Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 6424869, 24 pages
https://doi.org/10.1155/2022/6424869

Research Article

A Novel Smart Production Management System for the Enhancement of Industrial Sustainability in Industry 4.0

Varun Tripathi,[1] Somnath Chattopadhyaya,[2] A. K. Mukhopadhyay,[3] Suvandan Saraswat,[4] Shubham Sharma ,[5,6] Changhe Li,[7] S. Rajkumar ,[8] and Fasika Bete Georgise[9]

[1]*Department of Mechanical Engineering, Accurate Institute of Management & Technology, Greater Noida, Uttar Pradesh, India*
[2]*Indian Institute of Technology (ISM), Dhanbad, India*
[3]*Department of Mining Machinery Engineering, Indian Institute of Technology (ISM), Dhanbad, India*
[4]*Department of Mechanical Engineering, JSS Academy of Technical Education, Noida, India*
[5]*Department of Mechanical Engineering, IK Gujral Punjab Technical University, Main Campus, Kapurthala 144603, India*
[6]*Department of Mechanical Engineering, University Centre for Research and Development (UCRD), Chandigarh University, Mohali 140413, Punjab, India*
[7]*School of Mechanical and Automotive Engineering, Qingdao University of Technology, Qingdao 266520, China*
[8]*Department of Mechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia*
[9]*Department of Industrial Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia*

Correspondence should be addressed to Shubham Sharma; shubhamsharmacsirclri@gmail.com and S. Rajkumar; rajkumar@hu.edu.et

Received 28 October 2021; Accepted 24 February 2022; Published 13 April 2022

Academic Editor: Kuei-Hu Chang

In industry 4.0, shop floor management teams are increasingly focused on developing an unprecedented strategy to avoid financial losses and address the challenges and problems encountered in operations management. In the present scenario, the management teams use various process optimization approaches for operational control, including lean manufacturing, smart manufacturing, the internet of things, and artificial intelligence. The process optimization approach is used to maximize productivity within limited constraints on the shop floor. The present research aims to develop a smart production management system and suggest an efficient process optimization approach to enhancing industrial sustainability by identifying problems and challenges encountered in the complex shop-floor conditions in industry 4.0. The developed production management system has been prepared by classifying the challenges and problems found in the previous research work and organizing brainstorming sessions. The developed management system has been validated by a comprehensive investigation of a case study of an earthmoving machinery manufacturing unit. The analysis showed that the developed system could enhance operation excellence and industrial sustainability in industry 4.0 by optimizing the utilization of resources on the shop floor within limited constraints. The authors of the present article strongly believe that the developed production management system will improve operational excellence and would be beneficial for industry personnel and researchers in controlling operations management in shop floor management of heavy machinery manufacturing, including industry 4.0.

1. Introduction

In industry 4.0, the advantages of the process optimization methods have attracted industry persons and young researchers' attention in the shop floor management domain. Shop floor management, as a key component in industries, is used to maintain industrial sustainability and the stability of resource availability [1]. Process optimization approaches are used to improve productivity with limited resources. Process optimization thinking has focused more on increasing the efficiency of production processes [2]. At present time, several methods are used for process optimization in industries including lean manufacturing, smart manufacturing, internet of things, and artificial intelligence. The process optimization approach is the prevalent strategy in industry 4.0, and it is implemented to improve productivity and optimization of resources [3]. In addition, another author argued that the process optimization approach is applied to meet customer demand in terms of the product as the process optimization approach improves productivity by eliminating waste to achieve the industry's goal [4]. Striving this goal also provides a number of other benefits, which may include production time reduction and increased quality of the production processes, leading to a higher satisfaction level of customers in terms of product. Figure 1 shows the objectives of process optimization approaches in industry 4.0. According to Tripathi et al. [5], process optimization methods are implemented to improve production efficiency. The main advantages of the process optimization approach in industry 4.0 are below:

(1) To achieve a sustainable production management system

(2) To maximize the production rate and production flexibility within available resources

(3) To improve the flexibility, agility, customization, and adaptability in industry 4.0

(4) Ease of implementing industry 4.0 technologies on the production shop floor to the industry individuals

To evaluate the efficiency of production processes, overall production processes and activities are categorized. The categorization helps know if the activities involved contribute to the production process; if so, the activity adds value to the production and is known as value-added activities; and if not, the activity is non-value-added (NVA) and known as non-value-added activities (NVAA) [6]. The elimination of non-value-added activities continuously improves production processes and makes it easier to control production performance for shop floor management [7].

The shop floor management team encourages the synergistic implementation of the Lean concept with industry 4.0 technologies to eliminate waste and enhance industrial sustainability. For this, new models and strategies have been developed by previous researchers to strengthen operational performance and to know the present condition of industry 4.0 technologies. Sony et al. [8] proposed an integration model of industry 4.0 and lean management. The model was developed by reviewing previous literature, and in the study, vertical, horizontal, and end-to-end engineering models were integrated with the lean management methodology. This study provided 15 research propositions to advance the integrative mechanism of industry 4.0 and lean management for enhancing financial profitability by better utilization of resources. Tortorella et al. [9] examined the role of industry 4.0 technologies on the relationship between operational performance and lean production within Brazil. The study has organized a survey on implementing lean and industry 4.0 technologies by performance indicators, including productivity, quality, delivery, safety, and inventory. The collected data has been collected through questionnaires and analyzed by multivariate analysis and contingency theory. The result of the study revealed that entirely technological adoption could not be able to enhance operational performance. However, lean helps in process improvement and support in controlling operation management in industry 4.0. Kamble et al. [10] combined the empirical and exploratory research design to develop a framework for identifying and validating the performance measure for evaluating smart manufacturing systems in Indian small, medium, and microenterprises of auto-components. The data was collected by questionnaire on ten performance dimensions: flexibility, cost, quality, integration, time, optimized productivity, computing, real-time diagnosis and prognosis, and social and ecological sustainability. The result of the study revealed that the proposed performance system was proved able to evaluate the smart manufacturing system and its investments.

Figure 1: Aim of process optimization approach in industry 4.0.

Amjad et al. [11] developed a comprehensive implementation framework that integrated lean, green manufacturing, and industry 4.0 effectively. The developed framework was validated by implementing it in an auto-parts manufacturing firm. The result of the study showed that reduced the value-added time, lead time, non-value-added time, and greenhouses gases emission effectively by 24.68%, 25.60%, 56.20%, and 55%, respectively. The developed framework was able to achieve optimized and cleaner production with automation-based rapid and environmentally conscious manufacturing. Tortorella et al. [12] investigated the relationship between lean production and industry 4.0 through a survey organized with 110 different sizes and sectors of Brazilian manufacturing companies. The data were collected by a questionnaire and analyzed with the help of multivariate analysis. The result of the study indicates that lean production was positively associated with industry 4.0 techniques, and their integrated implementation can lead to enhance performance improvements.

Dahmani et al. [13] developed an eco-design industry 4.0 framework for investigating the relationship between industry 4.0 strategies and lean eco-design. The developed framework was based on the synergetic use of eco-design, industry 4.0, and lean design. The study revealed that the developed framework was able to provide cleaner products using suitable processes to help manufacturers design products and fulfill customer expectations. Varela et al. [14] proposed a structural equation model to quantitatively measure the effect of lean manufacturing and industry 4.0 on sustainability. The data was collected by 252 questionnaires obtained from industrial companies located in the Iberian Peninsula. The result of the study showed that it was not conclusive that lean manufacturing was correlated with any pillars of sustainability including environmental, economic, and social, whereas industry 4.0 showed a strong correlation with sustainability pillars.

Chiarini and Kumar [15] discussed the integration between principles and tools of lean six sigma and industry 4.0 technologies. The data were collected through direct observations and interviewing manufacturing managers of ten Italian manufacturing companies. The result showed that Lean Six Sigma could achieve effective outcomes from industry 4.0 applications. However, the integration needs reinvented mapping tools and implies an end-to-end integration and vertical and horizontal integration. Saxby et al. [16] assessed how well lean management supports continuous improvement in industry 4.0. Semistructured interviews of five quality specialists in manufacturing were used to collect data and opinions for lean management and industry 4.0. The result showed that lean management could integrate new technologies for effectively continuous support in industry 4.0.

Ciano et al. [17] developed a framework on the relationship between industry 4.0 technologies and lean techniques. The developed framework focused on six areas: manufacturing equipment and processes, workforce management, shop floor management, customer relationship, supplier relationship, and new product development. The data were collected through semistructured interviews, internal documents, websites, and annual reports on lean and industry 4.0 implementation projects. Implemented the developed framework in eight sectors, and it has been revealed that as a result, industries' insights strongly believe that the industry 4.0 technologies could empower lean management techniques. Ghaythan et al. [18] examined the impact of the integration of lean manufacturing and industry 4.0 technologies on the sustainable performance of industries. The data required for the analysis were collected from questionnaires collected by 112 petrochemical and plastics industries. The analysis results showed that lean manufacturing and industry 4.0 have a positive impact on sustainability performance. Rossini et al. [19] investigated the impact of interrelation between the industry 4.0 technologies and lean production on the improvement level of operational performance in European manufacturers. The data has been collected by a survey conducted with 108 European manufacturers and analyzed through multivariate technique. The analysis identifies the interrelation according to different contextual factors, including lean production implementation experience, business operating model, type of ownership, and company size. The finding suggests that European manufacturers should apply concurrent lean production of industry 4.0 to achieve a high degree of process improvement.

However, only a few studies have been done on the methodology developed to identify an efficient process optimization technique for enhanced productivity within restricted resources. Here, constraints mean the availability of resources for shop floor management. To improve the process, it is necessary to get rid of the challenges and difficulties faced by the industry [20]. Typically, a production system is developed to identify the challenges and difficulties associated with production in the industry, which helps know where to get rid of the challenges and difficulties of production have to improve [21]. Through this system, information about the processes is collected so that the level of the processes can be evaluated and the production can be improved. The objective of the present article is to develop a smart production management system to identify the problems and challenges encountered on the production shop floor in industry 4.0 and suggest an efficient process optimization approach for industrial sustainability. The present article provides a systematic functional approach to provide a sustainable shop floor management system and to further enhance operational excellence within limited constraints. The proposed methodology has been described in Figure 2. There are five stages in the proposed methodology. The first stage focuses on layout draw and preparing a checklist of ergonomics issues by considering shop floor factors, including workplan, working environment, and workload distribution according to different departments. In the second stage, the production conditions are analyzed by calculating different parameters and resources condition by considering shop floor factors, including time, cost, worker, and shop floor congestion in various departments. The third stage reviews the machinery conditions and availability by observing and analyzing different departments and using advanced condition monitoring systems to improve machinery efficiency and utilization. In the fourth stage, the production shop floor planning is modified by brainstorming, meeting, conversations with production management teams, and using the internet of things, digitization, and data acquisition system. Finally, in the fifth stage, production shop floor improvement is validated by comparing proposed, observed, and previous results by considering product performance, approach, throughput, and shop floor management in different departments. As this methodology comprises nineteen different factors and each and every respective factor is crucial while implementing the same in various departments likes in inspection, quality, production, and design in industry 4.0, for example, the work plan sector is highly significant in the inspection department, quality department, and industry 4.0 department. The same other factors are very much prominent the same in the different departments that will provide a sustainable shop floor management system within available resources.

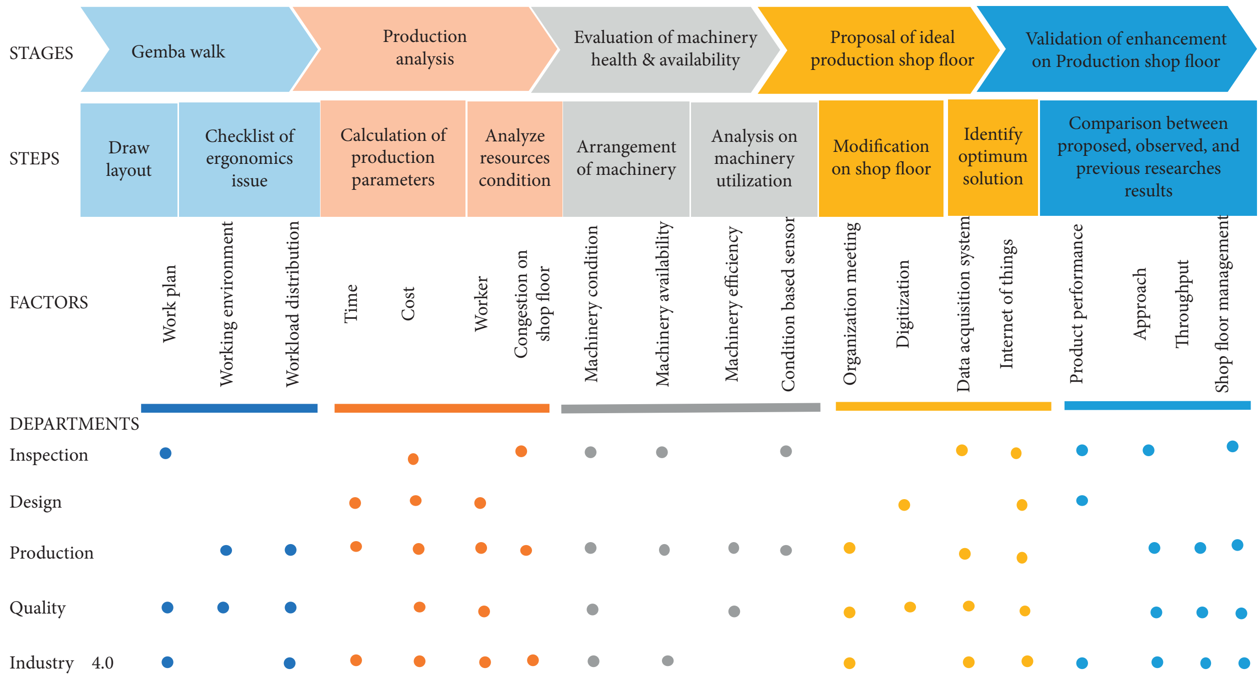


Figure 2: Proposed methodology.

2. Development of Novel Research Methodology

The literature review demands developing a research methodology to effectively implement the developed production management systems. The developed research framework helps implement the developed production management system and identification of NVAA so that appropriate action can be taken as per the production condition [22]. The present research methodology has been developed from a thorough analysis of factors of the production management system. Figure 3 illustrates the steps followed in the developed research methodology in the present research work.

The development of research methodology is a systematic way to implement process optimization methods that the elimination of waste in production can be possible. In previous researches, few researchers developed a methodology to improve the effectiveness of process optimization methods for shop floor management. In methodologies, emphasis was laid on determining the consumption of resources according to production and improving the production process. The following features distinguish the developed methodologies and prove to be important for the implementation of process optimization techniques.

(i) The developed methodology helps understand the reason of source of waste and investigated impact of working production processes on productivity in industry 4.0

(ii) The developed methodology provides a systemic illustration of material-flow, process-flow, time parameters (CT, LT, IT, and TT) to control the uncertainty in an advanced production environment

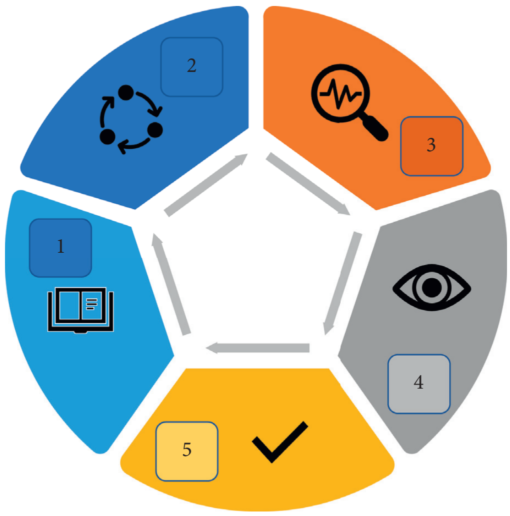
(iii) The developed methodology identifies problems and challenges by systematic analysis and helps provide an efficient action plan at beginning of production in industry 4.0

(iv) The developed methodology can be applied to any type of shop floor management in industry 4.0 and control overall process activities within available resources

3. Developments on the Process Optimization Approaches for Industrial Sustainability in Complex Environment

Researchers have proposed several methodologies of process optimization approaches for industrial sustainability in a complex environment. The complex environment includes discrepant working conditions, unexpected demand, over workload, lack of shop floor area, continuous working, and nonstandardization of work [23]. Process optimization concept originated from the Toyota production system and was developed by Taiichi Ohno's notion of "reduce time and cost by eliminating waste." Lean manufacturing, smart manufacturing, internet of things, and artificial intelligence are process optimization approaches and implemented for the elimination of waste. Waste means unnecessary activities performed in production that do not increase the product value [24]. Wastes have been classified into eight categories: overprocessing, overproduction, transportation, unnecessary motion, waiting, defects, and unutilized skill [25].

The process optimization approach is mostly preferred in industry 4.0 because it is capable of achieving production improvements with confined assets on automated production lines [26] and serves the purpose of process optimization while other techniques can be used in limited



1. Review of previous research work
   Discussion on previous research work on process optimization approach for production shop floor management.
2. Development of production management system
   Proposed a production management system to identify challenges and problems in industry 4.0
3. Deployment of proposed theory
   Implementation of developed theory in a case example of industry 4.0
4. Observation of production shop floor
   Observation of production processes and activities by gemba walk, virtual record, data acquisition system and discussion with industry persons.
5. Validation of developed system
   Industrial sustainability achieved in the production management, and comparative analysis between present and previous research work results.

Figure 3: Research methodology.

production conditions. Process optimization as an approach uses limited constraints that include the use of machinery, shop floor area, investment, production, process planning, and time [27]. The objective of process optimization is the minimization of waste in terms of time, manpower, machinery, and shop floor area. The concept of process optimization has been implemented by different techniques in industry 4.0; the techniques used in previous decades and in industry 4.0 are illustrated in Figure 4.

Lean manufacturing (LM) is a prevalent approach and has been used in most cases as found in the literature review. LM is used for the identification of NVAA by observation of shop floor conditions [28]. The cost incurred in these activities can neither be added to the production value nor paid by the customer [29]. Therefore, eliminating these activities from production is the only solution that is carried out by process optimization techniques [30]. It has been observed that LM is able to provide production enhancement in case of a manual assembly line, but if production line becomes semiautomated or fully automated, it does not work and the production management team must implement new techniques like integration of techniques.

In industry 4.0, production management team members emphasize on development of novel techniques and approaches for productivity enhancement in automated production lines. To accomplish this, several research works have been done in different automated production conditions, and smart manufacturing was found efficient in production management on the shop floor [31]. Smart manufacturing uses various techniques to the control management system in industry 4.0, including internet of things, digitalization, asset tracking system, artificial intelligence, and integration of smart manufacturing with other techniques such as lean, machine learning, and simulation. The complexity of the production situation has been increasing steadily over the past decade. Hence, in the current scenario of industry 4.0, more attention is paid to smart manufacturing techniques and hybrid approach with smart concept by the members of the management team. Because smart manufacturing has been found most suitable and efficient approach in productivity enhancement in previous research works.

As yet, several process optimization techniques have been implemented to improve the production on the shop floor [32]. An attempt has been made to tabulate all these techniques by Table 1 and presented a description of the application area and the results obtained. Figure 5 shows the techniques implemented in previous research for coping with problems and challenges. Table 2 illustrates the contribution of process optimization techniques in previous research works.

In research work over the past decades, authors have praised lean manufacturing for improving production, and other process optimization methods such as Kaizen and total quality management have also been used by some authors [22, 49, 71, 72, 85]. But it has been observed that smart manufacturing becomes the most preferred and prevalent approach in the past five years because of its higher adaptability in industry 4.0. This discussion of previous research endorses the utility of lean and smart manufacturing for process optimization. Researchers are skeptical about implementing procedures presented to address production challenges using lean and smart manufacturing, as the studies presented so far have proposed a specific approach and applied it only in confined situations. The authors of the present study are reviewing the methodologies presented in select previous studies to clarify the message. Following observations and research gap areas are identified:

(1) All the researchers that have developed the methodology of process optimization method applications in the manufacturing environment concluded that by improving the workflow on the shop floor, one can improve productivity and also concluded that this is not a generalized conclusion that can apply in all types of production conditions.

(2) There is no clarity in research on how to identify production challenges and problems in industry 4.0.

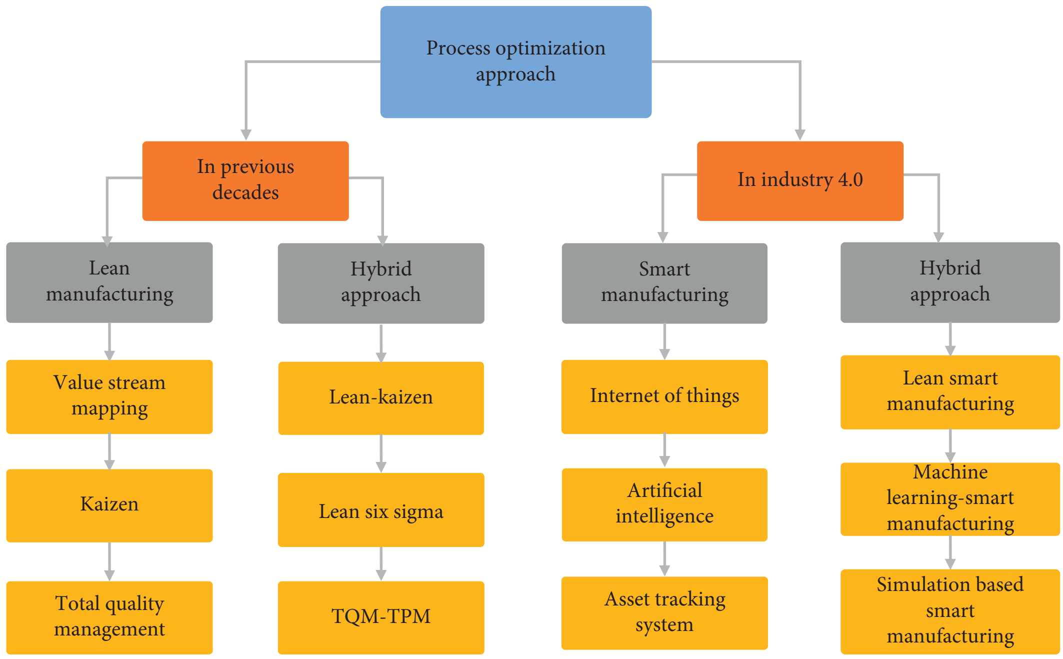


Figure 4: Process optimization techniques before Industry 4.0 (left) and under the framework of Industry 4.0 (right).

Therefore, the drawbacks of research to improve production through production mapping are clearly shown.

The objective of the present article is to develop a smart production management system to identify the problems and challenges encountered on the production shop floor in industry 4.0 and suggest an efficient process optimization approach for industrial sustainability. The research objective raised questions for the study are as follows:

(i) How to demonstrate the key message of process optimization through an efficient technique using a methodology for reducing wastes influencing productivity in industry 4.0

(ii) How to identify wastes in the industry 4.0 production environment by applying the proposed production management system

4. Scientific Gap in the Literature and Conceptual Paradigm Objectives of the Current Research Work

In industry 4.0, the production team members face several problems in enhancing operational excellence due to complexity in the shop floor environment [92]. It has been observed that if production teams ignore different circumstances and issues that can be developed by complexity in the shop floor environment, it results in considerable losses in financial profitability [93]. A comprehensive review of the production management systems developed in previous research has been found that the developed systems were not efficient at controlling operational excellence in all types of shop floor environments and could only increase productivity in certain limited production conditions. Therefore, the production management teams emphasize developing an intelligent system to eliminate the problems faced in different circumstances because of the complex shop floor environment [94].

The developed system helps provide a guideline for selecting a suitable approach for enhancing industrial sustainability in industry 4.0. The proposed smart system has been developed by various brainstorming sessions on problems and challenges faced in production shop floor management, including industry 4.0. The developed system provides a guideline for management teams to understand the actual shop floor conditions and help make an action plan at the beginning of production processes to achieve industrial sustainability enhancement. The developed smart production management system has been validated by enhancing industrial sustainability in the case of industry 4.0. It has been found that the developed system provided improvement in production time, worker's contribution, machinery utilization, operational excellence, and financial profitability by 17%, 18%, 28%, 35%, and 45%, respectively.

The present research aims to develop a smart production management system to identify the problems and challenges encountered in production on the shop floor in industry 4.0 and suggest an efficient process optimization approach for industrial sustainability. The developed smart management system can improve operational excellence in any complex shop floor environment within confined assets and the efficient to enhance sustainability in all industries, including automobile, mining machinery, mining, defense, aerospace, pharmaceutical, chemical, and so on. The authors of the present research article that the developed system would be preferred in shop floor management in industry 4.0 because it can implement a suitable approach by identifying exact problems in

Table 1: Description of previous research work, technique, and results.

Author(s)	Year	Techniques	Results: Improvement/reduction	Results: Optimized resources
Östlin and Ekholm [33]	2007	Value stream mapping (VSM)	Setup time	Manpower
Seth and Gupta [34]	2007	VSM, Kanban	WIP (work in process), inventory, production lead time (LT), processing time	Cost
Gati-Wechsler and Torres [35]	2008	TPM, 5S, JIT, Kanban	Inventory	NA
Sahoo et al. [36]	2008	VSM, Taguchi's method	Setup time, WIP inventory level, defect	NA
Pattanaik and Sharma [37]	2009	Cellular manufacturing system, VSM	Lead time (LT), setup time, waiting time, material handling time	Layout
Singh Sharma [38]	2009	VSM	LT, processing time, WIP	Manpower
Vinodh et al. [39]	2010	VSM	Cycle time (CT), idle time (IT), WIP inventory, defect, uptime (UT)	Manpower
Rahman and Al-Ashraf [40]	2012	VSM	Production LT, work-in-process inventory	Manpower, machine, layout
Rahman et al. [41]	2012	Kanban	Inventory	Cost
Chen et al. [42]	2013	VSM, radiofrequency identification	LT, waiting time	Shop floor area
Bertolini [43]	2013	VSM	Productivity, LT, defect	Cost
Longhan et al. [44]	2013	VSM	Productivity	Cost
Jeyraj et al. [45]	2013	VSM	Takt time (TT), LT	Machine, manpower
Das et al. [46]	2014	VSM, SMED, Kaizen	Setup time, WIP inventory	Shop floor area
Barbosa et al. [47]	2014	LM, TPM	Cycle time (CT), product quality	Layout
Kumar et al. [48]	2014	VSM, method study	LT	Layout
Ismail et al. [49]	2014	Lean Six Sigma, VSM	CT	NA
Singh et al. [50]	2014	LM	Cycle time, downtime	Cost
Santos et al. [51]	2015	5S, VSM, Kaizen,	Productivity	Manpower
Mwanza and Mbohwa [52]	2015	Total productive maintenance	Downtime	Machinery
Choi et al. [53]	2015	Smart manufacturing	Production enhancement	Cost
Rohani and Zahree [54]	2015	VSM, kaizen, Kanban, 5S	LT	NA
Esa et al. [55]	2015	SMED	Setup time	Manpower
Lu and Yang [56]	2015	VSM, Kaizen	Production, CT	Manpower
Tyagi et al. [57]	2015	VSM, Gemba walk	LT, quality	Cost
Choomlucksana et al. [58]	2015	Kaizen, 5S, poka-yoke	Processing time	Cost
Naqvi et al. [59]	2016	LM, Kaizen, 5S	LT, production	Layout, cost
Andrade et al. [60]	2016	VSM	LT, production time	Manpower
Thomas et al. [61]	2016	Lean Six Sigma	Production time	Cost
Garre et al. [62]	2017	5S, SMED	Productivity, total cycle time (TCT)	Layout
Asif and Singh [63]	2017	Internet of things	Productivity	Cost
Dadashnejad and Valmohammadi [64]	2017	VSM, overall equipment effectiveness	Productivity, quality	Machine
Diaz et al. [65]	2017	VSM	LT, CT, quality	Manpower
Méndez and Rodriguez [66]	2017	TPM, overall equipment effectiveness	Productivity	Manpower
Nagadi et al. [67]	2017	Smart manufacturing	Production time	Machinery
Gazra-Reyes et al. [68]	2018	VSM, TPM, just in time, Kaizen	Productivity, quality	Energy consumption
Gijo et al. [69]	2018	Lean Six Sigma	Defect	Cost
Stadnicka and Litwin [70]	2018	VSM, system dynamic analysis	Work-in-progress	Machine
Cannas et al. [71]	2018	Kaizen, Yamazumi chart, standardization	Performance	NA
Kumar et al. [72]	2018	VSM, Kaizen, poka-yoke, 5-why, brainstorming technique	Lead time, cycle time, inventory level, productivity, quality, rework elimination	Machine, manpower, cost

Table 1: Continued.

Author(s)	Year	Techniques	Results	
			Improvement/reduction	Optimized resources
Suhardi et al. [73]	2019	VSM, 5W1H (what, who, where, when, how, why), ECRS (eliminate, combine, rearrange, and simplify) principle	Lead time	Manpower
Saqlain et al. [74]	2019	Internet of things	Production time	Machinery, cost
Masuti and Dabede [75]	2019	VSM	Cycle time, lead time	Cost
Ramani and Lingan [76]	2019	VSM	Productivity	Cost
Priya et al. [77]	2019	Lean Six Sigma, just in time	Defect, quality	NA
Liao and Wang [78]	2019	Internet of things	Production time	Cost
Shou et al. [79]	2019	VSM	Production time	NA
Sharma et al. [80]	2019	5S	Productivity	Machine, cost, shop floor
Abubakr et al. [81]	2020	Smart manufacturing	Productivity	Machinery, cost
Torres et al. [82]	2020	Smart manufacturing	Production time	Cost, shop floor
Prasad et al. [83]	2020	VSM, 5S, Kaizen, Kanban, SMED	Productivity	Layout
Mittal et al. [84]	2020	Smart manufacturing	Production	Cost
Balamurugan et al. [85]	2020	Cause and effect diagram, failure mode effect analysis	Productivity	Machine, shop floor
Chien and Chen [86]	2020	Smart manufacturing	Production time	Machinery, cost
Amrani and Ducq [87]	2020	VSM, SMED, cellular layout	Setup time, cycle time, defect rate	Cost, manpower
Frankó et al. [88]	2020	Internet of things	Production time	Machinery, cost
Gaspar et al. [89]	2021	Internet of things	Production time	Cost
Reyes et al. [90]	2021	Lean and industry 4.0 technologies	Productivity	Cost
Vlachos et al. [91]	2021	Lean and internet of things	Productivity	Cost

the complex production environment. Figure 6 shows the current model of shop floor management that was being used by the production management team.

5. Proposed Production Management System

Industries face several challenges and problems in controlling the shop floor management. Therefore, to identify these problems and challenges, a smart production management system has been developed in the present research. In the production management system, the challenges and problems are classified in observed forms. The developed production management system has been evaluated by problems found in prior research and applied techniques. Table 3 classifies the challenges commonly encountered by industry in production and the problems associated with them.

Most of the researchers appreciated lean and smart manufacturing and acknowledged problems and challenges complexities in an industrial environment. Authors mostly suggested lean for improvement in production and shop floor management in the last decades. The smart manufacturing experience of researchers in production improvement is remarkably diverse and endorsed the reliability of smart manufacturing in shop floor management.

To get rid of the challenges and problems faced at the production shop floor, in the current research work, an extensive literature review was done on the work done in the production area and industry 4.0, and a production management system has been developed. The challenges and problems were categorized to prepare the developed system and the process optimization techniques applied in the previous research were brainstormed for them. A management system has been developed from the findings obtained from the brainstorming analysis. The authors are strongly believed that the developed production management system would be capable of providing higher throughput in all types of conditions in industry 4.0. The developed smart production management system has been illustrated in Figure 7. The proposed smart production management system follows four steps and is developed by multiple brainstorming sessions organized at the different department levels and using previous research works.

5.1. Experimentation of Proposed Theory in a Case Study for Industry 4.0. The present study has been carried out in an earthmoving machinery manufacturing unit in India. The industry currently has 52 people including managers, supervisors, and employees and operates in a single shift with 10 working hours. The present industry manufactures several types of machinery such as the skid-steer loader, cranes, and truck-mounted. This research work deals with skid-steer loader production processes. Skid-steer loader is an earthmoving machinery, and it is based on cutting-edge technology. The industry is facing stiff competition due to high manufacturing cycle time. Typically, production orders are received intermittently and mostly in small quantities.

The production lead time and quality are the main factors to face the competition of the industry. When the industry is faced with problems such as high costs and excessive lead time due to wastage, the level of production becomes exceedingly difficult to control. Production management is therefore vigilant about these problems and

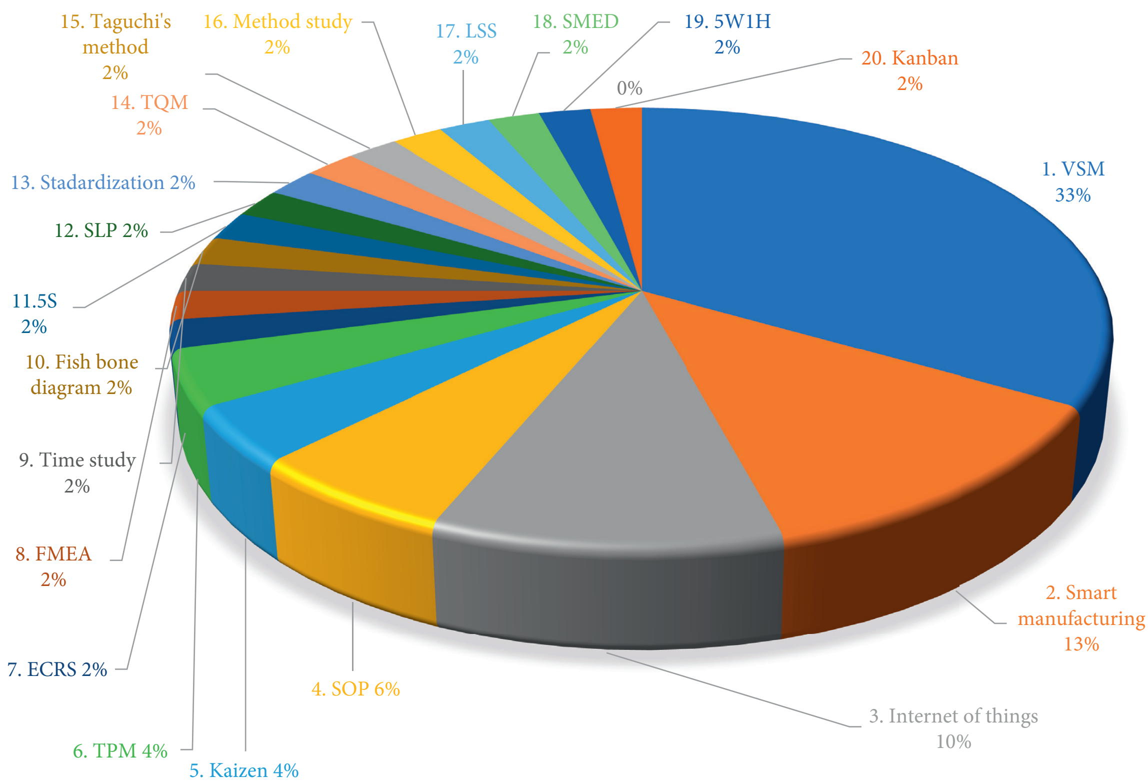


Figure 5: Implementation of process optimization techniques in previous researches.

Table 2: Contribution of process optimization techniques in previous research works.

S. No.	Process optimization techniques	Contribution (%)
1	VSM	33
2	Smart manufacturing	13
3	Internet of things	10
4	SOP	6
5	Kaizen	4
6	TPM	4
7	ECRS	2
8	FMEA	2
9	Time study	2
10	Fish bone diagram	2
11	5S	2
12	SLP	2
13	Standardization	2
14	TQM	2
15	Taguchi's method	2
16	Method study	2
17	LSS	2
18	SMED	2
19	5W1H	2
20	Kanban	2

emphasizes the implementation of process optimization methods for production on the shop floor. The problems found in controlling production in the current industry are illustrated by Figure 8.

5.2. Observation of the Production Shop Floor in Present Case Report. According to Womack and Jones [95], production planning plays an important role in achieving customer needs in the context of the product. For this, it is necessary to observe the precise production information and conditions of the industry. So those necessary arrangements can be made to deal with them. The basic production information has been collected by observation of shop floor, questionnaire, data acquisition system, interviews, and discussion with industry persons. The observation of the shop floor has

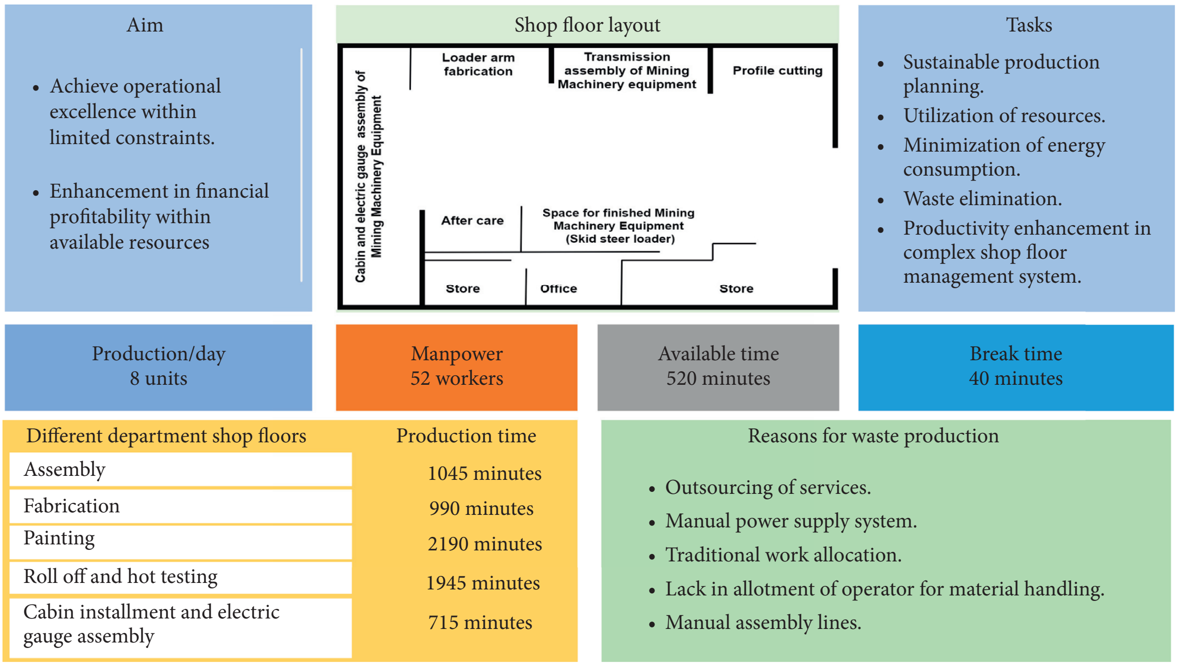


Figure 6: Current shop floor management model.

Table 3: Categorization of problems and challenges faced in production.

S. No.	Challenges	Problems	Categorization	Author and reference number	Implemented shop floor management technique
1	Productivity	Poor layout	P_1	Rahman and Al-Ashraf [40]; Saqlain et al. [74]	VSM, smart manufacturing
		Absenteeism	P_2	Singh and Sharma [38]	VSM, 5S
		Higher downtime	P_3	Santos et al. [51]; Chien and Chen [86]	VSM, smart manufacturing
		Unskilled worker	P_4	Jeyaraj et al. [45]	VSM
		Communication gap	P_5	Esa et al. [55]	Standard operating procedure (SOP)
		More workstation	P_6	Rohani and Zahree [54]	VSM, Kaizen
		Work overloaded	P_7	Garee et al. [62]	Single minute exchange of die (SMED)
		High setup time	P_8	Esa et al. [55]	SMED
2	Quality	Lack in worker sill	Q_1	Seth and Gupta [34]	VSM
		Lack of standard	Q_2	Rahman and Al-Ashraf [40]; Asif and Singh [63]	SOP, internet of things
		Defect	Q_3	Pattanaik and Sharma [37]	VSM
		Workload distribution	Q_4	Suhardi et al. [73]	5W1H technique, ECRS principle
		Inventory	Q_5	Masuti and Dabede [75]	VSM
3	Time	Lack in production planning	T_1	Balamurugan et al. [85]; Priya et al. [77]; Gaspar et al. [89]	Time study, fishbone diagram, failure mode effect analysis (FMEA), internet of things
		Downtime	T_2	Barbosa et al. [47]	Total productive maintenance
		Machinery utilization	T_3	Jeyaraj et al. [45]	VSM
		Wrong workload distribution	T_4	Chen et al. [42]	VSM
		Unsystematic layout	T_5	Ali Naqvi et al. [59]	Systematic layout planning
		Absentees	T_6	Amrani and Ducq [87]	Standardization
		Unskilled worker	T_7	Gati-Wechsler and Torres [35]	Total quality management (TQM)
		Communication gap	T_8	Esa et al. [55]	SOP
		Lack in material handling	T_9	Frankó et al. [88]	Asset tracking system

Table 3: Continued.

S. No.	Challenges	Problems	Categorization	Author and reference number	Implemented shop floor management technique
4	Cost	Downtime	C_1	Mwanza and Mbohwa [52]; Chien and Chen [86]	Total productive maintenance (TPM), smart manufacturing
		Lack in worker participation	C_2	Rahman et al. [41]	Lean manufacturing, Kanban
		Defects	C_3	Sahoo et al. [36]	Taguchi's method
		Inventory	C_4	Singh and Sharma [38]	VSM
		Unplanned workflow	C_5	Kumar et al. [72]; Ramani and Lingan [76]; Liao and Wang [78]	VSM, method study, internet of things
5	Customer satisfaction level in terms of product	Higher lead time	L_1	Östlin and Ekholm [33]; Liao and Wang [78]	VSM, internet of things
		Defects	L_2	Bertoloini [43]	VSM
		Standard	L_3	Ismail et al. [49]; Gijo et al. [69]	Lean Six Sigma
		Quantity	L_4	Longhan et al. [44]	VSM
		Design	L_5	Das et al. [46]; Mittal et al. [84]	VSM, SMED, Kaizen, smart manufacturing

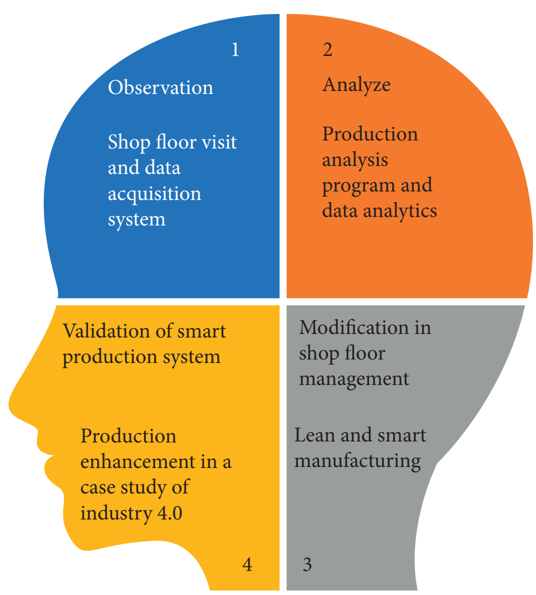


Figure 7: Proposed smart management system for industry sustainability in industry 4.0.

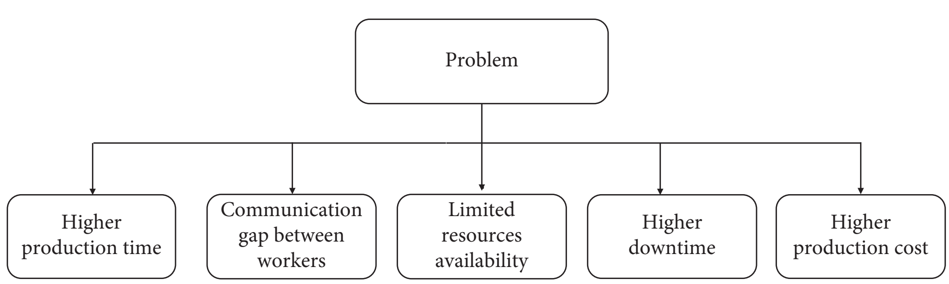


Figure 8: Observed problems of present industry.

been used to understand the working condition of production on the shop floor. The discussion with workers, supervisors, and managers has been used for the analysis of production information and shown by Table 4.

5.3. Analyze Present Production Shop Floor Management. The working condition map of production processes is shown in Figure 9. The working map demonstrates that the manufacturing orders are being received monthly and the

Table 4: Details of production collected from the observation of the shop floor.

Name of data	Quantity
Product name	Skid steer loader
Working time	560 minutes
Break time	40 minutes
Available time	520 minutes
Number of workers	52
Number of processes	18
Number of shifts	1
Number of shops	5
Production per day (PD)	8
Shop floor area	34 meter × 75 meter
Production line	Semiautomated
Production type	Pull
Material handling equipment	Hoist for material handling and forklift
Challenge	Productivity, time, quality, customer satisfaction level
Previous production record	WT: 580 minutes, BT: 80 minutes, PD: 9 minutes
Problems	P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, L_1, L_4
Working environment	Unfriendly due to more working hours and unplanned work
Working temperature	Workable
Maintenance type	Preventive
Outsourcing services	Painting (chassis and loader arm)
Number of components in the final product	Approximate 800
Implemented shop floor management technique	5 S

shop floor management department transmits the manufacturing instructions on daily basis to the supervisor and workers. In present production condition, a total of 18 processes are performed in the production of the skid steer loader, and the industry operates in one shift per day. The total cycle time (TCT) for manufacturing the skid-steer loader is 6,540 minutes whereas the total idle time (TIT) is 470 minutes. The skid-steer loaders are manufactured to the customers' demands mostly monthly. The industry normally maintains a product inventory of 15 units due to uncertainty in employee availability.

In the observed condition, the proposed production management system has been used to identify production problems and elimination of non-value-added activities. For the elimination of problems, the appropriate technique has been selected from the process optimization techniques implemented in the previous research work, as shown in Table 2. Table 5 shows the description of problems and challenges identified in production processes.

The production analysis program and data analytics were implemented for the identification of problems and non-value-added activities so that they could be eliminated with the appropriate action. Lean and smart manufacturing were found suitable to improve mostly processes, and additionally, internet of things, artificial intelligence, and embedded system have been applied in some other processes.

6. Result and Discussions

6.1. Development of a Modified Production Shop Floor Management. After the analysis of NVAA present in the production processes of skid-steer loader, various proposals for NVAA elimination have been developed by a discussion with the workers of industry, which are presented as follows:

(i) Improvement in shop floor management – The principle of lean smart manufacturing has been found effective for implementation at the following processes, namely wheel assembly, chassis manufacturing, cabin installment, and electric gauges assembly

(ii) Reduction of a number of workstations – The production planning at workstations has been improved by simulation and machine learning concepts

(iii) Reduction of work-in-progress–The unnecessary activities between production processes has been eliminated by the lean concept

(iv) Improvement in resource utilization – The utilization of machinery and workers has been improved by using artificial intelligence and the internet of things concept

(v) Reduction of high setup time – The internal activities (preparing setup jig and fixture, movement of chassis component, material handling of components by forklift and hoisting equipment, transportation of large parts for painting, and changing attachment tool) have been considered as external activities

(vi) Improvement in the communication gap between workers-organized meeting and conducting the training program

Table 6 shows the overall production modification suggested for proposed planning. The proposed modified production planning describing the various improvements incorporated in the production processes of the skid steer loader on the shop floor is shown in Figure 10.

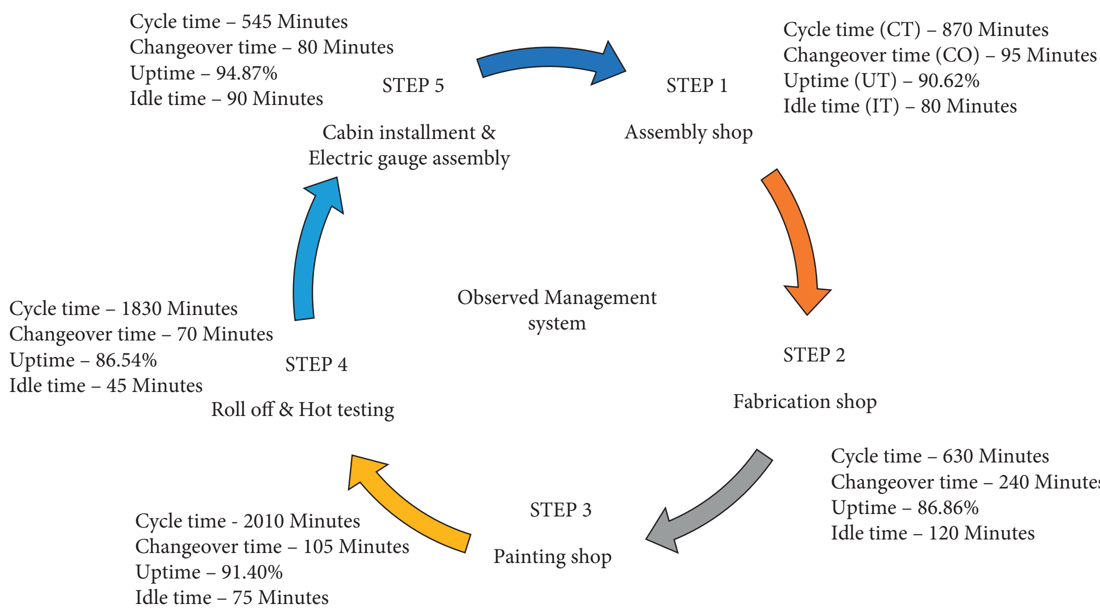


Figure 9: Observed production management condition.

Table 5: Challenges and problems identified in production processes.

S. No.	Process	Problem
1	Transmission assembly	$P_1, P_2, P_4, P_5, P_6, P_7, P_8, T_1, T_2, T_4, T_5, T_6, T_7, T_8, T_9, L_1$
2	Manufacturing of loader arm	$P_4, P_5, P_6, P_8, T_1, T_3, T_4, T_7, C_2, L_1$
3	Chassis manufacturing	$P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, L_1, L_4$
4	Wheel assembly	P_5, T_8
5	Chassis and loader arm fabrication	$P_1, P_3, P_4, P_5, P_8, T_3, T_7, T_9L_1$
6	Inspection of fabrication	$P_2, P_3, P_5, T_1, T_2, T_3, T_8$
7	Painting (baby parts)	P_8
8	Painting (large parts)	P_8
9	Engine assembly	$P_1, P_7, P_8, T_3, T_4, T_5, T_8, L_1$
10	Hydraulic pump and motor assembly	$P_1, P_7, P_8, T_3, T_4, T_5, T_8, L_1$
11	Inspection of assembly and roll off	T_1
12	Hot testing	$P_3, P_5, P_7, P_8, T_1, T_4, L_1$
13	Cabin installment	$P_4, P_5, P_7, T_1, T_4, T_7, T_8$
14	Electric gauges assembly	$P_4, P_5, P_7, Q_1, Q_4, T_1, T_4, T_7, T_8$
15	Final inspection	$P_1, P_5, P_6, P_7, T_1, T_4, T_8$

A similar work has been reported by Müller et al. [96] who discussed how natural language processing could improve the digital shop floor management concept to provide higher value for decision-makers and the shop-floor teams. The study presented a conceptual approach by integrating the fields of natural language processing and digital shop floor management to discuss assistant functions in digital shop floor management on the text data produced during problem-solving. The result of the study revealed that the developed approach was detailed, quick, and accurate by representing an actual condition in the company. Xu et al. [97] investigated the coexistence of two industrial revolution industry 4.0 and industry 5.0. In the study, five questions were selected by different sources, and the questions were rooted in industry and the scientific community. The study showed that the industrial revolution was driven by transformative technological advances that helped improve fundamental changes in the industry functions. These fundamental changes included social and economic consequences. It also concluded that the revolution upgrade had been required technological pushes and solutions. Mourtzis [98] discussed the benchmarking obtained in the evolution of manufacturing systems simulation technologies and investigated recent research and industrial revolution in the fields of manufacturing. The study showed that digitalization provides data and new technologies to assist in manufacturing simulation and product design in the new era.

6.2. Validation of Proposed Smart Production Management System. Present research methodology demonstrates its usefulness in terms of improved productivity, customer satisfaction level, resources utilization, and production time.

Table 6: Details of proposed production planning from the investigation of the production shop floor.

Name of data	Quantity
Product name	Skid-steer loader
Working time (WT)	600 minutes
Break time (BT)	90 minutes
Available time	510 minutes
Number of workers	52
Number of processes	10
Number of shifts	1
Number of shops	5
Production per day	12
Shop floor area	34 meter × 75 meter
Material handling equipment	Hoist for material handling and forklift
Challenge	Productivity, time, customer satisfaction level
Previous production record	WT – 520 minutes, BT – 40 minutes, PD – 8
Problems	Eliminated
Working environment	Aesthetic
Maintenance type	Condition-based maintenance
Outsourcing services	Painting (chassis and loader arm)
Number of components in the final product	Approximate 800
Implemented shop floor management approach	Lean smart manufacturing, internet of things, artificial intelligence, asset tracking system

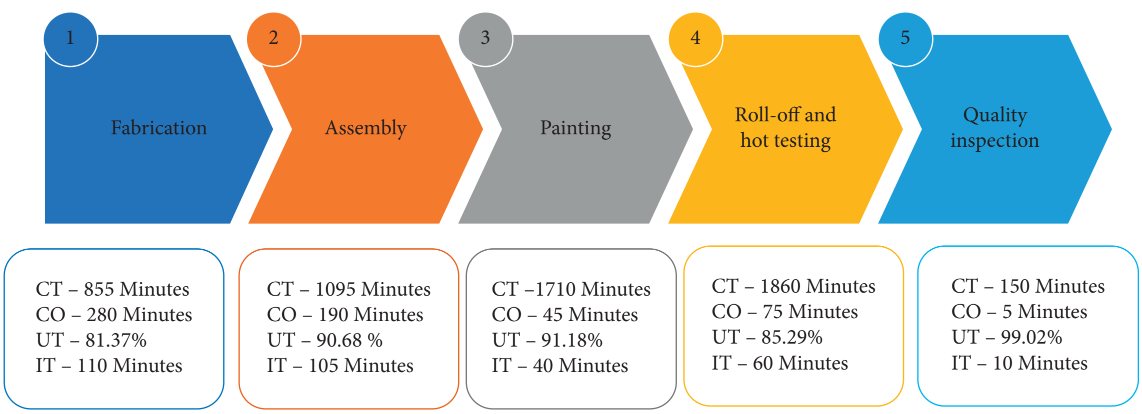
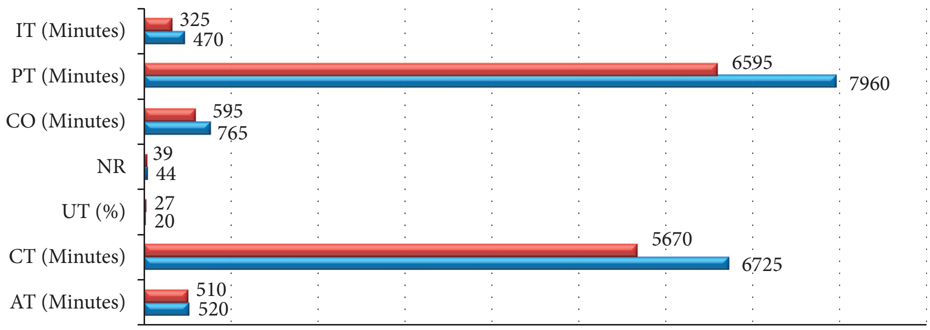


Figure 10: Modified production management system.

The case study revealed that the proposed production management system can provide precise identification of the challenges and problems responsible for production in industry 4.0 using a lean and smart manufacturing approach. The production management helps the management system implement a suitable shop floor management approach for the elimination of non-value-added activities. To validate the production management system presented, it was implemented in a production condition of industry 4.0, and it was found that production improved as per the standards set by the production management system. Production improvement has been calculated according to various parameters. These improvements are shown in Figure 11.

In line with the problems encountered in shop floor management, the present case example shows the elimination of non-value-added activities and the improvement in productivity levels that have been possible through the proposed smart production management system. To substantiate this statement, a comparative analysis was carried out from the present work from previous research work. It was found that the proposed production management system is better in eradicating of all production problems and non-value-added activities. The comparative analysis between some relevant previous research and the present study has shown in Table 7.

The related work has been reported by Mourtzis [99] designed a model of a real manufacturing system using discrete-event simulation and evaluated it by obtaining actual data obtaining from the copper industry. The study used the ANOVA method to highlight the effect of each decision variable on the model. The study demonstrated that the manufacturing system could obtain maximum throughput by utilizing actual data and available resources. Mourtzis [100] developed a framework for remote monitoring refrigerator and cold storage systems using wireless sensor networks and cloud technology for predictive maintenance. In the study, wireless sensor networks and the intelligent algorithm were integrated for predictive maintenance. The study showed that the developed framework could provide yielded promising results. Mourtzis [101] discussed the latest advances and challenges of machine tool evolution in the present industrial era in the manufacturing



	AT (Minutes)	CT (Minutes)	UT (%)	NR	CO (Minutes)	PT (Minutes)	IT (Minutes)
Modified	510	5670	27	39	595	6595	325
Observed	520	6725	20	44	765	7960	470

Figure 11: Production improvement by the presented production management system.

Table 7: Comparison between previous results and present study investigation.

Author's	Technique	Improvement (%)			Parameter	Optimized
		PT	CT	Defect		
Cinar et al. [20]	VSM	1.11	2.59	4	Production time, machinery utilization, quality	Machinery, cost
Liao and Wang [78]	Internet of things	NA	NA	NA	Product quality	Cost
Rahani and Al-Ashraf [40]	SMED, poka-yoke, standardization	NA	43	66	Production time, product quality	Cost
Chien and Chen [86]	Smart manufacturing	NA	NA	NA	Production time	Machinery
Ismail et al. [49]	LSS	16.79	NA	NA	Production time	Cost
Gijo et al. [69]	LSS	NA	NA	85.26	Quality	Cost
Asif and Singh [63]	Internet of things	NA	NA	NA	Production management	Cost
Das et al. [46]	VSM, SMED, kaizen	57.07	43.24	NA	Production time	Cost
Frankó et al. [88]	Internet of things	NA	NA	NA	Logistic task	Machinery, cost
Longhan et al. [44]	VSM	6.85	NA	NA	Production time	Cost
Choomlucksana et al. [58]	VSM	8.02	37.05	NA	Production time	Cost
Present study	Lean and smart manufacturing, internet of things, VSM	17.14	15.69	42	Production time, machinery and manpower utilization, quality	Manpower, machinery, cost, shop floor

domain. In addition, the study recognized emerging opportunities and identified implications from the implementation point of view.

6.3. Enhancement of Industrial Sustainability of the Developed Methodology for Industry 4.0 for Earthmoving Machinery Manufacturing Shop Floor Management System. The present research methodology can be applied to improve all types of earthmoving machinery manufacturing conditions in industry 4.0. This statement has been proved by an example: this example was of an earthmoving machinery manufacturing unit, in which production was improved by the implementation of the developed production management system in industry 4.0. The improvements obtained in the operational performance of production processes by process optimization techniques are shown in Table 8. The planning and execution of research methods in the manufacturing unit, and improvement in shop floor management has summarized in Table 9.

Productivity enhancement has been achieved effectively by the production management system developed in the present case study. The implementation of the developed methodology led to an improvement of up to 35% in the production by a 42% reduction in defects by the implementation of a suitable process optimization approach. The result of the study validates the author's statement about developed methodology and describes that the developed production management system would provide industrial sustainability in industry 4.0. The related work has been reported by Liu et al. [102] investigated the emerging industrial internet of things implementation in a cloud manufacturing system for addressed the challenge faced in the development of cloud manufacturing systems. The challenges included communication, efficient data acquisition, analysis of field-level manufacturing equipment, and query. Two industrial internets of things gateway for a 3D printer and a CNC machine tool validated the approach. The result showed that integrating various emerging industrial internet of things technologies in manufacturing systems

Table 8: Improvements in the parameters of production processes.

S. No.	Process	Process (modified)	Reduction (available time) minute	Improvement (uptime) %	Improvement (number of operators)	Improvement (changeover time) minute	Improvement (cycle time) minute	Improvement (production time) minute	Improvement (idle time) minute
1	Transmission assembly	Transmission assembly	10	0.56	1 (Increase)	5	45	60	10
2	Manufacturing of loader arm	Manufacturing of loader arm	10	2.72	1 (Increase)	15	15	35	5
3	Chassis manufacturing	Chassis manufacturing	10	0.62	1 (Increase)	5	15	40	20
4	Wheel assembly	Wheel assembly	10	0.88	1 (Increase)	5	25	30	0
5	Chassis and loader arm fabrication	Chassis and loader arm fabrication	10	2.34	2 (Reduce)	0	30	45	20
6	Inspection of fabrication								
7	Painting (baby parts)		10	10.53	1 (Decrease)	60		395	35
8	Painting (large parts)	Painting					300		
9	Engine assembly				1 (Increase)			90	
10	Hydraulic pump and motor assembly	Assembly (engine, hydraulic pump and motor)	10	7.16		40	35		15
11	Quality inspection and roll off	Quality inspection, roll off, and hot testing	10	1.24	0		525	545	10
12	Hot testing					10			
13	Cabin installment	Cabin installment and electric gauges assembly	10	3.29	2 (Reduce)	20	55	100	25
14	Electric gauges assembly								
15	Final inspection		10	1.9	0	10	10	25	5

Table 9: Implemented actions for improvement in production on the shop floor.

S. No.	Process	Cause of problem	Process optimization approach	Suggested action	Improvement in process time (%)
1	Transmission assembly	(i) There was no fixed place for different assembly processes (ii) Gearbox assembly has done at a different location (iii) Unnecessary transportation due to different locations of processes (iv) Lack of workers (v) Poor planning	Lean smart manufacturing	(i) All assembly processes were performed in one shop that also included gearbox assembly (ii) Prepared a systematic layout (iii) Increased number of workers (iv) Improved shop floor planning (v) Automated production line (vi) Asset tracking system	11.32
2	Manufacturing of loader arm	(i) Higher setup time (ii) Lack of workers (iii) Unawareness of the work (iv) Lack of action plan	Lean manufacturing	(i) Increased number of workers (ii) Organized meeting and training (iii) Improved action plan	9.21
3	Chassis manufacturing	(i) Manual material handling (ii) Unsystematic planning (iii) No sequence of production processes was determined (iv) Lack in worker skill	Value stream mapping and internet of things	(i) Prepared a systematic planning (ii) Organized appropriate training program (iii) Digitalization	9.19
4	Wheel assembly	(i) Unawareness of the worker	Embedded system	(i) Organized meeting (ii) Prepare to code for operations	15.78
5	Chassis and loader arm fabrication	(i) A Longer distance between chassis and loader arm shop (ii) Higher setup time	Smart manufacturing	(i) Both the shops were set up side by side in the revised layout (ii) Increased number of workers (iii) Dynamic modeling of shop floor (iv) Digitalization	8.108
6	Inspection of fabrication	(i) Higher setup time (ii) Unnecessary transportation for the inspection process (iii) No fixed location was decided for inspection	Internet of things, artificial intelligence	(i) Inspection has done at previous workstation (ii) Inspection has done just after completion of fabrication of loader arm and chassis (iii) Program for standard specification of product	
7	Painting (baby parts)	(i) Lack of worker	Embedded system	(i) Increase worker (ii) Automated production line	18.03
8	Painting (large parts)	(i) Lack of worker (ii) Painting of large parts from other industry	Lean manufacturing	(i) Increase worker (ii) Both painting processes were started out simultaneously	

Table 9: Continued.

S. No.	Process	Cause of problem	Process optimization approach	Suggested action	Improvement in process time (%)
9	Engine assembly	(i) Lack of worker (ii) Poor planning (iii) Unawareness of the worker	Lean smart manufacturing	(i) Increase worker (ii) Improved planning (iii) Organized meeting (iv) Simulation and modeling of workstation (v) Digitalization	21.17
10	Hydraulic pump and motor assembly	(i) Lack of worker (ii) Unsystematic layout (iii) Unawareness of the work	Smart manufacturing	(i) Increase worker (ii) Modified layout (iii) Organized meeting (iv) Automated production line (v) Digitalization	
11	Quality inspection and roll off	(i) Lack in production planning (ii) Unnecessary documentations	Artificial intelligence	(i) Improved production planning (ii) Prepare a coding-based specifications (iii) Digitalization	21.46
12	Hot testing	(i) Lack of worker (ii) No time limit decided (iii) Drawback in planning	Embedded system	(i) Increase worker (ii) Decided a time limit for processes (iii) Improved planning	
13	Cabin installment	(i) Unsystematic layout (ii) Unawareness of the work (iii) Lack in shop floor planning	Lean smart manufacturing	(i) Improvement in layout (ii) Organized meeting and training (iii) Improved shop floor planning (iv) Embedded system	19.05
14	Electric gauges assembly	(ii) Unsystematic layout (ii) Unawareness of the work (iii) Lack in shop floor planning (iv) Unnecessary movement	Lean smart manufacturing	(i) Improvement in layout (ii) Organized meeting and training (iii) Improved shop floor planning (iv) Cabin installment and electric gauges assembly have been done at one workstation (v) Automated machinery	
15	Final inspection	(i) Lack in planning (ii) Repeatedly deploy new workers for inspection (iii) Unawareness of the work	Smart manufacturing, artificial intelligence, embedded system	(i) Improvement in planning (ii) Experienced staff have deployed for inspection (iii) Organized meeting and training (iv) Automated machinery and embedded system (v) Digitalization	13.15

established the connection between the cloud manufacturing platform and field-level manufacturing equipment. Peng et al. [103] proposed a conceptual framework for flexible manufacturing strategy using the industrial internet. The study reviewed industrial Internet-enabled implementations in China in response to COVID-19 and discussed it from 3Rs' perspective, that is, supply chain resilience, manufacturer capacity recovery, and emergency response. The result provided preliminary study reflections and a flexible manufacturing strategy in the wake of the COVID-19 pandemic. Meissner et al. [104] identified different starting points for digital shop floor management using a cluster analysis based on survey data. The study showed three initial conditions for implementing digital shop floor

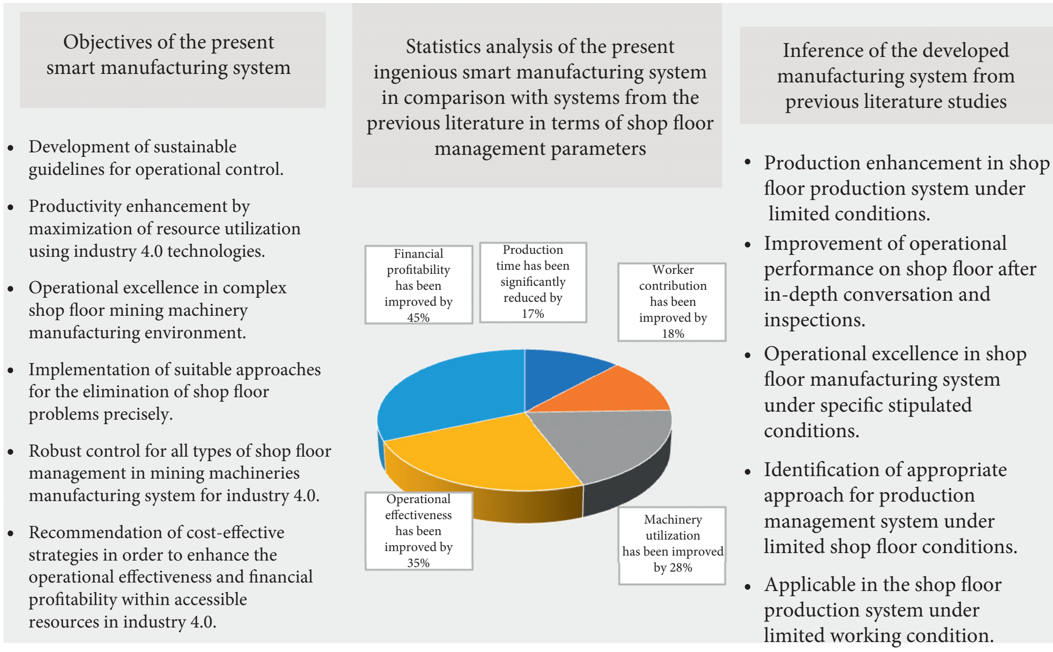


Figure 12: Comparatively benchmark analysis of the present smart manufacturing system for industry 4.0.

management in the German metal and electrical industry that can describe gradually. Furthermore, the results showed that digital shop floor management could remain competitive over the long term across all companies.

6.4. Sustainable Shop Floor Management System and Industry 4.0 Technologies. Implementing an efficient process optimization approach with industry 4.0 technologies for operational control in a complex environment plays a vital role in shop floor management [2, 3, 11, 17, 25, 32, 39, 55, 69, 82]. Industry 4.0 technologies enormously enhance productivity by maximizing operational excellence, workers' contributions, overall equipment effectiveness, and process adaptability [1, 3, 20, 26, 30, 88, 90, 92, 105]. The management team members emphasize using the process optimization approaches with industry 4.0 technologies because of problems faced in production control in complex shop floor manufacturing environments [4, 6, 27, 91]. Industry 4.0 technologies mainly include the internet of things, artificial intelligence, artificial neural network, digitalization, and asset tracking system. These technologies help enhance the overall efficacy of the process optimization approach on the shop floor and enhance productivity within limited resources. It has been observed that the production team members feel mental and physical comforted by implementing the process optimization approaches with industry 4.0 technologies in the complex production environment. Therefore, the efficiency of the shop floor management system can be improved by the integration of the process optimization approach with industry 4.0 technologies. Furthermore, the integrated approach can enhance industrial sustainability in complex production systems by establishing a safe and waste-free environment on the shop floor.

6.5. Performance of Lean Approach and Industry 4.0 Technologies. A methodology has been developed in the present research work to enhance industrial sustainability in industry 4.0 by eliminating waste using lean and smart manufacturing. The developed methodology is able to provide a positive working condition by establishing the aesthetic environment in shop floor departments by eliminating waste. The lean approach aims to maximize productivity by avoiding non-value-added activities in production planning on the shop floor. Non-value added activities are types that never provide any value in product/production processes, so the shop floor management teams always focus on making a strategy for the elimination of waste by avoiding non-value-added activities in production planning. Industry 4.0 technologies boost the effectiveness of the lean approach in operational control on the production shop floor. Industry 4.0 uses various techniques to enhance the lean approach including an asset tracking system, automated guided vehicle, digitization, radiofrequency identification system, smart condition monitoring system, and big data analytics. In the present scenario, the management team prefers industry 4.0 techniques to enhance productivity by maintaining industrial sustainability within limited constraints. It has been observed that satisfactory results may not be obtained by applying the methodologies developed in the previous research works to other management systems [3, 8, 22, 24, 27, 50, 64, 67, 69, 84]. Therefore, in the present research work, such a management system has been developed that can be applied in all types of production conditions. The developed methodology has been verified and proved by implementing it in different actual production conditions. The results show that the developed methodology provided a robust management system by effectively improving production time, worker's contribution, machinery utilization, operational excellence, and financial profitability by 17%, 18%, 28%, 35%, and 45%, respectively. Therefore, the developed methodology would be preferable by management team members because it helps in the decision-making phase according to problems and wastes found in different industrial scenarios and could be proved to benchmark for control and enhance operational excellence in industry 4.0. Figure 12 describes the benefits of the developed smart management system in comparison to previous systems in terms of production shop floor management factors.

6.6. Relation between Industry 4.0 and Lean Approach. The lean approach can enhance work performance by necessary improvements in the shop floor management system, and industry 4.0 techniques provide a method to improve productivity by maximizing the utilization of resources. The developed innovative system in the present research uses the integration of lean and industry 4.0 techniques to enhance work performance by optimizing the utilization of resources. The developed system provides industrial sustainability by improving various shop floor factors, including production time, work area, worker contribution, available time, and machinery performance. The developed system has been validated by implementing in an actual production condition of industry 4.0. The results obtained by the production system showed that the developed system is able to enhance productivity within limited constraints. Furthermore, the developed system proved cost-effective by minimizing unnecessary uses of resources. The lean approach improves work performance by eliminating unnecessary activities in the production processes, while industry 4.0 techniques improve operational conditions by establishing advanced systems on the production shop floor. In the present scenario, the shop floor management teams emphasize establishing industrial sustainability by improving operational excellence with minimum consumption of resources. Therefore, the developed system would be preferred by industry individuals in the shop floor management system because the developed system was found able to enhance industrial sustainability and financial profitability within limited constraints.

6.7. Potential Contribution of the Proposed Smart Manufacturing System in Managerially Impacts for Earthmoving/Mining Machinery Manufacturing Shop Floor Management. The proposed smart production management system has been developed on a lean and smart manufacturing approach to control production processes using limited resources and enhance productivity in existing financial conditions. The developed system provides a sustainable strategy for identifying problems and eliminating waste by monitoring operational performance on the shop floor. The integration of lean and innovative approaches is considered efficient by the shop floor management teams because this integration can enhance productivity and financial profitability within limited constraints [2, 3, 6, 20, 22, 26, 39, 55, 67, 74, 90, 105]. Furthermore, the developed smart shop floor management system helps in the decision-making stage to implement a suitable approach for maximizing productivity with available resources. Thus, it has been concluded that the lean and smart approach makes the shop floor management system effective and superior for production management by eliminating waste in the industry 4.0 environment.

7. Conclusions and Future Outlook

In the present research article, a smart production management system has been proposed to identify problems and challenges faced on the production shop floor in industry 4.0. The main findings obtained by the present research work are as follows:

(i) It has been observed that the innovative system developed can efficiently identify problems and challenges at the start of production processes in complex production shop floor conditions, thereby avoiding financial losses from production in industry 4.0

(ii) The developed system provides an agile system and guidelines for enhancement in industrial sustainability in heavy machinery manufacturing units.

(iii) It has been found that the developed system provided improvement in production time, worker's contribution, machinery utilization, operational excellence, and financial profitability by 17%, 18%, 28%, 35%, and 45%, respectively. In addition, it has been proved that using automated equipment in production lines and reduced working hours provide mental and physical comfort to workers. As a result, unprecedented improvement can be achieved in the production shop floor management.

(iv) A comprehensive analysis of previous research work found that smart manufacturing, lean smart manufacturing, artificial intelligence, machine learning, and the internet of things are emerging techniques for shop floor management in industry 4.0. They can be applied to maintain industrial stability in all types of production situations.

(v) The authors of the present research article strongly believe that the developed system would provide an intelligent key to industry individuals for enhancement in industrial sustainability of industry 4.0.

For the future prospects, and to concentrate on the present scenario of industry 4.0, the production shop floor management team members emphasize developing an innovative system to enhance industrial sustainability within available resources. A smart shop floor management system has been developed in the present research work to accomplish this need of the production management teams. The efficacy of the developed model has been tested in an actual complex shop floor condition of an earthmoving machinery manufacturing unit. The result showed that the developed system efficiently controlled the shop floor management in heavy machinery manufacturing systems, including industry 4.0, by implementing a suitable approach to eliminate production problems and waste elimination. In future research, the adaptability of the developed system may be improved by applying it in other shop floor environments of industry 4.0. Furthermore, the proposed shop floor management system can be improved by integrating with different lean and intelligent approaches.

Abbreviations

LM: Lean manufacturing
LSS: Lean Six Sigma
VSM: Value stream mapping
SMED: Single minute exchange of die
TPM: Total productive maintenance
JIT: Just in time
TQM: Total quality management
SOP: Standard operating procedure
SLP: Systematic layout planning
LT: Lead time
PT: Production time
CO: Changeover time
NR: Number of operators
CT: Cycle time
AT: Available time
TT: Takt time
IT: Idle time
UT: Uptime
TCT: Total cycle time
TIT: Total idle time
WT: Working time
BT: Break time
PD: Production per day
NVAA: Non-value-added activities.

Data Availability

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] M. Ramadan, B. Salah, M. Othman, and A. A. Ayubali, "Industry 4.0-based real-time scheduling and dispatching in lean manufacturing systems," *Sustainability*, vol. 12, no. 6, Article ID 2272, 2020.

[2] V. Tripathi, S. Saraswat, and G. D. Gautam, "A study on implementation of various approaches for shop floor management," *Lecture Notes in Electrical Engineering*, vol. 766, pp. 371–387, 2021.

[3] V. Tripathi, S. Chattopadhyaya, A. K. Mukhopadhyay et al., "An innovative agile model of smart lean-green approach for sustainability enhancement in industry 4.0," *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 7, no. 4, p. 215, 2021.

[4] S.-V. Buer, J. O. Strandhagen, and F. T. S. Chan, "The link between industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda," *International Journal of Production Research*, vol. 56, no. 8, pp. 2924–2940, 2018.

[5] V. Tripathi, S. Chattopadhyaya, A. Bhadauria et al., "An agile system to enhance productivity through a modified value stream mapping approach in industry 4.0: a novel approach," *Sustainability*, vol. 13, no. 21, Article ID 11997, 2021.

[6] P. Zheng, H. wang, Z. Sang et al., "Smart manufacturing systems for Industry 4.0: conceptual framework, scenarios, and future perspectives," *Frontiers of Mechanical Engineering*, vol. 13, no. 2, pp. 137–150, 2018.

[7] R. Ben Ruben, S. Vinodh, and P. Asokan, "Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study," *Production Planning & Control*, vol. 28, no. 15, pp. 1193–1211, 2017.

[8] M. Sony, "Industry 4.0 and lean management: a proposed integration model and research propositions," *Production & Manufacturing Research*, vol. 6, no. 1, pp. 416–432, 2018.

[9] G. L. Tortorella, R. Giglio, and D. H. van Dun, "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement," *International Journal of Operations & Production Management*, vol. 39, no. 6/7/8, pp. 860–886, 2019.

[10] S. S. Kamble, A. Gunasekaran, A. Ghadge, and R. Raut, "A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A review and empirical investigation," *International Journal of Production Economics*, vol. 229, Article ID 107853, 2020.

[11] M. S. Amjad, M. Z. Rafique, and M. A. Khan, "Leveraging optimized and cleaner production through industry 4.0," *Sustainable Production and Consumption*, vol. 26, pp. 859–871, 2021.

[12] G. L. Tortorella and D. Fettermann, "Implementation of industry 4.0 and lean production in brazilian manufacturing companies," *International Journal of Production Research*, vol. 56, no. 8, pp. 2975–2987, 2018.

[13] N. Dahmani, K. Benhida, A. Belhadi, S. Kamble, S. Elfezazi, and S. K. Jauhar, "Smart circular product design strategies towards eco-effective production systems: a lean eco-design industry 4.0 framework," *Journal of Cleaner Production*, vol. 320, Article ID 128847, 2021.

[14] L. Varela, A. Araújo, P. Ávila, H. Castro, and G. Putnik, "Evaluation of the relation between lean manufacturing, industry 4.0, and sustainability," *Sustainability*, vol. 11, no. 5, pp. 1439–1519, 2019.

[15] A. Chiarini and M. Kumar, "Lean six sigma and industry 4.0 integration for operational excellence: evidence from Italian manufacturing companies," *Production Planning & Control*, vol. 32, no. 13, pp. 1084–1101, 2021.

[16] R. Saxby, M. Cano-Kourouklis, and E. Viza, "An initial assessment of Lean Management methods for Industry 4.0," *The TQM Journal*, vol. 32, no. 4, pp. 587–601, 2020.

[17] M. P. Ciano, P. Dallasega, G. Orzes, and T. Rossi, "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study," *International Journal of Production Research*, vol. 59, no. 5, pp. 1386–1410, 2021.

[18] A. Ghaithan, M. Khan, A. Mohammed, and L. Hadidi, "Impact of industry 4.0 and lean manufacturing on the sustainability performance of plastic and petrochemical

organizations in Saudi Arabia," *Sustainability*, vol. 13, no. 20, 20 pages, Article ID 11252, 2021.

[19] M. Rossini, F. Costa, G. L. Tortorella, and A. Portioli-Staudacher, "The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers," *International Journal of Advanced Manufacturing Technology*, vol. 102, no. 9-12, pp. 3963–3976, 2019.

[20] Z. M. Çınar, A. Abdussalam Nuhu, Q. Zeeshan, O. Korhan, M. Asmael, and B. Safaei, "Machine learning in predictive maintenance towards sustainable smart manufacturing in industry 4.0," *Sustainability*, vol. 12, no. 19, Article ID 8211, 2020.

[21] A. Aziz, O. Schelén, and U. Bodin, "A study on industrial IoT for the mining industry: synthesized architecture and open research directions," *IoT*, vol. 1, no. 2, pp. 529–550, 2020.

[22] T.-L. Nguyen, "STEAM-ME: a novel model for successful kaizen implementation and sustainable performance of SMEs in vietnam," *Complexity*, vol. 2019, Article ID 6048195, 23 pages, 2019.

[23] W. D. Leong, S. Y. Teng, B. S. How et al., "Enhancing the adaptability: lean and green strategy towards the industry revolution 4.0," *Journal of Cleaner Production*, vol. 273, Article ID 122870, 2020.

[24] V. Tripathi, S. Saraswat, and G. D. Gautam, "Development of a systematic framework to optimize the production process in shop floor management," *Lecture Notes in Mechanical Engineering*, vol. 2021, pp. 57–66, 2021.

[25] S. Choudhary, R. Nayak, M. Dora, N. Mishra, and A. Ghadge, "An integrated lean and green approach for improving sustainability performance: a case study of a packaging manufacturing SME in the U.K," *Production Planning & Control*, vol. 30, no. 5-6, pp. 353–368, 2019.

[26] A. Cherrafi, S. Elfezazi, K. Govindan, J. A. Garza-Reyes, K. Benhida, and A. Mokhlis, "A framework for the integration of Green and Lean Six Sigma for superior sustainability performance," *International Journal of Production Research*, vol. 55, no. 15, pp. 4481–4515, 2017.

[27] S. Kamble, A. Gunasekaran, and N. C. Dhone, "Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies," *International Journal of Production Research*, vol. 58, no. 5, pp. 1319–1337, 2020.

[28] A. Belhadi, S. S. Kamble, K. Zkik, A. Cherrafi, and F. E. Touriki, "The integrated effect of big data analytics, lean six sigma and green manufacturing on the environmental performance of manufacturing companies: the case of north africa," *Journal of Cleaner Production*, vol. 252, Article ID 119903, 2020.

[29] M. Tayyab, B. Sarkar, and B. Yahya, "Imperfect multi-stage lean manufacturing system with rework under fuzzy demand," *Mathematics*, vol. 7, no. 1, p. 13, 2018.

[30] R. Črešnar, V. Potočan, and Z. Nedelko, "Speeding up the implementation of industry 4.0 with management tools: empirical investigations in manufacturing organizations," *Sensors*, vol. 20, no. 12, Article ID 3469, 2020.

[31] V. Tripathi and S. Saraswat, "Lean manufacturing for shop floor of automotive industries: a study," *Journal of Experimental & Applied Mechanics*, vol. 9, no. 2, pp. 258–265, 2018.

[32] G. Yadav, S. Luthra, D. Huisingh, S. K. Mangla, B. E. Narkhede, and Y. Liu, "Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies," *Journal of Cleaner Production*, vol. 245, Article ID 118726, 2020.

[33] J. Östlin and H. Ekholm, "Lean production principles in remanufacturing - a case study at a toner cartridge remanufacturer," in *Proceedings of the IEEE International Symposium on Electronics and the Environment 2007*, pp. 216–221, Orlando, FL, USA, May 2007.

[34] D. Seth and V. Gupta, "Application of value stream mapping for lean operations and cycle time reduction: an Indian case study," *Production Planning & Control*, vol. 16, no. 1, pp. 44–59, 2005.

[35] A. M. Gati-Wechsler and A. S. Torres, "The influence of lean concepts on the product innovation process of a brazilian shoe manufacturer," in *Proceedings of the PICMET Portl. Int. Cent. Manag. Eng. Technol. Proc. 2008*, pp. 1137–1144, Cape Town, South Africa, August 2008.

[36] A. K. Sahoo, N. K. Singh, R. Shankar, and M. K. Tiwari, "Lean philosophy: implementation in a forging company," *International Journal of Advanced Manufacturing Technology*, vol. 36, no. 5–6, pp. 451–462, 2008.

[37] L. N. Pattanaik and B. P. Sharma, "Implementing lean manufacturing with cellular layout: a case study," *International Journal of Advanced Manufacturing Technology*, vol. 42, no. 7–8, pp. 772–779, 2009.

[38] B. Singh and S. K. Sharma, "Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm," *Measuring Business Excellence*, vol. 13, no. 3, pp. 58–68, 2009.

[39] S. Vinodh, K. R. Arvind, and M. Somanaathan, "Application of value stream mapping in an Indian camshaft manufacturing organisation," *Journal of Manufacturing Technology Management*, vol. 21, no. 7, pp. 888–900, 2010.

[40] A. R. Rahani and M. Al-Ashraf, "Production flow analysis through value stream mapping: a lean manufacturing process case study," *Procedia Engineering*, vol. 41, no. Iris, pp. 1727–1734, 2012.

[41] N. A. A. Rahman, S. M. Sharif, and M. M. Esa, "Lean manufacturing case study with kanban system implementation," *Procedia Economics and Finance*, vol. 7, no. Icebr, pp. 174–180, 2013.

[42] J. C. Chen, C. H. Cheng, P. B. Huang, K. J. Wang, C. J. Huang, and T. C. Ting, "Warehouse management with lean and RFID application: a case study," *International Journal of Advanced Manufacturing Technology*, vol. 69, no. 1–4, pp. 531–542, 2013.

[43] R. G. Bertolini, "Lean manufacturing in the valve pre-assembly area of a bottling lines production plant: an Italian case study," in *Proceedings of the 2013 International Conference on Industrial Engineering and Systems Management (IESM)*, Agdal, Morocco, October, 2013.

[44] Z. Longhan, L. Hong, and X. Shiwei, "Production process improvement based on value stream mapping for CY company," in *Proceedings of the 2013 6th International Conference on Information Management, Innovation Management and Industrial Engineering*, vol. 3, pp. 226–229, Xi'an, China, November 2013.

[45] K. L. Jeyaraj, C. Muralidharan, R. Mahalingam, and S. G. Deshmukh, "Applying value stream mapping technique for production improvement in a manufacturing company: a case study," *Journal of the Institution of Engineers: Series C*, vol. 94, no. 1, pp. 43–52, 2013.

[46] B. Das, U. Venkatadri, and P. Pandey, "Applying lean manufacturing system to improving productivity of airconditioning coil manufacturing," *International Journal of Advanced Manufacturing Technology*, vol. 71, no. 1–4, pp. 307–323, 2014.

[47] G. F. Barbosa, J. Carvalho, and E. V. G. Filho, "A proper framework for design of aircraft production system based on lean manufacturing principles focusing to automated processes," *International Journal of Advanced Manufacturing Technology*, vol. 72, no. 9–12, pp. 1257–1273, 2014.

[48] M. K. Kumar, A. J. Rajan, R. K. B. Navas, and S. S. Rubinson, "Application of lean manufacturing in mass production system A case study in Indian manufacturing unit," in *Proceedings of the 2014 IEEE International Conference on Industrial Engineering and Engineering Management*, pp. 702–706, Selangor, Malaysia, December 2014.

[49] A. Ismail, J. A. Ghani, M. N. Ab Rahman, B. Md Deros, and C. H. Che Haron, "Application of lean six sigma tools for cycle time reduction in manufacturing: case study in biopharmaceutical industry," *Arabian Journal for Science and Engineering*, vol. 39, no. 2, pp. 1449–1463, 2014.

[50] S. Singh Amin, R. Atre, A. Vardia, and B. Sebastian, "Lean machine manufacturing at Munjal Showa limited," *International Journal of Productivity and Performance Management*, vol. 63, no. 5, pp. 644–664, 2014.

[51] Z. G. d. Santos, L. Vieira, and G. Balbinotti, "Lean manufacturing and ergonomic working conditions in the automotive industry," *Procedia Manufacturing*, vol. 3, pp. 5947–5954, 2015.

[52] B. G. Mwanza and C. Mbohwa, "Design of a total productive maintenance model for effective implementation: case study of a chemical manufacturing company," *Procedia Manufacturing*, vol. 4, pp. 461–470, 2015.

[53] S. Choi, B. H. Kim, and S. Do Noh, "A diagnosis and evaluation method for strategic planning and systematic design of a virtual factory in smart manufacturing systems," *International Journal of Precision Engineering and Manufacturing*, vol. 16, no. 6, pp. 1107–1115, 2015.

[54] J. M. Rohani and S. M. Zahraee, "Production line analysis via value stream mapping: a lean manufacturing process of color industry," *Procedia Manufacturing*, vol. 2, pp. 6–10, 2015.

[55] M. M. Esa, N. A. A. Rahman, and M. Jamaludin, "Reducing high setup time in assembly line: a case study of automotive manufacturing company in Malaysia," *Procedia - Social and Behavioral Sciences*, vol. 211, pp. 215–220, 2015.

[56] J.-C. Lu and T. Yang, "Implementing lean standard work to solve a low work-in-process buffer problem in a highly automated manufacturing environment," *International Journal of Production Research*, vol. 53, no. 8, pp. 2285–2305, 2015.

[57] S. Tyagi, A. Choudhary, X. Cai, and K. Yang, "Value stream mapping to reduce the lead-time of a product development process," *International Journal of Production Economics*, vol. 160, pp. 202–212, 2015.

[58] J. Choomlucksana, M. Ongsaranakorn, and P. Suksabai, "Improving the productivity of sheet metal stamping subassembly area using the application of lean manufacturing principles," *Procedia Manufacturing*, vol. 2, pp. 102–107, 2015.

[59] S. A. Ali Naqvi, M. Fahad, M. Atir, M. Zubair, and M. M. Shehzad, "Productivity improvement of a manufacturing facility using systematic layout planning," *Cogent Eng*, vol. 3, no. 1, 2016.

[60] P. F. Andrade, V. G. Pereira, and E. G. Del Conte, "Value stream mapping and lean simulation: a case study in automotive company," *International Journal of Advanced Manufacturing Technology*, vol. 85, no. 1-4, pp. 547–555, 2016.

[61] A. J. Thomas, M. Francis, R. Fisher, and P. Byard, "Implementing Lean Six Sigma to overcome the production challenges in an aerospace company," *Production Planning & Control*, vol. 27, no. 7–8, pp. 1–13, 2016.

[62] P. Garre, V. V. S. Nikhil Bharadwaj, P. Shiva Shashank, M. Harish, and M. Sai Dheeraj, "Applying lean in aerospace manufacturing," *Materials Today Proceedings*, vol. 4, no. 8, pp. 8439–8446, 2017.

[63] A. Asif and R. Singh, "Further cost reduction of battery manufacturing," *Batteries*, vol. 3, no. 4, p. 17, 2017.

[64] A.-A. Dadashnejad and C. Valmohammadi, "Investigating the effect of value stream mapping on overall equipment effectiveness: a case study," *Total Quality Management and Business Excellence*, vol. 30, no. 3-4, pp. 466–482, 2019.

[65] I. C. Diaz, Y. Jin, and E. Ares, "Cycle time study of wing spar assembly on aircraft factory," *Procedia Manufacturing*, vol. 13, pp. 1019–1025, 2017.

[66] J. D. Morales Méndez and R. S. Rodriguez, "Total productive maintenance (TPM) as a tool for improving productivity: a case study of application in the bottleneck of an auto-parts machining line," *International Journal of Advanced Manufacturing Technology*, vol. 92, no. 1-4, pp. 1013–1026, 2017.

[67] K. Nagadi, L. Rabelo, M. Basingab, A. T. Sarmiento, A. Jones, and A. Rahal, "A hybrid simulation-based assessment framework of smart manufacturing systems," *International Journal of Computer Integrated Manufacturing*, vol. 31, no. 2, pp. 115–128, 2018.

[68] J. A. Garza-Reyes, V. Kumar, S. Chaikittisilp, and K. H. Tan, "The effect of lean methods and tools on the environmental performance of manufacturing organisations," *International Journal of Production Economics*, vol. 200, pp. 170–180, 2018.

[69] E. V. Gijo, R. Palod, and J. Antony, "Lean Six Sigma approach in an Indian auto ancillary conglomerate: a case study," *Production Planning & Control*, vol. 29, no. 9, pp. 761–772, 2018.

[70] S. Dorota and P. Litwin, "Value stream mapping and system dynamics integration for manufacturing line modelling and analysis," *International Journal of Production Economics*, vol. 208, pp. 400–411, 2019.

[71] V. G. Cannas, M. Pero, R. Pozzi, and T. Rossi, "Complexity reduction and kaizen events to balance manual assembly lines: an application in the field," *International Journal of Production Research*, vol. 56, no. 11, pp. 3914–3931, 2018.

[72] S. Kumar, A. K. Dhingra, and B. Singh, "Process improvement through Lean-Kaizen using value stream map: a case study in India," *International Journal of Advanced Manufacturing Technology*, vol. 96, no. 5-8, pp. 2687–2698, 2018.

[73] B. Suhardi, N. Anisa, and P. W. Laksono, "Minimizing waste using lean manufacturing and ECRS principle in Indonesian furniture industry," *Cogent Eng*, vol. 6, no. 1, pp. 1–13, 2019.

[74] M. Saqlain, M. Piao, Y. Shim, and J. Y. Lee, "Framework of an IoT-based industrial data management for smart manufacturing," *Journal of Sensor and Actuator Networks*, vol. 8, no. 2, pp. 25–2, 2019.

[75] P. M. Masuti and U. A. Dabade, "Lean manufacturing implementation using value stream mapping at excavator manufacturing company," *Materials Today Proceedings*, vol. 19, pp. 606–610, 2019.

[76] P. V. Ramani and L. K. Lingan, "Developing a lean model to reduce the design process cost of gas insulated switchgear foundation using value stream mapping - a case study,"

International Journal of Construction Management, vol. 0, no. 0, pp. 1–9, 2019.
[77] S. Krishna Priya, V. Jayakumar, and S. Suresh Kumar, "Defect analysis and lean six sigma implementation experience in an automotive assembly line," *Materials Today Proceedings*, vol. 22, pp. 948–958, 2020.
[78] W. Liao and T. Wang, "A novel collaborative optimization model for job shop production-delivery considering time window and carbon emission," *Sustainability*, vol. 11, no. 10, Article ID 2781, 2019.
[79] W. Shou, J. Wang, P. Wu, and X. Wang, "Value adding and non-value adding activities in turnaround maintenance process: classification, validation, and benefits," *Production Planning & Control*, vol. 31, no. 1, pp. 60–77, 2019.
[80] S. S. Sharma, D. D. Shukla, and B. P. Sharma, *Analysis of Lean Manufacturing Implementation in SMEs: A " 5S " Technique*, Springer, Singapore, 2019.
[81] M. Abubakr, A. T. Abbas, I. Tomaz, M. S. Soliman, M. Luqman, and H. Hegab, "Sustainable and smart manufacturing: an integrated approach," *Sustainability*, vol. 12, no. 6, pp. 2280–2319, 2020.
[82] D. Torres, C. Pimentel, and S. Duarte, "Shop floor management system in the context of smart manufacturing: a case study," *International Journal of Lean Six Sigma*, vol. 11, no. 5, pp. 823–848, 2020.
[83] M. Mohan Prasad, J. M. Dhiyaneswari, J. Ridzwanul Jamaan, S. Mythreyan, and S. M. Sutharsan, "A framework for lean manufacturing implementation in Indian textile industry," *Materials Today Proceedings*, vol. no, 2020.
[84] S. Mittal, M. A. Khan, J. K. Purohit, K. Menon, D. Romero, and T. Wuest, "A smart manufacturing adoption framework for SMEs," *International Journal of Production Research*, vol. 58, no. 5, pp. 1555–1573, 2020.
[85] R. Balamurugan, R. Kirubagharan, and C. Ramesh, "Implementation of lean tools and techniques in a connecting rod manufacturing industry," *Materials Today Proceedings*, vol. 33, 2020.
[86] C.-F. Chien and C.-C. Chen, "Data-driven framework for tool health monitoring and maintenance strategy for smart manufacturing," *IEEE Transactions on Semiconductor Manufacturing*, vol. 33, no. 4, pp. 644–652, 2020.
[87] A. Amrani and Y. Ducq, "Lean practices implementation in aerospace based on sector characteristics: methodology and case study," *Production Planning & Control*, vol. 0, no. 0, pp. 1–23, 2020.
[88] A. Frankó, G. Vida, and P. Varga, "Reliable identification schemes for asset and production tracking in industry 4.0," *Sensors*, vol. 20, no. 13, pp. 3709–3724, 2020.
[89] P. D. Gaspar, C. M. Fernandez, V. N. G. J. Soares, J. M. L. P. Caldeira, and H. Silva, "Development of technological capabilities through the internet of things (IoT): survey of opportunities and barriers for IoT implementation in Portugal's agro-industry," *Applied Sciences*, vol. 11, no. 8, p. 3454, 2021.
[90] J. Reyes, J. Mula, and M. Díaz-Madroñero, "Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management," *Production Planning & Control*, vol. 0, no. 0, pp. 1–16, 2021.
[91] I. P. Vlachos, R. M. Pascazzi, G. Zobolas, P. Repoussis, and M. Giannakis, "Lean manufacturing systems in the area of Industry 4.0: a lean automation plan of AGVs/IoT integration," *Production Planning & Control*, vol. 2021, Article ID 1917720, 14 pages, 2021.
[92] F. Brocal, C. González, D. Komljenovic, P. F. Katina, M. A. Sebastián, and J. L. Garciá-Alcaraz, "Emerging risk management in industry 4.0: an approach to improve organizational and human performance in the complex systems," *Complexity*, vol. 2019, Article ID 2089763, 13 pages, 2019.
[93] V. Tripathi, S. Saraswat, G. Gautam, and D. Singh, "Shop floor productivity enhancement using a modified lean manufacturing approach," *Lecture Notes in Mechanical Engineering*, vol. 2021, pp. 219–227, 2021.
[94] V. Tripathi, S. Saraswat, and G. D. Gautam, "Improvement in shop floor management using ANN coupled with VSM: a case study," *Proceedings of the Institution of Mechanical Engineers - Part C: Journal of Mechanical Engineering Science*, vol. 2022, Article ID 095440622110620, March 2022.
[95] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Simon & Schuster, New York, 1996.
[96] M. Müller, E. Alexandi, and J. Metternich, "Digital shop floor management enhanced by natural language processing," *Procedia CIRP*, vol. 96, pp. 21–26, 2021.
[97] X. Xu, Y. Lu, B. Vogel-Heuser, and L. Wang, "Industry 4.0 and Industry 5.0-Inception, conception and perception," *Journal of Manufacturing Systems*, vol. 61, pp. 530–535, 2021.
[98] D. Mourtzis, "Simulation in the design and operation of manufacturing systems: state of the art and new trends," *International Journal of Production Research*, vol. 58, no. 7, pp. 1927–1949, 2020.
[99] D. Mourtzis, J. Angelopoulos, and N. Panopoulos, "Robust engineering for the design of resilient manufacturing systems," *Applied Sciences*, vol. 11, no. 7, Article ID 3067, 2021.
[100] D. Mourtzis, J. Angelopoulos, and N. Panopoulos, "Design and development of an IoT enabled platform for remote monitoring and predictive maintenance of industrial equipment," *Procedia Manufacturing*, vol. 54, pp. 166–171, 2021.
[101] D. Mourtzis, "Machine tool 4.0 in the era of digital manufacturing," in *Proceedings of the 32nd European Modeling & Simulation Symposium (EMSS 2020)*, pp. 416–429, Athens, Greece, September 2020.
[102] C. Liu, Z. Su, X. Xu, and Y. Lu, "Service-oriented industrial internet of things gateway for cloud manufacturing," *Robotics and Computer-Integrated Manufacturing*, vol. 73, Article ID 102217, 2022.
[103] T. Peng, Q. He, Z. Zhang, B. Wang, and X. Xu, "Industrial internet-enabled resilient manufacturing strategy in the wake of COVID-19 pandemic: a conceptual framework and implementations in China," *Chinese Journal of Mechanical Engineering*, vol. 34, no. 1, 2021.
[104] A. Meissner, D. Scherer, and J. Metternich, "Starting points for digital shop floor management in production enterprises," *Procedia CIRP*, vol. 104, pp. 212–216, 2021.
[105] V. Tripathi, S. Chattopadhyaya, A. K. Mukhopadhyay, S. Sharma, C. Li, and G. Di Bona, "A sustainable methodology using lean and smart manufacturing for the cleaner production of shop floor management in industry 4.0," *Mathematics*, vol. 10, no. 3, p. 347, 2022.