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Research Article

Development of a Data-Driven Decision-Making System Using Lean and Smart Manufacturing Concept in Industry 4.0: A Case Study

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

[1]*Department of Mechanical Engineering, Accurate Institute of Management & Technology, Greater Noida, UP, 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, Punjab, India*
[6]*Mechanical Engineering Department, University Center for Research & Development, 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, Awasa, Ethiopia*

Correspondence should be addressed to Shubham Sharma; shubham543sharma@gmail.com and S. Rajkumar; rajkumar@hu.edu.et

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Nowadays, industries are emphasizing the implementation of a smart shop floor management method because of different types of problems faced in controlling the production activities in Industry 4.0. Several shop floor management methods are currently implemented in the present Industry 4.0 scenario, including lean manufacturing, logistics, Internet of things, smart manufacturing, cyber-physical system, and artificial intelligence. The present research work is focused on the development and Taguchi validation methodology of a data-driven decision-making system using L_9 orthogonal array for smart shop floor management based on the relationship between production sustainability and constraints. The proposed system has been validated by a comprehensive investigation of a case of mining machinery manufacturing unit. The result of the investigation revealed that productivity has been enhanced by effective controlling of production activities on the shop floor. Taguchi L_9 orthogonal array method of design of experiments is implemented to enhance flexibility for shop floor control and meanwhile minimize the production time due to inefficient operating conditions on the shop floor. Taguchi method was implemented for critical conditions affecting production lead time and resource utilization. The authors have detailed discussion on developing present novel hybrid integration of lean and smart manufacturing approaches to enhance operational excellence in production activities and other complicated manufacturing environment on the shop floor within available resources. The present finding demonstrates that the adopted digital technologies under smart manufacturing with lean manufacturing are found to be cost-effective approach under different environmental conditions. The proposed system has significantly improved the efficiency of production management and operational performance by using smart systems and has proved effective in improving the financial position by making a safer shop floor management approach. In this article, a robust problem-solving system is provided. The present work aims to introduce revolutionary methods for Industry 4.0 that would result in productivity enhancement and beneficial impact on industry persons by improving the smart shop floor management. The study also provides valuable perspective and sustainable guidelines to facilitate industry individuals to implement lean and smart manufacturing for productivity enhancement in the production environment of Industry 4.0.

1. Introduction

Nowadays, the primary demand of Industry 4.0 is to control production within available resources. For this, advanced shop floor management methods are used to control the production in the present scenario [1]. The main objective of shop floor management is to maximize productivity within limited constraints [2, 3]. In Industry 4.0, smart manufacturing, logistics, Internet of things, lean manufacturing, cyber-physical system, and artificial intelligence are used for operation management on the shop floor [4]. These methods are based on different principles, but they have the same objective—how to optimize the production processes efficiently. These methods are used to control the operational excellence of production processes in different working conditions. Figures 1(a) and 1(b) describe methods and objectives of advanced shop floor management in Industry 4.0.

The shop floor management concept was originated from Toyota Production System after the crisis in production management in terms of higher production time, higher cost, poor quality, insecure environment, and higher resource utilization [5]. The concept is used to eliminate sources of non-value-added activity (waste) and to plan an efficient work plan for productivity enhancement [6, 7]. With the passage of time, the production system changes and the need for advanced methods started increasing. To accomplish this, traditional methods are changed and modified. The developed methods are implemented to enhance production in Industry 4.0 [8]. The main aim of developed methods is to eliminate waste found in different production conditions on the shop floor [9]. In previous research, several strategies were used to identify waste found in production conditions and to investigate the real shop floor condition and constraints of the relevant production management system. Figure 2 illustrates the strategies implemented in previous research works to identify wastes.

Previous research shows that production performance depends on several factors like production planning, activities, intelligent system availability, working environment, automation adaptability, sensors, and availability of resources [10]. However, the improvements in productivity from the discussed methodology were poorer than the improvements achieved from a systematic strategy using the advanced shop floor management concept. The advanced shop floor management approach is introduced as a production reformer, and it helps to increase productivity within limited constraints [11]. Constraints are the limits of the management system, and they are found in mainly three forms in industries. Figure 3 describes the constraints faced in the production management system on the shop floor in Industry 4.0.

The shop floor management approaches are used to eliminate waste found in production processes in the industry [12]. Previous researchers have been used in various methods to enhance operational performance in production processes by eliminating waste. Table 1 shows what has been done so far in the past in terms of the methodology used in previous research works.

Researchers have been appreciated smart manufacturing, lean manufacturing, and the Internet of things to production enhancement in Industry 4.0. Other shop floor management methods like Kaizen and lean six sigma have been used by some researchers. Because these methods can be applied only in specific production situations with many limitations. These methods use traditional strategies which are not beneficial in Industry 4.0. To increase the effectiveness of all these methods, they were integrated with advanced shop floor management methods and called the hybrid approach. The hybrid approach has been implemented in previous research, which mainly includes lean smart manufacturing, lean Kaizen, and smart Kaizen. The authors of the present research are studying the methodologies developed in previous research works to clarify the message. The research gap and conclusion identified by previous research work are as follows:

(i) All the studies that have developed the system for shop floor management applications in the production environment concluded that improving the work plan can reduce production parameters but concluded that this is not a generalized strategy that can apply in all types of the Industry 4.0 production environment.

(ii) There is no clarity in previous research on how to enhance production in Industry 4.0 by identification of waste. Therefore, the shortcomings of the previous studies reported in the literature were mainly the lack of control systems implemented for smart shop floor mapping in factories.

However, only a few studies in the open literature studied the methodology development to control shop floor management for enhancement in productivity in Industry 4.0. Nevertheless, several methodologies have been developed to improve the production process using shop floor management methods. This study analyses advanced shop floor management methods implementation in Industry 4.0 by a developed methodology. The following questions are raised as part of the research work objective:

(i) How to demonstrate the problem-solving key of shop floor management in Industry 4.0 through an efficient method using a methodology for reducing nonproductive activities (waste) influencing productivity level.

(ii) How to identify wastes in the production environment by applying the proposed methodology. Here, the production environment refers to higher productivity levels within limited constraints.

The present research work is focused on the development of a novel methodology using lean and smart manufacturing for control of uncertain production management system based on the relationship between shop floor management and resource availability.

2. Research Methodology

The development of a methodology is a systematic strategy to implement shop floor management methods that the regulation of production can be possible. In previous studies,

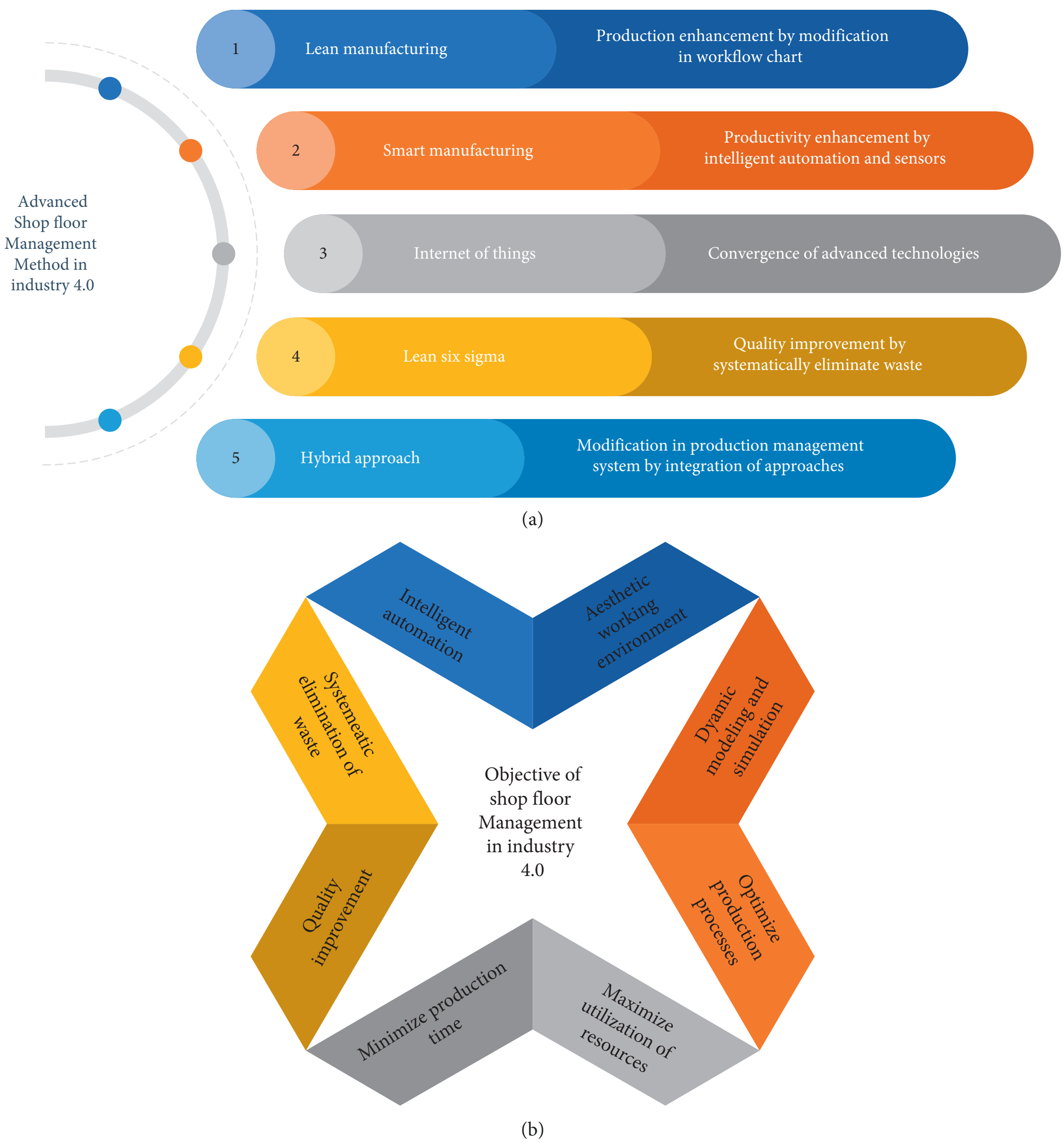


Figure 1: (a) Illustration of shop floor management methods in industry 4.0. (b) Illustration of objective of advanced shop floor management in industry 4.0.

researchers developed a system to improve the effectiveness of shop floor management methods for enhancement in productivity. In the proposed methodology, emphasis was laid on improving the control of resource utilization according to the shop floor management system in Industry 4.0. The following features distinguish the proposed methodology and prove essential for implementing the shop floor management method:

(i) The proposed system helps in identifying the reason for waste and source of waste and investigates the impact of the shop floor management method on the production environment in Industry 4.0.

(ii) The proposed data-driven decision-making system provides a systemic illustration of the shop floor, and it helps the management system to control production process and activities in smart factory.

(iii) The developed system enhances production within limited constraints, through advanced shop floor management methods including smart manufacturing, Internet of things, and cyber-physical system.

(iv) The proposed system can be implemented in Industry 4.0 and obtain industrial sustainability using smart sensor-based system.

The data-driven decision-making system has been developed to improve and regulate the production processes within limited constraints. Figure 4 describes the proposed system for shop floor management in Industry 4.0.

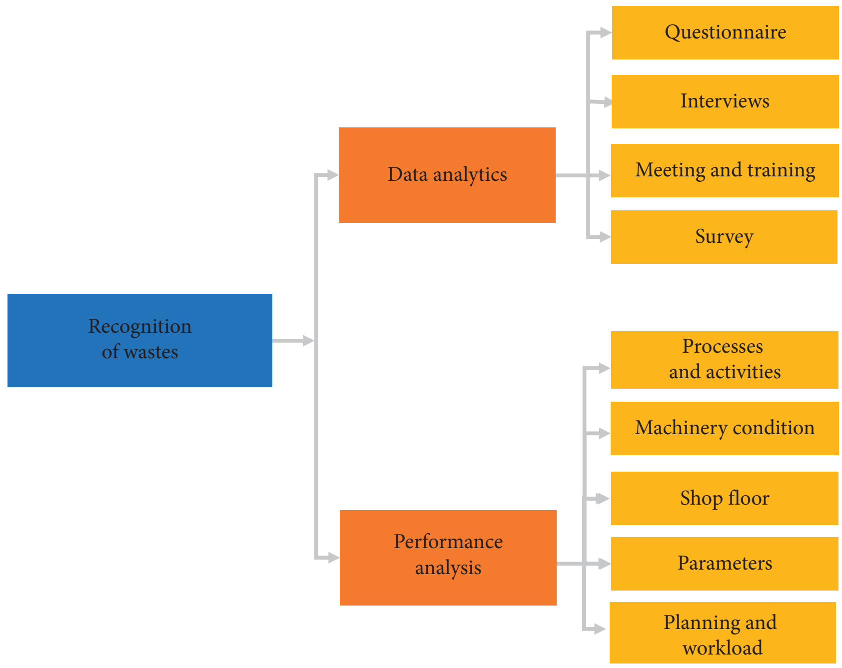


FIGURE 2: Strategies implemented in previous works in recognition of wastes.

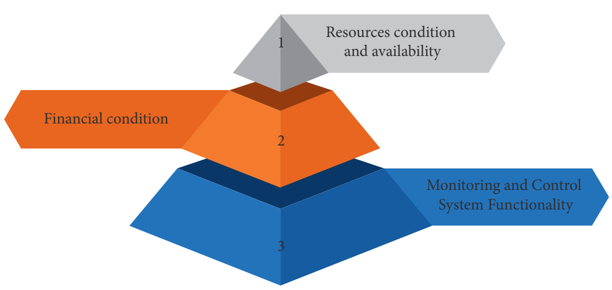


FIGURE 3: Constraints faced in operation management on the shop floor in industry 4.0.

3. Developed Data-Driven Decision-Making System for Shop Floor Management

The main objective of the data-driven decision-making system is to control uncertain production activities within limited constraints, and it has been possible by the elimination of waste found in production processes on the shop floor. The developed system is an effort to improve the manageability of the shop floor management system to enhance productivity within limited constraints in Industry 4.0.

3.1. Product Information. This case example deals with the improvement in production on a semiautomated assembly line in a leading earthmoving machinery manufacturing unit. This assembly line was dedicated to producing a skid-steer loader. Skid-steer loader is earthmoving machinery and is based on cutting-edge technology. The skid-steer loader is a marvel in the mining machinery industry, complete with maneuverability, compactness, and versatility. The present industry is unable to meet the needs of the customers within the available constraints and is facing continuous customer complaints regarding the quality of the product. This results in dissatisfaction in customers and looking to go to other manufacturers who can provide better mining equipment within the specified time. The actual information of production condition has been collected by Gemba Walk, discussion with workers in meeting, previous records, and direct observation. Table 2 describes previous production records of the shop floor management system.

3.2. Analysis of Shop Floor Management. Lean and smart manufacturing was adopted to investigate the efficiency of the present production management system. A sample case of the earthmoving equipment assembly unit was selected as an example. The production shop floor data have been summarized by an analysis of production factors. A flow chart was developed to understand the actual activities performed on the shop floor. Figure 5 shows production processes performed on the shop floor. The waste related to the production process was identified from the activities being carried out at workstations and by analyzing the production parameters derived from them; the actual state of production was evaluated as was in the proposed methodology. Table 3 describes resources available at the workstation of the present case and it has been analyzed by observation and discussion with workers.

The problems faced by the management system in the present case have been identified by the analysis of resources and actual performance of production processes on the shop floor. To do this, production condition is evaluated by calculating the production parameters and identifying the problems faced on workstations. The production parameters such as lead time (LT), idle time (IT), available time (AT),

Table 1: Description of previous research works according to implemented work methodology.

References	Medium of observation	Analysis of factors	Method	Result
Ramani and Lingan [13]	Survey	Production activities, workload, work plan	Value stream mapping (VSM)	Productivity improvement
Shou et al. [14]	Questionnaire, interview	Production activities, production parameters	VSM	Reduction in production time
Saqlain et al. [15]	Work plan	Production processes, work plan	Internet of things	Productivity enhancement and prognosis of production line
Gijo et al. [16]	Survey	Machinery condition	Lean six sigma	Reduction of cost and defects
Mittal et al. [17]	Survey, interview	Production process, production parameters, work plan	Smart manufacturing	Smart manufacturing able to improve production management system
Stadnicka and Litwin, [18]	Survey	Production process, production parameters, work plan	VSM	Reduction in production time
Asif and Singh [19]	Production activities, work plan	Production processes, work plan	Internet of things	Cost reduction
Cannas et al. [20]	Survey	The production process, machinery condition	Lean manufacturing, Kaizen	Improvement in production time and work performance
Das et al. [21]	Survey	The production process, work plan, production parameter	VSM, Kaizen, single minute exchange of die	Reduction in production time, work-in-process inventory, congestion on the shop floor, and improvement in workplace safety
Chien and Chen [22]	Production activities	Production processes, work plan, machinery	Smart manufacturing	Improved machinery effectiveness, reduced production time
Gaspar et al. [23]	Survey	Production processes, work plan	Internet of things	Proved superior decision-making method
Kumar et al. [24]	Survey, meeting	Production activities, production parameter, work plan, machinery availability	Lean manufacturing, Kaizen	Reduction in production time, manpower, and machinery setting time
Méndez and Rodriguez [25]	Interview, meeting	Production activities, machinery condition, work plan, production parameter	Total productive maintenance	Improvement in productivity and quality
Thomas et al. [26]	Survey, meeting	Production processes, production parameter, work plan	Lean six sigma	Reduction in production time and cost.
Lu and Yang [27]	Survey	The production process, work plan, production parameters, workload	Lean manufacturing, Kaizen	Reduction in production time and improvement in resource utilization
Torres et al. [28]	Survey	Production process, work plan	Smart manufacturing	Smart manufacturing proved an efficient method for shop floor management
Tyagi et al. [29]	Survey, interview, meeting	Production process, work plan, production parameter	VSM	Reduction in production time
Andrade et al. [30]	Survey	Production process, production parameter, workload	VSM	Reduction in production time and improved utilization of work position.
Frankó et al. [31]	Work plan	Production processes on the shop floor	Internet of things	Enhanced efficiency of logistic task
Seth and Gupta [32]	Survey	Production process, work plan, production parameter, workload	VSM	Improvement in production and reduction in work-in-process inventory
Liao et al. [33]	Production processes, work plan	Production activities, machinery condition, work plan,	Internet of things	Reduction in cost and improvement in customer satisfaction in terms of product
Vinodh et al. [34]	Survey, questionnaire	Production process, work plan, production parameter, machinery availability	VSM	Reduction in production time and defects
Beliatis et al. [35]	Work plan, interview	Traceability of the product	Industrial Internet of things	Reduction in bottleneck and lead time
Horak et al. [36]	Work plan	Vulnerability of the production line	Industrial Internet of things	Cyber-attack responsible of malfunction of Internet of things devices and failure of production line

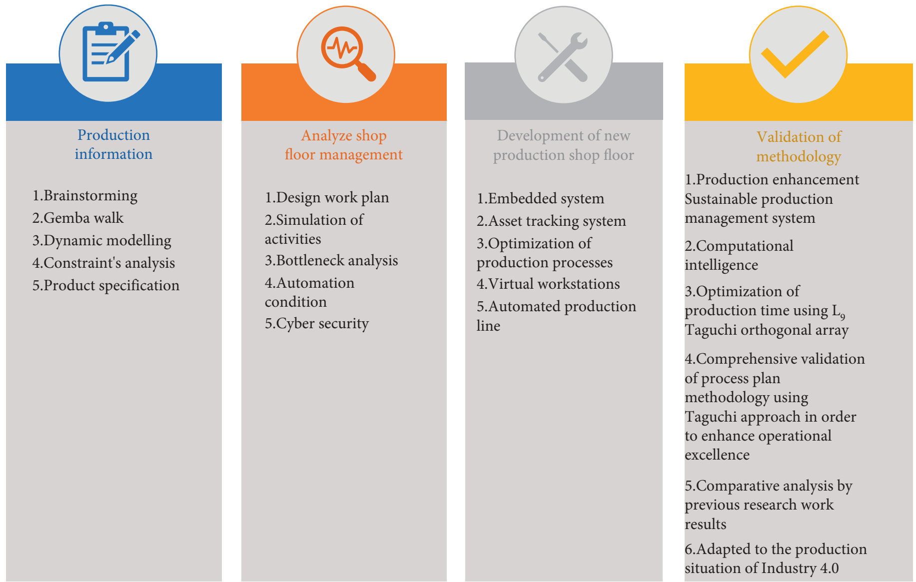


Figure 4: Proposed data-driven system for shop floor management in industry 4.0.

Table 2: Observed production condition on the shop floor.

Production condition	Quantity
Working time	570 minutes
Break time	50 minutes
Available time	520 minutes
Production time	Job shop production
Number of shops	10
Number of product/days	6
Number of processes	18
Number of employees	52
Number of workers	44
Number of shifts	1
Shop floor area	34.5 meter × 76 meter
Material handling equipment	Hoist, forklift
Customer requirement	Time, service, quality, cost
Constraints	Manpower, shop floor area, material handling tool, present shop floor working environment, machinery, budget
Production problems	Higher distance between workstations, breakdown of material handling equipment, lack of production planning, congestion on the shop floor, improper clamping
Process for higher production time	Outsourcing services like painting

uptime (UT), cycle time (CT), change over time (CO), value-added time (VAT), and non-value-added time (NVAT) of production processes have been calculated and shown in Table 4. The problems faced on present production shop floor management system have been described in Table 5.

3.3. Development of New Production Shop Floor. Planning and execution of new production shop floor include four steps according to the working environment: elimination of non-value-added activities, optimization of production processes, proposal of action plan for the elimination of waste, and illustration of production planning a flow chart. The steps refer to improvement in overall production processes on the shop floor. This type of step involves all the optimization of production processes, identification of non-value-added activities, resources, and work plan. The proposed data-driven decision-making system aims to provide a guideline to industry persons for improving production on the shop floor using lean and smart manufacturing. The steps involved in the proposed methodology are shown in Figure 6.

The next step is to develop a workflow chart by optimization of production processes by a suitable method, and the new workflow chart will help the production manager clearly understand the production processes and propose an action plan for the elimination of waste. With all the details of production shop floor management, a workflow sheet has been prepared and presented in Figure 7.

Table 6 shows the proposal of the action plan prepared for smart production shop floor management in all activities.

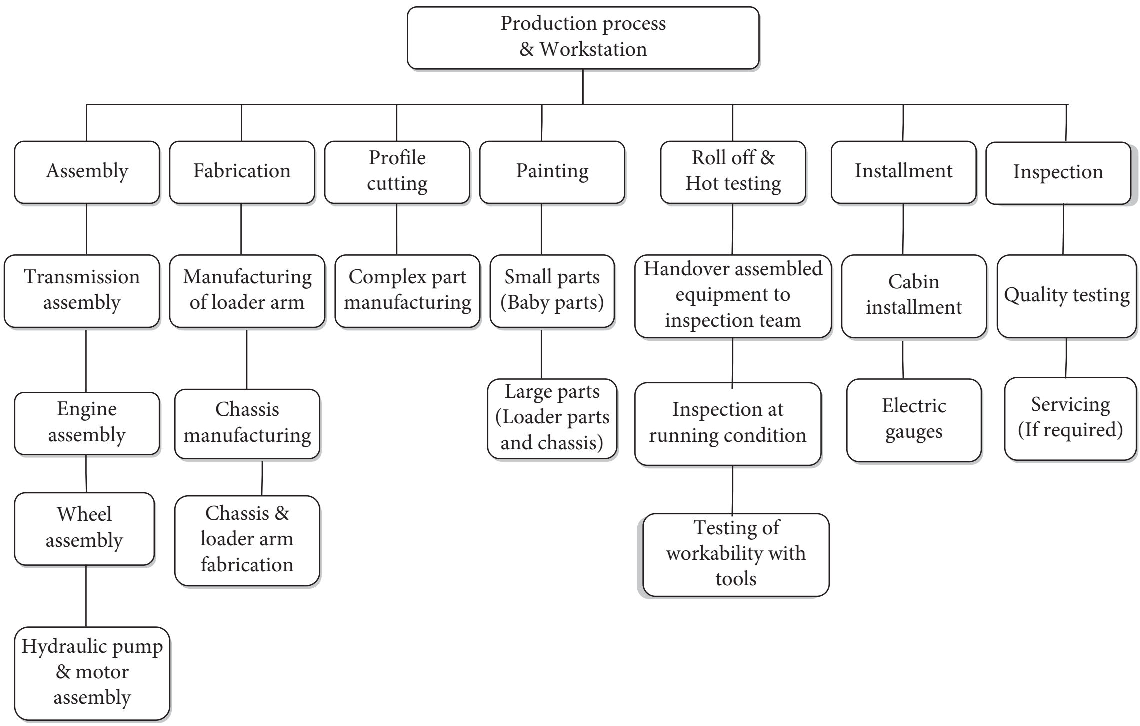


Figure 5: Observed production plan on shop floor.

Table 3: Resource availability on the present production shop floor.

Workstation	Shop floor management method	Resources				
		Manpower	Shop floor area (square meter)	Machinery condition	Machinery position	Material handling equipment
Transmission assembly	Lean manufacturing	4	72.5	Ok	Unplanned	Manual
Engine assembly	Lean six sigma	2	18.7	Poor	Planned	Manual
Wheel assembly	Smart manufacturing	2	16.36	Ok	Planned	Manual
Hydraulic pump assembly	Lean manufacturing	2	12.53	Ok	Unplanned	Manual
Hydraulic motor assembly	Lean manufacturing	2	12.53	Ok	Unplanned	Manual
Manufacturing of loader arm	Lean manufacturing	3	71.23	Ok	Planned	Hoist
Chassis manufacturing	Lean manufacturing	5	45.99	Poor	Unplanned	Manual
Chassis and loader arm fabrication	Lean six sigma	3	56.125	Insufficient	Unplanned	Forklift
Complex part manufacturing	Smart manufacturing	1	113.94	Ok	Planned	Hoist
Painting (baby part)	Lean manufacturing	2	89.02	Ok	Planned	Hoist
Painting (loader and chassis)	Lean six sigma	Outsourcing	72.5	Not available	Not available	Forklift
Handover of equipment to the inspection team	Lean manufacturing	2	72.5	Not required	Not required	Manual
Inspection at running condition	Lean manufacturing	4	837.47	Not required	Not required	Not required
Testing of tools workability on field	Lean manufacturing	4	72.5	Ok	Planned	Manual
Cabin installment	Smart manufacturing	2	110.800	Malfunctioning	Planned	Hoist
Electric gauge assembly	Lean manufacturing	2	89.04	Ok	Planned	Manual
Quality inspection	Lean six sigma	2	135.66	Ok	Unplanned	Not required
Servicing	Lean manufacturing	2	Not required	Ok	Unplanned	Manual

Table 4: Analysis of present production processes on the shop floor.

S.No.	Process	AT (minute)	UT (%)	No. of operators	CO (minute)	CT (minute)	NVAT (minute)	IT (minutes)
1	Transmission assembly	520	82.69	8	90	360	105	15
2	Manufacturing of loader arm	520	87.50	3	65	245	95	30
3	Chassis manufacturing	520	85.58	4	75	265	140	65
4	Wheel assembly	520	97.12	3	15	150	25	10
5	Chassis and loader arm fabrication	520	79.81	3	105	300	150	45
6	Inspection of fabrication	520	97.12	3	15	60	45	30
7	Painting (baby parts)	520	95.19	2	25	315	55	30
8	Painting (large parts)	520	90.38	1	50	300	1490	1440
9	Engine assembly	520	93.27	2	35	190	50	15
10	Hydraulic pump and motor assembly	520	95.19	2	25	120	45	20
11	Roll off and hot testing	520	89.42	6	55	2370	165	110
12	Cabin installment	520	96.15	2	20	185	60	40
13	Electric gauges assembly	520	95.19	3	25	195	70	45
14	Final inspection	520	98.08	2	10	160	35	25

Table 5: The problems faced by the management system in production processes.

S.No.	Name of shop	Problems	Source of problem
1.	Transmission	1. Long-distance between workstations 2. Unplanned location of machinery 3. Lack of material handling equipment 4. Lack of safety on the shop floor 5. Improper workload	(i) Lack of workload allotment (ii) Ergonomics issues (iii) Absence of condition monitoring system (iv) Lack of production planning
2.	Fabrication	1. Workplaces are not decided 2. More workstations 3. Lack of fabrication plan 4. Lack of fabrication equipment	(i) Inefficient production workflow (ii) Lack of layout
3.	Profile cutting	1. Mostly shutdown. 2. Higher setup time 3. Rarely required 4. Lack of skilled workers	(i) Absence of smart control system (ii) Lack of awareness
4.	Engine assembly	1. A longer distance between workstations 2. Higher material handling time 3. Lack of workers 4. Poor arrangement for material handling	(i) Safety issues (ii) Manual power control system (iii) Lack of work allotment plan
5.	Painting	1. Painting of larger parts has been done in another plant 2. Required extra worker for inspection of larger part painting 3. Fewer number of workers in the painting shop 4. Ergonomics issues	(i) Outsourcing of services (ii) Logistics issues (iii) Traditional safety equipment (iv) Congestion at the workstation
6.	Hot testing	1. No timeline set for the workstation 2. Due to the lack of shop floor area at the next workstation, the movement time of the product is not determined	(i) Lack of work plan (ii) Parking in open space due to shortage of area on the shop floor
7.	Cabin installment	Lack of worker's experience Malfunctioning in machinery	(i) Lack of training and meetings (ii) Manual control system
8.	Electric gauge assembly	1. Lower worker skills 2. Higher workload	(i) Worker's involvement in more than one shop (ii) Lack of workload plan
9.	Quality inspection	1. Non-detection of faults 2. Unnecessary change of workers	(i) Manual inspection (ii) Lack of workload plan

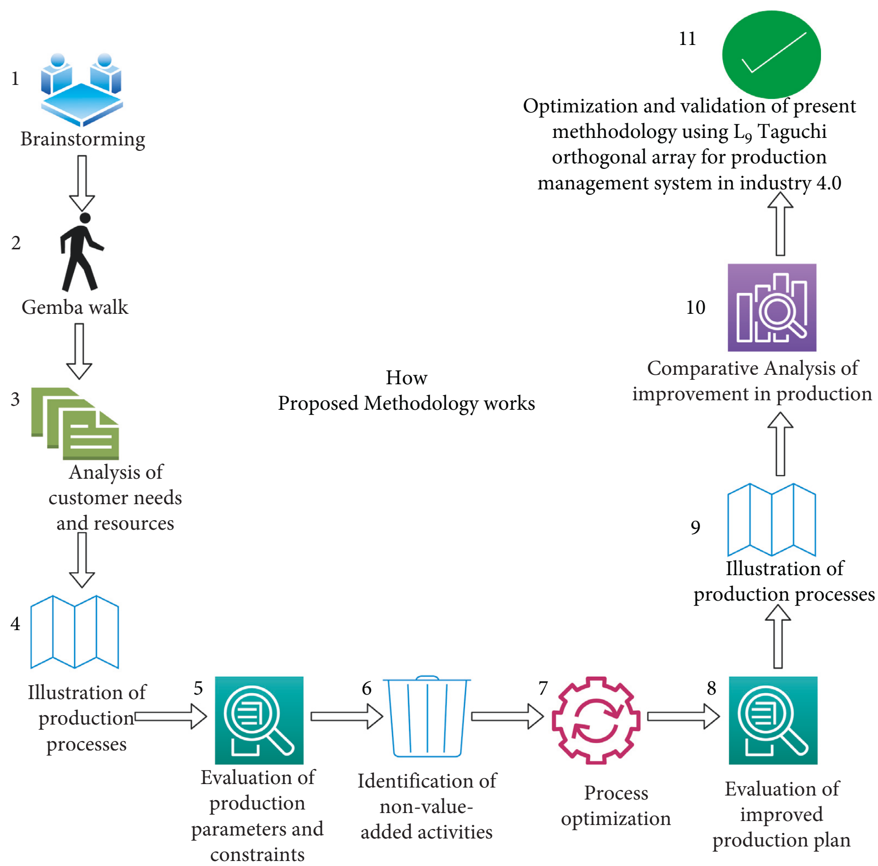


Figure 6: Modified production plan.

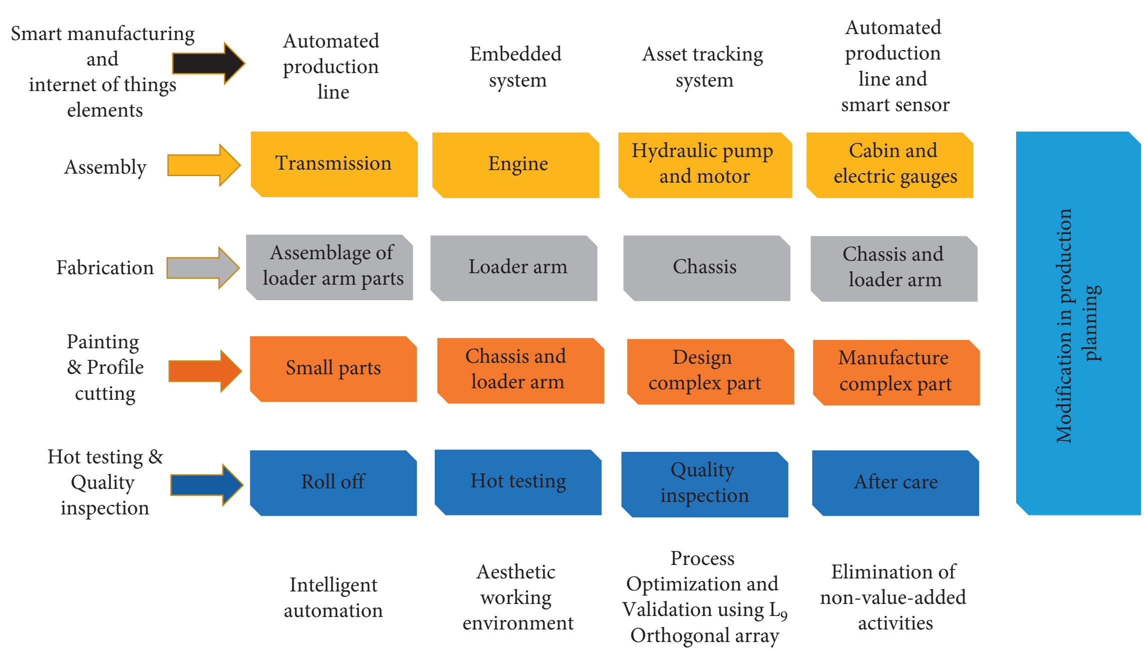


Figure 7: Modified new production management system.

Table 6: Proposed action for production planning.

S. No.	Name of shop	Proposed action	Non-value-added activity	Suggested smart production management system	Process optimization
1.	Transmission	(i) Reduced distance between workstations (ii) Machinery placed at the planned location (iii) Provide material handling equipment (iv) Followed up safety norms on the shop floor (v) The workload has been decided according to the skill of the workers	Transportation, inventory, motion, non-utilized talent	Automated production line	Yes
2.	Fabrication	(i) Decided workload according to the skill of the workers (ii) Reduced number of workstations (iii) Developed fabrication planning (iv) Arranged fabrication equipment in a systematic manner	Non-utilized talent, motion, waiting, defect	Embedded system	Yes
3.	Profile cutting	(i) Organized training for operators (ii) Eliminate unnecessary activities	Non-utilized talent, motion	Embedded system	NA
4.	Engine assembly	(i) Improvement in layout (ii) Reduced distance between workstations (iii) Increased number of workers (iv) Arranged material handling equipment in a proper manner	Transportation, inventory, motion, non-utilized talent, excess processing	Automated production line	Yes
5.	Painting	(i) Increased number of workers (ii) Provided safety equipment for workers (iii) Both the processes were started simultaneously	Motion, waiting, overproduction	Embedded system	Yes
6.	Hot testing	(i) Decided timeline on the workstation (ii) Increased shop floor area in layout	Motion	Embedded system, asset tracking system	Yes
7.	Cabin installment	(i) Organized meetings and training	Excess processing, motion	Automated production line, embedded system	Yes
8.	Electric gauge assembly	(i) Replaced operator by skilled operator (ii) Decided workload distribution	Excess processing, non-utilized talent, inventory	Embedded system	Yes
9.	Quality inspection	(i) Improve production planning (ii) Eliminate unnecessary activities	Motion, excess processing	Automated production line	Yes

After the review of the production management system, it has been decided that which workstation and production process needed to improve. The review process was done by production workflow analysis session and evaluation of production parameters. The calculation of each parameter used in production shop floor management has been discussed in Table 7.

4. Results and Discussion

4.1. Development of the Current System in Order to Enhance the Operational Performance by Using Hybrid Integrated Lean and Smart Manufacturing Methodology. In line with the research, the objective raised the result demonstrated non-value-added activities and production time reduction and

Table 7: Improvement in production parameter in product.

S. No.	Process	AT (minute)	UT{UT = (AT – CO)/ AT)} (%)	Number of workers	CO (minute)	CT (minute)	NVAT (minutes)	Idle time (minutes)
1	Transmission assembly	520	85.58	7	75	340	85	10
2	Manufacturing of loader arm	520	88.46	4	60	245	80	20
3	Chassis manufacturing	520	86.54	5	70	250	130	60
4	Wheel assembly	520	98.08	3	10	135	20	10
5	Chassis and loader arm fabrication	520	79.81	5	105	320	160	45
6	Painting	520	90.38	2	50	240	1470	1420
7	Engine assembly	520	93.27	3	35	180	50	15
8	Hydraulic pump and motor assembly	520	96.15	3	20	120	40	20
9	Roll off and hot testing	520	91.35	7	45	2310	135	90
10	Cabin installment and electric gauge assembly	520	94.23	3	30	330	75	45
11	Final inspection	520	98.08	2	10	150	30	20

provided benefits in production improvement within limited constraints through the proposed methodology using the shop floor management method for the mining machinery assembly unit in Industry 4.0. In this production management application study, production time reduction was successfully achieved by reducing the waste by facing the challenges of complex environments of the production shop floor. Authors used a new methodology on production shop floor conditions, logically followed only production workflow which does not get into the concept of production management methods, like production parameters, production factors within limited contraints which have been promoted by the previous researchers. The study reports overall production time reduction within available constraints on the production shop floor. To know actual improvement achieved by proposed methodology implementation, an analysis has done between previous condition and improved condition of the production shop floor. The analysis of production enhancement has been shown in Table 8.

The similar results have been found out by Dehghani et al. [37], who proposed a new game-based optimization algorithm named dart game optimizer. The quality and ability of the performance of dart game optimizer was checked by twenty-three objective functions and was compared with other eight optimization algorithms, including particle swarm optimization, genetic algorithm, gravitational search algorithm, grey wolf optimizer, teaching learning-based algorithm, grasshopper optimization algorithm, marine predators algorithm, and whale optimization algorithm. The result of the study showed that the developed algorithm was efficient and able to exploit and explore in solving different optimization problems. Dehghani et al. [38] developed a new optimizer named multileader optimizer to solve optimization problems. The designed optimizer was used to conduct the algorithm toward a quasi-optimal solution by using information from population members. The result of the study showed that the developed algorithm was superior in solving optimization problems. Dehghani et al. [39] developed a binary model of orientation search algorithm named binary orientation search algorithm. The twenty-three benchmark test functions tested the developed model. The result of the study showed that the developed model was able to solve optimization problems efficiently.

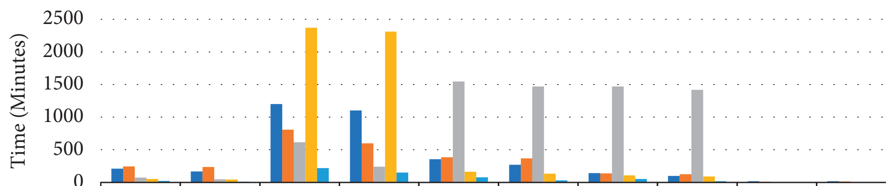
Dehghani et al. [40] developed a spring search algorithm to solve single-objective constraints optimization problems. The functionality of the developed algorithm was evaluated by thirty-eight established test mark functions and compared with other eight optimization algorithms, including a teaching learning-based algorithm, genetic algorithm, gravitational search algorithm, grasshopper optimization algorithm, particle swarm optimization, a spotted hyena optimizer, a grey wolf optimizer, and emperor penguin optimizer. The result of the study showed that the developed algorithm has superior exploitation and exploration capabilities compared to other algorithms.

The proposed methodology has been efficiently implemented in the present case example of Industry 4.0, in which systematic work planning has been helpful for the reduction in congestion on the shop floor and results in productivity enhancement. Productivity improvement on the shop floor in terms of production parameters has been shown in Figure 8.

The similar results have been reported by Dhiman and Kumar [41], who developed a metaheuristic algorithm called spotted hyena optimizer. The developed algorithm was implemented to one unconstrained engineering design problem and five real-life constraints and compared with eight algorithms on twenty-nine benchmark test functions. The result of the study demonstrated that the developed algorithm was better than other metaheuristic algorithms. Dhiman and Kaur [42] developed a bio-inspired algorithm named sooty tern optimization algorithm for constrained industrial problems. The developed algorithm was implemented to solve six constrained industrial applications and compared with nine algorithms over forty-four benchmark functions. The result of the study revealed that the developed model was able to solve constrained problems and was efficient in comparison to other algorithms. Kaur et al. [43] proposed a bio-inspired algorithm named tunicate swarm algorithm. The performance of the tunicate swarm algorithm

Table 8: Analysis of improvement in terms of production parameter and utilization of resource.

Name of shop	Production parameters					Utilization of resource		
	CT (minutes)	CO (minutes)	IT (minutes)	NVAT (minutes)	UT (%)	No. of worker	Machinery	Shop floor area (square meter)
Assembly	45	25	5	30	3.97	2	Yes	224.9
Fabrication	305	95	105	190	12.56	2	Yes	0
Painting	375	25	50	20	4.35	0	NA	89.1
Roll off and hot testing	60	10	20	30	1.76	1	NA	837.5
Installment	50	15	40	55	2.71	2	Yes	110.8
Inspection	10	0	5	5	0	3	Yes	0



	CO (P1)	CO (P2)	CT (P1)	CT (P2)	NVAT (P1)	NVAT (P2)	IT (P1)	IT (P2)	Worker (P1)	Worker (P2)
Assembly	210	170	1200	1105	355	270	145	100	20	19
Fabrication	245	235	810	600	385	370	140	125	10	14
Painting	75	50	615	240	1545	1470	1470	1420	3	2
Hot testing	55	45	2370	2310	165	135	110	90	6	7
Quality inspection	25	10	220	150	80	30	55	20	5	2

Production shop and parameter

Assembly
Fabrication
Painting
Hot testing
Quality inspection

Figure 8: Analysis on parameter between present and proposed shop floor (P1-observed shop floor condition, P2-modified shop floor condition).

was evaluated on seventy-four benchmark test problems by ANOVA test. The result of the study revealed that the developed algorithm was able to provide a better optimal solution compared to other algorithms. Dhiman and Kumar [44] developed an optimization algorithm called emperor penguin optimizer. The performance of the developed algorithm was evaluated on forty-four benchmark test functions by implementing seven nonlinear and mixed-integer structural problems. The result of the study demonstrated that the developed algorithm was able to provide better results than other metaheuristic problems. Dhiman and Kumar [45] proposed a bio-inspired algorithm named seagull optimization algorithm. The performance of seagull optimization algorithm was compared with forty-four benchmark functions. The result of the study revealed that the developed algorithm was able to solve large-scale constrained problems and was efficient in comparison to other optimization algorithms.

Due to the problems encountered in production shop floor management, the present case study shows the elimination of waste and the improvement in productivity levels that have been possible through the proposed system. To substantiate this statement, a comparative analysis was performed on the present research work with previous research works. It was found from the analysis that the proposed methodology is superior in the elimination of each production problem and non-value-added activities in Industry 4.0. The comparative analysis on some important production conditions between previous researches and the present study has been shown in Table 9.

The related work has been revealed by Dhiman et al. [46], who developed a metaheuristic algorithm named emperor penguin optimizer. Twenty-five benchmark functions validated the output of the developed algorithm. Furthermore, the result of the study demonstrated that the developed algorithm was superior in comparison to other algorithms. Dhiman [47] developed a bio-inspired metaheuristic optimization approach named emperor penguin and salp swarm algorithm. The efficiency of the developed algorithm was evaluated by convergence analysis, scalability analysis, ANOVA test, and sensitivity analysis. The result of the study revealed that the developed algorithm was superior and provided optimal solutions compared to other algorithms. Dhiman et al. [48] developed a bio-inspired optimization algorithm named rat swarm optimizer to solve optimization problems. In the study, the performance of the developed algorithm was validated by comparing it with eight optimization algorithms. The result of the experiment revealed

Table 9: Benefits of the proposed methodology in comparison of previous methodologies.

Industry condition	Previous methodologies			Proposed methodology	
	Authors	Changes	Status	Changes	Status
Production capacity	[25]	10.7%	Improved	66.67%	Improved
Production cost	[5]	40%	Improved	46%	Improved
Production lead time	[34]	1.07%	Improved	11.10%	Improved
Manpower requirement	[36]	26.08%	Improved	34.09%	Improved
Utilization of machinery	[25]	8.9%	Improved	16.67%	Improved
Shop floor utilization	[21]	NA	Improved	33.55%	Improved
Reduction of defects	[16]	85.26%	Improved	88.89%	Improved
Setup time reduction	[24]	65.85%	Improved	72.37%	Improved
Working environment	[21]	NA	Improved	Safety, working time, workload	Improved

that the developed algorithm was efficient in solving real-world optimization problems. Vaishnav et al. [49] performed a logical analysis on total death, total cases, and total recovery reported in the pandemic of COVID-19. In the study, decision tree regression and random forest models were used to perform logical analysis. The result of the study revealed that the prediction accuracy of the random forest model and a regression model was 76% and 70%, respectively.

After a comparison of the proposed data-driven decision-making system with previous research works as suggested in the literature, it has been concluded that majorly three drawbacks were found in previous systems. The drawbacks included the inability to produce within limited resources, giant gaps in resource utilization, and poor working conditions on the production shop management. The present article proposed a data-driven decision-making system that pays attention to these drawbacks. The proposed methodology was proved superior by productivity enhancement obtained in results within limited constraints in Industry 4.0. The comparison between results obtained by the previous methodology and presented methodology as discussed in Table 8 revealed that the proposed system is able to provide superior results within limited constraints in Industry 4.0.

4.2. Implementation of L_9 Taguchi Orthogonal Array to Reduce Production Time. The management teams were curious to optimize production processes in the present industry for operational enhancement because they were facing several problems in production management, including higher cycle time, inefficient workers, higher downtime, and excess power consumption. In the present work, brainstorming sessions have been organized with team members and workers to recognize the exact reason for problems in the production processes on the shop floor. Brainstorming sessions have concluded that the main reasons for the problem were the excess movement of workers due to lack of workload distribution, breakdown of material handling equipment due to lack of planning, shop floor congestion, disarrangement of machinery, outsourcing, and lack of monitoring system. Therefore, three parameters, including cycle time, number of operators, and available time, influenced operational performance on the shop floor. In the study, Minitab is used to design experiment-based Taguchi method considering three parameters with three levels in which level 1 is lowest and 3 is highest (Table 10).

Analysis of variance is used to identify the relative significance of the individual production parameters as illustrated in Table 11. The table can conclude that the idle time, cycle time, and non-value-added time reduction have contributed efficiently.

ANOVA proved that number of operators is the most significant parameter effecting the production time and it contributes 74.78% to obtain minimum production time. Available time is also another significant parameter, and its contribution is 22.40%, while cycle time is insignificant. Table 12 shows the model summary.

The operational performance of production processes is analyzed by Taguchi's L_9 orthogonal array method and expressed in signal-to-noise ratio. This analysis is performed to obtain the precise operational setting for production time on the Industry 4.0 shop floor. Tables 13 and 14 illustrate the response table for the signal-to-noise ratio (smaller is better) and the means. Figures 9 and 10 show the analysis found on the signal-to-noise ratio.

Response table for S/N ratio and means signifies that no. of operators is the important factor that effects production time followed by available time and cycle time.

Main effects plot for production time reveals that available time of 520 minutes, cycle time of 5260 minutes, and number of operators of 44 yield minimum production time.

4.3. Validation of Methodology. The results of validation are compared with the estimated with the optimum production parameters. Minimum production time could be obtained at available time of 520 minutes, cycle time of 5260 minutes, and number of operators of 44 based upon the response plots as shown in Figures 5 and 6 of production time analysis. This indicate that the obtained optimal setting of controllable factors for available time, cycle time, and number of operators results in the lower production time. As a result, Taguchi validation method as great potential application in highly competitive mining machinery shop floor industry due to its reliability and predictive accuracy in managing the process operating factors and limited number of trial experimentation required, which saves time, effort, and

Table 10: Experimental data used for the analysis.

Available time (mins)	No. of operators	Cycle time (mins)	PT (mins)	SNRA3
490	43	5245	7820	−77.8641
490	44	5260	8510	−78.5986
490	45	5280	7544	−77.552
520	43	5260	8280	−78.3606
520	44	5280	8832	−78.9212
520	45	5245	8004	−78.0661
560	43	5280	7590	−77.6048
560	44	5245	8510	−78.5986
560	45	5260	7590	−77.6048

Table 11: Analysis of variance.

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*	Percentage contribution
Available time (mins)	2	0.46562	0.46562	0.232809	47.84	0.020	22.40%
No. of operators	2	1.55439	1.55439	0.777196	159.69	0.006	74.78%
Cycle time (mins)	2	0.04896	0.04896	0.024481	5.03	0.166	2.36%
Residual error	2	0.00973	0.00973	0.004867			0.47%
Total	8	2.07871					

Table 12: Model summary.

S	R-Sq	R-Sq (adj)
0.0698	99.53%	98.13%

Table 13: Response table for signal-to-noise ratios.

Level	Available time (mins)	No. of operators	Cycle time (mins)
1	−78.00	−77.94	−78.18
2	−78.45	−78.71	−78.19
3	−77.94	−77.74	−78.03
Delta	0.51	0.97	0.16
Rank	2	1	3

Table 14: Response table for means.

Level	Available time (mins)	No. of operators	Cycle time (mins)
1	7958	7897	8111
2	8372	8617	8127
3	7897	7713	7989
Delta	475	905	138
Rank	2	1	3

resources. As far as optimization and plan validation is concerned, the production time has been optimized by using L_9 Taguchi orthogonal array by considering available time, cycle time, and number of operators as input parameters. This novel process optimization methodology has been strongly recommended to detect, mitigate, and eliminate the production uncertainties and non-value-added activities within available resources in order to achieve vital progressive objectives of Industry 4.0.

A smart system should monitor some types of validations (constraints, resource conditions, workload distribution, workflow flexibility, shop floor capability, etc.). As discussed above, each type of validation is related to production efficiency or operational excellence on the shop floor [50]. Production efficiency means that the desired production process parameters can be improved by maximizing resources. At the same time, operational excellence demonstrates that eliminating waste can improve the desired production process parameter. The types of validations should be evaluated to investigate the production system's actual effectiveness and significant for the improvement in production efficiency and elimination of waste [51].

The developed system has been implemented to optimize production processes and identify waste. The proposed data-driven decision-making system uses the lean and smart manufacturing concept to execute production planning on the shop floor. Production evaluation shows that the production system has improved in terms of productivity level, floor layout, safety, production time, working environment and worker efficiency. The validation of the proposed methodology involves four levels of action according to the present industrial working environment: analysis of production enhancement in terms of production parameter and utilization of resources; comparison of improvement on the shop floor in terms of production conditions; comparative analysis between proposed system and previous system as suggested in previous research work; and validation of methodology by analysis of improvement achieved in production. These levels help validate the proposed methodology and can give the management system confidence that it can provide improvements in the production system with increased productivity in Industry 4.0. Figure 11 describes improvement obtained on the production shop floor in terms of production parameter within available resources, and it validates that the proposed methodology will be helpful for the production management system in Industry 4.0.

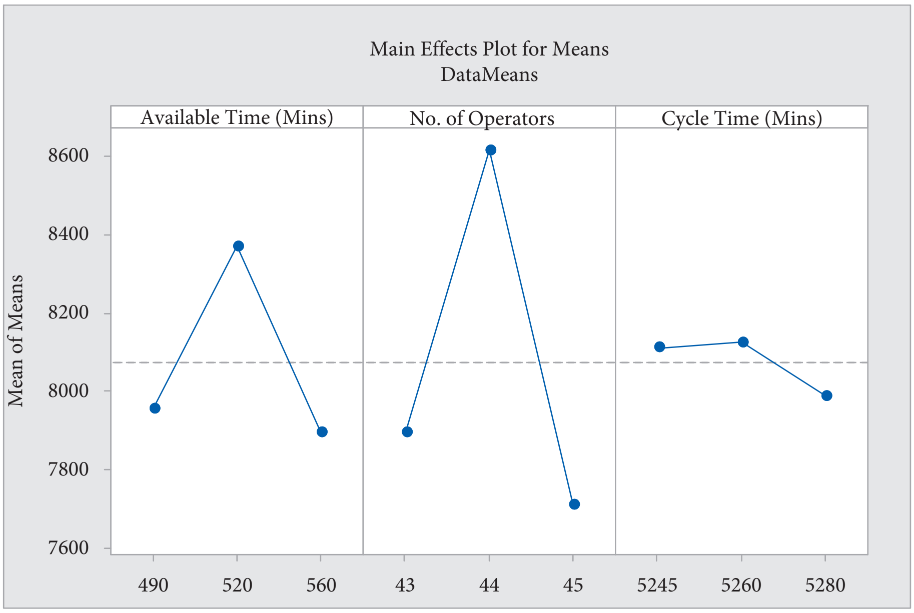


Figure 9: Main effect plot for production time.

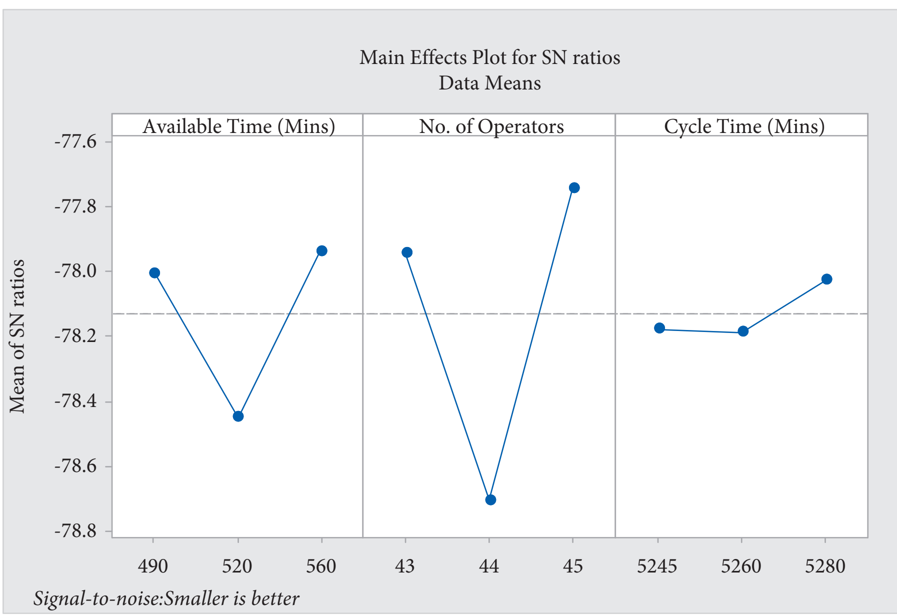


Figure 10: Signal-to-noise ratio for production time.

5. Notable Contributions of Lean and Smart Manufacturing Concept in Industry 4.0

The production management team members emphasize developing a decision-making system to enhance operational excellence in complex manufacturing environments, including Industry 4.0, using process optimization methods. Various process optimization methods that have been used in previous research work for shop floor management include smart manufacturing, artificial neural network, lean manufacturing, Internet of things, and cyber-physical system. In an extensive literature review, it has been found that the researchers and industry individuals preferred to implement lean manufacturing concept on the shop floor, but industrial revolutions and changes have led to a demand for new methods in shop floor management. The researchers focus on developing a hybrid method for operations management on the shop floor to accomplish this. The hybrid method uses the integration of two or more methods to enhance the adaptability of operational excellence in production processes on the shop floor. Lean and smart manufacturing concepts works as hybrid method and fulfil this need of the industry individuals to enhance productivity within limited constraints. Implementing lean manufacturing in the shop floor management, including Industry 4.0, can effectively improve operational excellence when

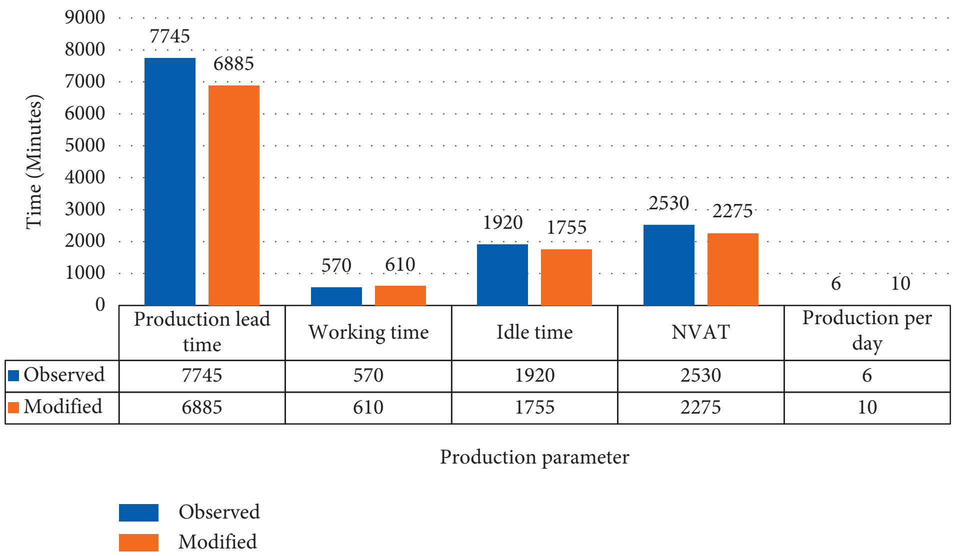


Figure 11: Improvement obtained in production parameters.

integrated with the smart manufacturing concept. Ghobakhloo and Ching [52] discussed the identification of determinants of smart manufacturing-related information and digital technologies. The data for analysis were collected from an electronic survey and questionnaire organized in Malaysian and Iranian small and medium enterprises. The results showed that smart manufacturing-related information and digital technologies were costly for most small and medium enterprises and significantly influenced by the imposition from the environment. Tripathi et al. [53] developed an agile system to improve operational performance using a methodology coupled with VSM. The developed method was validated by improving the operating performance of a production management system in Industry 4.0 environment. Furthermore, the result of the study revealed that the developed system was able to enhance operational excellence by eliminating waste within available resources in Industry 4.0.

Li [54] developed a conceptual model using lean, smart manufacturing and implemented it in the bicycle industry. The result of the study demonstrated that lean and smart manufacturing could enhance operational excellence of the management system by setting up a smart factory platform in Industry 4.0. Dey et al. [55] proposed smart chain management for imperfect production processes where demand rate was variable and demand depended on the advertisement. The study developed a mathematical model to identify imperfect items in production processes for making more innovative processes. The results revealed that the developed model could help managers reduce total costs and enhance system profit. Chiarini and Kumar [56] investigated on the integration of Industry 4.0 technologies and lean six sigma. The analysis has been done by direct observations and interviewing experts and managers of ten Italian manufacturing industries. The result demonstrated that lean six sigma could enhance outcomes effectively by using Industry 4.0 technologies. Amjad et al. [57] developed a framework for integration of green manufacturing, lean manufacturing, and Industry 4.0 in harmonious way. The framework was validated by implementing in an auto-parts manufacturing industry. The result of the study demonstrated that the developed framework was efficiently optimized and reduced the lead time, value-added time, greenhouses gas emission, and non-value-added time emission effectively by 25.60%, 24.68%, 55%, and 56.20%, respectively.

It has been observed that the hybrid methods attract the attention of researchers in operation management on the shop floor because of the enhancement of operational excellence within limited constraints [4, 12, 16, 24, 26, 47, 56, 58]. The present research work focuses to develop a data-driven decision-making system using lean and smart manufacturing for smart and safer shop floor management. The developed system has been validated by implementing it in an actual production condition for the shop floor management. The study revealed that the developed data-driven decision-making system enables the shop floor management teams to enhance productivity and industrial sustainability by eliminating waste within available resources in Industry 4.0. Figure 12 demonstrates the benefits of the developed data-driven decision-making system compared to previous research outcomes regarding standardized factors of the shop floor management system.

Lean and smart manufacturing is a prevalent approach for operation management on the shop floor and it is used to enhance operational performance by optimization of processes and elimination of waste. Lean and smart concept helps industry individual in improvement in operational control on the shop floor by understanding and analyzing actual production condition. The management teams use various standard parameters to evaluate the observed production system using lean and smart manufacturing. The parameters include available time, uptime, worker, changeover time, cycle time, idle time, and non-value-added time.

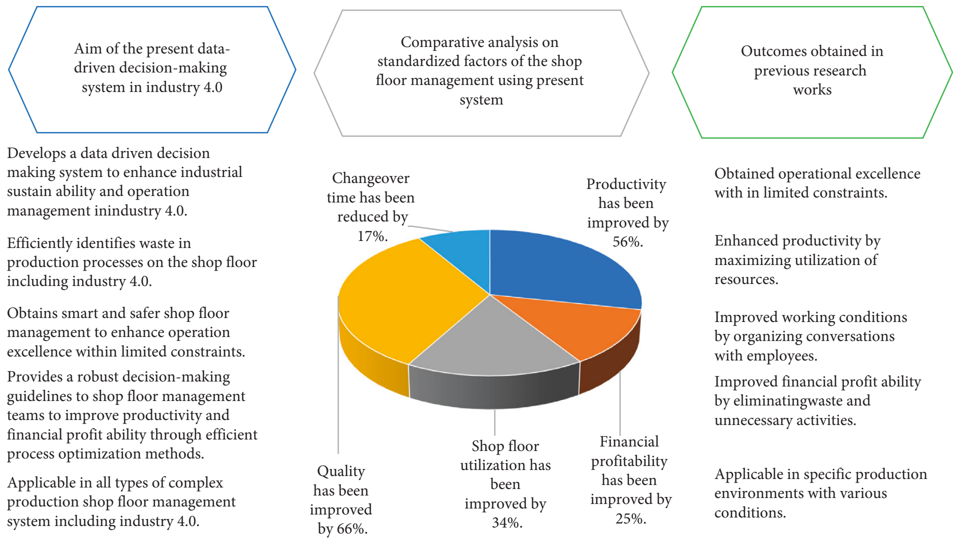


Figure 12: Description of benefits of the developed system in comparison with findings of previous research works.

In previous research works, it has been observed that available time has been calculated by finding the difference between total working hours and break time; uptime is measured as the difference between available time and changeover time and the ratio between their available time; the number of operators has been calculated by observing allotment of workers at each workstation; change over time has been computed by observing time taken for changing time between two processes including setup time; cycle time has been calculated by completion time of each process; the non-value-added time has been computed by the sum of changeover time and idle time; and idle time has been measured by observing the time in which no any activity performed. These parameters are used to investigate the actual performance of the shop floor management system. The researchers and management teams used all the parameters in previous research works to identify the primary source of the problem. The parameters help industry individuals to understand and control production processes by implementing a robust action plan.

Ramani and Lingan [13] improved the performance of the production management system by implementing value stream mapping in an industry of gas-insulated switchgear design. Value stream mapping is a lean-based method to enhance productivity by eliminating waste. The management team members drew an actual shop floor diagram using the value stream mapping principle to identify and eliminate sources of waste. Results showed a 30% improvement in productivity and a 30% reduction in man-hours. Sutharsan et al. [59] examined the application of the lean concept in the Monoblock pump industry using value stream mapping. Value stream mapping improved the workflow chart diagram of production processes by eliminating waste by calculating parameters including available time, lead time, value-added time, and cycle time. The study showed a reduction in lead time, cycle time, and defect rate by 1.4 days, 12.8 minutes, and 2%, respectively. Sahoo et al. [5] developed a systematic strategy to implement Taguchi's method's lean concept. The developed strategy was implemented in a forging industry for improvement in operational performance by the elimination of waste. The study's result revealed a significant reduction in non-value-added activities, shop floor area, and lead time by 72 minutes, 27%, and 325 minutes, respectively. Tripathi et al. [60] developed a model for shop floor management using an artificial neural network coupled with value stream mapping. The developed model was implemented in an earthmoving equipment machinery manufacturing unit. In the study, value stream mapping was used to enhance operational performance by eliminating waste. In addition, various parameters were analyzed, including available time, uptime, cycle time, uptime, non-value-added time, and the number of workers, to understand the present production shop floor condition. The developed model was machine learning-based and tested by proposed shop floor management. The result of the study revealed that the developed model was efficient for prediction purposes with mean absolute error and mean square error.

6. Conclusions

In the present research article, a methodology has been developed for robust regulation of shop floor management in uncertain production conditions in Industry 4.0. It has been observed that lean and smart manufacturing is able to control uncertain production conditions on the shop floor in Industry 4.0. The proposed data-driven decision-making system enables the management team to enhance productivity and industrial sustainability within limited constraints in Industry 4.0. From the reported result, it was observed that the proposed system significantly improved the efficiency of production management and operational performance by suggesting smart systems. The results of the study showed that a substantial reduction in production time and cost has been achieved. In this article, the authors suggested an ingenious methodology that allows a simultaneous optimization and process parameter validation that is production time by using Taguchi approach in order to provide more flexibility and productivity efficiency for shop floor management in Industry 4.0. Based on the results obtained under validation of Taguchi method, ANOVA results evidenced that number of operators is the most significant parameter effecting the production time and it contributes 74.78% to obtain minimum production time. Available time is also another significant parameter, and its contribution is 22.40%, while cycle time is insignificant. The developed data-driven decision-making system would be a benchmarking and problem-solving for enhancement in productivity and provide a smart production management system using lean and smart manufacturing principles in Industry 4.0. The authors of the present research work strongly believe that the developed system would be beneficial to industry individuals in the smart production shop floor management system in the uncertain condition in Industry 4.0. The study helps control operational excellence by reducing waste and idle time through the Taguchi L_9 orthogonal array method and enhancing its effectiveness using lean and smart manufacturing. Thus, we can suggest that the advanced Taguchi approach could be applicable for industrial environments at optimal production process parameter with high-quality statistical design to enhance the operational excellence. Furthermore, the finding can be used for those production conditions where the production time and resources consumption increase due to excessive changes in adjustments of production processes.

7. Future Scope

The implementation of an appropriate strategy is a crucial decision for shop floor management. Therefore, industry people emphasize developing a robust decision-making system and guidelines to make this decision right [6, 9, 16, 26, 53, 56, 58, 60, 61]. The present research focuses on developing a data-driven decision-making system for sustainable shop floor management using lean and smart manufacturing concepts. The developed system has been validated by implementing it in a real production shop floor management condition of Industry 4.0. The result revealed that the developed system could enhance production efficiency and financial profitability within limited constraints. Furthermore, the developed decision-making system's efficacy can be improved by implementing lean principle with other process optimization methods for shop floor management in different production conditions, including Industry 4.0.

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.

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