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A Sustainable Productive Method for Enhancing Operational Excellence in Shop Floor Management for Industry 4.0 Using Hybrid Integration of Lean and Smart Manufacturing: An Ingenious Case Study

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Abstract: In industry 4.0, industry individuals implement lean and smart manufacturing to improve shop floor management systems. Shop floor management is used to control operational performance and enhance production within limited constraints. Various shop floor management approaches are used in the present scenario of industry 4.0, and mainly include value stream mapping, total productive maintenance, Internet of Things, artificial intelligence, machine learning, and fuzzy logic. The present research aims to develop an open innovation method to achieve sustainability in shop floor management systems in industry 4.0 by using lean and smart manufacturing concepts. The proposed method has been validated by an enhancement obtained in a real case of the shop floor management system in industry 4.0. The authors are confident that the proposed method would provide sustainability in the shop floor management system within limited constraints in industry 4.0.

Keywords: industry 4.0; smart manufacturing; lean manufacturing; internet of things; shop floor management

1. Introduction

Lean smart manufacturing is the integration of several techniques including value stream mapping (VSM), total productive maintenance (TPM), Internet of Things (IOT), computational intelligence (CI), fuzzy logic (FL), artificial intelligence (AI), asset tracking system (ATS), cyber-physical system (CPS), etc. The lean smart manufacturing (LSM) concept is used to enhance production in industry 4.0 within limited shop floor management constraints [1]. Constraints mean manufacturers' limitations that include budget, time, and industry positions. Shop floor management is an important key in industry 4.0 and is used to control production activities by eliminating idle activities and providing economic sustainability in operational performance [2]. The main goals of the shop floor management system (SFMS) in industry 4.0 have been illustrated in Figure 1. In addition, some authors argued that effective shop floor management is necessary to meet customer needs in terms of quality and cost, and to achieve this management, team members emphasize implementing an appropriate method to maximize production within available resources [3,4]. To accomplish this, lean and smart manufacturing concepts are used to enhance production within limited constraints. According to Kamble et al. [5], smart manufacturing (SM) is used to improve the production systems by monitoring production processes on the shop floor. Process optimization is a prevalent approach in industry 4.0 and is used to control operational performance and enhancement of production within limited constraints including budget, energy consumption, shop floor area, workforce, and machinery [6].

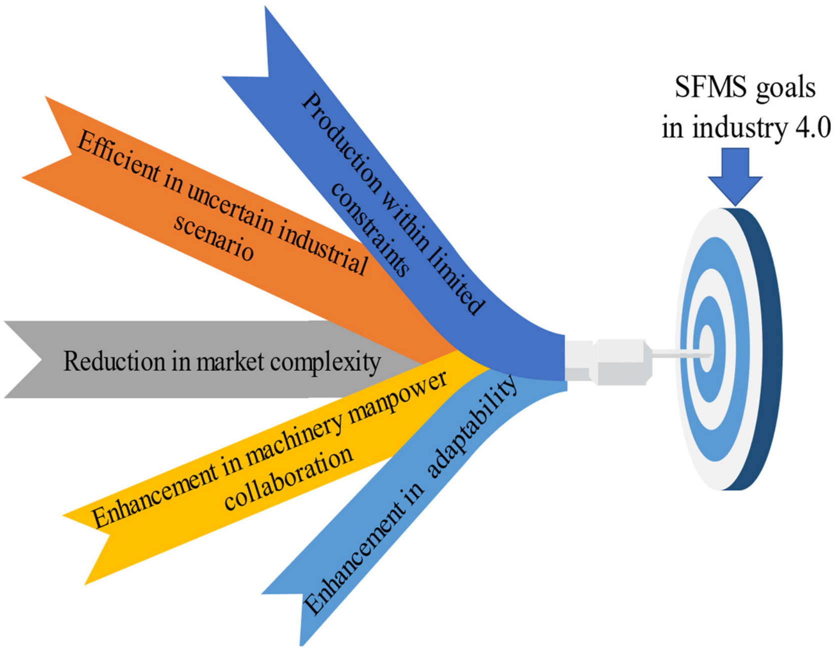

Figure 1. Goal of SFMS in industry 4.0.

The lean and smart concept works as a booster in industry 4.0 and improves the decision-making ability of the industry individuals in terms of manpower and machinery. The objective of lean and smart is to develop a positive impact in all aspects of operational performance on the overall production shop floor [7]. The lean and smart concepts have been implemented to control production management by analyzing the real-time of operational activities. The real-time analysis helps to understand actual production conditions on the shop floor [8]. Several techniques are used to implement the lean and smart concepts in shop floor management in industry 4.0. Figure 2 illustrates the techniques [9,10] used to implement lean and smart manufacturing in previous research works.

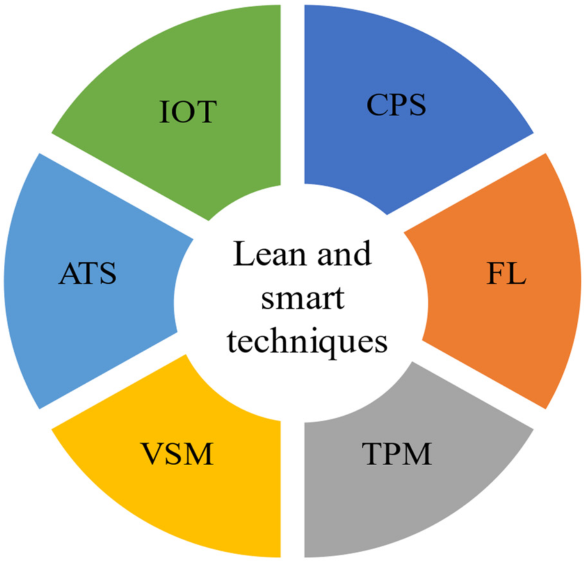

Figure 2. Techniques used to implement lean and smart concept.

Nowadays, a smart production system plays a vital role in industry 4.0 to achieve economic sustainability in complex production shop floor conditions [11]. The management team members face different problems in the present scenario because of the complexity in the production shop floor, which includes economic condition, quality variation, standardization demands, competitive environment, and customer terms changes in the context of products [12]. As a result of these problems, the industries have to face very bad consequences. The possible consequences arising out of problems in the current scenario of industry 4.0 are shown in Figure 3.

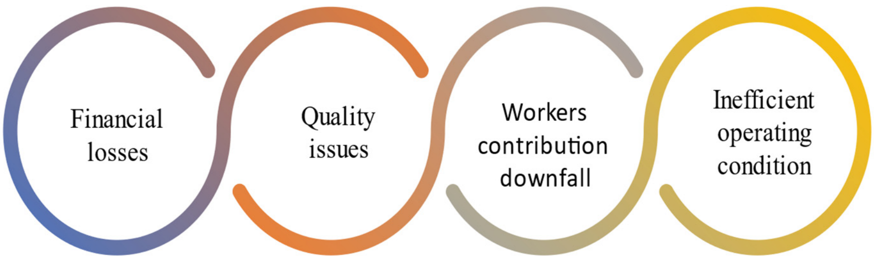

Figure 3. Potential outcomes from problems in SFMS in industry 4.0.

To get rid of these problems, shop floor management team members emphasize developing an open innovation method to maintain excellence in shop floor management in industry 4.0. Ciano et al. [13] presented a framework for the relationship between lean and industry 4.0 technologies. In the study, semi-structured interviews, internal documents, websites, and annual reports were used to collect data on lean and industry 4.0 projects. It was shown, in the result, that industry 4.0 technologies efficiently empower lean management techniques. Amjad et al. [14] developed a framework using lean, green, and industry 4.0 and implemented it in the auto parts manufacturing industry. The result of the study verified that the developed framework was able to achieve cleaner production with environmentally conscious manufacturing by improving non-value-added time and greenhouse submission by 56.20% and 55%. Sahoo et al. [15] presented a systematic methodology using lean and Taguchi's method and implemented it in a forging industry. The result showed that the developed methodology was able to enhance operational performance by eliminating waste and reduced lead time, shop floor area, and non-value-added activities by 325 min, 27%, and 72 min.

The present research aims to develop an economically sustainable method to achieve operational excellence in shop floor management systems using a hybrid integrating lean and smart manufacturing concept in industry 4.0. The developed method helps operations management members of the floor management team to achieve the production demand within limited constraints by analyzing real-time production data. The consistency of the presented method has been validated by eliminating the problem encountered in a real production case on the shop floor within limited constraints and achieving an increase in production.

1.1. Background to Lean Manufacturing and Decision-Making Criteria

In the present dynamic trends in shop floor management, industry individuals focus on enhancing operational performance in available resources. Various approaches are used for shop floor management in the present scenario including lean manufacturing, smart manufacturing, computational intelligence, kaizen, and artificial neural networks. The shop floor management approaches are used for waste management and productivity maximization in available resources. Lean manufacturing is used to improve operational performance by eliminating waste on the shop floor. The main objective of lean manufacturing is described in Figure 4.

Figure 4. Objectives of lean manufacturing on the shop floor.

Lean manufacturing helps industry individuals in achieving operational excellence by improving operations management system efficiency on the shop floor. Singh et al. [16] implemented a value stream mapping technique for improvement in production. Value stream mapping is a lean-based technique used to enhance productivity by modifying workflow. In the study, value stream mapping was implemented on an auto parts manufacturing unit. The result showed that value stream mapping was able to reduce lead time, cycle time, and work in process inventory by eliminating waste and idle activities. Seth et al. [17] implemented the lean approach and Taguchi method to improve the manufacturing of power transformers. In the study, Gemba walk, value stream mapping, and systematic questioning techniques were used to improve operational performance on the shop floor. The result showed that non-value-added activities and cycle time were reduced by 29.78% and 17.3% effectively. Kumar et al. [18] discussed the lean-kaizen principal implementation using value stream mapping in a spindle kick-starter manufacturing industry. In the study, poka-yoke and brainstorming tools were used to eliminate defects. The result revealed that manpower requirement, value-added time, and production were improved by 40%, 75.25%, and 69.47% effectively. Cheng et al. [19] integrated the lean concept with the radiofrequency identification technique for improving warehouse management efficiency. Value stream mapping was used to improve operational performance and waste management on the shop floor. The results showed that the integration of lean with the radiofrequency identification technique was effectively reduced by 87%. Andrade et al. [20] implemented the value stream mapping concept in the auto parts industry. It has been observed, by analyzing operational activities, that waste was present in an assembly line of clutch discs. The result revealed that value stream mapping with simulation was a good decision-making approach for improvement in the production process. Industry individuals have implemented a lean approach for improvement in operational performance by waste management and the elimination of non-value-added activities on the shop floor. The lean approach was only able to enhance operations management in manual production lines on the shop floor.

1.2. Introduction to Smart Digital Manufacturing: An Efficient Approach for Productivity Enhancement on Mining Machinery Manufacturing Shop Floor Management

The operations management teams are striving to implement sustainable shop floor management for achieving productivity enhancement in the industry. Sustainable shop floor management helps to enhance operational performance in all types of production conditions within limited constraints. Researchers and industry individuals use several hybrid approaches for improving the operational condition on the shop floor. A hybrid approach is used to enhance the efficiency of the individual approach by boosting up their applicability on the shop floor. In the present scenario, various hybrid approaches are used includes lean-kaizen; lean six sigma; lean and smart; digital lean; lean and green; lean, green, and smart; and lean and total quality management. The researchers encourage the integration of various shop floor management approaches for achieving economic sustainability in operations management and operational excellence in industry 4.0. In the previous research works, several strategies and methods have been developed for improving operational performance using advanced techniques. Sony et al. [21] developed a hybrid model using lean and industry 4.0 by reviewing previous research works. The study provided fifteen propositions for research to advance the hybrid model of lean and industry 4.0. The propositions were used for enhancing resource utilization and financial profitability. Serrano-Ruiz et al. [22] developed a multidimensional conceptual model by reviewing previous works in the smart manufacturing scheduling domain from the industry 4.0 perspective. The model was developed to enhance the job shop scheduling process efficiency using smart manufacturing scheduling. The result showed that the study was able to provide guidance for researchers regarding the digital transformation of job shops. Amjad et al. [23] investigated the possibility of collaboration between facets of Industry 4.0 and large manufacturing constituents. The result showed that the large manufacturing constituents can integrate with Industry 4.0 facets and able to provide economic, operational, and environmental benefits.

Chiarini et al. [24] discussed the integration of the principle of lean six sigma with industry 4.0 technologies. In the study, data were collected by observations and interviewing managers of ten construction companies based in Italy. The result revealed that the lean six sigma was able to provide efficient outcomes for industry 4.0 applications. Lee et al. [25] developed a framework using the integration of CPS, business applications all together into an end-to-end design, and digital twins of different perspectives of a shop floor design from the unit level. In the study, a time machine was developed to evaluate the performance of virtually different designs. The results revealed that the framework was able to provide predictable and expected outcomes and satisfy short and long-term business requirements. Zhuang et al. [26] proposed a digital twin-based smart production management framework and approach for control complex product assembly shopfloors. The proposed framework was implemented in a satellite assembly shop floor. The result showed that the study provided a predictive manufacturing in the product assembly stage and control for a satellite assembly shop floor.

Caiado et al. [27] developed a fuzzy logic-based model for supply chain management in industry 4.0. The model was developed through focus groups, interviews, a literature review, and a case study, from model design to model evaluation. The model was validated by implementation in a real manufacturing organization. The result showed that the model was able to provide a robust tool for diagnostic and digital readiness in industries.

It has been observed by reviewing previous research works in the domain of shop floor management that the industry individuals are facing problems in achieving operational excellence through an individual approach. Industry individuals are focused on developing a hybrid approach to eliminate the problems and enhance the efficiency of individual approaches in shop floor management. The objective of the present research is to develop a sustainable efficient method for achieving operational excellence in shop floor management using a hybrid integrated approach of lean and smart manufacturing in industry 4.0. The developed method helps to enhance the production rate within limited constraints and available resources by eliminating waste and idle activities found in the shop floor management systems, including industry 4.0. The developed method has been evaluated and validated by implementation in a real-life shop floor management condition in a mining machinery manufacturing industry. The novelty of the present research lies in the fact that the developed method has been reported for the first time, and this method helps to enhance operational performance and yield efficacy of production processes on the shop floor, including industry 4.0. The developed method would be advantageous for young researchers and industry individuals in enhancing the efficiency of the shop floor management system.

1.3. Hybrid Integrated Lean and Smart Manufacturing: Sustainable Method, Elements, and Application in Industry 4.0

In the present dynamic trend of industry, industry personnel support implementing an integrated hybrid approach for achieving productivity enhancement on the shop floor. The lean and smart approach is a hybrid approach used for improving operations management system efficiency on the shop floor. Lean is used to eliminate waste and the smart concept is used to enhance operational excellence by providing safer and paperless working on the shop floor. The smart approach can provide an accurate solution for improving the efficacy of the operations management systems on the shop floor in industry 4.0. Researchers of the present study developed a sustainable method for achieving operational excellence on the shop floor by improving various parameters including overall equipment effectiveness, working environment, workforce efficiency, financial profitability, and production time. The main elements of the developed method include an asset tracking system, cloud computing, smart operations monitoring system, smart condition monitoring system, digitization, and the Internet of Things. The elements are used to enhance the production rate by maximizing resource utilization by implementing smart and digital systems in the shop floor management systems. The developed method could provide a positive working environment on the shop floor, and this statement has been validated by being implemented in a mining machinery manufacturing environment and enhancing operational performance. The developed method provides a decision-making key for achieving operational excellence in mining machinery manufacturing shop floors in industry 4.0.

2. Literature Review

Researchers and shop floor management teams have appreciated the implementation of integrated lean and smart manufacturing concepts to enhance operational excellence within available resources. Psomas et al. [28] discussed a systematic literature review on the research gap in lean manufacturing. In the study, 120 articles were collected from various journals including Science Direct, Emerald Online, Taylor & Francis, and Springer Link. The articles were published between 2005 and 2016. Research gaps were grouped into logical topics by applying a simple affinity diagram. The study concluded that the presented lean manufacturing research gap could be used by researchers for the development of lean manufacturing. Strozzi et al. [29] discussed the scientific literature on the smart factory concept. In the study, a dynamic methodology was implemented. The methodology was combined with a systematic literature review approach with the bibliographic networks' analysis. The method adopted in this study was used from bibliographic networks to explore emerging topics. The dynamic analysis carried out in the study allowed the uncovering of research directions for the development of the smart factory concept.

In the present study, previous research works are thoroughly reviewed and analyzed. The authors have described the previous research work in two sections, including methods developed for enhancing operational performance on the shop floor and the implementation of advanced shop floor management approaches for achieving operational excellence. In the present study, several databases have been used to collect research works as shown in Figure 5. Selected articles were published between the years 2009–2022, of which 2 articles were published in the period 2009–2013, 15 articles were published in the period 2014–2018, and 24 articles were published in the years 2019–2022.

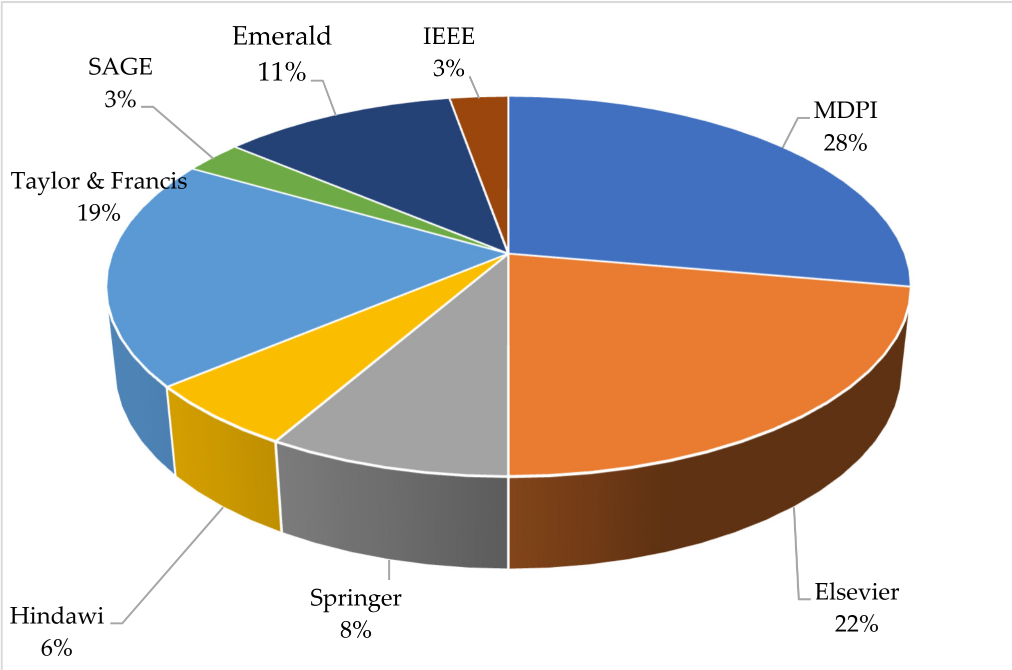

Figure 5. Database used for collection of research work in present study.

Implementation of Advanced Shop Floor Management Approaches and Techniques for Achieving Operational Excellence

In industry 4.0, industry individuals demand an agile, systematic, and sustainable shop floor management system to control operational performance in available resources. The shop floor management system enhances the actual production conditions by implementing improvement in operations management and utilization of resources. To do this, several methods and approaches have been proposed and implemented in previous research works. The main purpose of the proposed methods was to enhance productivity by eliminating waste on the shop floor within available resources. The outcome of previous research works in terms of results, method, and innovation has been illustrated in Table 1.

Table 1. Description of outcomes of previous research works.

Author	Year	Innovation	Techniques	Result
Li et al. [30]	2017	Presented an SM framework of industry 4.0.	SM	Observed present SM framework able to obtain improvement in workload and efficiency in SM system.

Table 1. *Cont.*

Author	Year	Innovation	Techniques	Result
Ren et al. [31]	2018	Developed a framework of shop floor material delivery through real-time manufacturing big data.	SM	Improved the shop floor material delivery performance by using real-time and multi-source manufacturing big data.
Saqlain et al. [32]	2019	Developed an IOT framework to support monitoring and controlling industrial data.	IOT	The presented framework can improve productivity and the prognosis of production lines.
Li et al. [33]	2019	Implemented LSM in a bicycle industry.	LSM	Validated that LSM efficient to obtain production enhancement. This study reconfirmed the benefits of combining lean production and smart manufacturing through a literature review and empirical evidence.
Mittal et al. [34]	2019	Developed a roadmap of SM.	SM	The developed framework was able to provide an efficient production management system in SMEs.
Frank et al. [35]	2019	Discussed the patterns of adoption for industry 4.0 technologies in manufacturing firms.	SM	Observed that flexibilization, advanced automation, and virtualization are frontiers in the complexity of implementation of industry 4.0.
Torres et al. [36]	2019	Discussed characterization of a shop floor management system through digital shop floor features and smart technologies.	SM	Concluded that important features in shop floor management were data analytics, real-time monitoring, use of real-time digital visualization tools, use of mobile devices, and automated report generation and notification.
Wang et al. [37]	2019	Discussed a framework of SM shop floor system based on the Ubiquitous Augmented Reality technology.	SM	The study described the ability of shop floor systems based on the Ubiquitous Augmented Reality technology to integrate task scheduling with communication between the users and system.

Table 1. *Cont.*

Author	Year	Innovation	Techniques	Result
Kamble et al. [38]	2019	Investigated the direct effect of industry 4.0 technologies on sustainable organizational performance with lean manufacturing practices.	LM, SM	Observed that industry 4.0 technologies are an enabler of lean manufacturing practices and leading to enhancement of sustainable organizational performance.
Saqlain et al. [26]	2019	Developed an IOT framework to support monitoring and controlling industrial data.	IOT	The presented framework can improve productivity and the prognosis of production lines.
Caiado et al. [27]	2020	Presented a model of operations and supply chain management.	FL	Obtained a robust tool for digital readiness in industry 4.0.
Saxby et al. [39]	2020	Identified how the LM provides continuous improvement in industry 4.0.	LM	The adaptability of lean can be enhanced by integration with some new techniques.
Abubakr et al. [40]	2020	Highlighted the challenges faced by the management systems to integrate a sustainable smart manufacturing performance.	SM	Improved environmental quality of the manufacturing sectors.
Frankó et al. [41]	2020	Discussed a novel solution for global asset management for industry 4.0.	IOT	Found that the system is an efficient implementation of asset tracking because of the cooperation of the different technologies and subsystems. The main benefits of the system were its high scalability and the possibility of continuous adaptation.
Aziz et al. [42]	2020	Analyzed the present state of information technology in the mining industry.	Industrial IOT	The adoption of industrial IOT can provide improvements in operational performance by the standard management systems.
Gaspar et al. [43]	2021	Investigated technological capabilities of IOT.	IOT	Positively helped managers to take efficient decisions through monitoring and measuring.
Lee et al. [25]	2021	Presented a framework integrating digital twins of different perspectives of a shop floor design all together into an end-to-end design solution.	CPS	Provided a new system on the shop floor to fulfil the short and long-term business requirements and help to generate predictable and expected outcomes.

The authors appreciated the development of a smart method to control the activities on the shop floor using lean and smart techniques and achieve improvement in the management system. Previous researchers suggested mostly smart manufacturing concepts in recent years. The present study reviewed the methods presented in previous research works and concluded that no generalized solution was developed that could be applied in industry 4.0 to all types of production conditions on the shop floor. The present research aims to develop an economic sustainable efficient method using hybrid integration of lean and smart manufacturing concepts. The developed method has been implemented and evaluated by implementing in a real-life operations management condition on the shop floor. The developed method would provide a convenient strategy in shop floor management in industry 4.0. This statement has been validated by improvement obtained in a real case study of shop floor management in industry 4.0.

3. An Innovative Shop Floor Management Model Using Hybrid Integrated Lean and Smart Manufacturing for Achieving Operational Excellence in Industry 4.0

Industry 4.0 is demanding a new method to control SFMS due to advancement and changes in production conditions day-by-day. To meet this demand, an open innovation method is required to control shop floor management in industry 4.0 and production complexity. The developed method has been used with the lean and smart manufacturing concept. The developed method has been developed by the literature review on previous research works. The authors believed that the developed method would help shop floor management team members in the decision-making stage. The developed method enhances adaptability in industry 4.0 by the establishment of SFMS through lean and smart techniques. The method has been developed by keeping in mind that the method could be implemented in all production complexity conditions and uncertain production conditions in industry 4.0. The developed method has been illustrated by Figure 6.

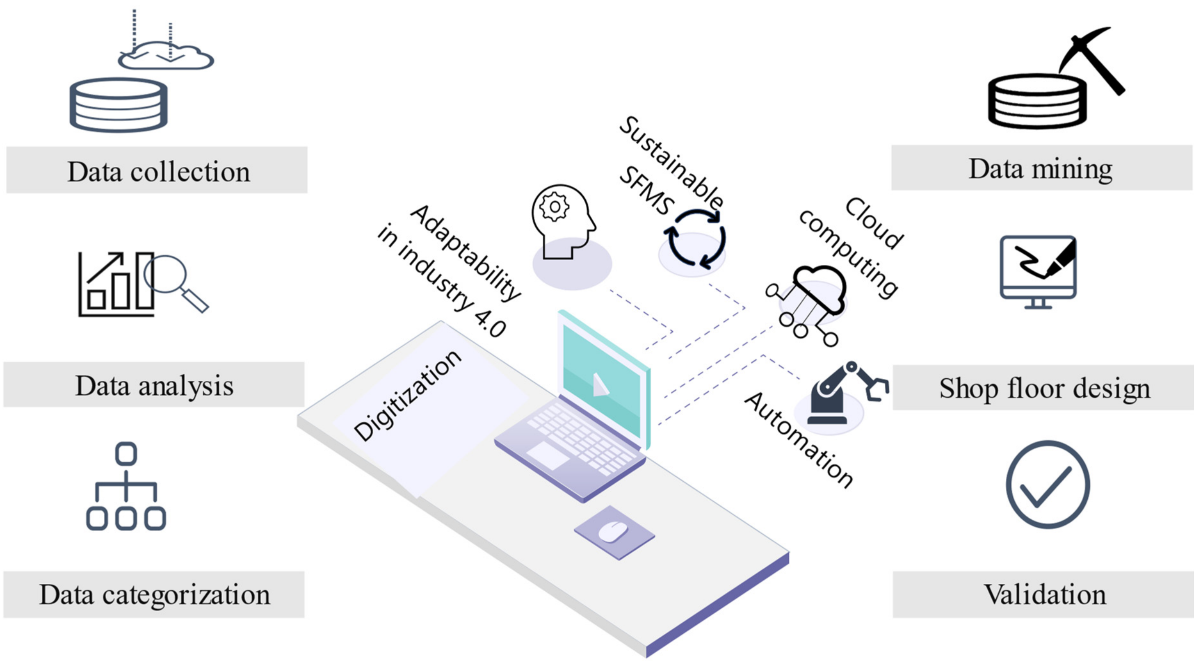

Figure 6. Proposed innovation shop floor management method.

The proposed method consists of six steps. In step 1, data collection has been used to collect production information by various sources includes previous records, discussion, interviews, industrial visits, and visualization at workstations. Step 2 illustrates data analysis by calculating parameters like lead time, idle time, changeover time, logistics system, downtime, and workflow. Step 3 categorizes overall data according to SFMS to visualize the actual production condition. Step 4 identifies the source of the problems and main anomalies responsible for poor consequences faced by management team members. Step 5 provides an efficient shop floor design to reduce idle activities by the elimination of problems, and finally step 6 validates the proposed method by a result comparison of the production enhancement achieved in a real case study. The description of steps used in the proposed shop floor management system has been elaborated in Figure 7.

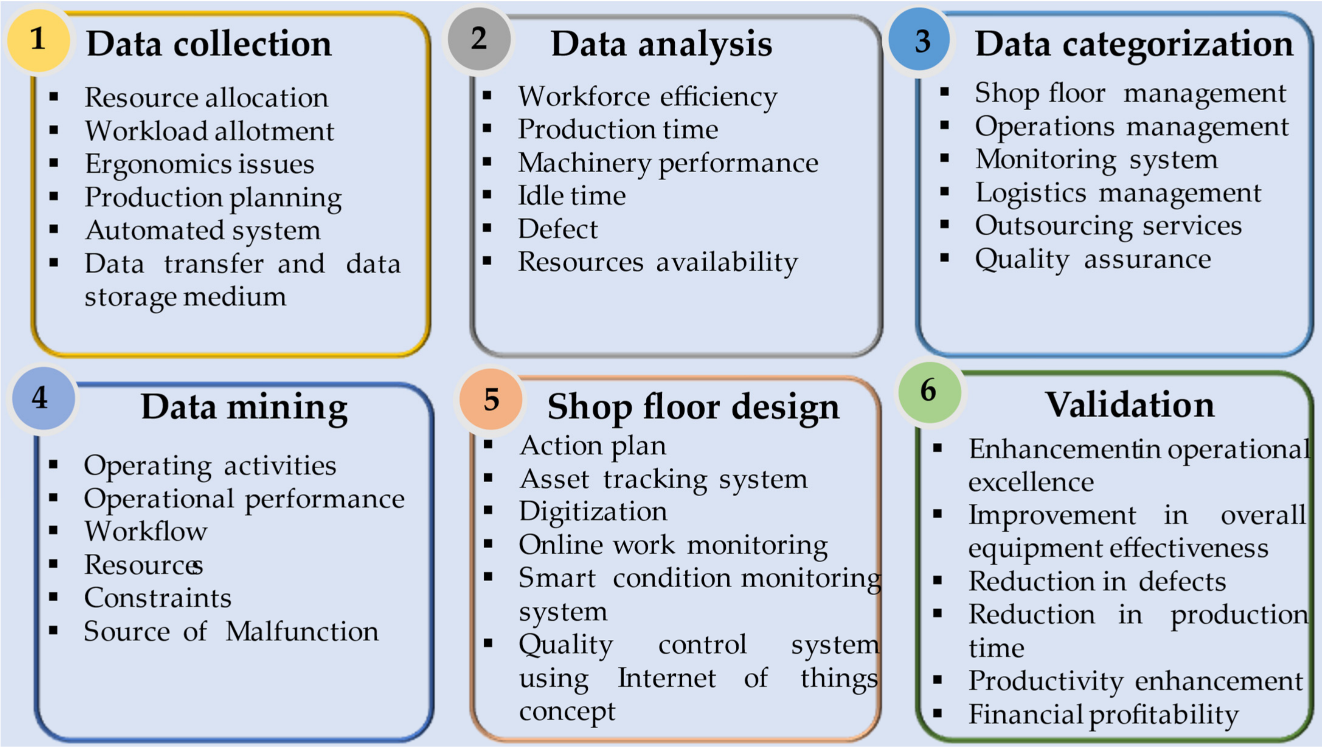

Figure 7. Description of phases used in proposed shop floor management method.

In the first step of the proposed shop floor management method, the data and information of the operations management are collected. The collected data and information help to provide an idea for understanding the actual operational conditions, constraints, and limitations. In the second step, the collected data have been analyzed by calculating different parameters such as lead time, uptime, idle time, workforce, resource utilization, energy consumption, defect, and machinery health. The analysis provides an idea of the present production condition by understanding bottleneck activities and problems in operations management on the shop floor. In the third step, the source of problems is discussed and categorized according to the different departments present on the shop floor. The categorization provides a description of issues faced in operations management on the shop floor. The fourth step suggests an action plan for eliminating the source of problems, and it is completed by analyzing overall production processes and activities participating in operations management on the shop floor. In the fifth step, the shop floor is modified and designed for achieving operational excellence and yield efficiency in production processes. Different smart systems are used to control operational performance using cloud computing, digitization, and Internet of Things techniques. Finally, in the sixth step, the improvements are analyzed and compared with observed conditions. The result of the analysis validates the proposed shop floor management method as efficient for operations management.

4. Implementation of Proposed SFMS Method in a Real Production Condition

The proposed SFMS method has been implemented in a real production condition case of a mining machinery assembly unit. The industry currently has 46 individuals including operators, supervisors, and workers with approximately 570 working minutes. The present industry manufactures mainly skid steer loaders. The skid steer loader is a type of mining machinery and is also used in earthmoving works. It works on cutting-edge technology. The present management system was facing higher competition because of higher cycle time and idle time. The industry was receiving the order on an intermittent basis due to complexity in production shop floor conditions. The members of the shop floor management team were concerned with developing an efficient method to get rid of the problems. The proposed method has been implemented to improve present production conditions.

4.1. Data Collection

The data in the present industry have been collected by various sources including discussion, industry visits, interviews, previous records, meeting, workstation inspection, and real time study on the shop floor. The authors take the help of industry individuals for reviewing the information and condition of present production conditions. Table 2 shows details of the present shop floor management system.

Table 2. Details of present shop floor management system.

Observed Data	Source	Quantity/Amount
Product name	Records and visited	Skid steer loader
Number of workers	Records	46
Number of employees	Discussion	52
Number of shops	Visited	5
Operational condition	Visited	Semi-automation
Number of workstations	Records and visited	25
Working time	Records and discussion	570 Minutes
Routine downtime	Records and visited	75 Minutes
Cycle time	Inspection	6800 Minutes
Idle time	Discussion and inspection	470 Minutes
Ergonomics issues	Meeting and discussion	Shop floor congestion and safety issues
Working condition	Inspection and discussion	Unfriendly
Guidelines	Records, inspection, and visited	Not available
Operating system	Records and visited	5
Data storage medium	Records, discussion, and interviews	Manual and storage device
Data transfer source	Inspection	Electronic devices
Production planning	Records, discussion, and interviews	Random
Approach	Records, discussion, and inspection	5S, six sigma
Condition monitoring system	Records, visited, and inspection	Not available

4.2. Data Analysis

The data analysis has been used to evaluate actual SFMS conditions by the calculation of different production parameters [4,12,22,42]. In the present SFMS, a total of 5 shops including 15 processes were used in the assembly of the final product. The calculation shows the cycle time was to be 6800 min while the idle time was 470 min [32,33,35,38,40]. It has been observed that, typically, the current industry used to finalize 10 products in advance due to production problems and kept them in store so that future production orders could be handled in any case. It has been observed, by the present SFMS analysis, that the management team members were facing several problems as illustrated in Table 3.

Table 3. Description of present SFMS condition.

Shop	Cycle Time	Idle Time	Downtime	Problem
Assembly	2895	140	240	Ergonomics issues, poor work allotment, number of defects, congestion between workstations
Fabrication	860	110	105	Machinery malfunction, safety issues, continuous changing in platform
Painting	2015	105	330	Lack of control of material handling equipment, random gap between parts, outsourcing of services
Hot testing	1830	45	150	Lack of planning, variation in timing, parking at random positions
Quality inspection	1030	115	165	Manual and unplanned processes, irregular time gap between processes, continuous changing of the operators

4.3. Data Categorization

The data categorization helps to describe source of problems found in each department. The data categorization provides an easy platform to management team members in identifying the main reasons for problems [1–3,6]. Table 4 describes the data categorization according to concerned departments.

Table 4. Data categorization according to concerned departments.

Department	Probable Reason
Production	Lack of machinery and worker collaboration, poor supervision, unavailability of data storage device, manual work allotment
Operation	Lack of policy, inefficient workflow, congestion at workstations, repetition of processes
Logistics	Outsourcing of services, unnecessary movements, involvement of one worker in more than one shops, lack of transmission system
Maintenance	Unavailability of condition monitoring system, manual records, lack of standardization
Quality control	Manual and offline monitoring, repetition of processes

It has been observed by data categorization that the management team members need to be vigilant about identifying sources of actual reasons by suitable techniques.

4.4. Data Mining

Data mining plays a vital role in SFMS and is used to eliminate anomalies in production processes on the shop floor [44,45]. This step has been used to identify idle activities and proposed an action plan to optimize production processes. The present method uses data mining to enhance operational performance by analyzing production data and helps to obtain efficient production planning. Table 5 illustrates the detail of the analysis used in data mining performed in the present SFMS.

Table 5. Analysis on anomalies found in present SFMS.

Factor	Anomalies	Suggested Action
Machinery	Higher vibration, heating, breakdown, excess energy consumption	Online monitoring and measurement
Manpower	Non-involvement, inefficiency	Work allotment by a feedback system, transfer, and previous data records
Layout	Unnecessary stoppage during operations, random distance	Analyzed optimum path decision, online controlling system
Quality	Data error, missing parts	Smart sensors, online monitoring
Constraints	Variation, unavailability	Online analysis system, smart devices

The suggested action has been decided by several brainstorming sessions, interviews, and discussions with management team members. The management team members believed that the present SFMS could be improved by the implementation of the suggested actions.

4.5. Optimal Design of Shop Floor

The current shop floor has indeed continuously been enhanced with the deployment of data mining by adopting suggested activities. The modified shop floor design focuses on enhancing production rate, quality, resource utilization, and financial profitability by implementing the Internet of Things, lean, smart, cloud computing, digitization, and automation. The developed shop floor design thus optimizes the operational conditions and activities by online monitoring and controlling operational performance and workflow on the shop floor. The proposed shop floor design is shown in Figure 8.

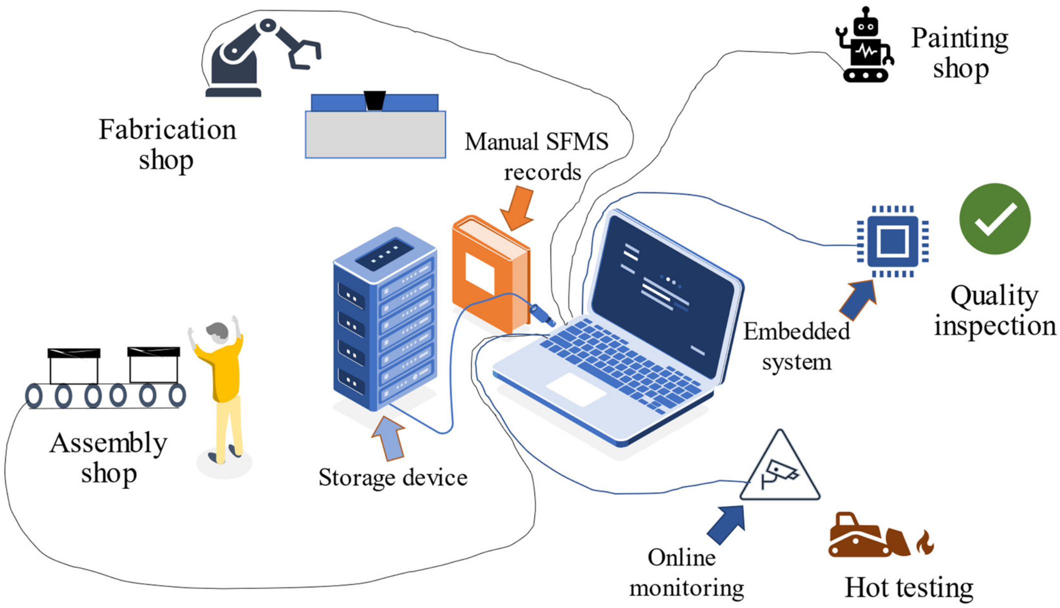

Figure 8. Proposed design of shop floor.

4.6. Validation

The proposed shop floor has been tested under various conditions; the design of the shop floor reflects the use of various tools and methods which help in improving operational efficiency. The results obtained by deploying the proposed shop floor design are described in Figure 9. The proposed innovation SFMS method has been validated in industry 4.0 by comparing the results of previous research work conducted in the relevant areas. Table 6 shows a comparison of the current results and the results of previous research works.

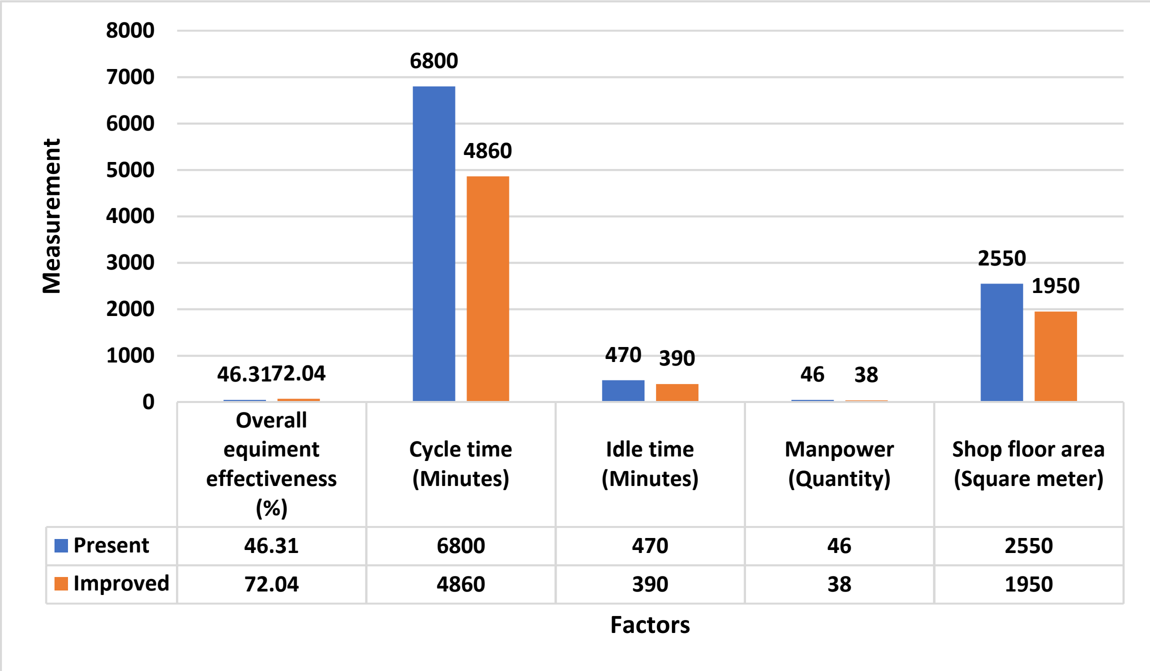

Figure 9. Results obtained by proposed shop floor design.

Table 6. Comparison between results obtained in previous and present research work.

Author	Improvement (%)				
	Production time	Resource	Cost	Defect	Logistics
Vinodh et al. [46]	1.11	Machinery	Reduced	4	Improved
Liao et al. [47]	Reduced	Energy	14.58	NA	Improved
Chien et al. [48]	Reduced	Machinery	Reduced	NA	NA
Thomas et al. [49]	16.79	Manpower	Reduced	NA	NA
Asif et al. [50]	Reduced	Energy	20	Reduced	NA
Present study	71.45	Machinery, Manpower	60	85	Improved

5. Results and Discussion

The SFMS should be implemented according to different factors including operational conditions, limited available resources, machinery manpower collaboration status, and working environment. The proposed method fulfills the overall criteria as discussed and could be implemented in any type of production scenario in industry 4.0. This statement has been validated by enhancement in the SFMS throughput achieved in a real case study. Figure 10 shows the improvement achieved by the proposed SFMS method in the present case study. Table 7 describes the action plan for improvement in the shop floor management system. Table 8 shows the comparison between some relevant research works and the present study.

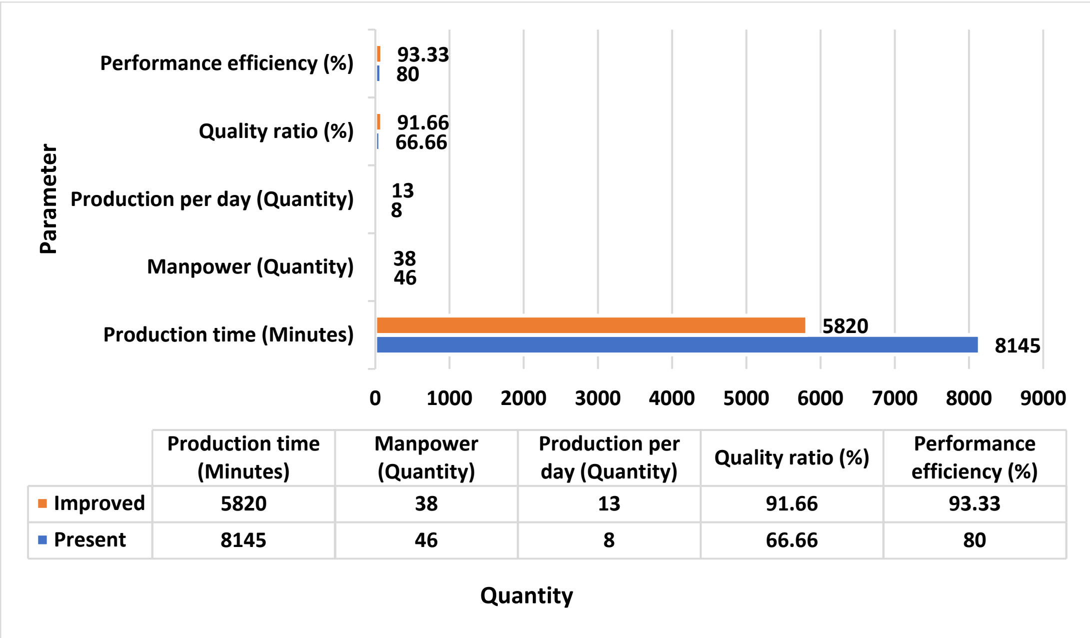

Figure 10. Analysis on improvement achieved by proposed SFMS method.

Table 7. Action plan for improvement in operations management on the shop floor.

Sl. No.	Shop	Identified Problem	Action
1.	Assembly	Lack of production planning and congestion on the shop floor	Eliminate idle activities and deploy a smart monitoring system
2.	Fabrication	Downtime and lack of planning	Provide automation and smart condition monitoring system
3.	Painting	Outsourcing of services and material handling issues	Implement Internet of Things concept for controlling activities
4.	Hot testing	Higher idle time	Use online monitoring system with digitization technique
5.	Quality inspection	Lack of planning	Provide a smart monitoring system with cloud computing concept to control activities, working span, and quality standard

Table 8. Comparison between parameters improved in previous research work and present research investigation.

Author	Approach	Parameters				
		Reduced Production Time	Financial Profitability	Workers' Efficiency	Reduced Defects	Machinery Utilization
Chien and Chen [48]	Smart manufacturing	✗	✗	✗	✗	✓
Ismail et al. [51]	Lean six sigma	✓	✓	✗	✗	✗
Gijo et al. [52]	Lean six sigma	✗	✓	✗	✓	✗
Reyes et al. [53]	Lean and industry 4.0 technologies	✓	✓	✗	✗	✗
Frankó et al. [41]	Internet of Things	✗	✓	✗	✗	✓
Mittal et al. [34]	Smart manufacturing	✗	✓	✗	✗	✗

Table 8. *Cont.*

Author	Approach	Parameters				
		Reduced Production Time	**Financial Profitability**	**Workers' Efficiency**	**Reduced Defects**	**Machinery Utilization**
Vlachos et al. [54]	Lean and Internet of Things	✓	✓	✗	✗	✗
Chen et al. [19]	VSM, radiofrequency identification	✓	✗	✗	✗	✗
Present study	Lean and smart manufacturing	✓	✓	✓	✓	✓

The developed method of shop floor management can provide an improvement in operations management by achieving operational excellence in the industry 4.0 working environment. The method is able to improve all types of production conditions and this statement was validated by implementing it in the mining equipment manufacturing industry. It has been observed that the developed method efficiently improved production time, cost, defect, and overall equipment effectiveness by 71.45%, 60%, 85%, and 25.73%, respectively. The result of the present research shows that the integration of lean and smart manufacturing in the developed method provides a more intelligent and sophisticated system and helps to obtain the main objective of improving operational efficiency and reducing defects within limited constraints.

6. Contribution of Current Method in Shop Floor Management System, including Industry 4.0

The operations management team members emphasize developing a sustainable method to enhance operational performance on the shop floor. In an exhaustive literature review, it has been found that the researchers preferred to implement lean and smart manufacturing concepts. It has been observed that changes in production conditions in industry 4.0 have led to a demand for new approaches to shop floor management. The researchers focused on developing an integrated method for production management on the shop floor, including industry 4.0. The research output of the current research work has been compared with previous research studies. The comparison is shown in Figure 11.

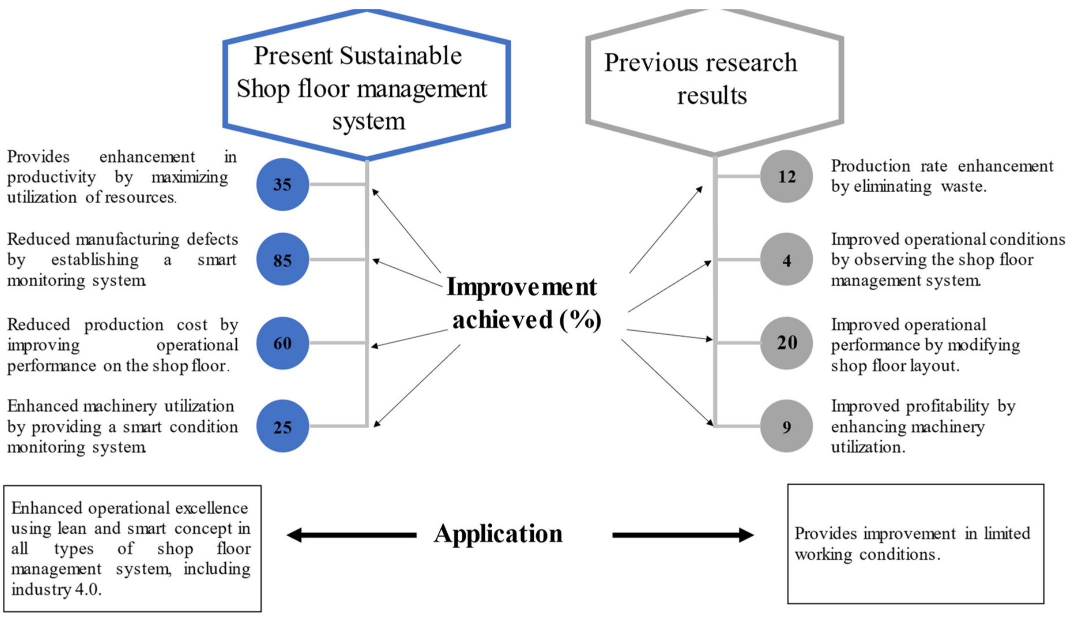

Figure 11. Application and contribution of the proposed method in shop floor management.

7. Enhancement of Shop Floor Management Efficiency in Industry 4.0 Using the Developed Method

Industry personnel emphasize enhancing the efficiency of the shop floor management system with available resources and suitable approaches. Various hybrid approaches are used to enhance operational performance on the shop floor, mainly including lean six sigma, smart lean, digital lean, and lean-kaizen. Nowadays, the smart lean concept is used to enhance the efficacy of operations management on the shop floor by eliminating waste and idle activities. In reviewing the previous research articles, it has been found that the lean approach was able to improve operational performance in traditional production lines only. In the present study, an economically sustainable method has been developed using an integrated hybrid approach of lean and smart manufacturing. The developed method could enhance the efficiency of shop floor management through waste management efficiently in available resources.

7.1. A Novel Method for Achieving Excellence and Economic Sustainability in Operations Management on the Shop Floor in Industry 4.0

The implementation of a sustainable approach with an efficient method is a crucial decision for researchers and industry personnel. A suitable method facilitates achieving improvements in operations management by modifying appropriate changes in production activities. In the present scenario of industry 4.0, various advanced techniques are used for providing workflow flexibility, financial profitability, condition monitoring, and monitoring on the shop floor. Advanced techniques help to improve the efficacy of approaches and they include asset tracking systems, paperless Kanban, the radio frequency identification system, and the Internet of Things. The advanced techniques can improve the economic sustainability of the operations management system on the shop floor by developing a safe and modern working environment with limited constraints.

7.2. Implementation of Lean and Industry 4.0 Technologies for Shop Floor Management

In the present research work, a sustainable method has been developed to enhance the excellence and efficiency of the operations management system using an integrated hybrid lean and smart approach. Lean and smart manufacturing has been used to enhance the production rate by monitoring and controlling production activities on the shop floor. The technologies used in industry 4.0 enhance the effectiveness of lean-based techniques by providing digital and smart systems. Industry 4.0 technology such as digitization provides a new platform for controlling operational and workflow control on the shop floor. The platform helps industry personnel in monitoring shop floor management digitally with paperless works. In the present scenario, various technologies have been used for achieving economic sustainability in shop floor management systems including digitization, radiofrequency identification systems, embedded systems, asset tracking systems, etc. Industry 4.0 technologies are able to enhance the shop floor management system's efficiency through waste elimination.

7.3. Managerial Impacts and Contribution to Operations Management on the Shop Floor

In the present research work, the method has been developed based on digital lean and smart manufacturing approaches to monitor variations in operational performance under limited constraints. The developed method provides productivity enhancement in industry 4.0 by achieving operational excellence, yield efficiency of production processes, and financial profitability. Digital lean provides strategic flexibility to industry individuals in achieving improvements in operational conditions on the shop floor. Smart manufacturing is beneficial for enhancing shop floor management efficiency using advanced technologies. The developed method helps industry individuals in the decision-making phase for maximizing productivity and resource utilization within limited constraints. It has been concluded that the integrated hybrid lean and smart approach can provide economic sustainability in operations management on the shop floor in industry 4.0.

8. Conclusions

In the present research work, an innovative method has been developed using a hybrid integrated lean and smart manufacturing concept for achieving economic sustainability in **SFMS** through the **identification of problems faced in industry 4.0. The main outcomes obtained by the present article are as follows:**

i. The developed innovation method follows the rational steps to achieve economic sustainability in SFMS and can be implemented within limited constraints in industry 4.0.
ii. It has been observed that overall operational performance and production has been increased by 13.33% and 33.33%, respectively, and this has been achieved by the deployment of online monitoring, embedded system, smart sensors, storage devices, and a smart control system.
iii. It has been observed that the SFMS can be improved by the implementation of smart techniques includes IOT, CPS, ATS, and AI, and the smart techniques are able to provide unprecedented production enhancement in industry 4.0.
iv. It has been concluded that the integration of smart manufacturing with the lean concept is an emerging approach in industry 4.0.
v. The authors believe that the proposed open innovation SFMS method would bring a revolution in industry 4.0 and help industry persons in controlling operation performance.

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