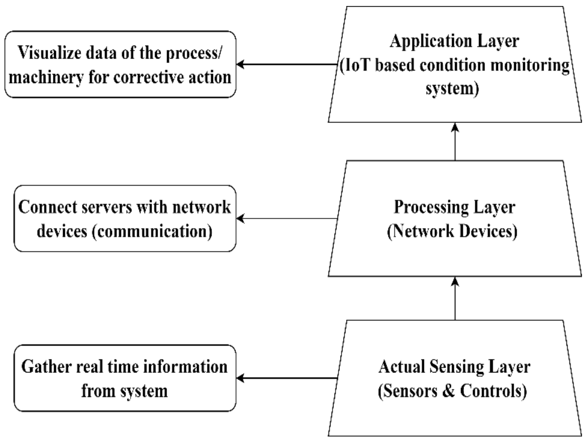

Fig 2: Layers of I4.0

The use of such new-age technologies in Industry 4.0 has benefited the industries. They have reduced the time of manufacturing, increased the efficiencies at various levels, reduced wastes, and increased profitability as well [12], [29-30]. At the consumers' end, it has helped by enhancing customization, reducing cost, and better deliveries redefining consumerization [31-33]. But the studies of a few researchers [31], [34-35] have expressed concerns over the effects of Industry 4.0. According to them, the systems and components of Industry 4.0 require more materials, more energy, more fuel, and more disposable equipment [31]. The other immediate disadvantages also include costly systems, the requirement of high technical skills and rise in pollution accompanied by deforestation [31], [35].

Thus, it can be said that Industry 4.0 contributes more on improving the efficiency and effectiveness, but it is much less concerned about the human cost that comes into play due to process optimization [36]. It can be estimated that after a few years, the problems related to employment can occur in Industry 4.0 resulting in pressure from labour unions and politicians which could further create a rift between people and industries [36]. It is thus essential to move ahead of the dehumanized concept of Industry 4.0 and look for a human-centric approach [37]. Hence an evolvement of more human-centric industry is essential. This paved the way for the development of Industry 5.0, or human-centric industry [38]. The Industry 5.0 is evolved from industry 4.0, where the focus from the economic perspective has been transferred more to the social and ecological well-being [39]. Industry 5.0 promises to employ resources that have been modified to meet the demands of the manufacturing sector. In Industry 5.0 there is a Human-robot cooperation that produces flexible business models. Corporate technologies are redefining the trend with Industry 5.0. It causes sustainable policies to arise, such as waste management and low waste generation, which can increase the effectiveness of businesses [40-42]. Though proposed in the early 2020s by the European Union, this revolution is yet to reach the factory floors as still majority of industries are yet to adopt Industry 4.0. The technology requirements of Industry 4.0, the skills, and the investments are yet to mature and have not yet been adopted by a majority of industries and they are still facing resistance at various levels in industries [43-46], making it difficult for the adoption of Industry 4.0 and Industry 5.0.

To achieve the desired output in any production system, appropriate maintenance is essential. Over a period of time with the growth in industries there began the development and transformation of maintenance activities as well. This is because the life and functioning of the components in the industry are very much essential for the smooth functioning of that particular industry. The early maintenance which

was concentrated on the reactive mode also known as breakdown maintenance has been transformed into the predictive mode in recent years [47], [48]. The condition-based maintenance associated with preventive or proactive maintenance in Industry 4.0 is often termed as maintenance 4.0 [49], [50]. Similarly, maintenance 4.0 when amalgamated with sustainability is termed maintenance 5.0 [51-53].
In subsequent sections the transition of maintenance focusing on maintenance 4.0 and maintenance 5.0 with the reference to triple bottom line i.e. from a sustainability point of view is discussed and in the final section, the conclusion has been drawn.

2. Maintenance 4.0

The maintenance activities form a very important function for any industry. A good maintenance practice is very essential to counter productivity losses, maintain quality, and enhance overall performance. From the second industrial revolution maintenance activities started gaining importance [54]. Till the Second World War [WW-II] maintenance was the reactive type of maintenance. Further from the 1940s to 1970s the preventive type of maintenance gained momentum [54-56]. Then came the periodic maintenance, and until recently when industries have not paced themselves with I4.0 reliability-centered maintenance [RCM] is followed [57], [58]. The current highly practiced maintenance strategies involve reactive maintenance, preventive maintenance, predictive maintenance, and condition-based maintenance [54] [56] [57].
But among others, condition-based maintenance and predictive maintenance have gained momentum in the last couple of decades [54] [56] [57], [59]. With the progress of the industrial sector, maintenance has also evolved from maintenance 3.0 to maintenance 4.0. The major characteristics of maintenance 4.0 include IoT-based condition monitoring, event-driven architecture, prognosis life cycle, proactive computing, E-maintenance support, and interaction with other industrial operations[60], [61], [62]. This proactive maintenance in Industry 4.0 scenario can be divided into three layers viz., user interaction layer, real-time processing layer, and data layer [60],[61][62]. Now, these three layers are concurrent with the three layers of Industry 4.0 mentioned in Fig 2. The individual layers of Maintenance 4.0, their technologies, and selection are mentioned further.

2.1 Actual Sensing Layer

The first and foremost layer of Maintenance 4.0 is the actual sensing layer. The actual sensing layer is the user interaction layer where IoT enabled sensors are installed for actual condition monitoring [60]. The condition monitoring is the heart of maintenance in Industry 4.0[63]. This coordinated condition monitoring is carried through sensors that sense the anomalies and the health of the machinery and the systems. As shown in Fig 3 sensors are installed on the critical machines and machine elements to extract real time data for further processing. The common type of sensors used here detect the noise, vibration, pressure, temperature, speed, etc. which help in understanding the condition of the system. The most used sensors used are the vibration-based condition monitoring sensors. In vibration-based condition monitoring piezoelectric sensors commonly known as accelerometers are used [64], [65]. These sensors are low cost, have high resolution, detect vibration at low frequencies, and consume low power [66], [67]. The sensors used can be of contact as well as of non-contact type. The Micro Electromechanical Systems [MEMS] sensors have also become popular in Maintenance 4.0 due to miniaturization, integration of systems, and mass production [68], [69].

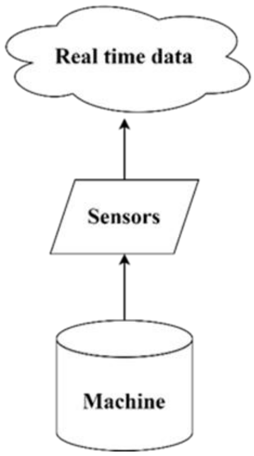

Fig 3: Actual sensing layer

The important task in the actual sensing layer of maintenance 4.0 is the selection of adequate technology here for data acquisition through sensors. This selection depends upon numerous factors which include the type of equipment and machinery i.e. technical features of the system, critical processes of the machinery, accuracy, range of sensors, operation costs, installation cost, and the factory conditions. With the proper selection of the monitoring sensors, it is very important to locate them at the right places to extract the correct and useful features of the system [70]. This layer is very critical for the functioning of maintenance 4.0. Hence, proper selection and placement of the sensors is pivotal for the smooth functioning of maintenance 4.0.[71].
The IoT-based sensors used here in the actual sensing layer have reduced the necessity of individual machine testing as done previously before the implementation of Maintenance 4.0. Also, these sensors have interconnected the machine equipment, thus enabling the combined monitoring of the systems. This has resulted in quick and secure condition monitoring of equipment, making the maintenance tasks quicker. Regardless of the plethora of advantages provided by these sensors, there are a few disadvantages associated with them. These IoT-enabled sensors carry a huge amount of data with them, posing a risk to the security of data, again as the systems are integrated it hampers entire systems due to the data breach [72], [73]. The Radio Frequency Identification [RFID] labels associated with these sensors when wrongly or inadequately labelled, can affect the identification in the status of the machine, causing erroneous analysis of the machine's health [73]. In some cases, the quality of the data obtained from the IoT-enabled sensors is less than the actual physical wired condition monitoring sensors [74]. Thus, at this actual sensing layer of maintenance 4.0, the over-dependence on the IoT-enabled sensors can affect the performance of the systems. Hence a logical use of human intervention is necessary at this layer.

2.2 Processing Layer

After the actual sensing layer is a processing layer where there are servers, gateways, and communication devices which can be wired or wireless devices used to transport the signals. Majorly used wireless devices include, Long Range Wide Area Networks [LoRaWAN], Narrow Band Internet of Things [NB-IoT], ZWave and LowPAN [Low Power Wireless Personal Area Networks], Wireless Local Area Networks [WLAN], Low-Rate Wireless Personal Area Networks [LR-WPAN], Bluetooth low-energy [BLE] and Zigbee [74], [75]. Here too the selection of communication devices plays a vital role. The processing layer also called the middleware[4]. As shown in Fig. 4, in the processing layer the network and communication devices collect the real time data extracted by the IoT enabled sensors placed on the machines and transfer or transport this real time data with a very low response time further to the application layer.

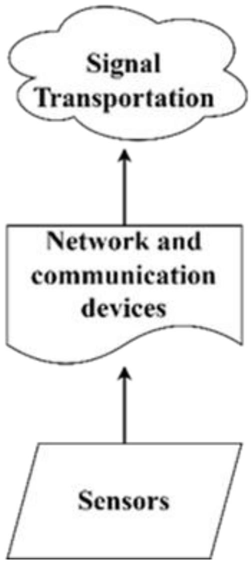

Fig 4: Processing layer

Middleware serves as a mediator between software programs, as its name implies, while it can also help with data interchange between hardware and software. Benefits of middleware include its compatibility with various operating systems, support for industry standards in protocols, and capacity to facilitate service interactions between diverse devices, networks, and applications[4]. The factors that determine the selection of the network and communication devices of this middleware include distance, energy, accuracy of data, and operational cost.

From maintenance 4.0 perspective, at this layer, the signals of the machine health probed by the sensors are transferred or communicated to the storage and analysis layer of maintenance 4.0. As mentioned earlier in the actual sensing layer, a huge amount of data is collected from the actual sensing layer. This data needs to be transferred very effectively to the final layer. Hence, it is necessary that the communication devices, whether wired or wireless which are the basis of the cyber-physical system [CPS] of the maintenance 4.0 should work seamlessly.

2.3 Application Layer

In the application or data layer, there are cloud or data storage devices along with Storage, Processing, Analytics, and Management [74],[75]. This layer as illustrated in Fig. 5 collects the real time data from the sensors transported by communication devices to its data processing and storage devices like cloud. The data received at this layer is processed and proper decision is made to take corrective action in maintenance. The devices and cloud selection here also depend upon the actual system, operational cost, and energy expenditure.

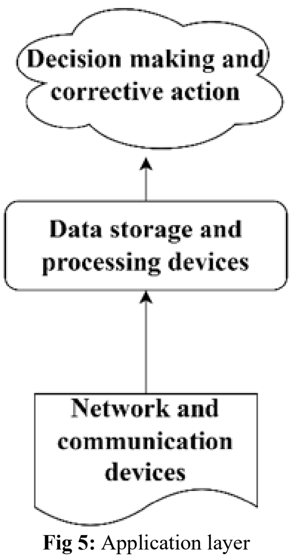

Fig 5: Application layer

The data received at this layer for analysis is huge. As real-time data is generated, quick and accurate decision-making is possible when viewed from the maintenance perspective, reducing downtime. The huge data collected is also subject to security breaches[76]. Network latency can also affect the data causing errors in decision making. Hence, it is necessary to select a reliable cloud provider and implement effective security measures.

Now, these layers which require various technologies and relevant devices consume energy. This energy consumption can be managed effectively by integrating an Energy Management System [EMS] and maintenance management system[77]. As Industry 4.0 itself is complex, the maintenance activities involved in it are complex in nature. In Industry 4.0 it is very much important to select the proper maintenance strategy i.e., essential to optimize maintenance. It is best to have a dynamic and adaptable maintenance plan that can be adjusted to the unique requirements of the system and its surroundings [78], [79] .

Along with the problem associated with energy, maintenance 4.0 also involves problems related to the workforce. The complex technologies that are to be adapted to effectively implement maintenance 4.0 need adaptation from the workforce, the workforce needs to learn complementary skills else can lead to conflict with workers. There is also a problem related to poor understanding and implementation of the technologies, which in turn also require the implementation of and selection of proper technology[80]. Here, the decisions to conduct a specific maintenance are motivated by the real time data instead of the workforce experience which was the case in previous maintenance strategies. Thus, the credibility of maintenance increases drastically, resulting in improvement in the efficiency of associated material and human resources as well as the efficacy of ongoing maintenance activities. Throughout a technological object's whole life cycle, an increasing amount of dynamically changing data is generated. Data-based maintenance is inspired by data-based production technologies. Several advantages of this strategy, including increased availability and efficiency of the business's technical resources, lower expenses, and greater adaptability in meeting customer needs, serve as a motivator for both machine manufacturers and users to adopt and use new technologies [79], [80]. Thus maintenance 4.0 can be used with better efficacy when the technologies, workforce, and data are managed properly.

3. Maintenance 5.0

The activities involved in Maintenance 4.0 are over-reliant on technology and there is too little man-machine [technology] interaction. Thus, it is also considered a dehumanized approach [37]. To move ahead of this dehumanized approach of Industry 4.0, Industry 5.0 is coined, which is more human-centric. Now for Industry 5.0 the corresponding maintenance can be termed maintenance 5.0. The technologies that are involved in maintenance 5.0 are [i] human-machine-interactive technologies; [ii] smart materials and bio-inspired technologies; [iii] Digital twins and real-time simulations; [iv] energy-efficient data transmission, storage, and analysis technologies; [v] Artificial Intelligence; and [vi] energy-efficient and renewables technologies for storage and autonomy [52], [81-84].

The human-machine interactive systems in maintenance 5.0 can be said to be effective when they are found sustainable, where the current as well as the future needs of the workforce and society with the optimum energy consumption, materials processing, and product lifecycles are balanced [51], [82]. The human variables like safety, stress, and skill development are shared in the creation of maintenance plans and decision-making processes. To achieve this, it could be necessary to develop human-centered models and methods that consider the well-being and job satisfaction of employees as well as the impact of human factors on the efficiency of maintenance procedures and the dependability and availability of systems [51].

4. Sustainability and maintenance

4.1 Triple Bottom Line (TBL)

When the term human-centric development is discussed, it necessarily means sustainable development. The concept of sustainable development was developed by John Elkington, an English planner, psychologist, and sustainability consultant, in 1994 when he introduced the "triple bottom line" model, which suggests that economic development policies and practices should be balanced with equal consideration for social and environmental outcomes [83]. In Fig. 6 the triple bottom line as the three axes of sustainability is illustrated. The three axes include the economic, social, and ecological axes. The point where these three axes converge can be said to be truly sustainable development.

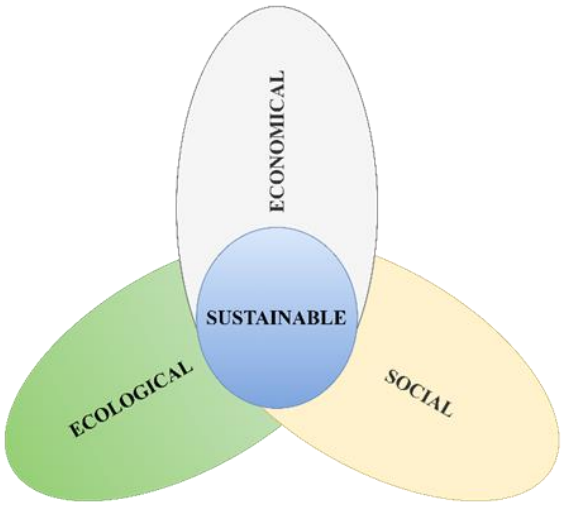

Fig 6: The 'triple bottom line' as the axes of sustainability

It is essential to study the maintenance from the TBL perspective as the activities carried under maintenance in any production system affect the volume in which the goods are produced (economical axis of TBL), the surrounding environment (ecological axis of TBL) as well as the health, safety and social welfare of the people (social axis of TBL) [85]. Currently the industries focus more on the key performance indicators (KPIs) like availability, productivity, reliability rather than sustainability performance indicators [85]. In maintenance 4.0 as the activities are data driven, there is increase in efficiency of human and material resources [79]. The use of digital twins in maintenance 4.0 also prevents the risk of events involved in servicing the critical machine parts, located at accident prone zone of the factory shop [79].

The industrial case study conducted by El Kihel [86] at SFAB has put forth the contribution of maintenance 4.0 from sustainability perspective focusing on the axes of TBL. This company has 72 products consisting of 12 flavors producing 400,000 units per day. From the ecological perspective there is an increase in energy efficiency, boiler efficiency and decrease in plastic waste which saw a reduction from 680 kg to 95 kg after implementation of maintenance 4.0. From economical perspective the real time monitoring has helped in increasing the Overall Equipment Effectiveness [OEE] drastically from 52.34 % to 80.58% over a span of two years. From the social perspective there has been a decrease in major accidents by 100%, reduction in minor accidents by 95 %, reduction in absenteeism by 90% [86]. It is the indication that maintenance 4.0 has a positive effect on the TBL axes of sustainability.

4.2 United Nations Sustainable Development Goals (UNSDGs)

Moving along with the "triple bottom line [TBL]" the United Nation has proposed sustainable development goals [SDG]. There are 17 SDGs and their 139 targets [87-89]. These goals were proposed in 2015 and are set for 2030[88]. The Sustainable Development Goals [SDGs] and the Paris Climate Agreement require major reforms in every country, calling for collaboration between business, academia, government as well as civil society. Of these 17 SDGs, there are numerous SDGs that can be related to the activities carried out under maintenance 4.0 and maintenance 5.0.

Recently there are attempts to corelate Industry 4.0 with SDGs [90], [91], [92]. The case study by [92] in Indonesia is one of its kind. The use of IoT and the ICT for processing of the waste, its recycling, its onsite treatment, and the concerned supply chains of waste management involving the stake holders had a positive impact on some of the SDGs. The study revealed that SDG3 (well being for all), SDG6 (availability of water and sanitation for all), SDG8 (inclusive growth for all), SDG12 (sustainable consumption and production patterns) and SDG13 (action to combat climate change) have positively impacted by using industry 4.0 based smart waste management in Indonesia [92].

5. Sustainable development goals & maintenance 5.0 w.r.t triple bottom line

The studies carried [90], [91], [92] have helped in understanding the effect of Industry 4.0 on SDGs. But the exact effect of maintenance 4.0 and maintenance 5.0 is still undetermined. The activities carried out under Maintenance 4.0 & Maintenance 5.0 have a direct effect on the sustainable development goals. Of the 17 SDGs few SDGs are directly affected by maintenance 5.0 These SDGs include SDG3, SDG6, SDG7, SDG8, SDG9, SDG11, SDG12, SDG13, SDG14 and SDG 15. These SDGs also are part of the TBL axes, where few SDGs are concerned with the ecological axis, few with the economical axis and few with the social axis of the TBL. A detailed table (Table 1) is presented below to indicate the relations of the SDGs with the concerned TBL axes.

Table 1: Relation of SDGs & TBL of maintenance 5.0.

SDGS	ECOLOGICAL	ECONOMICAL	SOCIAL
SDG3	-	-	√
SDG6	√	-	-
SDG7	√	√	-
SDG8	-	√	√
SDG9	-	√	-
SDG11	√	-	-
SDG12	√	√	-
SDG13	√	-	-
SDG14	√	-	-
SDG15	√	-	-

The ecological, economical and the social axis of the TBL with their relation with SDGs from maintenance 5.0 perspective is discussed further.

5.1 Ecological

The foundations of Industry 5.0, the first industrial revolution with a focus on humans, include a methodical approach to waste prevention, an effective logistics design, the 9R [Refine, Recover, Reinovate, Recognize, Reconsider, Realize, Reduce, Reuse, and Recycle] principles of industrial upcycling, and the assessment of life standards and creative inventions to produce high-quality custom products [93]. This definition throws light on the environmental factor of sustainability. The systems/ technologies which are also used in Industry 4.0 and 5.0 have also brought some significant improvements in order to become sustainable. According to [86] the work consisting of Industry 4.0 and sustainability has increased tremendously from 2015 onwards. The effective implementation of Industry 4.0 systems has increased the overall equipment efficiency, and energy efficiency and has also contributed to waste management by reducing the waste [86].

The Life Cycle Assessment Analysis [LCA] in maintenance 4.0 due to condition-based maintenance and predictive maintenance has shown positive trends in increasing life of the equipment [94]. Environmental indicators like global warming potential, Ozone layer depletion, Aquatic eco-toxicity, Terrestrial eco-toxicity, and Acidification are studied [94]. From a strategic standpoint, the interpretive structural modeling technique [ISM] is used to develop the structural relationships among the factors of sustainability and technology [95].

In a similar way to ISM the relation between the ecological factors and the sustainable development goals in maintenance 5.0 can be studied. To analyze the effect on ecology and their respective SDGs, the SDGs are arranged as the functions of land, water, climate change, and consumption as shown in Fig. 7

SDG 6 and SDG 14 are based on the water. To have clean water and to conserve water resources are the nucleus of these SDGs. Similarly, SDG 11 and SDG 15 are based on land are focus on habitable land for all species. It is well established that manufacturing and process industries generate wastes and effluents. These wastes can be in the form of water wastes or solid wastes. These wastes have a very severe effect on terrestrial as well as aquatic ecosystems [96]. Considering only the paper and pulp industry in India, it is estimated that it consumes 100-250 m3 of water per ton of paper generating about 75-225 m3 of wastewater [96]. Thus, to attain SDG 6 and SDG 14 enough care of water should be taken. The water should be used economically and water- waste should be treated well before disposal. Similarly, for SDG 11 and SDG 15, waste should be disposed of properly so that they do not contaminate land. As mentioned in [86], the activities of maintenance 5.0 have reduced the waste. But still, a detailed study to the extent of reduction of various wastes is to be done considering various performance indicators.

SDG 13 emphasizes climate change and efforts to mitigate climate change. Here, the wastes and effluents from industry affect the climate at large. The greenhouse gases [GHGs] in the industries are to be studied and their reduction due to maintenance 4.0 can be quantified as done by SDG 7 and 12 are related to the consumption pattern where SDG 7 focuses on energy and SDG 12 on consumption and production. As stated in [86], the energy efficiency by maintenance 5.0 has increased along with the rise in productivity addressing SDG 7 and SDG 12 respectively. But, the new systems installed for maintenance 5.0 have increased the material consumption. As studied [94], the increased life of equipment, thus addressing SDG12. Yet, system consumption with overall consumption of material is to be studied and the net sustainability w.r.t SDG12 can be found.

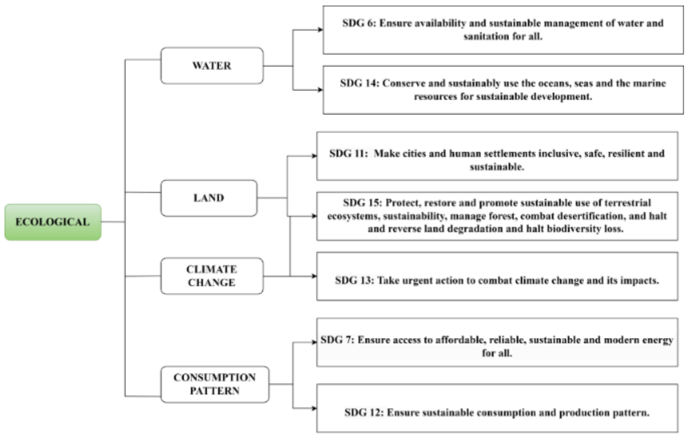

Fig 7: Ecological SDGS of Maintenance 5.0

5.2 Economical

The Economic sustainability takes on a new meaning in the TBL method; it encompasses more than just typical corporate capital. In this way, the effect that a company's activity has on the economic environment in which it functions ought to be considered when measuring corporate capital. Businesses that contribute to the general economic well-being of their networks and community will continue to be prosperous in the future. The concepts of circular and green economy are very much pivotal in the economic sustainability pillar [93].The circular economy focuses on reusing, repairing, recovering, refurbishing, rethinking, remanufacturing, and recycling the resources [93].

The goal of Industry 4.0 and 5.0 industries' technologies is to increase equipment availability while reducing downtime and boosting productivity through e-maintenance and smart maintenance practices, which have become increasingly popular with the advent of Industry 4.0. Given that maintenance expenses might account for 15% to 40% of the total costs associated with producing goods, this growth is justified. [97]. To measure the economic performance, it is necessary to measure the overall equipment effectiveness [OEE] which depends upon availability, performance, and quality. The architectural layers used in Maintenance 5.0 help to monitor the machine and the equipment continuously which simplifies the system and reduces the overall cost [98]. The high installation cost required in setting a maintenance 5.0 can be compensated by the high OEE, reduction in delivery time, increased product quality and productivity, improved customer satisfaction, and increase in sales over the years [86].

The SDGs concerned with the economic aspect of sustainability are illustrated in Fig. 8.

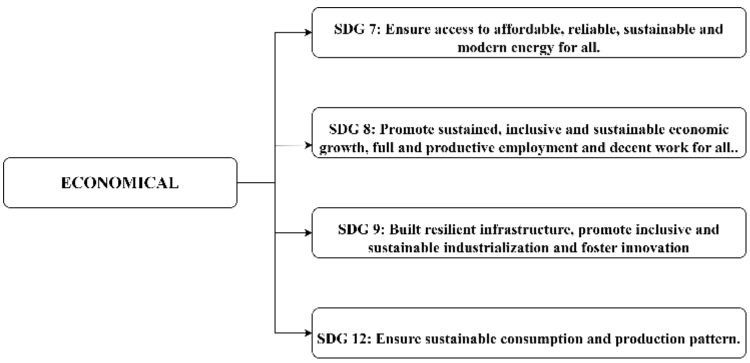

Fig 8: Economical SDGS of Maintenance 5.0

SDG7 is concerned with the cost and availability of energy, where, as already discussed maintenance 5.0 helps in reducing the energy consumption thereby reducing the cost associated with energy. The economic aspect of SDG 8 is economic growth, where reduced downtime, increased quality of products, lesser waste, and improved O.E.E have increased productivity. SDG 9 talks about resilient infrastructure and innovation. For the activities in maintenance 5.0, the interactive systems give real-time results, creating a defect-free industrial system set up. Again, the rise in productivity has addressed the consumption pattern of SDG12.

5.3 Social

The society or the social aspect of TBL plays a very important role in Maintenance 5.0. The lack of digital skills can become a prime obstruction in effectively implementing the technologies that are termed as smart. Yet the major barrier remains the disruptions in the employment arena, where the newly emerged development in technology brings automation which can outrightly affect the existing jobs; this can lead to challenges in the job/employment markets [45]. This definitely can be a resisting factor for the implementation of maintenance 5.0. However, studies [99] have shown that the jobs lost during the transition or adoption of new technology are countered by the rise in jobs soon due to such advanced technologies.

Even then there are positive implications of maintenance 5.0. The real-time data has helped in reducing the risks and accidents on the shop floor. The major accidents have reduced to 95%- 100%, and there is a 90% reduction in absenteeism, resulting in a rise in confidence among employees, team spirit, motivation along satisfaction [86].

The SDGs concerned with the social aspect of sustainability are illustrated in Fig. 9.

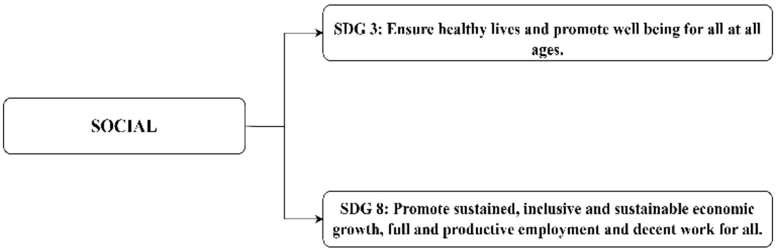

Fig 9: Social SDGS of Maintenance 5.0

SDG 3 discusses the well-being of individuals, while SDG 8 discusses employment and decent work for all. As industry 5.0 itself is society driven by the principles of maintenance 5.0 also address social SDGs i.e. SDG 3 and SDG 8. The reductions in accidents as stated in [86] and the increased job satisfaction have promoted the well-being of the employees employed under maintenance 5.0. It has also created a decent workspace.

6. Conclusion

For the last couple of decades, industries around us have been transforming at a rapid pace. Industry 4.0 has integrated intelligent digital technologies with the manufacturing processes. This has thus made over-reliance on the cyber-physical system and has therefore reduced human intervention. But, with a growing requirement to develop systems and industries that are human-centric, sustainable, and resilient, there has been a need to embrace a new industrial revolution viz., Industry5.0. Hence from the maintenance perspective, there is a need to adopt maintenance 5.0.

In this work, maintenance 4.0 and maintenance 5.0 are explored extensively. The layers involved in maintenance 4.0 are discussed, wherein the benefits and shortcomings of each layer are put forth. For each of these layers discussed, it is found that there is over dependence on technology and a little dependence on human intervention, which have their own disadvantages [93], [100]

Then the comprehensive study of human-centric maintenance 5.0 is carried out from the sustainability perspective. The Triple Bottom Line [TBL] of sustainability and the 10 relevant UN Sustainable Development Goals [SDGs] are studied. The effect of the activities of maintenance 5.0 on the TBL and SDGs is discussed extensively. The studies carried out have expressed maintenance 5.0 as sustainable where the aspects of productivity, O.E.E, and energy efficiency are considered to express the systems as sustainable. Few authors [43], [90], [95], [101], [102] have determined the key performance indicators [KPIs] of sustainable maintenance, relationships amongst them, their relative importance, and their rank by using the interpretive structural model [ISM], Fuzzy Analytical Hierarchy Process [F-AHP], Decision making, trial evaluation laboratory [DEMATEL] and elimination & choice expressing reality [ELECTRE III]. However, knowing only KPIs, relative importance, and their rank will not measure the adaptiveness of M5.0; the quantification of performance indicators w.r.t. sustainability needs to be explored. From the literature review, the following research opportunities can be derived:

- Quantifying sustainability in maintenance 4.0 and maintenance 5.0 considering TBL axis.
- Developing the sustainability indices for key performance parameters of maintenance activities such as downtime, availability, Remaining Useful Life [RUL], energy consumption, etc. to demonstrate the extent of sustainability.
- Linking the sustainability indices with various SDGs and then quantifying them in order to assess the impact of the implementation of M 5.0.
- To implement M5.0 in industry, specific digitalization architecture can be developed.

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