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An Implementation Framework to Attain 6R-Based Sustainable Lean Implementation–A Case Study

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ABSTRACT The concepts of lean manufacturing operations and sustainability are congruent in nature, marked by the facet of improving organizational efficiency. However, only difference lies in the definition of waste. This definition is given a new dimension by sustainability by incorporating the extensive scope of reductions in the environmental consequences in the form of 6R (reduce, reuse, recycle, recover, redesign and remanufacture); which requires a consolidated integrated approach. Therefore, as to affirm the requirement, a systematic literature review has been carried out which scrutinized previous researches in view of their originality, methodology, objectives and limitations. Based on this literature study, 25 most related approaches (lean and sustainable integrated approaches) were selected and their originality was investigated. Investigation revealed that few research articles are integrating lean and sustainable approaches. This study identifies the gap of the integration of lean practices with 6Rs and a framework was developed which implemented on the case study that carries ability to attain 6R based sustainable lean production systems. Because of more social and environmentally friendly atmosphere achieved through 6R based implementation, the results achieved are 50% decrease in heating cost by redesigning furnaces (from oil furnaces to gas furnaces), 36.33% improvement in value added time, 40.14% in lead-time and 22% reduction in labour utilization. This improvement indicates that use of proposed integrated framework is highly beneficial for any kind of manufacturing sector.

INDEX TERMS Lean Production, sustainable development, lead-time reduction, manufacturing systems, operational research.

I. INTRODUCTION

Lean manufacturing is a concept with a systematic approach to eliminate waste (non-value added) in a system to enable it for continuous improvement for maximizing customer value. It has received considerable amount of attention from practitioners and researchers since its introduction by Toyota manufacturing system by Taiichi Ohno. It is a concept that non-value added activities (overproduction, excess processing, unnecessary inventory, unnecessary motion, excessive transportation, defects in products, waiting time) can reduced by successful implementation of lean practices [1]–[3]. Successful implementation of lean manufacturing results in improvement of manufacturing operations, productivity, quality, cost in general performance of the organization and can be utilized in any organization. However, few organizations learn symbolic advancement by employing lean techniques. Organizations are unable to facilitate the ongoing improvements. Less than 10% British organizations were successful in implementation of lean techniques. It is believed that this failure is due to lack of knowledge of lean concept, organization culture, management attitude and unreliable information for utilization of lean techniques [4]. Moreover, lean is such a powerful tool that it aids in removing wastes

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from non-manufacturing processes as well e.g. order handling, optimization of distribution centres [5]. Consequently, some organizations misapply wrong lean practices [6]. There are a few mathematical tools [7] which can aid practitioners in decisions but cannot fully take up a venture that hinges around continuous improvement. Organizational cultural variations and level of attention by mangers have direct impact on the effectiveness of lean implementation because it influences individual behaviours [8]. There is no doubt on the benefits of lean, however, it has been highlighted by past researchers to attain production keeping in view the both social and environmental aspects [9].

Sustainable manufacturing in any industry can be defined as " the creation of manufactured products which use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers economically sound [10]. Sustainability of non-renewable resources is getting more difficult inch by inch. In consequence of warning generated by UN World Commission for Environment and Development, many industries continue to relegate environmental protection and social responsibility to position below economic performance [11]. Despite the fact, that many practices in the previous years have highlighted contradictory beliefs regarding long-term effect and worldwide scalability. To cope with this contradiction there are several researches conducted to evaluate sustainable manufacturing. In one of the popular approach "Triple Bottom Line" (TBL) framework proposed by Elkington [12] which counsels industries and organizations to evaluate their performance using a multidimensional perspective. TBL accounts for three pillars (economic, environmental, and social) as the base of successful sustainable development, and thus used as a metric for performance measurement in industries. Leon and Calvo-Amodio [13] argue that this study is most relevant to environmental and economic sustainable performance and more research is needed regarding the third pillar of TBL. The approach named as 6R (reduce, reuse, recycle, recover, redesign and remanufacture) extension of previously used 3R (reduce, reuse, recycle) described by Russell *et al.* [14] draws attention to all the aspect across the life-cycle to assist sustainable manufacturing [15]. Though various researchers narrate sustainability indicators in their research but there is no universal standard for calculation of sustainable performance [16], [17]. Furthermore, development of sustainability reporting in the production practice can be identified [18]. The use of lean practices as an accelerator to acquire better strategies for sustainable manufacturing is widely discussed [19].

Through extensive examination, it was concluded that case study appears to be the most appropriate methodology in order to validate the approaches towards sustainable lean implementation. Delving further, it was deduced that out of case study classifications, longitudinal type is apposite than cross sectional case study. Upon literature review, the common grounds for framework consolidation in the context of sustainable lean implementation were identified which in turn helped in tracing the steps. The division into various steps is necessitated by perspective of monitoring and controlling, however, they need to be closer to previously employed sustainable implementation approaches [20]. Further investigation revealed the profuse use of Value Stream Mapping as an appropriate tool for the aforementioned integration. The steps have been described in detail in Table 2.

Lean is often defined in terms of the five lean principles (value, identify value stream, value flow, pull value, perfection) derived from Japanese manufacturing industry [21]. A product goes through various stages before it is transformed into a form where it can be sold. In this context, value is added at various stages through this transformation process, which is known as a value stream [22]. Value stream is comprised of all the process, activities both VA and non-value added (NVA). Lean practices and sustainable performance of a firm are two sides of the same coin [23]. Rafique *et al.* [24] argue that in previous researches, almost 25.6% have utilized VSM for lean implementation as the most appropriate methodology. VSM is a priceless tool for strategic planning. It facilitates to visualized and understand the flow of material and information in a production line. It enables to identify and reduces errors, losses, lead-time, cost of product [25]. However, traditional VSM methodology has not succeeded in environmental and social performance, in fact, it only accounts for economics of a manufacturing line. In this regard, different approaches are highlighted in literature which combines the traditional VSM with additional metrics to assess environmental and social effects [10]. There are no hard and fast rules for performance calculation of sustainable manufacturing. A systematic literature review regarding lean and green manufacturing shows that however there are a few frameworks that cater to the environmental performance of manufacturing operations; there has not been an integrated framework that employs the use of 6R Technique integrated with lean manufacturing to accommodate the eco-friendly perspective. Furthermore, the developed frameworks cater to specific manufacturing domains, and could not be extended to different manufacturing sectors. In addition to that, lean techniques such as Kaizen have been implemented to improve environmental performance but there has been no use of 6R technique which hinges on re-using the materials to promote recycling and remanufacturing. In case of sustainability, the developed models have not discussed the correlation of the established indicators. Even though in case of environmental performance, recycling and ISO standardization is discussed; use of 6R remains a gap that needs to be filled. Therefore, it substantiates a need to consolidate an integration approach using 6R that is convenient, scalable and carries a capability of implementation in whole manufacturing sector, rather than confining to automotive segment This triggered interest of researches and practitioners towards LM and effects on sustainable performance [16].This research attempt to propose an integrated framework which is the prerequisite of the time.

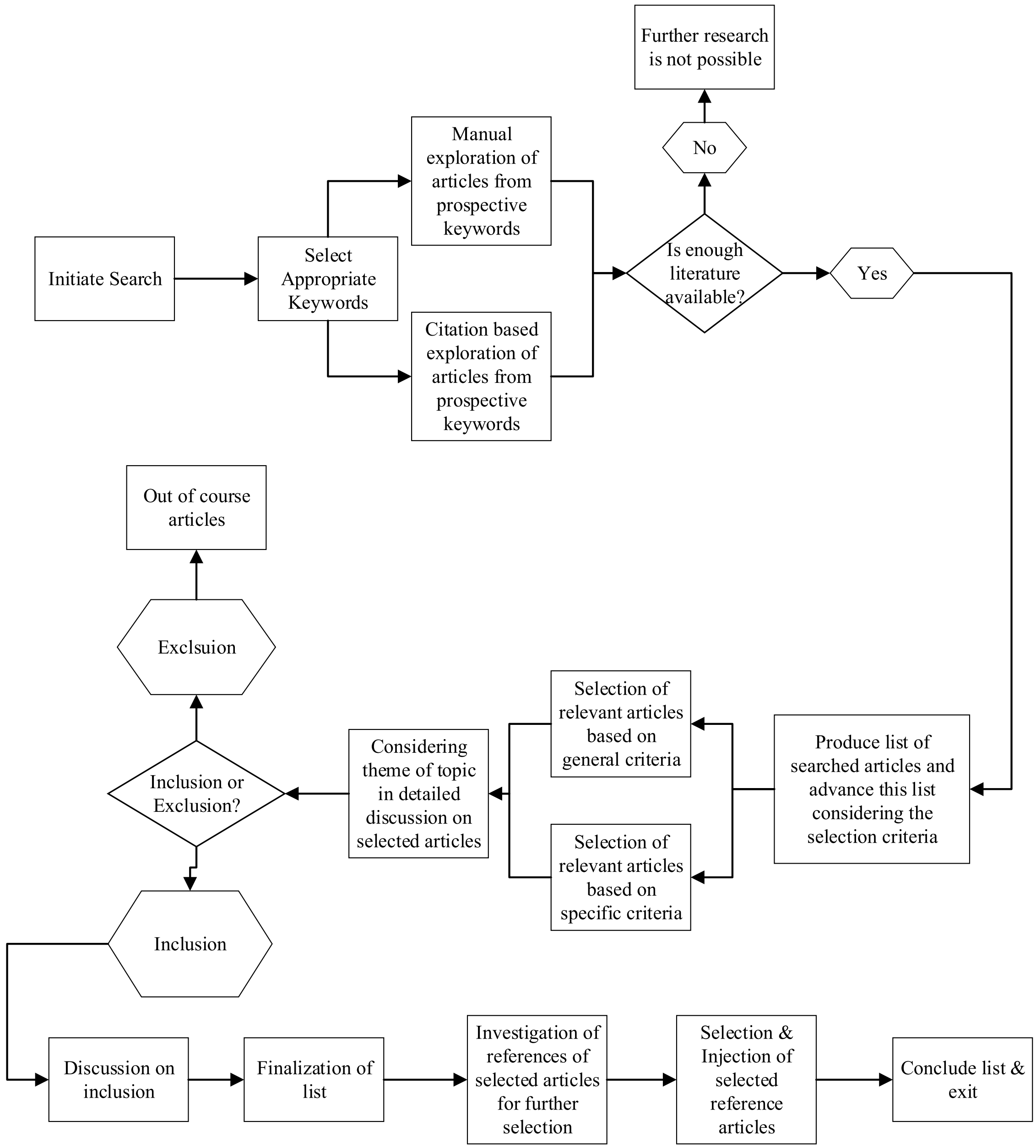

FIGURE 1. **Search and selection criteria.**

II. METHODOLOGY

In order to examine the previous researches, a systematic literature review study is planned to be conducted. In first step, the research gap is confirmed through selection of previous approaches as per relevance of their research topic with available literature [26]. In this regard, Figure 1 shows a search and selection criteria that helps to attain an in-depth search of relevant data and selection of related approaches is practiced. The major task was to evaluate the originality and contribution of the available literature to confirm the gap. The development of new sustainable implementation approach will begin after validating of contributions and originality. There are several implementation approaches proposed in the past like checklist, road map, conceptual model, framework and theoretical model [24], [27] and the main task is the selection of most suitable approach based on reviewing available approaches. Next step is the selection of most convenient method for the selected implementation approach. Frequently used methodologies for implementation are surveys, questionnaires, interviews, case studies, observation and experiments [24], [27]–[29]. In result of in-depth review of previous approaches, it is revealed that, most of the researches related to lean consider case studies [30]. The next phase was to find the steps needed which resulted in the construction of framework for lean implementation and successful working of proposed framework. Hence, in order to develop the framework, the structure of methodology is formulated into two phases as previously used by researches like Rafique *et al.* [31] who achieved magnificent consequences. Although current, research methodology associated to the same origin but held its own concerns towards leading phases.

A. SEARCH CATEGORY

In context of this research, a systematic literature review was carried out. There are different search engines/databases available and it was essential to select the database in accordance with the aim of this research. In this regard, the databases like Science-direct, Springer, Elsevier, Emerald, World Scientific, EBSCO, IEM, and ASEM are recommended by many previous researchers [27]–[29], [31]. Period of present research started from 2000 and the ending year is 2019. To collect relevant publications combinations, keywords used to search are sustainable lean manufacturing, sustainable lean framework, lean frameworks, lean roadmaps, sustainable development, Triple bottom line, value stream mapping, sustainable VSM, Green VSM, combination of Triple bottom line and Value stream mapping, integrated framework to achieve sustainable lean manufacturing.

B. SELECTION CATEGORY

In research methodology, the selection phase is most important and critical after search phase. The selection phase is further subdivided into two broad categories same like that of Rafique *et al.* [31] in their research.

1) GENERAL PHASE

Various sustainable lean implementation approaches present in available literature and emphasize on two stages as mentioned below.

Stage 1 Investigation of Originality and Contribution: As the development of framework is the key task that plays pivotal role in successful implementation of lean, the focus is to conquer specific boundaries of the existing sustainable lean implementation approaches by contribution of a new sustainable lean implementation approach that is not from existing approaches. Hence, keeping this in view, investigation of selected publications based on their novelty and contributions was carried out to find out the gap in the previous researches of sustainable lean implementation in manufacturing regime. After scrutinizing the contribution and originality, selection of appropriate implementation approach is next step in this regard. Many researches argue that selection of implementation approach depends upon the scope of research.

2) SPECIFIC PHASE

This phase of selection criteria is utilized to study and select practices for the development of the complete framework and for the validation of framework through case study. Commonly, implementation approach in previous literature utilized some common practices for the selection of appropriate practices and steps to achieve development of implementation framework. It is necessary to review literature related to current research regime. In this regard, it is revealed that methodology used in previous publications concerns to dig out what are the elements utilized by previous researchers to develop a implementation framework and to find out the standard elements used in the field of sustainable lean manufacturing [24], [30], [32].

III. A STATE OF ART LITERATURE REVIEW & FRAMEWORK DESIGN

The concept of lean manufacturing is not new. First, it was introduced in Toyota Production System (TPS) to increase efficiency by implementation of JIT approach at production line [33]. The core concept of lean manufacturing is value addition through reducing costs, downtime, lead-time, and inventory. Numerous lean tools/techniques are available but main appropriate selection of lean tools contributes to better waste elimination. In this regard, VSM is considered as the one of the best aid of lean to manufacturing industries [34]. VSM is a process modelling tool help to visualize VA (Value added) and NVA (Non value added) in the production line.

The comprehensive literature review suggests that there is dearth of integration approach that amalgamates lean and sustainable manufacturing through 6R. Most of the developed frameworks have lacked scalability i.e. either they have covered a single process or a single manufacturing sector. There is a requirement for consolidating a framework of global nature that involves the whole manufacturing domain. In addition to that, the framework needs to simplistic, but holistic in nature for ease of applicability. In order to undertake this enterprise, the authors selected a case study approach since investigation revealed that case study is the most suitable methodology for validation of sustainable lean implementation approach and among the type of case studies; longitudinal case is more suitable then cross-sectional case study. Use of case study type is highly linked with type of approach on this subject investigation of selected articles. Hence, Table 1 and Fig. 1 clearly show that implementation framework approaches used longitudinal case study methodology to verify framework. Investigation further revealed that proposed frameworks ulitized some common and essential practices for sustainable lean implementation to develop a framework. Main task is to describe steps through which sustainable lean implementation can be made. For monitoring and controlling these steps are further divided into substeps/stages. In order to select appropriate steps, in depth inspection of available related reseachers is necessary. In this regard, there is no defined rule in steps selection but it must be implicit and should match with previous sustainable implementation approaches [20]. Considering 26 selected publications mentioned in Table 1; it is revealed that 17 out of 26 implementation approaches utilized VSM as a most appropriate technique for integrating lean and sustainability; considered as the most appropriate one. As mentioned earlier, steps can be selected by reviewing available literature as

TABLE 1. Literature review.

Sr No	Author /year	Methodology	Application sector	Contribution & originality	Findings	Limitations
1	Sawhney, et al. [35]	Longitudinal case study	Manufacturing Industry	Integrated lean and environmental performance	Provide help for improvement of environmental performance in specific processes	Framework is design for specific processes
2	Abdulmalek and Rajgopal [34]	Longitudinal case study	Manufacturing Industry	A simulation based lean implementation approach.	Provide help to evaluate potential outcomes of lean Implementation through simulation verifications.	The sphere of planning is limited in the selected case study.
3	Torres Jr and Gati [36]	Longitudinal case study	Manufacturing Industry	Integrated lean and environmental performance	This study aids in improvement of environmental performance in specific processes	The developed framework is designed for specific processes
4	Kuriger and Chen [37]	Literature review	Manufacturing Industry	A simulation based lean implementation approach.	Provides help in evaluating potential outcomes of lean implementation through simulation verifications.	The sphere of planning is limited in the selected case study and needs to be expanded.
5	Paju, et al. [38]	Literature review	Manufacturing industry	Proposed model Integrate the traditional VSM and environmental performance.	The model provides help to visualize the effect of environmental management and social/ economic losses in the production process.	The model does not provide a clear picture of waste in the system and does not identify the areas for improvement from an integration perspective.
6	Torielli, et al. [39]	Literature review	Manufacturing Industry	Integrated traditional VSM with sustainability matrices	The proposed model helps to explore the impact of value stream on the operational performance, energy efficiency, and environmental sustainability.	The proposed approach lacks the sustainability dimension since it does not carry social, environmental and economic metrics.
7	Azevedo, et al. [40]	Longitudinal Case study	Automotive industry	Proposed framework combined VSM, DES, and LCA	In this study a goal orientated approach is proposed for process mapping.	The framework is hypothetical in nature and needs to verified through implementation in case studies
8	Jabbour, et al. [41]	Questionnaire based survey	Automotive industry	Proposed framework is based on four pillars to integrate lean and green.	The selected pillars help in improving economic, environmental, sustainability; whilst using lean practices	The proposed framework is conceptual in nature and needs practical validation. In addition to that, the framework is confined to application in foundries only.
9	Aguado, et al. [42]	Longitudinal case study	Manufacturing Industry	Proposed theoretical framework to examine effect of Lean and Green practices on the sustainability. Performance.	The authors identified conceptual relationships between green and lean supply chain management practices.	The proposed framework has been designed for automotive supply chains and needs to be checked from a strictly manufacturing perspective in various industries.
10	Chiarini [43]	Cross-sectional case studies	Manufacturing Industry	Framework combined Environmental management, operational performance, human resources and lean manufacturing	The framework provides help to investigate effects of environmental management on operational performance, human resources and lean manufacturing.	The framework is conceptual and has undergone empirical testing only. It should be tested via a case study.

TABLE 1. ***(Continued.)*** **Literature review.**

Sr No	Author /year	Methodology	Application sector	Contribution & originality	Findings	Limitations
11	Wong and Wong [44]	Longitudinal case study	Manufacturing industry	Utilization of environmental innovation results in improvements in lean manufacturing	The model provides help in reducing the consumption of raw materials and the energy; consequently improving quality.	Model is hypothetical and needs practical validation.
12	Jadhav, et al. [45]	Literature review	Automotive Industry	Explores the effect of lean tools on Environmental performance	Research revealed that implementation of lean tools/techniques aids in identification and reduction of environmental impact.	Research only discusses motorcycle-manufacturing industries. The diverse environmental problems of various industries need to be addressed.
13	Faulkner and Badurdeen [10]	Longitudinal case study	Manufacturing Industry	Combined sustainable development and societal aspect in lean with sustainable development.	Proposed framework provides help in improving operational management to obtain operational sustainability.	The framework does not account for economic and environmental performance.
14	Brown, et al. [46]	Cross sectional case studies	Manufacturing industry	Developed a framework that explores eight Lean practice bundles for successful implementation of Lean	Proposed framework helps to improve resource consumption and human culture.	Implementation of this framework is quite complicated
15	Pampanelli, et al. [47]	Longitudinal case study	Automotive Manufacturing	Integrated sustainability metrics with traditional VSM	Comprehensive model was developed to assess the three bottom pillars (TBL) of sustainability performance in manufacturing.	Needs further investigation, particularly through industrial case studies.
16	Wang, et al. [48]	Cross-sectional case studies	Automotive Industry	Proposed method evaluated environmental, social and economic, performance in manufacturing	Sus-VSM provides help to assess energy consumption, water usage, raw material usage, societal aspects and environmental hazards.	Case studies only discuss development of current state Sus-VSM to assess the current sustainability performance development of future state Sus-VSM is necessary
17	Ng, et al. [49]	Longitudinal Case study	Manufacturing Industry	Proposed a five-step Lean & Green Model that merge Lean and sustainability	Through use of VSM, productivity was increased and environmental impact was reduced.	The developed model needs to be expanded to a holistic level.
18	Resta, et al. [50]	Cross-Sectional case study	Automotive industry	Investigated auto firms' performance well in terms of lean, green and social practices	This research provides theoretical framework to improve economic, environmental and social practices of automotive companies.	The correlating and conflating indicators need to be studied.
19	Vinodh, et al. [51]	Longitudinal case study	Automotive industry	Integrated Lean, Green and carbon-value efficiency concept to improve sustainability.	The authors provided an integrated stepwise implementation of lean and green practices to improve cycle time and continuous flow processing	Proposed Framework did not incorporate social and economic pillars of suitability and requires further testing.
20	Edtmayr, et al. [52]	Longitudinal case studies	Automotive industry	Model investigates existing PSS operations strategy, and provides help to improve PSS operations	Provides help in systematic application of lean thinking in managing PSS operations	Application of model is highly linked with the company type and with be tested in other sectors.
21	Cherrafi, et al. [53]	Cross-sectional case study	Manufacturing Industry	Value stream mapping (VSM) combined with life-cycle assessment (LCA)	The framework helps to visualize sustainable manufacturing performance.	Proposed framework does integrate any social metrics and requires practical validation.

TABLE 1. ***(Continued.)*** **Literature review.**

Sr No	Author /year	Methodology	Application sector	Contribution & originality	Findings	Limitations
22	Helleno, et al. [16]	Cross-sectional case studies	Manufacturing industry	Proposed model integrated sustainable management and VSM to improve resource efficiency	Model helps in calculating the resource waste and prevention of disposal by the use 3R concept	Proposed VSM based model only accounts for disposal process' effect on sustainable management and requires holistic approach.
23	Stoycheva, et al. [54]	Literature Review	Automotive industry	Developed a Framework which Integrated Green and lean Six sigma	Proposed framework provides help to identify weaknesses, strengths and reduced resource consumption of industry.	The framework should be spread across various processes for comprehensive testing.
24	Dadashnejad and Valmohammadi [55]	Longitudinal case study	Not mentioned	Proposed a conceptual model to integrate a new group of sustainability indicators into the VSM tool to assess manufacturing processes	Conceptual model brings a new group of indicators associated with economic, social and environmental dimensions	The developed sustainability models and indicators are preliminary and need to be developed further.
25	Muñoz-Villamizar, et al. [56]	Longitudinal case study	Automotive industry	Developed a MCDA framework to evaluate sustainable manufacturing	Framework tries to provide help in resolving decision-making problem regarding sustainable manufacturing	The managerial implications are unclear and need to be addressed for effective implementation.
26	Rehman, et al. [57]	Longitudinal case study	Plastic Manufacturing Industry	Provided knowledge regarding the effects of improvement opportunities identified through VSM	Proposed a questionnaire which helps to identify loss points, make the right decisions and to choose the best methods and lean tools for improvement	Research has been carried out a single manufacturing industry and needs to be scalable for implementation in other sectors.

mentioned in Table 2 and the order of selection steps completely depend upon the framework requirements.

IV. PROPOSED FRAMEWORK

To conquer some barriers and challenges related to sustainable lean manufacturing in previous proposed frameworks in present, a new framework is constructed based on 4 stages and 17 elements as mentioned in Table 2. Monitoring and controlling process are connected with each phase to confirm outcomes.

Phase 1 (Preparation Phase): This is the starting phase of the lean implementation and helps to improve attitude of personnel involved. Previously, several frameworks have been proposed but it is discovered that very few researchers include expert lean team in their frameworks. On the other hand, some researches argue that lean experts team building may provide help to improve effectiveness of lean implementation. It should be included in the lean implementation plan [58]. It has been noticed that adoption of lean concept in majority of organization need transfer of knowledge and reviewing of lesson learned. In result, improvement in way of thinking can be expected. Hence, in order to build an expert team who has a command on lean tools/techniques, the following steps need to be followed:

- Formation of lean expert team
- Build sustainable lean knowledge with trainings
- Review lesson learned on sustainable manufacturing
- Get command on implementation tools/techniques related to lean, suitability management.

After achieving above metrics team would be able to define strategic goals.

Phase 2 (Current Assessment Phase): After building lean implementation expert team's next main task is the selection of data collection methodology. In this regard, several methods are practiced but lean experts and practitioners suggest that "go to Gemba walk" is the most appropriate methodology. After collecting data, next major task is identification of product family and sustainable manufacturing requirements related to it. Selection of a product which goes through almost all operations carries some problems. Next step is the development of current state map to assess the operational and sustainable management related waste in the system. Steps in sequence are given below.

- Define data collection methodology (go to Gemba walk)
- Identify product family and sustainable manufacturing requirements related
- Create current value stream map to identify the (economic, environmental, social) sustainable manufacturing waste present in current system
- Identify the (economic, environmental, social) sustainable manufacturing waste present in current system.

TABLE 2. Development of implementation framework.

Phases	Define required Steps	Reference from previous literature
Phase 1- Preparation phase	1. Formulation of lean Expert Team	Anvari, et al. [20], Rafique, et al. [24], Mostafa, et al. [27], Womack and Jones [59], Garza-Reyes, et al. [60]
	2. Build Sustainable lean knowledge with trainings	Anvari, et al. [20], Rafique, et al. [24], Mostafa, et al. [27], Boyer [61]
	3. Review lesson learned on sustainable manufacturing	Mostafa, et al. [27], Abdulmalek and Rajgopal [34], Scherrer-Rathje, et al. [62]
	4. Get command on implementation tools/techniques related to lean, suitability management	Rafique, et al. [24], Mostafa, et al. [27]
	5. Define strategic Goals	Garza-Reyes, et al. [60]
Phase 2- Current assessment phase	1. Data Collection Methodology	Mostafa, et al. [27], Jasti and Kodali [30], Garza-Reyes, et al. [60]
	2. Go to Gemba Walk at Actual place	Rafique, et al. [24], Abdulmalek and Rajgopal [34]
	3. Identify product family and sustainable manufacturing requirements related to it.	Rafique, et al. [24], Garza-Reyes, et al. [60]
Phase 3- Analysis and elimination phase	1. Create Current state VSM	Rafique, et al. [24], Mostafa, et al. [27], Abdulmalek and Rajgopal [34], Garza-Reyes, et al. [60]
	2. Identify and measure Sustainable waste in current system	Rafique, et al. [24], Garza-Reyes, et al. [60]
	3. 6R Implementation	Jawahir, et al. [15]
	4. Waste Eliminate/Minimize (Eight guideline Questions)	Anvari, et al. [20], Rafique, et al. [24], Rother and Shook [25], Mostafa, et al. [27], Pampanelli, et al. [47], Ng, et al. [49], Garza-Reyes, et al. [60]
	5. Propose future state map (verified through simulation)	Rafique, et al. [24], Rother and Shook [25], Mostafa, et al. [27], Ng, et al. [49], Garza-Reyes, et al. [60], Singh and Sharma [63]
Phase#4Action phase	1. Formulation of implementation plan for future state map 2. Implementation of plan to achieve future state map 3. Follow through outcomes of implementation plan 4. Sustainable improvements	Anvari, et al. [20], Rafique, et al. [24], Rother and Shook [25], Mostafa, et al. [27], Abdulmalek and Rajgopal [34], Ng, et al. [49], Garza-Reyes, et al. [60], Kumar and Phrommathed [64], Behrouzi and Wong [65]

Phase 3 (Analysis and Elimination Phase): After the development of current state map and identification of wastes, the next task is the analysis to identify the opportunities to eliminate/minimize identified waste by utilizing 6R approach. 6R approach is used to reduce (manufacturing cost, production time, raw material, & energy consumption) with the help of repairing, remanufacturing, reusing, recovering and redesigning of used material which provides help to improve environmental, social, economic performance in conjunction with lean. To propose future state map, eight guideline questions provided step by step improvement plan. Present study combined 6R approach with eight lean guideline questions while considering their effects on sustainable lean manufacturing performance.

Phase 4 (Action Phase): This is last phase in which development and documentation of plan for implementating future state map is carried out. Documentation will provide help to resolve problems identified by follow-ups in implementation of plan. Following steps are required to fulfill this phase.

- Formulation of plan for implementation future state map.
- Implementation of plan to achieve future state map.
- Follow through outcomes of implementation plan.

After the fruitful construction of implementation framework for identified product family it should be implemented on all other processes to improve overall efficiency of Industry. Normally it takes 3 to 5 years for complete implementation of lean practices.

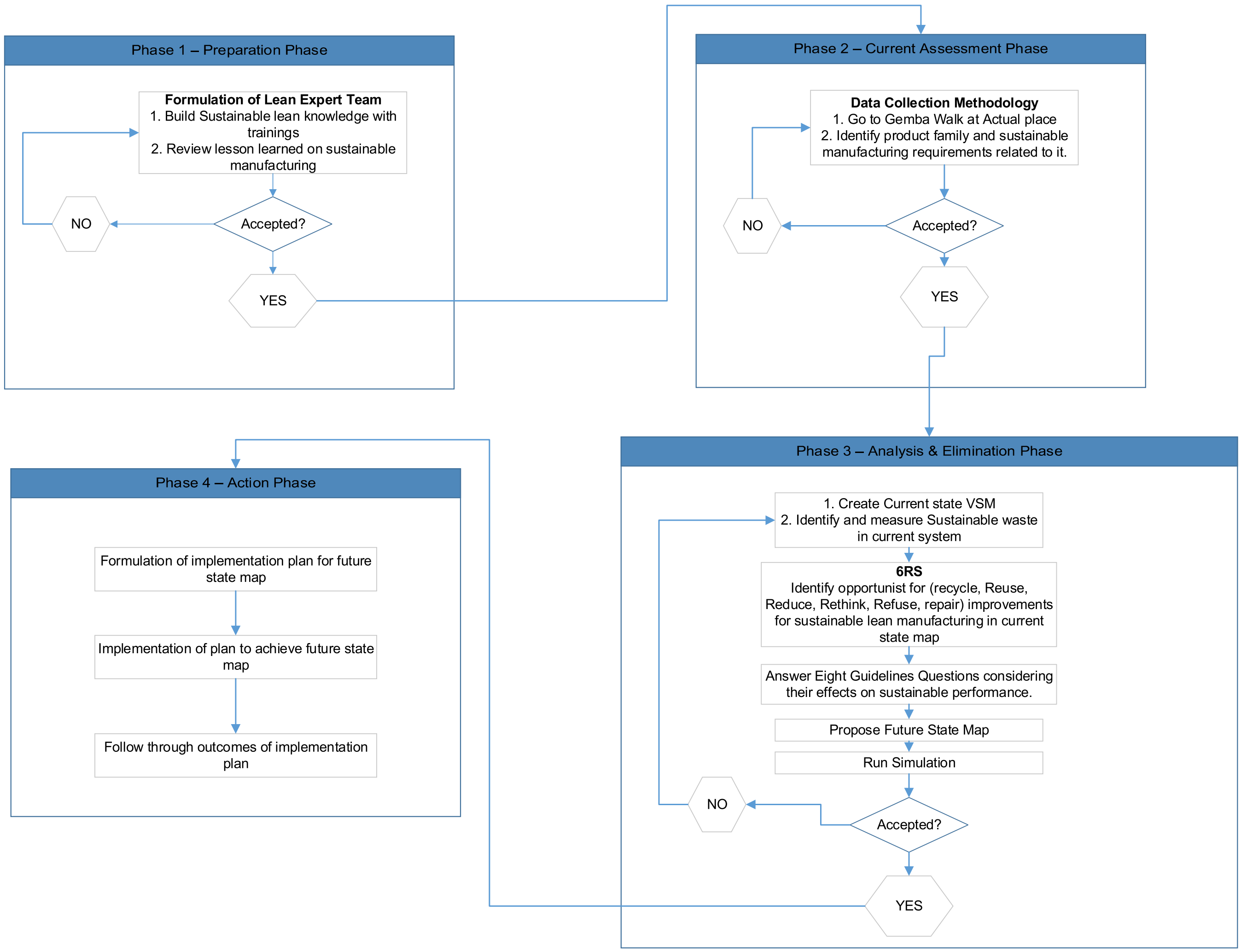

FIGURE 2. Implementation framework.

V. FRAMEWORK IMPLEMENTATION ON CASE STUDY

A. PHASE 1- PREPARATION PHASE

It is seen that in development and consolidation of a successful appoach, validation of proposed framework plays a vital role. Proposed approach can be validated by employing several methodologies; in this respect it has been found that among methodology types (conceptual model, case studies, checklist, descriptive planning) case study is the most commonly used methodology. We have seen in literature review that only a few researches have utilized other methodologies; furthermore, case studies are divided into two categories; ''longitudinal case studies'' and ''cross-sectional case studies''. Among these two types, as literature suggests, longitudinal case study is found to be most suitable for implementation framework approach because it provides in-depth information associated with single case. On the other hand, cross-sectional case studies provide generic information of two or more cases. After making decision to use case studies methodology type, next step is the selection of most appropriate data collection mode. In this aspect, the result of numerous scholar's works testified that case studies employed interview and on-site observations for practical data (cycle times, inventories) collection. Motive of present study is to provide an approach which can help managers to achieve sustainable development goals in their organizations and industries. From this perspective, implementation approach should be able to contribute with in-depth knowledge; as in identification and measurement of non-value-added activates, followed by generic help to reduce barriers in the way of successful sustainable manufacturing. Hence, in order to fulfill this task, present study has selected a manufacturing industry (PRRR) as a longitudinal case which is a fasteners (Bolts, nut etc) manufacturing company. In this sense, the framework will be verified and the proposed research will facilitate other industries in the same regime.

The nature of the case study is such that it provides a complete example of successful implementation due to large and complex variety of products that involve intricate processes. Generally, such type of manufacturing industries face challenges to improve their performance in using conventional lean tools/techniques. PRRR is sole manufacturer of railroad related products in the country, manufacturing more than 300 items. Major items of this industry are different types of bolts, nuts, washers, elastic rail clips, bearing plates, slide chairs and railroad tools (spanners, beaters).

B. PHASE 2- CURRENT ASSESMENT PHASE

Data collection in a high variety industry is a difficult task it is entirely dependent upon the nature of case. However, there are several research works proposed in previous literature to evaluate appropriate data collocation techniques. Based on available literature it is revealed that practical observation on site, interviews, documental information of company are most common and appropriate data collection techniques for case studies methodology. In present study practical observation of the plant has been selected as a data collection methodology and in order to do so, GEMBA Walk is a briliant approach. It is the most popular management technique that provides help to understand the actual system and to create a current state map; consequently contributing with in-depth information about operations involved, waste involved and explores improvement opportunities in current system. In this respect, the nut manufacturing production line has been selected. Investigation of previous literature revealed that with the objective to identify and measure problems (waste) and opportunities for improvement in current system perspective of management of company plays important role. After acquisition of data related to waste involved in selected production line, next assignment for team leader is the identifications of barriers regarding sustainable lean implementation and collection of relevant data in present case. In this regard, variety of barriers have been argued, which include top management interest and policies, organizational culture, technology level, and financial factor. In this regard, practical observations were not only limited to actual measurements, but also involved interviews of management personnel and employees involved.

Second important task is the analysis of collected data to sketch the current state and future state map. In this regard, present study follows the most appropriate methodologies from ''Learning to See'' presented by Rother and Shook [25] to design and analyze current and future state map. Further, simulation modeling tool has been used to confirm the accuracy and precision of the current and future state map. This is first attempt in the history of subject company to implement the lean tools and techniques with the motive of sustainable manufacturing. In order to do so, necessary requirements including basic knowledge, proper implementation strategy, proper planning and lessons learnt from previous experience help in successful lean implementation. To overcome some obstacles in the way of sustainable manufacturing, top management decided to implement 6R-Based lean approach in their industry by using value stream mapping, in line with Rother and Shook [25] where preliminary steps inlcude Value Stream Mapping and waste identiication.

C. ANALYSIS & ELIMINATION PHASE

1) DEVELOPMENT OF CURRENT STATE MAP

Current state value stream map is the visual representation of the current value stream in order to collect data for the drafting of current state map. Rother and Shook [25] recommended an approach ''go to Gemba walk'' (practical observation on site) which helped in data collection regarding material flow, process flow, inventory level, process cycle time, change over time and number of workers involved. In Figure 3, the current state map has been drafted in which small boxes represent individual process and number of workers involved in it. Each process carries an individual data box that contains information regarding cycle time (CT), change over time (COT). It is pertinent to mention that this data has been collected by actual real-time observation. Further, triangle in front of process indicates inventory. After collecting all essential data, all processes are connected with the help of arrows which show how every process takes place. The timeline at the bottom of map regarding value-added and non-value-added activities time has been divided into two-parts; upper part represents lead time whereas the lower line indicates value added time. This activity is used to thoroughly calculate the total lead time and total process time/value-added time.

In present case PRRR production control department receives orders on annual, bi-annual and semi-annual Basis. Customers have the liberty to make amendment in their orders on monthly basis. Further, production control department calculates total required raw material based on annual procurement plan provided by customers and forecasts their emergency needs accordingly. After taking orders from customers, production control gives monthly forecast information to the supplier and fortnightly orders are made irrespective of the forecast. Total lead time of bolts manufacturing unit is 4 month 17 days with 1440.8 mins value-added time.

2) IMPLEMENTATION OF 6RS APPROACH TO IDENTIFY OPPORTUNITIES IN CURRENT STATE MAP

Development of sustainable manufacturing system has become a primary requirement of manufacturing industries in present circumstances. To identify and analyze sustainable manufacturing concept, there are three main levels in any production line; products, processes involved in creation of the products and the system; liaison between them results in achieving required goals. In this regard present study utilized 6R approach to improve these levels; whereas 6R approach at product level is basically a closed loop multiple life cycle approach. Essentially there are four main stages of product life cycle (pre-manufacturing, manufacturing, use, and post-use). In 6R approach the element of::

- 'Reduce' provides assistance in reduction of resource usage, energy consumption, waste and health hazard

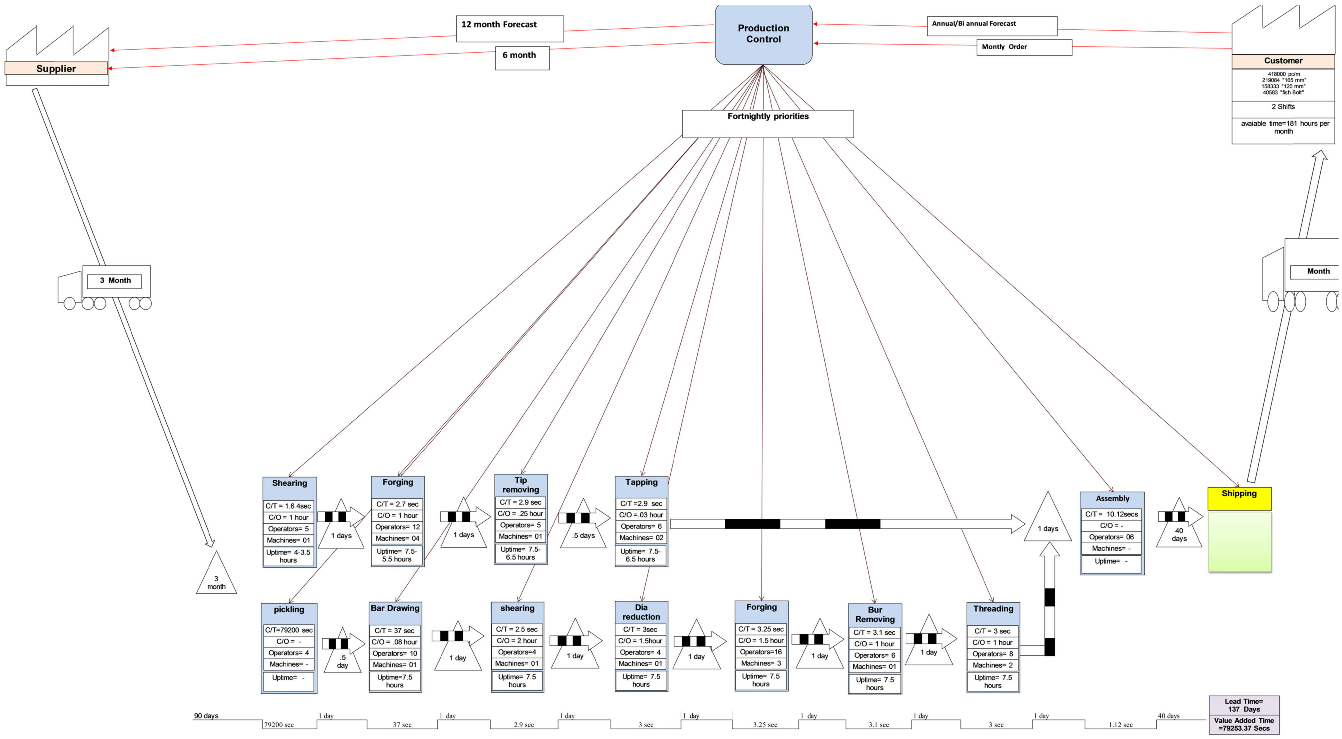

FIGURE 3. Current state map.

- 'Reuse' recommends the usage of useable scrap generated during production, whole product or its component after completion of its life-cycle in this manner minimize the usage of new material.
- 'Recycle' refers to conversion of waste into useable material after post-use cycle
- 'Recover' is an action of collecting end-of-life products, sorting, recovering useable products or components from released products for post-use.
- 'Redesigning' provides ease in remanufacturing process.
- 'Remanufacture' refers to the re-processing of used products or restoration of it to the original state or like new form.

Present study attempts to incorporate 6R approach with lean tools/techniques with the objective of converting traditional manufacturing into sustainable manufacturing. In order to achieve this task, longitudinal case study in fasteners manufacturing industry has been conducted and the results indicate that integration of 6R approach with lean techniques leads toward creation of sustainable products, process and system. In this regard, proposed approach was found suitable for sustainable development in all aspects (environmental, economic, social) of sustainability; as defined by the Triple-Bottom-Line (TBL).

3) DEVELOPMENT OF FUTURE STATE MAP THROUGH IMPLEMENTATION OF 6R BASED APPROACH

In order to produce bolts, there are two diffident production lines are running simultaneously as shown in Figure 3: Current State Map. The upper production line presents the nut manufacturing unit and lower one shows the bolt manufacturing unit; which are looped in assembly section at thr end. In an effort to identify waste elimination opportunities with the help of 6R approach in current state, the author of research practically attended shop floor.

In the current scenario, the nut manufacturing unit consists of four processes (shearing, forging, tip removing, tapping). In the shearing process, mechanical press is used to shear mild steel bar by utilizing punch or die. Normally 12 feet long bars of different diameters are cut into pre-determined sizes. Overproduction, defects, unnecessary inventory waste and noise pollution have been observed in this processs. In this regard, 6R approach suggests to reduce and recycle these by mean of Single Minute Exchange of Die (SMED).

Production of small batches can be obtained which consequently enable the process to use Just In Time (JIT) manufacturing technique. Defects can be minimized by enhancing manufacturing skills and knowledge of worker. Further, unusable material (non-recoverable defective piece, scrap) will be recycled. In order to keep inventory level low at first, process reduction in supplier lead time provided assistance. After shearing process produced pieces move to the forging section where first they are heated in a locally constructed Furnace up to 1200°C approximately. After that, manual forging presses are used to convert heated round pieces into a defined hexagonal shape. In this process the wastes identified are defects in production, environmental pollution which can be reduced, remanufactured and recycled. Defects can be decreased by employing proper skills and knowledge, material and equipment. Furthermore, defective product may be remanufactured and recycled. Next step is the tip removal process, which is achieved with the help of mechanical press. Unnecessary WIP inventory has been found which can be reduced by decreasing the cycle time. The holed nuts are then moved to the tapping process where manual machines are used for the threading of nuts with controlled lubrication mechanism; that provides assistance in reducing wear and tear. Usually over-processing takes place to obtain required quality of threads Effective processing at initial level is the best possible solution to reduce over-processing waste. Then the finished nuts are sent to the assembly section where they are coupled with bolts. Lower production line represents complete bolt manufacturing unit as mentioned above.

In bolt production unit bolt of different sizes and geometry are produced with the same production processes. It starts with pickling of round bars to make them rust and contaminant free with the help of dilute H2SO4. In pickling process, 6R approach suggests to reduce unnecessary inventory. In present case, this is the stage where inventory can be decreased by employing proper planning to reduce supplier lead time and to improve forecast accuracy. Second process is bar drawing in which a round bar drawing machine is used to reduce the cross-sectional area of a round/square bar to attain exact determined sizes; performed by pulling bar through diameter reduction dies. After drawing, the length of bar increases since the volume remains same. It was observed that overproduction and defects wastes are present which can be countered either by reduction or recycling in the current process. In order to reduce defects during manufacturing, skill and knowledge level of workers plays vital role as mentioned above. The elimination of overproduction can be achieved by adopting Just In Time (JIT) approach and idle workers can be used in other sections. Third process is shearing in which round bar is cut into defined pieces. Identified wastes are over-production and defects, which be reduced by utilizing pull system and effective working. After shearing cut pieces shifted to the dia reduction process where the diameter of threading portion is reduced to improve mechanical properties such as strength, hardness and surface finishing. For this purpose, mechanical press is used and worker manually places the piece into the die. Observation revealed that this process has over-production and defects waste; arising due to misplacement of workpiece by worker. It can be reduced by proper training of operator or by replacing with automatic machine.

Next process is head forging; in which defined portion is heated up to 800°C to 1200°C, depending upon material specifications. Head is forged into pre-determined shape; major waste being the production defects. Among 1000 work pieces 76 got rejected by quality supervisor. In order to reduce it, new equipment, proper material, skilled staff is compulsory. After head forging, bolts shifted are to bur removing machine where extra material that was produced in result of head forging are removed. The entity is then further shifted to the threading process where two threading machines are used for threading of bolts, among these first machine is for rough threading and second one is for finish threading. While viewing from 6R perspective the team indicates over-processing waste which can be eliminated or reduced by understanding work requirement, adopting better techniques and using better equipment. After threading, the bolt is sent to the assembly section where it is coupled with nuts.

Future state map is a visual representation of lean transformation it is created to tackle identified problem in current state map. It describes ultimate improvement goals and provide help information of action plan to achieve them. Inspection of current state map revealed several waste like too much difference between overall lead time and total value added time, each process is running on its own schedule and carries further improvement opportunities, initial and Work in process large inventories, poor quality. There are several methods to create future state map author of present study utilizing eight guideline questions explained in the book learning to see by (Mike Rother and John Shook) which provide a systematic way to improve current state.

Q1. What is the take time of bolt manufacturing unit?

Takt time is the maximum time needed to produce a product to meet customer demand. It is simply calculated by dividing the daily available time by the daily demand of the customer. In present case, daily demand of bolt according to the customer is 16,720 pieces and the total amount of time is 7.5 hours so the calculated takt time is 0.027 minutes (1.61 seconds). This means that unit must produce one bolt every 1.61 seconds otherwise, customer's demand can not met. It helps to determine when production is falling behind schedule as early as possible instead at the end of the day. However, unit must attempt to produce below then takt time 1.61 seconds to accommodate any variation during production.

Q2. Is there is need for finish goods supermarket?

PRRR mostly produces four types of bolts by utilizing same processes. Customers provide demand on annual basis which may increase or decrease unpredictably. Currently, bolts manufacturing unit is producing two types of bolts which are then stored in an inspection shed (holding area) from where products are shipped to the customers. This is done on the basis of FIFO methodology, while considering the customers demand. Present research recommends to retain the same idea used in the current state map.

Q3. Where can PRRR can introduce continuous flow?

It has been observed from the current Value Stream map most of the processes have more cycle time than the calculated takt time which shows that the production is falling behind customer demand. On the other hand cycle time cannot be reduced unless technology level or process nature is improved. Present study recommends to introduce continuous flow between supplier, production unit and shipping. In order to achieve this task, the use of supermarket and establishment of cellular manufacturing where possible provides help in waste reduction. In the present case, there are two sections; tip removing and tapping which can be combined to work as a single workstation named as T1 Cell and run by 6 workers instead of 11. Moreover, bolt bar drawing section, bolt shearing and diameter reduction sections are combined to form a new continuous flow cell named as S1 and run by 12 workers instead of 18. Further, bur removing and bolt threading are merged to form a new cell named as T2 and handled by 10 workers instead of 14.

Q4. Where will PRRR needs to employ pull supermarket system?

Pull supermarket system provides help to control production of upstream processes in the production line. Introduction of supermarkets that are controlled by a kanban system limits the amount of inventory in the system. When a part leaves the system, the kanban informs the first process first; as a result of which it re-produces same part. In present case, after successful creation of cells, to develop continuous flow between them, 5 supermarkets are needed. One supermarket is needed before pickling section and nut shearing section, second between nut shearing and nut forging sections, third before T1 cell, fourth before S1 cell and fifth before T2 cell.

Q5. What single point in the production chain (the "pacemaker" process) should PRRR schedule?

Pacemaker process is a single selected and scheduled process in value stream which controls the production pace of all upstream process and links the downstream processes with upstream processes (Rother & Shook 1999). In present case, bolt forging has been selected as a single scheduling point for nut manufacturing unit. In the current VSM, production control department dispatches instructions to all processes individually but in future state map bolt forging will only receive work directions from control department hence upstream process will only produce products when pacemaker releases signal; consequently curtailing overproduction.

Q6. How should PRRR level the production mix at pacemaker process?

The answer is to distribute the production of various products evenly at the pacemaker process; which means that multiple small batches of each product need to be scheduled for unifrom production distribution. This helps in reducing lead time, WIP and finish goods inventory and allow flexibility in product mix. In present case manufacturing unit produces only one type of product family that used 100% of the same processing operations. Duggan (2002) argues that if products pass through 80% or more similar processing operations then they constitute product family. Since PRRR bolt manufacturing unit produces only one type of product family which means that the company does not need to level its production mix.

Q7. What consistent increment of work (the pitch) should PRRR release and take away at the pacemaker process?

The period of time required to produce one container of products in a production area. Basically, it is a measure of how the pacemaker process performs in accordance with customer demand. This allowed to schedule how the frequency of increment (pitch) is to be released and withdrawn at the pacemaker process. It is calculated by multiplying the customer demand rate (takt time) by the finish products quantity at the pacemaker process. In present case finished bolts are packed in a single square containers having capacity of 1000 pieces per container. Whereas customer, if order is delivered in containers size production, should also be made in container. Daily customer demand for bolt manufacturing calculated in previous section is 16720 pieces and can be produced in 16.72 containers and daily available working hours are 7.5, which means that approximately 2.22% container should be made every hour.

Q8. What process improvements will be necessary for PRRR value stream to flow the future-state design describes?

While thinking from 6R perspective to successfully achieve planned future state map following process improvements are required.

- Improve raw material and finish goods handling technology
- Reduce long change over time of processes by attempting to adopt single minute exchange of die (SMED) method and improve overall maintenance capabilities of manufacturing units by employing total productive maintenance (TPM)
- In nut shearing, PRRR should reduce overproduction, defects, noise pollution, changeover time; recover reuseable product from defective products; remanufacture it and further recycle unusable material
- In forging section of nuts and bolt, heating technology and layout of forging machines should be redesigned to reduce cycle time. Moreover, by adopting TPM, SMED and remanufacturing defects and changeover time can be reduced. There should be a narrative to recover reusable products from defective products and finally recycle unusable (non-recoverable defective piece, scrap) material
- Redesign/improve cooling technology of forged nuts-bolts in forging sections.
- In tapping cell T1, it is advised to redesign cell technology for elimination of over processing waste
- Redesign and improve material loading/unloading technology in pickling section
- Addition of a new automated bar drawing machine, redesigning cell layout in cell S1 and improvement in technology in order to reduce cycle time
- In threading cell T2, it is advised to redesign cell technology and employ effective processing to eliminate over processing and defective waste

After implementation of above-mentioned plans (Question 1 to Question 8) future state map for bolt manufacturing unit is sketched in figure 4.

Three new cell workstations, namely, S1 Cell, T1 and T2 cells are constructed in production system. Five supermarkets are added in order to obtain pull production. It should be noted that production control only grant instruction to the bolt forging section (pacemaker process).

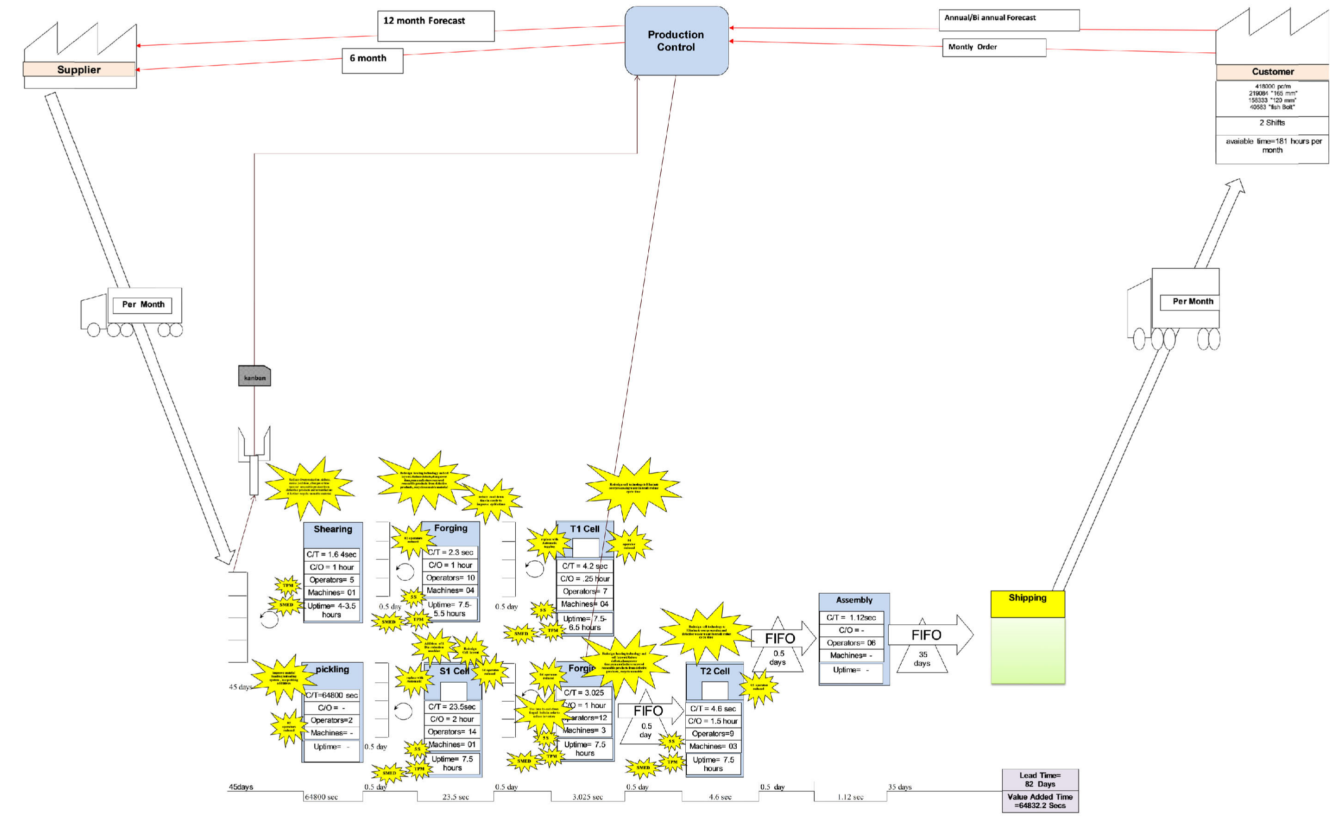

FIGURE 4. Future state map.

D. ACTION PHASE

The main benefit observed in the present case study is a decrease of nearly 36.33% (79253.37 sec to 50452.37 sec) in overall value-added time as shown in Fig. 5 and 40.14% (from 137 days to 82 days) in lead time shown in Fig. 6. Furthermore, other major improvements are 22% (86 to 67 personnel) reduction in labour utilization shown in Fig. 7 and decrease up to 50% (from 2 Million to 1 Million per Month), as shown in Fig. 8, heating cost by redesigning furnaces (from oil furnaces to gas furnaces) which are more environmental and social friendly. The results clearly indicate that use of proposed integrated framework is highly beneficial.

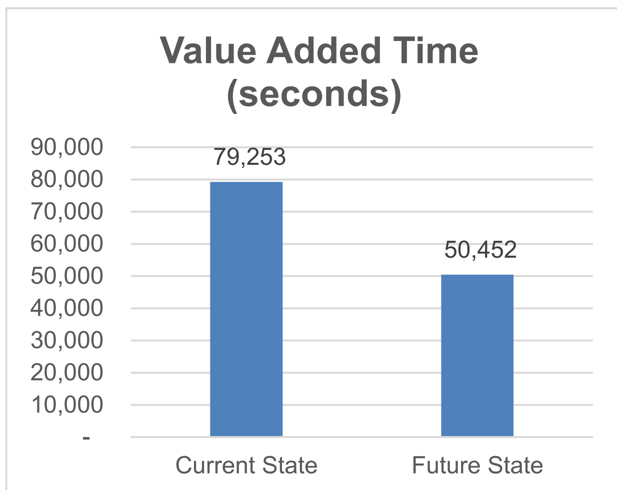

FIGURE 5. Comparison of value-added time.

VI. DISCUSSION

Sustainable manufacturing does not only limit to production of sustainable products, it also provides help to transform conventional processes to sustainable processes. To obtain this goal, researcher proposed different implementation approaches including framework, conceptual model, and roadmaps. Main concern of all these approaches is to provide a complete step by step implementation plan of tools and techniques to eliminate waste of every type. In this regard, waste identification and measurement is the first step and VSM is the most appropriate tool. However, major focus of traditional VSM is more towards cost minimization and it neglects the focus towards parameters of sustainable manufacturing. Therefore, the focus is on the investigation of previous literature to confirm the existence of a research gap. In this regard, originality of the most related 25 articles has been investigated. Investigation revealed that few research articles [10], [16], [60] worked on integrating lean

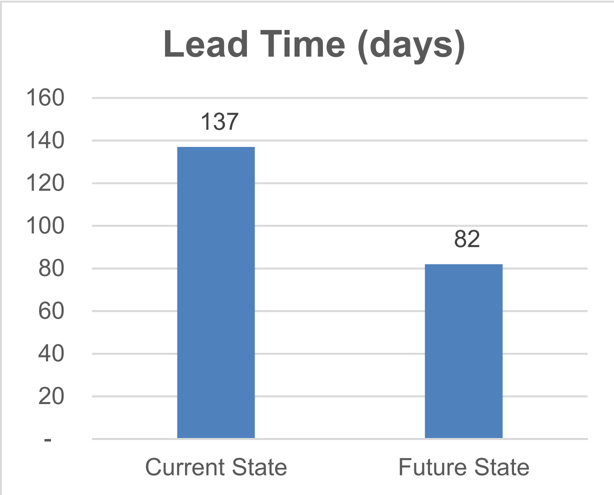

FIGURE 6. Comparison of lead time.

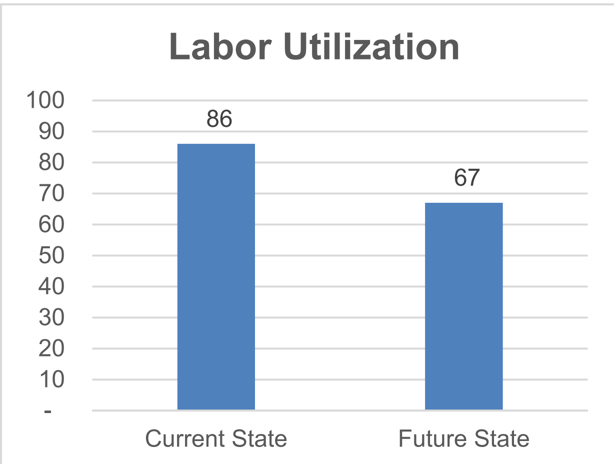

FIGURE 7. Comparison of labor utilized.

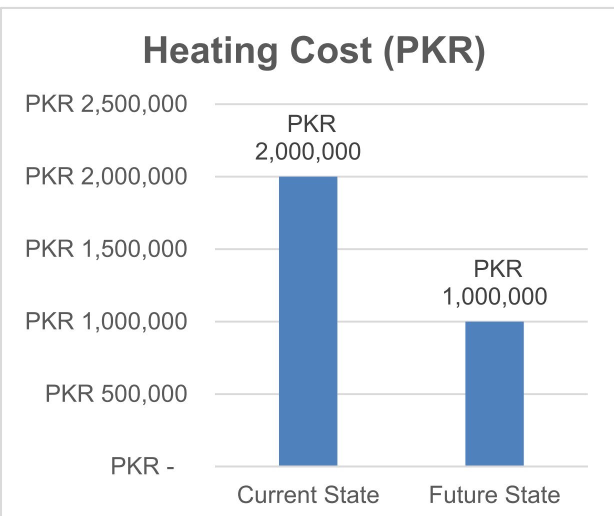

FIGURE 8. Comparison of heating cost.

and sustainability approaches and provided positive impact on sustainable manufacturing. But integration of lean practices with 6Rs is still missing and confirms the requirement of implementation framework that combine 6Rs and lean practices. Subsequently, the present study proposed a novel implementation framework in which 6R approach and VSM are integrated and provides help to minimize negative impact on environment, economic, and social aspects of sustainable manufacturing. As referenced above, the current research has affirmed the necessity of suitable execution approach for the sustainable lean implementation through integration of lean and 6R approach. In order to propose implementation approach, the first leading task is the selection of appropriate implementation approach type. Table 1 demonstrated the most widely recognized and appropriate methodology type is framework implementation same as previously suggested by Rafique *et al.* [31] in their research study. Next major step is the selection of methodology for validation of proposed framework. In this regard, the results of Jasti and Kodali [30], Rafique *et al.* [31] shows that the case study is the most suitable methodology for framework implementation. There are two types of case studies available in previous literature, which are longitudinal case studies and cross-sectional case studies [66]. Further execution indicated that longitudinal case studies are appropriate methodology for implementation of framework approach [31]. Step/elements selection was next important task after confirmation of suitable methodology. In this regard, present study tries to find out step that has been utilized by different researchers. In-depth investigation of selected publications revealed that VSM is suitable tool for lean implementation. Table 1 clearly points out that 18 out of 26 Implementation approaches used VSM which is 69% of total; and out of these 18, 6 proposed Implementation framework future and out of these 6, 4 implementation approaches adopt longitudinal case study type which is 66% of total present study. Regarding the number of phases, different researches have employed mostly 3 to 5 phases and each phase is evaluated at the end for checking its validity [20], [27]. Selected steps are divided into four phases in this framework. Table 3 describes the reduction of wastes through 6R approach.

The present research differs from previous research works in such a manner that he results obtained in this scenario have dual-beneficial nature. Firstly, the research provides a systematic integration framework of implementation of 6R techniques in conjunction with lean manufacturing, then testaments the efficacy of the integration by bringing about a decrease of nearly 36% in overall value-added time, more than 40% reduction in overall lead time, 22% reduction in labour utilization and direct decrease of heating cost by 50% redesigning furnaces from an environmental perspective, which was achieved by replacing oil furnaces by gas furnaces that provide higher efficacy and register lower pollution levels. It can be seen that conjunction of lean and 6R practices improves the economic and environmental performance, which ultimately directs towards a sustainable manufacturing system. The social sustainability is achieved through better working conditions as a result of lean manufacturing, and better on job health by use of eco-friendly fuel in furnaces.

TABLE 3. Integration of 6R & seven wastes.

Process	Identified waste	6r-element used to conquer waste	Tools
Nut shearing	Overproduction, Defects, Unnecessary Inventory , Noise Pollution, Waste & Excess Changeover Time	Reduce, Recover, Recycle	SMED,TPM, Skilled Workers
Nut forging	Defects, Environmental Pollution	Redesign, Reduce, Recover, Recycle	5S, TPM, Improve Technology
T1 Cell	Over-Processing	Redesign, Reduce	Improved Technology
Pickling	Inventory	Redesign ,Reuse	Improve Loading/Unloading Technology
S1 Cell	Overproduction and Defects	Reduce ,Redesign	TPM, 5S,SMED, Improved Technology, Just In Time Manufacturing, Introduce Pull System.
Forging	Defects	Reduce	5S,TPM,SMED,Improve skills, Improve technology
T1 Cell	Over-processing	Reduce, Redesign	5S,Improve technology
Assembly	-	-	-

Moreover, it will help in instilling a culture of recycling an environmental management amongst the employees.

VII. CONCLUSION

The purpose of sustainable lean is to promote the scheming of sustainable processes to reduce the consumption of resources. To achieve this, there is a need to join new procedures and methodologies through the traditional operational methodologies and this present investigation proposed a creative implementation structure which incorporates lean and sustainable approaches through consolidating lean standards with 6R. In order to attain this new framework, an extensive literature review was conducted which clearly indicated the existence of research gap through examining 27 most relevant articles that have been selected on the basis of search and selection criteria. The literature study further reveals that at present, there is a need to merge lean with other approaches to attain sustainable product. In order to do so, integration of lean approaches (VSM) and 6R is proposed as the VSM is most common and suitable approach for lean implementation and the aim of 6R approach is to reduce environmental and economic wastes. Hence, the sound approach is the design and development of well-structured and comprehensive framework. In this aspect, the selected articles have been further scrutinized and it was confirmed that implementation framework is the most appropriate approach and longitudinal case study will be most helpful to implement this. Considering this factor, an implementation framework has been proposed which is divided into four phases and subdivided into 17 steps. These steps provided complete implementation strategy. First phase is preparation phase which mainly concerns with human involvement and awareness towards lean. Second phase was current state assessment phase and focuses on identifying wastes in current state. Third phase was analysis and elimination phase. In this phase 6R approach and eight guideline questions are integrated to proposed future state map. Final phase was an action phase and it focused on the proper implementation. In this perspective, the proposed framework attempts to improve sustainability performance by providing practical help to the manufacturing industries of different sizes.

The major outcome of this study is a simplistic but holistic sustainable manufatcuring framework that hinges on integration of lean manufacturing and 6R techniques, thereby making it easy to implement and adopt by manufatcuring sector. The present case study suggests that extremelely favorable results are acheieved by integration that improves social, economic and environmental performance. This shall help in organziations in moving towards a sustainable manufacturing environment, in line with UN Sustainable Development Goals by impoving econmic frowth, proviing decent work opportunities and esuring responsible production and consumption. In comparison to previous reseraches, this enterprise finds its real time application in manufatcuring sector in the quest of achieving sustainability. The scope of this study is limited to manufaturing sector only but the framework is scalable and flexible enough to cover whole supply chain, which needs to be validated through case study.

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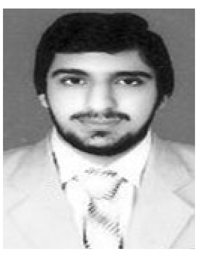

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