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RESEARCH ARTICLE - SYSTEMS ENGINEERING

Lean Approach to Enhance Manufacturing Productivity: A Case Study of Saudi Arabian Factory

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Abstract

In a present competitive market, manufacturing industries are compelled to follow a systematic approach to understand and improve manufacturing plant performance. A variety of management tools and philosophies are adopted by different industries to identify areas of opportunity for minimization of waste and maximization of production productivity. Lean manufacturing is a philosophy of waste minimization, productivity enhancement and continuous improvement. This paper considers Saudi Arabian factory as a case study. Accordingly, an approach is presented to measure the manufacturing plant performance and total productivity. Productivity benchmarking is done based on baseline productivity, and manufacturing plant performance index. The detailed case study analysis is done by gathering data from different manufacturing departments. By adopting lean approach, the manufacturing industry was able to improve its performance in each manufacturing departments. After improvement, the whole manufacturing plant performance index improved from 0.77 to 0.86, and the total factor productivity is increased by 11.45%. This case study focuses on resources utilization, man and material movements, production bottlenecks and percentage rejection. Thus, this paper is about the application of lean tools in a company and proposing an approach to apply it in Saudi Arabian factory, and the results can be applied to any other manufacturing company.

Keywords Manufacturing · Lean tools · Productivity · Value stream mapping

1 Introduction

High volatility in global markets demands for manufacturing system that are productive, flexible, reliable and cost-effective. In the present competitive scenario, there is a challenge to identify areas of opportunity for minimization of cost and maximization of productivity. It is vital to focus on manufacturing process flows and non-value adding activities within the process. The lean production framework which is originally initiated in Japan offers methods and tools to focus on value-added and non-value-added activities. Lean manufacturing principle/approach choice, implementation and achievement depend on the type of organization and the flexibility of the organization to adopt the requisite change [1–3]. It is evident that lean tools [4] prove their positive effects on operational and economic performance in multiple cases. For example, Saravanan et al. [5] implemented value stream mapping and work standardization as lean tools to improve productivity in a pre-assembly line of gearbox manufacturing company. Dhiravidamani et al. [6] adopted only two lean tools, namely kaizen and value stream map, and implemented these tools in a foundry division of an auto part manufacturing industry which resulted in improved manufacturing performance. Muñoz-Villamizar et al. [7] used value-added lean and green practices to integrate, measure, control and improve manufacturing productivity.

The paper contributes to the categorization of lean tools, their benefits and challenges. The findings from this study and adopted approach will be the guideline to other

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manufacturing sectors similar to water heater manufacturing industry. It also contributes by introducing an approach to do the manufacturing plant total productivity benchmarking. The detailed case study analysis is done by gathering data from different manufacturing departments in a Saudi Arabian factory. Further, productivity benchmarking is done based on three key indices—productivity variability, baseline productivity and manufacturing plant performance index (MPI).

This paper is organized into eight sections. Section 2 reviews the literature on lean tool adoption, derived benefits and the challenges faced by numerous types of industries. A systematic approach is adopted to measure and improve manufacturing performance through a lean manufacturing approach in Sect. 3. Data collection and current state analysis of the manufacturing plant are presented in Sect. 4 as a case study. Subsequently, Sect. 5 presents measures took to enhance the total productivity using lean tools. Section 6 presents productivity evaluation after improvements; subsequently before and after improvement comparative analysis is done and presented in Sect. 7. Finally, the paper concludes with discussion in Sect. 8.

2 Literature Review

Researchers have adopted numerous lean approaches [8–26] and also justified their implementation, it terms of benefits and their applications. Table 1 highlights notations used to categorize lean tools and benefits. These notations are also used in Tables 2 and 3 to summarize the lean manufacturing tools adopted and benefits reported by researchers for their case studies. Abdulmalek and Rajgopal [25] adapted value stream mapping and total productive maintenance in the steel industry and reported minimization of manufacturing lead time and work-in-process inventory. Taj [27] evaluated the performance of about 65 Chinese manufacturing industries that adopted lean manufacturing practices. In these industries, the impact of lean approach was measured in terms of inventory and maintenance efforts. For a garment industry in Bangladesh, Ferdousi [28] examined implementation of small lot size, physical arrangement of equipment, total preventive maintenance, continuous improvement and 5S, where the impact of lean approach reported is maximization of profit through minimization of labour costs, lead time and manufacturing costs. Researchers [29–33] discussed the

Table 1 Notations used to categorize lean tools description and benefits

Notation	Lean tools description	Notation	Lean tools benefits
T1	5S(sort, set, shine, standardize and sustain) [26]	B1	Reduce labour costs
T2	Andon [9]	B2	Reduce lead time
T3	Bottleneck analysis [17]	B3	Reduce manufacturing cycle time
T4	Continuous flow [11]	B4	Reduce manufacturing costs
T5	Gemba (real place) [13]	B5	Improve overall productivity
T6	Heijunka (level scheduling)	B6	Improve quality
T7	Hoshin Kanri (policy deployment)	B7	Improve labour productivity
T8	Jidoka (autonomation) [8]	B8	Improve profitability
T9	Just-In-Time (JIT) [14, 16]	B9	Reduce motion and transportation
T10	Kaizen (continuous improvement) [13, 15]	B10	Removal of bottlenecks
T11	Kanban (pull system) [16]	B11	Reduce wastes
T12	KPIs (key performance indicators)	B12	Reduce WIP
T13	Muda (waste) [18]	B13	Reduce processing time
T14	Overall equipment effectiveness (OEE) [12, 19]	B14	Reduce finished goods inventory
T15	PDCA (plan, do, check, act) [17]	B15	Improve on-time delivery
T16	Poka-Yoke (error proofing) [20]	B16	Reduce defects
T17	Root cause analysis	B17	Increase uptime
T18	Single-minute exchange of dies (SMED) [21]	B18	Improve healthcare facilities design
T19	Six Sigma [22]	B19	Reduce delays
T20	SMART goals	B20	Improve cost-effective delivery
T21	Standardized work [8]	B21	Improve supply chains performance
T22	Takt time	B22	Enhance total operation time
T23	Total productive maintenance (TPM) [24]	B23	Reduce non-value-added activities
T24	Value stream mapping (VSM) [25]	B24	Reduce overtime costs
T25	Visual factory [23]	B25	Improve environmental performance

Table 2 Lean tools adopted by industries

Year	Type of industry	References	T1*	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25
2007	S[#]	[25]											✓	✓										✓	✓	✓	
2009	G	[28]	✓			✓	✓	✓					✓						✓	✓							
2010	M	[30]	✓											✓												✓	
2010	M	[34]										✓	✓	✓										✓		✓	
2012	A	[32]										✓			✓	✓		✓					✓	✓			
2012	A	[31]			✓		✓					✓							✓								
2013	SC	[35]												✓												✓	
2015	H	[36]		✓												✓										✓	
2015	M	[37]										✓		✓										✓		✓	
2015	M	[38]	✓							✓	✓								✓							✓	
2015	P	[33]										✓		✓										✓		✓	
2016	SC	[39]				✓								✓												✓	
2017	H	[40]							✓																		
2017	M	[41]				✓	✓					✓											✓				
2018	M	[5]																					✓	✓		✓	
2018	M	[6]										✓												✓	✓	✓	
2018	A	[42]									✓		✓													✓	
2019	M	[43]									✓														✓		
2019	M	[7]													✓											✓	
2019	M	[44]	✓			✓								✓												✓	
2019	M	Our study			✓		✓		✓			✓		✓	✓	✓		✓		✓						✓	

[#]S: steel industry; G: garment; M: manufacturing; A: automotive; SC: supply chain; H: health care; P: process

Table 3 Lean benefits addressed in the past literature

Year	References	Lean benefits addressed (*refer Table 1)																								
		B1*	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23	B24	B25
2007	[25]		✓										✓													
2009	[28]	✓	✓	✓	✓	✓	✓		✓					✓												
2010	[30]			✓									✓			✓	✓	✓		✓						
2010	[34]		✓			✓		✓					✓	✓	✓											
2012	[32]							✓	✓	✓		✓														
2012	[31]			✓		✓					✓	✓	✓													
2013	[35]	✓																				✓	✓			
2015	[36]																		✓							
2015	[37]		✓	✓									✓	✓												
2015	[38]													✓										✓	✓	
2015	[33]		✓	✓								✓														
2016	[39]																					✓				
2017	[40]																			✓	✓					
2017	[41]			✓		✓	✓					✓	✓													
2018	[5]			✓		✓																				
2018	[6]		✓					✓									✓							✓		
2018	[42]							✓					✓										✓	✓		
2019	[43]					✓																				
2019	[7]					✓																				✓
2019	[44]					✓		✓																		
2019	Our study		✓	✓		✓		✓		✓	✓			✓			✓							✓		

implementation of value stream mapping, takt time and 5S in automobile and other manufacturing firms, focused on-time delivery, bottlenecks and productivity.

Apart from manufacturing industry, number of researchers used lean approach in supply chain management also, for example, Chen, Cheng and Huang [35] applied value stream mapping and radio frequency identification technologies to improve efficiency and effectiveness of the supply chain. Bortolotti et al. [39] investigated supply network characteristics using value stream mapping and just-in-time philosophy. Whereas, Chan and Tay [41] suggested how to organize line balancing, work standardization and kaizen for productivity improvement in a printing industry. It is evident that recently researchers [41, 43–45] also adopted a combination of lean tools to minimize wastes in a manufacturing organization. In this paper, the authors have examined the effect of implementing mix of lean approaches/tools to enhance the multifactor productivity in Saudi Arabian-based manufacturing industry.

3 Adopted Approach

It was the third quarter of the financial year 2018, and water heater manufacturing industry in Saudi Arabia in consideration was reviewing manufacturing plant productivity. After a satisfactory review, everyone present in the meeting was highly optimistic and expected a significant increase in the manufacturing productivity contrary to their present productivity level. However, for the second quarter (Q2) of the financial year, manufacturing had gone down by 7.5% compared to the first quarter (Q1). Whereas, demand in Q2 had gone up by 4.01% compared to last quarter (Q1). Management finds that over the last two quarters the manufacturing process rejection and rework rate has gone up by 16% in total. A target was set to improve their manufacturing flows by assigning their resources (man, machine, material and money) carefully and to have a competitive edge in the global dynamic market to meet demand economically. For an academic case study when we approached the management in support of systematic lean approach and ensured an enhancement in their manufacturing plant productivity, the management of industry agreed and narrated about the above review meeting. Thus, the objective is set to deal with productivity enhancement in water heater manufacturing industry in Saudi Arabia as a case study using multiple lean tools.

The case industry is manufacturer of water heaters and caters mainly to Middle East market. They manufacture various types of models of water heaters. Due to competitive market, the management is forced to ensure that water heater manufacturing plant must cater dynamic customer demands and should enhance the manufacturing plant productivity. Thus, the objective was set to enhance manufacturing plant productivity using mix of lean tools.

To start with the manufacturing plant is visited number of times and collected numerous historical data related to time study, shutdowns, maintenance and start-up approval; demand and manufacturing plans; and performance history such as manufacturing plant throughput, utilization and availability. Value stream map, bottleneck study, availability and utilization analysis, flow and distance-travelled mapping and productivity measurement are done to map the current state of the manufacturing plant. Current state value steam map of the manufacturing plant and outcome of other studies are considered to explore future possible improvements. After implementation of the improvements, value stream map and productivity analysis are also done to map the improved state of the manufacturing plant. Finally, impact of adopted approach to enhance manufacturing plant productivity using multiple lean tools is justified by having comparative analysis before and after improvement. Refer to Fig. 1 for the above stated adopted approach. Whereas, the following subsections present the approach adapted to measure and benchmark the manufacturing plant several productivities and also presents an approach to estimate performance indices for each manufacturing department and one lean performance index for the whole manufacturing plant.

3.1 Productivity Measurement and Benchmarking

Any manufacturing plant productivity is directly influenced by a number of factors. It is a measure of actual output per combined unit of labour, machine and overhead, reflecting the contributions of all factors of manufacturing. Productivity is measured in different ways, such as theoretical, actual and baseline productivity. Performance of the manufacturing plant is determined by comparing actual versus theoretical productivity. The theoretical productivity is a maximum achievable under perfect manufacturing plant operating conditions. But, shortage of machines, material, labour and or tools, mismatch between planned and actual demand, overtime, delay, breakdowns and other poor conditions are factors that may combine to form the manufacturing plant operational inefficiency. In order to determine absolute efficiency of the manufacturing plant, one must compare actual versus baseline productivity. Baseline productivity is the highest sustainable productivity level achievable under typical manufacturing plant operating conditions.

Benchmarking is an important continuous improvement process that enables any manufacturing plant to enhance their performance by identifying, adapting and implementing the best operations management practices within their manufacturing plant. Productivity benchmarking is done based on three key indices—productivity variability, baseline productivity and manufacturing performance index. The

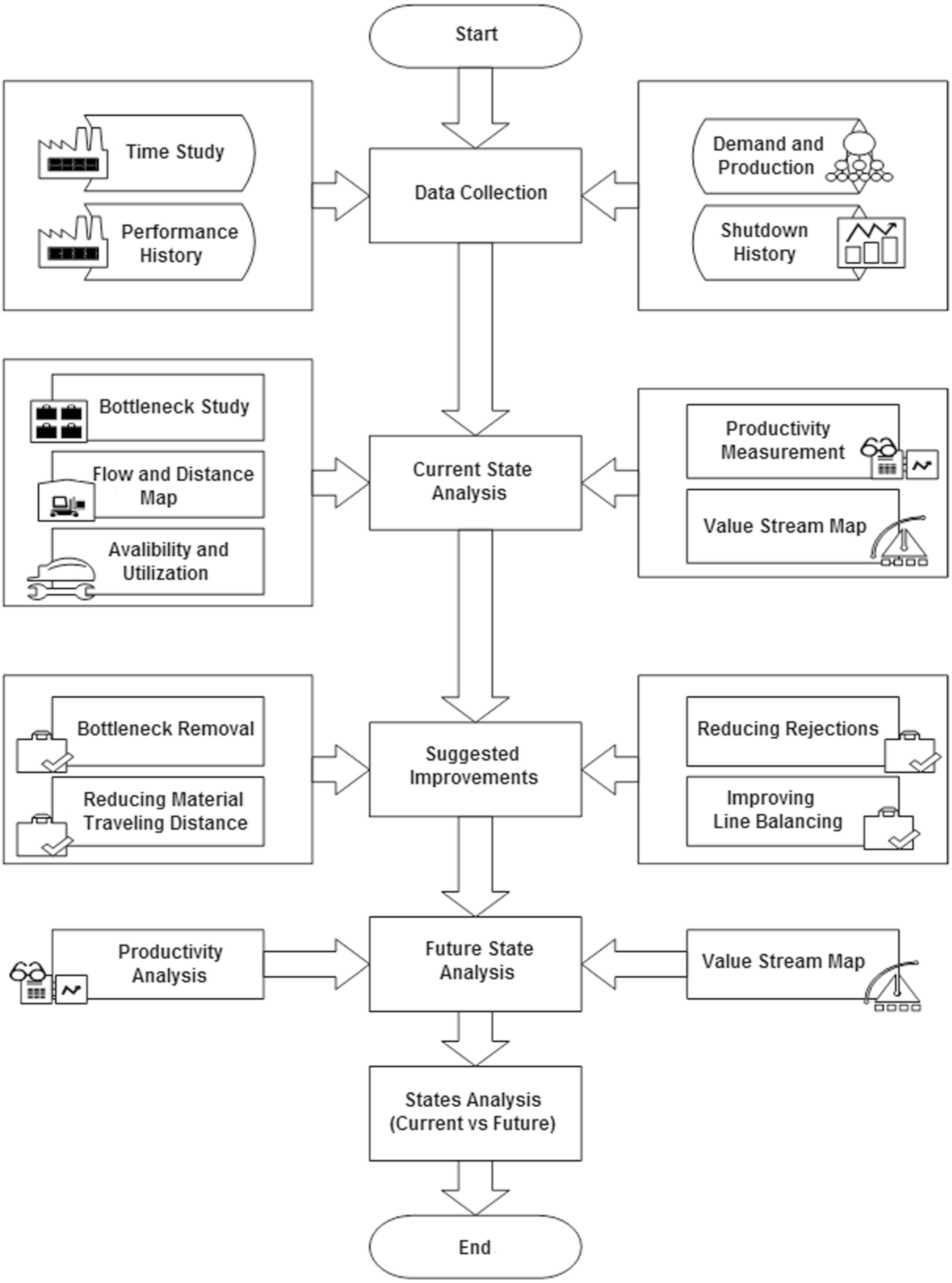


Fig. 1 Adopted approach

manufacturing plant performance is defined as ratio of actual productivity over expected (baseline) productivity. Details are here below in the following subsections.

3.2 Theoretical Productivity

To calculate theoretical productivity over labour hour, machine hour and overhead costs, refer to Eqs. 1–3 [45, 46]. As these three single-factor productivities have different units of measurement and can be combined to estimate multifactor productivity on cost basis, refer to Eq. 4.

$$\text{Labour hourly productivity}_{\text{therotical}} = \text{LHP}_{\text{t}}^{j} = \frac{Q_{\text{pp}}^{j}}{\left(T_{\text{pp}}^{j} \times N_{\text{pl}}^{j}\right)} \quad (1)$$

$$\text{Machine hourly productivity}_{\text{therotical}} = \text{MHP}_{\text{t}}^{j} = \frac{Q_{\text{pp}}^{j}}{\left(T_{\text{pp}}^{j} \times N_{\text{pm}}^{j}\right)} \quad (2)$$

$$\text{Overhead cost productivity}_{\text{therotical}} = \text{OHP}_{\text{t}}^{j} = \frac{Q_{\text{pp}}^{j}}{C_{\text{poc}}^{j}} \quad (3)$$

$$\text{Multifactor productivity}_{\text{therotical}} = \text{MFP}_{\text{t}}^{j} = \frac{Q_{\text{pp}}^{j}}{\left(C_{\text{l}}^{j} \times N_{\text{pl}}^{j} + C_{\text{m}}^{j} \times N_{\text{pm}}^{j}) * T_{\text{pp}}^{j} + C_{\text{poc}}^{j}\right)} \quad (4)$$

In Eqs. 1–4, for manufacturing department j ($j \in 1$ to m), Q_{pp}^{j} is planned manufacturing quantity, T_{pp}^{j} is planned manufacturing hours, N_{pl}^{j} is planned number of labours, N_{pm}^{j} is planned number of machines, C_{poc}^{j} is planned overhead cost (i.e. total cost of indirect material, energy consumed and other miscellaneous consumption), C_{l}^{j} is labour cost per hour and C_{m}^{j} is machine cost per hour. $\text{MFP}_{\text{m}}^{j}$ is theoretical multifactor productivity for the manufacturing department j.

3.3 Actual Productivity

Similarly, to calculate actual productivity over labour hour, machine hour and overhead costs (refer to Eqs. 5–8) [45, 46].

$$\text{Labour hourly productivity}_{\text{actual}} = \text{LHP}_{\text{a}}^{j} = \frac{Q_{\text{ap}}^{j}}{\left(T_{\text{ap}}^{j} \times N_{\text{al}}^{j}\right)} \quad (5)$$

$$\text{Machine hourly productivity}_{\text{actual}} = \text{MHP}_{\text{a}}^{j} = \frac{Q_{\text{ap}}^{j}}{\left(T_{\text{ap}}^{j} \times N_{\text{am}}^{j}\right)} \quad (6)$$

$$\text{Overhead cost productivity}_{\text{actual}} = \text{OHP}_{\text{a}}^{j} = \frac{Q_{\text{ap}}^{j}}{C_{\text{aoc}}^{j}} \quad (7)$$

$$\text{Multifactor productivity}_{\text{actual}} = \text{MFP}_{\text{a}}^{j} = \frac{Q_{\text{ap}}^{j}}{\left(\left(C_{\text{l}}^{j} \times N_{\text{al}}^{j} + C_{\text{m}}^{j} \times N_{\text{am}}^{j}\right) * T_{\text{ap}}^{j} + C_{\text{aoc}}^{j}\right)} \quad (8)$$

In Eqs. 5–8, for manufacturing department j ($j \in 1$ to m), Q_{ap}^{j} is actual manufacturing quantity, T_{ap}^{j} is actual manufacturing hours, N_{al}^{j} is actual number of labours, N_{am}^{j} is actual number of machines, C_{aoc}^{j} is actual overhead cost, C_{l}^{j} is labour cost per hour and C_{m}^{j} is machine cost per hour. $\text{MFP}_{\text{a}}^{j}$ is actual multifactor productivity for manufacturing department j.

3.4 Baseline Productivity

Baseline productivity is called benchmark productivity or the next target productivity for the whole manufacturing plant or department of the plant. Baseline productivity is determined with respect to 10% of the total planned workdays that have the highest manufacturing plant actual productivity, the number of days in the baseline set being not less than five [47]. Refer to Eqs. 9–12 to calculate baseline (benchmark) productivity, where the number n defines the size of the baseline set.

$$\text{Labour hourly productivity}_{\text{baseline}} = \text{LHP}_{\text{b}}^{j} = \frac{\sum_{1}^{n} \text{LHP}_{\text{a}}^{j}}{n} \quad (9)$$

$$\text{Machine hourly productivity}_{\text{baseline}} = \text{MHP}_{\text{b}}^{j} = \frac{\sum_{1}^{n} \text{MHP}_{\text{a}}^{j}}{n} \quad (10)$$

$$\text{Overhead cost productivity}_{\text{baseline}} = \text{OHP}_{\text{b}}^{j} = \frac{\sum_{1}^{n} \text{OHP}_{\text{a}}^{j}}{n} \quad (11)$$

$$\text{Multifactor productivity}_{\text{baseline}} = \text{MFP}_{\text{b}}^{j} = \frac{\sum_{1}^{n} \text{MFP}_{\text{a}}^{j}}{n} \quad (12)$$

Subsequently, the entire manufacturing plant theoretical, actual and baseline productivities are estimated using Eqs. 13–15, respectively, where W^{j} is a weight estimated for manufacturing department j as the ratio of the department j cycle time over the whole manufacturing plant total cycle time. Refer to Eq. 16 for W^{j} weight estimation.

$$\text{Manufacturing plant productivity}_{\text{therotical}} = \text{MPP}_{\text{therotical}} = \sum_{j=1}^{m} \left(W^{j} \times \text{MFP}_{\text{t}}^{j}\right) \quad (13)$$

$$\text{Manufacturing plant productivity}_{\text{actual}} = \text{MPP}_{\text{actual}} = \sum_{j=1}^{m} \left(W^{j} \times \text{MFP}_{\text{a}}^{j}\right) \quad (14)$$

$$\text{Manufacturing plant productivity}_{\text{baseline}} = \text{MPP}_{\text{baseline}} = \sum_{j=1}^{m}\left(W^j \times \text{MFP}_{\text{b}}^j\right) \tag{15}$$

$$W^j = \frac{\text{manufacturing department } j \text{ cycle time}}{\text{whole manufacturing plant cycle time}} = \frac{\text{CT}^j}{\text{CT}} \tag{16}$$

In Eq. 16,

$$\text{CT} = \sum_{j=1}^{m} \text{CT}^j$$

3.5 Manufacturing Plant Performance Index

When the manufacturing plant exhibits higher variability in productivity, it means poor performance. In the same way, when the manufacturing plant exhibits lower variability in productivity it means good performance [47]. Manufacturing plant performance index (MPI) is a dimensionless measure and should not be negative [47]. A higher value of MPI indicates better performance of the manufacturing plant. To estimate MPI for each manufacturing department and whole plant, refer to Eqs. 17 and 18, respectively.

$$\text{MPI for manufacturing department } j = \text{MPI}^j = \frac{\text{MFP}_{\text{a}}^j}{\text{MFP}_{\text{b}}^j} \tag{17}$$

$$\text{MPI for whole manufacturing plant} = \text{MPI}^{\text{plant}} = \frac{\text{MPP}_{\text{actual}}}{\text{MPP}_{\text{baseline}}} \tag{18}$$

4 Data Collection and Current State Analysis

The manufacturing plant of water heater consists of a number of manufacturing/manufacturing departments, which starts from press department and ends at the assembly and packaging.

4.1 Data collection

Gemba [13] (i.e. walking and visiting the manufacturing plant as a team) is an activity used to assess the flow of material, flow of information, tasks performed by operators, and so on. Gemba team members have interaction with operators, welders, technicians, assemblers, quality inspectors and other concern employees to diagnose issues in the manufacturing plant. Data related to monthly shutdown hours, percentage rejection and overall utilization of each manufacturing department are summarized in Table 4.

4.2 Current State Analysis

VSM is used to map value-added and non-value-added activities required to deliver the right quantity of product to the right customer at the right time. In the whole manufacturing cycle, total value-added time is 993.37 s per unit, whereas non-value-added time is 435.43 s per unit (refer to Fig. 2). The boiler manufacturing department has major waste in terms of non-value-added time (refer to Fig. 2 and Table 4) and rework. Anode fixing department has service time 34 s per unit (refer to Table 4) and is the bottleneck department, with an hourly manufacturing rate of 105.88 units. From the same Table 4, it is evident that the boiler manufacturing department has 87% of whole manufacturing plant total rejection, and an average monthly shutdown is 43.67 h. Therefore, the team studied failure/rejection documents and prepared Pareto chart for the boiler manufacturing department and found that circular welding and nipple welding are responsible for 77.4% of rejection (refer to Fig. 3). Similarly, the flow and distance map (refer to Fig. 4) reveals that the total travelled distance is 40,395 m/week. Whereas, flow from the press department to boiler manufacturing department and then to outer shell manufacturing department represents 64.57% of the total flow and distance travelled.

Table 4 Data for each manufacturing department in the plant

Manufacturing department	Cycle time (secs per unit)	Average shutdown (hours per month)	Rejection (% per month)	Overall effectiveness (%)	Non-value-added activity (secs per unit)
Press department	9.85	8.36	2	73.87	51.21
Boiler department	30.62	43.67	87	46.56	225.54
Shot blasting department	26.64	8.02	2	75.01	9.74
Anode fixing department	34	3.39	1	76.48	55.5
Outer shell department	27.32	8.35	7	75.22	55.49
Final assembly and packaging	26.91	8.43	2	75.97	37.95

4.3 Productivity Measurement and Benchmarking: Current State

The theoretical productivity reflects a maximum achievable under perfect operating conditions. But, mismatch between planned and actual demand, overtime, delay, breakdowns and other poor conditions results in drop of productivities. For the current state, the planned and actual monthly manufacturing quantities, manufacturing hours, number of labours, number of machines and other costs are as presented in Table 5. The information presented in Table 5 leads to estimate theoretical productivities (refer to Eqs. 1–4) and actual productivities (refer to Eqs. 5–8) for the current state and outcome presented in Table 6.

Benchmarking is an important continuous improvement process of identifying, adapting and implementing the best operations management practices. The baseline productivities are calculated (refer to Eqs. 9–12) based on the past recorded actual productivities. Baseline productivities for all manufacturing department ($j = 1$ to 6) are summarized in the same Table 6.

Manufacturing performance index (refers to Eq. 17) over multiple factors is computed for each manufacturing department; the outcome is summarized in Table 6. Total cycle time to process a unit at current state (refer to Fig. 2 and Table 5) is used to calculate the weights for each manufacturing department. Any improvement in the current state in terms of time will lead to variation in weights, so these weights are dynamic and independent. To estimate current state performance of the whole plant, manufacturing plant total productivity model is adopted (refer to Eqs. 13–18).

$$\mathrm{MPP}_{\mathrm{therotical}} = \sum_{j=1}^{6}\left(W^{j} \times \mathrm{MFP}_{\mathrm{t}}^{j}\right) = \begin{bmatrix} 0.083 * 98.63 + 0.413 * 15.82 + 0.069 * 53.22 \\ +0.065 * 90.56 + 0.213 * 32.75 + 0.158 * 22.87 \end{bmatrix} = 34.81$$

$$\mathrm{MPP}_{\mathrm{actual}} = \sum_{j=1}^{6}\left(W^{j} \times \mathrm{MFP}_{\mathrm{a}}^{j}\right) = \begin{bmatrix} 0.083 * 59.43 + 0.413 * 9.64 + 0.069 * 33.81 \\ +0.065 * 58.52 + 0.213 * 23.03 + 0.158 * 15.29 \end{bmatrix} = 22.35$$

$$\mathrm{MPP}_{\mathrm{baseline}} = \sum_{j=1}^{m}\left(W^{j} \times \mathrm{MFP}_{\mathrm{b}}^{j}\right) = \begin{bmatrix} 0.083 * 85.02 + 0.413 * 13.07 + 0.069 * 42.69 \\ +0.065 * 72.52 + 0.213 * 26.44 + 0.158 * 19.30 \end{bmatrix} = 28.76$$

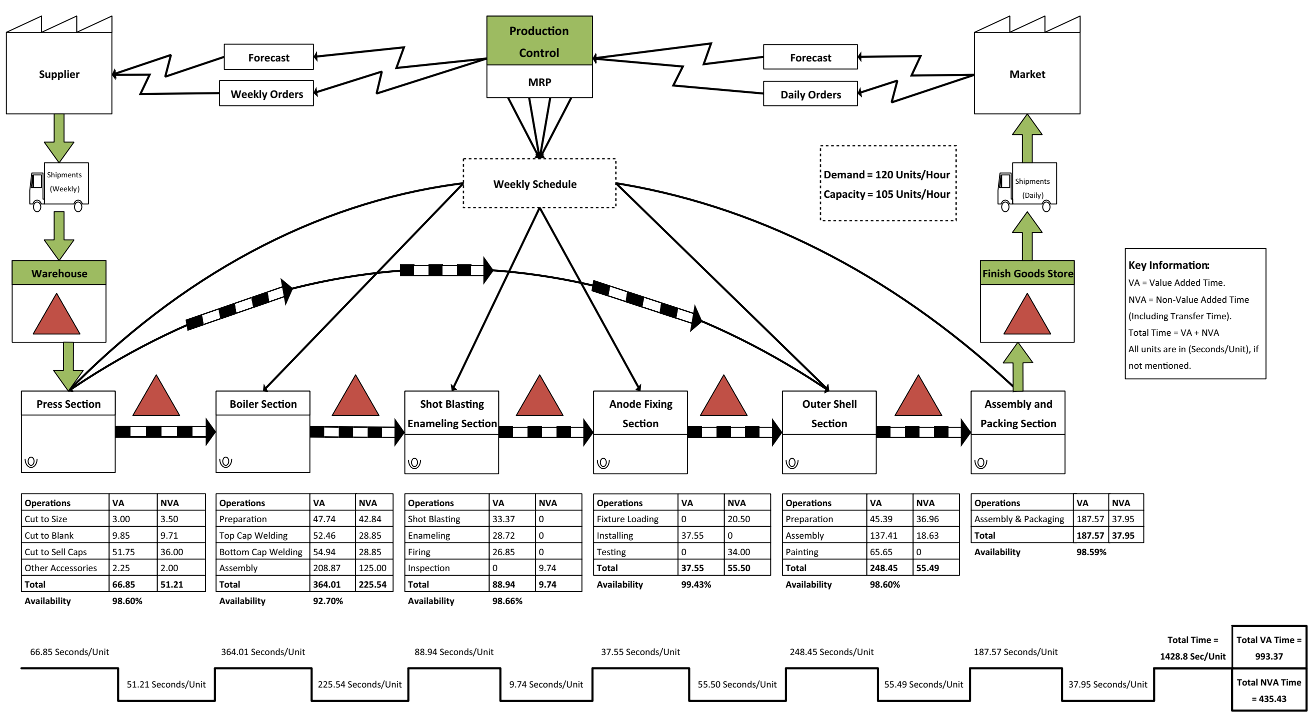
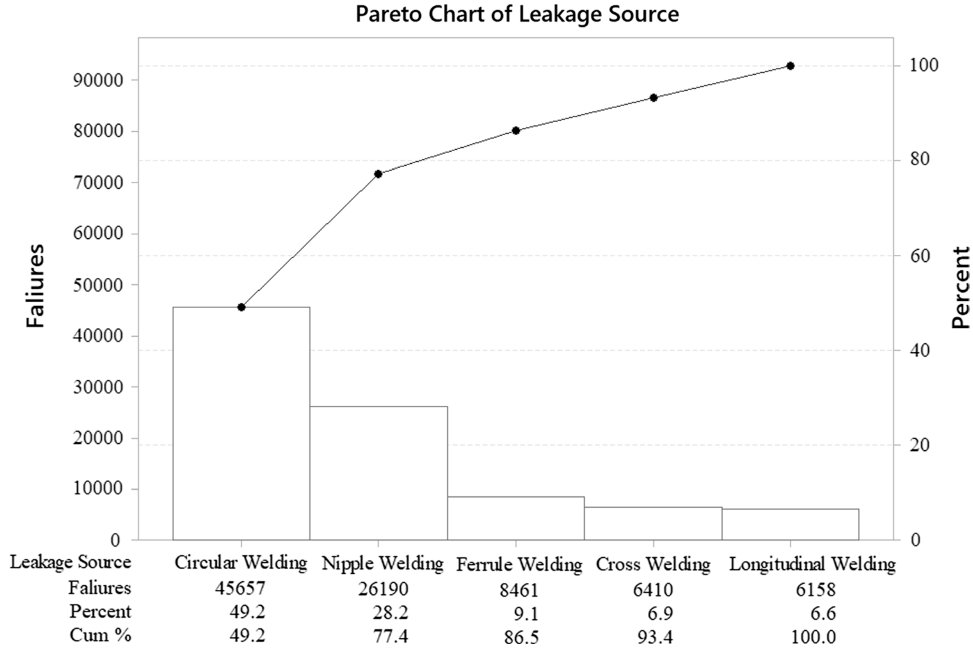


Fig. 2 Current state value stream map

Fig. 3 Pareto chart



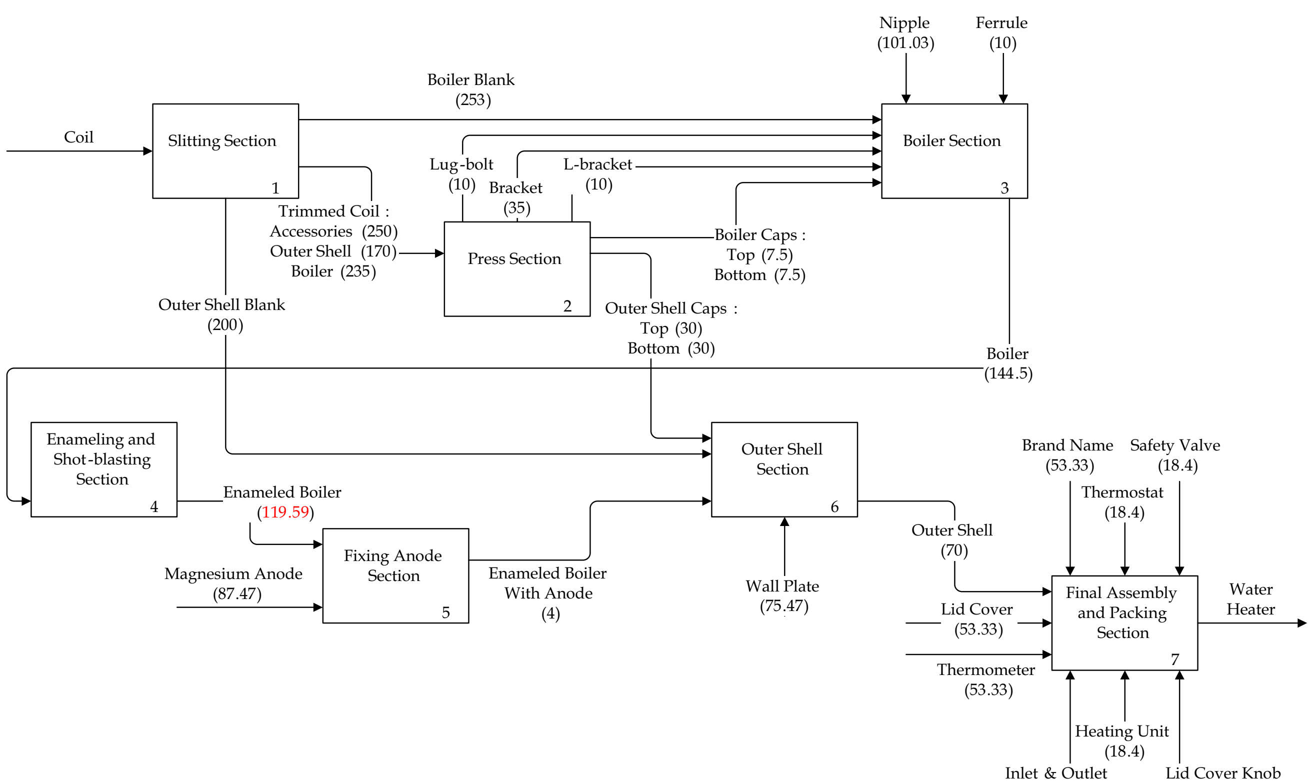


Fig. 4 Flow and distance mapping

$$\text{MPI for whole manufacturing plant} = \text{MPI}_{\text{current}} = \frac{\text{MPP}_{\text{actual}}}{\text{MPP}_{\text{baseline}}} = \frac{22.35}{28.76} = 0.777$$

Table 5 Current state planned and actual monthly manufacturing quantities, manufacturing hours, number of labours, number of machines and other costs

Manufacturing departments	j	Q^j_{pp}	T^j_{pp}	N^j_{pl}	N^j_{pm}	C^j_{pc}	Q^j_{ap}	T^j_{ap}	N^j_{al}	N^j_{am}	C^j_{ac}	C^j_{l}	C^j_{m}	CT^j	W^j
Press department	1	60,000	575	2	2	10,173	53,020	566.90	3	3	13,896	18.7	25.5	118.06	0.083
Boiler department	2	60,000	575	9	19	3791	29,796	524.37	8	17	2977	18.7	25.5	589.55	0.413
Shot blasting department	3	60,000	575	1	6	3270	51,495	565.70	2	8	4823	18.7	25.5	98.68	0.069
Anode fixing department	4	60,000	575	2	3	760	53,479	571.07	3	4	951	18.7	25.5	93.05	0.065
Outer shell department	5	60,000	575	6	8	1395	53,274	565.32	8	10	1932	18.7	25.5	303.94	0.213
Final assembly and packaging	6	60,000	575	13	8	5287	54,078	565.22	19	10	7649	18.7	25.5	225.52	0.158

Table 6 Theoretical productivities and actual productivities for the current state

Manufacturing departments	j	LHP^j_t	MHP^j_t	OHP^j_t	MFP^j_t	LHP^j_a	MHP^j_a	OHP^j_a	MFP^j_a	LHP^j_b	MHP^j_b	OHP^j_b	MFP^j_b	MPI^j
Press department	1	52.17	52.17	5.90	98.36	31.12	31.12	3.82	59.43	44.33	44.33	3.36	85.02	0.70
Boiler department	2	11.59	5.49	15.83	15.82	7.09	3.34	10.01	9.64	9.67	4.46	13.10	13.07	0.74
Shot blasting department	3	52.17	17.39	18.35	53.22	30.27	11.35	10.68	33.81	44.11	12.68	13.40	42.69	0.79
Anode fixing department	4	52.17	34.78	78.95	90.56	31.16	23.37	56.23	58.52	38.24	28.68	70.16	72.52	0.81
Outer shell department	5	17.39	13.04	43.01	32.75	11.74	9.40	27.57	23.03	14.22	10.34	33.80	26.44	0.87
Final assembly and packaging	6	8.03	13.04	11.35	22.87	5.02	9.54	7.07	15.29	6.35	11.43	8.81	19.30	0.79

To maximize the whole manufacturing plant performance through pre-evaluation of the manufacturing plant, a systematic lean continuous improvement approach is adopted. If both the actual and the baseline performance become equal, then it means the maximum productivity is achieved. As objective is to enhance productivities for the manufacturing plant, suggested improvements, their impact on the manufacturing plant performance index and comparative analysis are presented in the following sections.

5 Measures Taken to Enhance Productivity Using Lean Tools

After studying current state, various issues are identified in the manufacturing plant, such as non-value-added time per unit, rejection percentage, bottleneck, the total flow and distance travelled. These issues directly or indirectly affects the productivity of the manufacturing plant, and the current state manufacturing performance index is measured as 0.7796, which is far behind benchmark. To enhance the manufacturing plant productivity and to counter these issues, mix of lean tools were identified and used.

From the outcome of the current state value stream map, productivity measurement and benchmarking, it is evident that the boiler manufacturing department has maximum non-value-added time per unit and has maximum rejection percentage. Priority is set to do improvement at boiler manufacturing department.

5.1 Cause and Effect Diagram

A cause and effect diagram or fishbone diagram helps to identify the possible causes of reworks or rejections (refer to Fig. 5). Circular welding and nipple welding are responsible for 77.4% of rejection (refer to Fig. 3). Walked through the manufacturing plant as a team and had formal talk with welders assigned for circular and nipple welding. They highlight that welding fumes, spatter on welding areas, cylinder leakages, welding gas mixture percentages and lack of flow rate gauges are the causes of reworks and or rejections. Team suggested use of an alternative gas mixture and adopted 5S for gauges. After proper implementation, this in return decreases NVA time at boiler manufacturing department by 33.6% and increases hourly output by 15%.

5.2 Bottleneck Analysis

Current value stream map analysis (refer to Fig. 2) brings to notice that the fixing anode department is a bottleneck with a process time of 34 s per unit. Here in the anode fixing department, a robotic arm brings the boiler to the semi-automated leakage test station and fills the air, and a quality inspector at the station visually inspects the leakage. We suggested an additional robotic arm, which reduces the bottleneck station process time to 17 s per unit and as a result, hourly capacity increases to 150 units. As an alternative, also suggested to standardize the operation sequence, cycle time of the fixing anode department reduces to 29 s per unit and as a result, hourly capacity increases to 124 units.

Management of the industry accepted to standardize operational sequence, citing cost constraints.

5.3 Lean Kaizen

The goals of lean kaizen were set to reduce the overall lead time, the number of delays and excess transportation in the manufacturing plant. The data were collected by direct observation as explained in Sect. 4. Accordingly, a distance measuring wheel to follow the manufacturing flow of products or labour through the manufacturing departments is used to draw a flow and distance mapping (refer to Fig. 4). The total distance travelled is calculated before and after the improvements to determine time savings. According to Harries et al. [48], each step of walking is equivalent to 0.762 m for 0.6 s. After identifying root cause of wastes using 5 why, Kaizen events were proposed in the plant layout to reduce material movement, such as redesigned material movement from press manufacturing department to boiler manufacturing department, and also to outer shell manufacturing department. Similarly, it suggested to eliminate the manual material handling at outer shell manufacturing department. Thus, the distance travelled is reduced by 198 m, saving total 155.91 s per unit.

5.4 Assembly Line Balancing

As walked through the manufacturing plant, team observed that in the final assembly-packaging department most activities are performed manually. There seems to be some flexibility to reassign labour and resources across the final assembly and packaging department. The process of aligning assembly operations to minimize output fluctuations, operational downtime and eliminate wastes is termed as assembly line balancing. Assembly line balancing is concerned with readjusting the size and assignment of the work force. Cycle time of the assembly-packaging department and required takt time are used to estimate theoretical number of stations required for the assembly-packaging department. The theoretical minimum number of workstations required is equal to 9. Using precedence data (refer Table 7) for final assembly-packaging department, adopted shortest task time and ranked positional weight approach to readjust size and the assignment of the activities at workstations. The shortest task time approach results in 12 workstations with total 101.2 s idle time. The ranked position weight approach outcomes 11 workstation and 77.38 s total idle time. So, the ranked position outcome is adopted for assembly line balancing.

6 Productivity Evaluation: After Improvement

Based on the improvements stated in Sect. 5, a new VSM is drawn (refer to Fig. 6). It shows that the total value-added time is 918.78 s per unit, whereas non-value-added time is 368.07 s per unit. For the improved state, the actual monthly

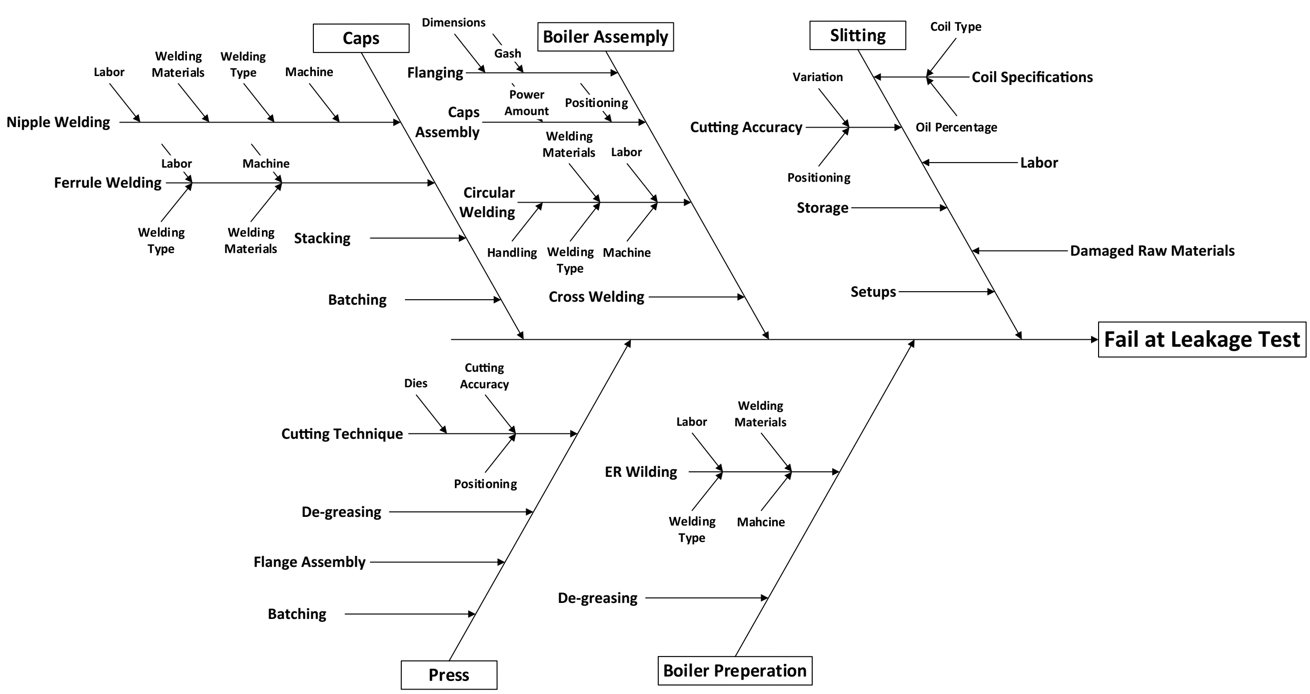


Fig. 5 Cause and effect diagram for boiler rejection

manufacturing quantities, manufacturing hours, number of labours, number of machines and other costs are as presented in Table 8, where the actual productivities are calculated (refer to Eqs. 5–8) and presented in Table 8. Theoretical and the baseline productivities remain same as calculated in Sect. 4.3 (refer to Table 6). Total cycle time to process a unit after improvements (refer to Fig. 6) is changed and used to calculate the weights for each manufacturing departments (refer to Table 8). The whole plant performance index after improvements is calculated as hereunder (refer to Eqs. 13–18).

7 Before and After Improvement Comparative Analysis

The goal was to maximize the manufacturing plant performance through a systematic lean approach. VSM current state highlights that percentage share of the value-added activities (VA) for the entire manufacturing plant is around 69%. Whereas, from new VSM (after improvements) the value-added activities (VA) for the entire manufacturing plant are around 73%. Furthermore, through the

$$\mathrm{MPP}_{\text{therotical}} = \sum_{j=1}^{6} \left(W^{j} \times \mathrm{MFP}_{\mathrm{t}}^{j} \right) = \begin{bmatrix} 0.076 * 98.63 + 0.435 * 15.82 + 0.077 * 53.22 \\ +0.058 * 90.56 + 0.237 * 32.75 + 0.117 * 22.87 \end{bmatrix} = 34.13$$

$$\mathrm{MPP}_{\text{actual}} = \sum_{j=1}^{6} \left(W^{j} \times \mathrm{MFP}_{\mathrm{a}}^{j} \right) = \begin{bmatrix} 0.076 * 69.43 + 0.435 * 9.65 + 0.077 * 41.76 \\ +0.058 * 58.62 + 0.237 * 26.40 + 0.117 * 17.48 \end{bmatrix} = 24.38$$

$$\mathrm{MPP}_{\text{baseline}} = \sum_{j=1}^{m} \left(W^{j} \times \mathrm{MFP}_{\mathrm{b}}^{j} \right) = \begin{bmatrix} 0.076 * 85.02 + 0.435 * 13.07 + 0.077 * 42.69 \\ +0.058 * 72.52 + 0.237 * 26.44 + 0.117 * 19.30 \end{bmatrix} = 28.15$$

$$\text{MPI for whole plant} = \mathrm{MPI}_{\text{after improvement}} = \frac{\mathrm{MPP}_{\text{actual}}}{\mathrm{MPP}_{\text{baseline}}} = \frac{24.38}{28.15} = 0.8661$$

Table 7 Task assigned to workstation based on precedence data for final assembly and packaging line

Task	Process	Time (secs per part)	Precedence	Minimum task time	Rank positional weight
A	Fixing stickers and thermometer	13.22	–	2	2
B	Ferrule fixing	3.1	–	1	3
C	PU foam injection, wall spacer fixing	12.43	–	1	2
D	Remove nipple plug cover, install inlet/outlet.	25.03	–	10	1
E	Install plastic bag, install carton	24.2	A, B, C	3	3
F	Unload boiler from overhead conveyor, assemble flange	24.39	E	4	4
G	Insert heating unit element with flange and insert nut	18.43	F	5	5
H	Assemble and tighten nuts	9.33	G	6	6
I	Insert thermostat and tighten screw	22.44	H	7	7
J	Electrical test	12.92	I	8	8
K	Insert lid cover	8.07	I	8	8
L	Tighten lid cover screws and assemble knob lid cover	13.2	K, J	9	9
M	Insert accessories	27.01	D, L	11	10
N	Fix carton stickers, put manual book, carton taping	9.15	M	12	11
	Total task time in second	222.92			

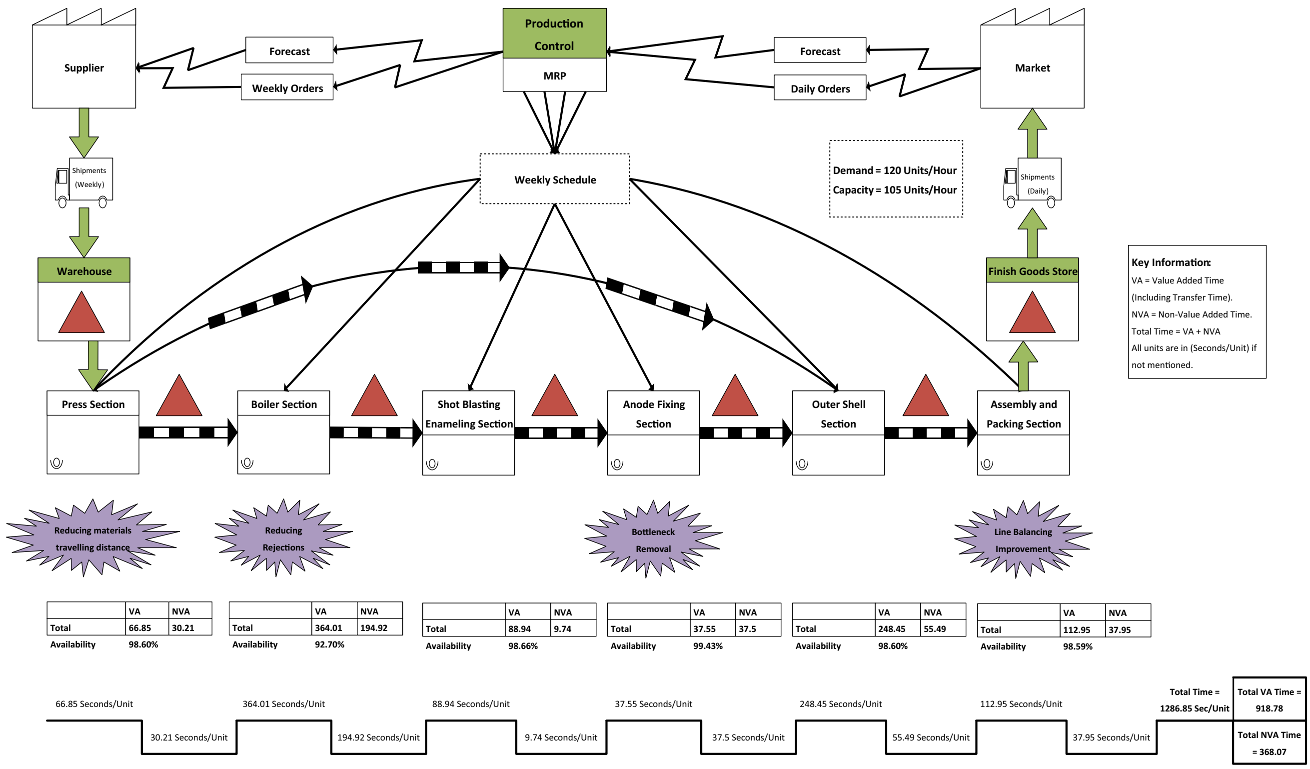


Fig. 6 Improved state value stream map

implementation of mix lean approaches, such as VSM, kaizen (continuous improvement) and bottleneck, additional benefits were obtained through the reduction in rework and failure occurring due to issue concern to welding operation at boiler manufacturing department. Further benefits were also obtained by redesigning interdepartmental and intradepartmental material flow. The manufacturing plant current state productivity assessment reveals that actual multifactor productivity for the boiler manufacturing department is very low 9.64 compared to other manufacturing departments, whereas the press department exhibits maximum 59.43 actual multifactor productivity. And, the entire manufacturing plant current state total actual productivity is measured as 22.35, which is away from both a maximum theoretically achievable total productivity 34.81 and the baseline productivity level. The entire manufacturing plant current state MPI is found to be positive and equal to 0.777; while desired MPI is 0.826. This difference pursues the industry management and decision makers for desired improvement activities in the current state manufacturing plant. Figure 7 shows the comparison between various performance indexes, and from the graphs it is evident that labour hour performance index component has significant influence on the whole plant performance, whereas overhead hour performance index component has negligible influence.

Management strives to achieve maximum productivity under typical manufacturing plant operating conditions. So, lean approach was adopted to enhance productivity of water heater manufacturing plant at Saudi Arabia. After improvement, total actual multifactor productivity (MFP) of whole manufacturing plant extents to 24.38, is better than current state actual MFP, but it is away from both estimated maximum theoretical achievable MFP and estimated baseline MFP. By comparing the current state entire manufacturing plant performance index (MPI) with MPI of improved state, it is found that MPI for the improved state is valued to be

Table 8 Improved state planned and actual monthly manufacturing quantities, manufacturing hours, number of labours, number of machines and other costs

Manufacturing departments	j	Q^j_{ap}	T^j_{ap}	N^j_{al}	N^j_{am}	C^j_{ac}	C^j_l	C^j_m	CT^j	W^j	LHP^j_a	MHP^j_a	OHP^j_a	MFP^j_a	MPI^j
Press department	1	53,020	566.9	3	3	13,896	18.7	25.5	97.06	0.075559	32.195	32.195	8.065	69.431	0.82
Boiler department	2	50,297	524.37	8	17	2977	18.7	25.5	558.93	0.435114	8.084	3.798	11.349	9.651	0.74
Shot blasting department	3	51,495	565.7	3	8	4823	18.7	25.5	98.68	0.07682	30.273	12.713	12.107	41.760	0.98
Anode fixing department	4	53,479	571.07	3	4	951	18.7	25.5	75.05	0.058425	35.285	26.454	63.794	58.615	0.81
Outer shell department	5	53,274	565.32	8	10	1932	18.7	25.5	303.94	0.23661	15.185	10.526	31.285	26.396	0.99
Final assembly and packaging	6	54,078	565.22	19	10	7649	18.7	25.5	150.9	0.117472	6.860	10.768	8.100	17.480	0.91

positive 0.866, and it is better than the estimated desired benchmarked MPI 0.825. The percentage actual productivity growth from current state to improved state of water heater manufacturing plant is now 11.45%, which a good achievement.

8 Conclusion

The Saudi Arabian manufacturing organization in consideration was interested for a systematic approach to understand and enhance their manufacturing plant productivity through a lean manufacturing approach. An approach is presented to measure and benchmark manufacturing plant performance. To remain competitive, management of the manufacturing plant should have an appropriate, simple and easily implemented continuous assessment strategy based on lean manufacturing principles. Current state value stream mapping is used to explore future improvements. With this strategy, the total value-added (VA) and non-value-added (NVA) time is reduced by 7.5% and 15.47%, respectively. Savings on VA and NVA time are due to minimization of material travelling distance and rejections, improvements at bottleneck and balancing the assembly line.

Four improvement strategies were adopted to improve the plant. Fishbone diagram and Pareto tools were used to find the causes and effect of rejection. Maximum percentage of reworks or rejection were found in welding department. The bottleneck analysis is for standardization of operation sequence and to minimize the total cycle time. The leakage test at the fixing anode department is the bottleneck station and by standardizing the operation sequence. Cycle time of the fixing anode department reduces by 14.70%. Lean kaizen approach used to reduce waste and improve the efficiency and, accordingly, identified root cause of wastes in the plant layout. Redesigning of material movement among manufacturing departments results 198 m less distance travel, saving total 155.91 s per unit. Assembly line balancing was used to reduce the number of labours at the assembly and packaging department by aligning assembly operations. By adopting lean approach, the manufacturing industry was able to improve its performance in each manufacturing departments. After improvement, the whole manufacturing plant performance index improved from 0.77 to 0.86 and the productivity is increased by 11.45% and total cycle time is reduced by 9.93%. Thus, validate the impact and use of lean approach to enhance the manufacturing plant productivity.

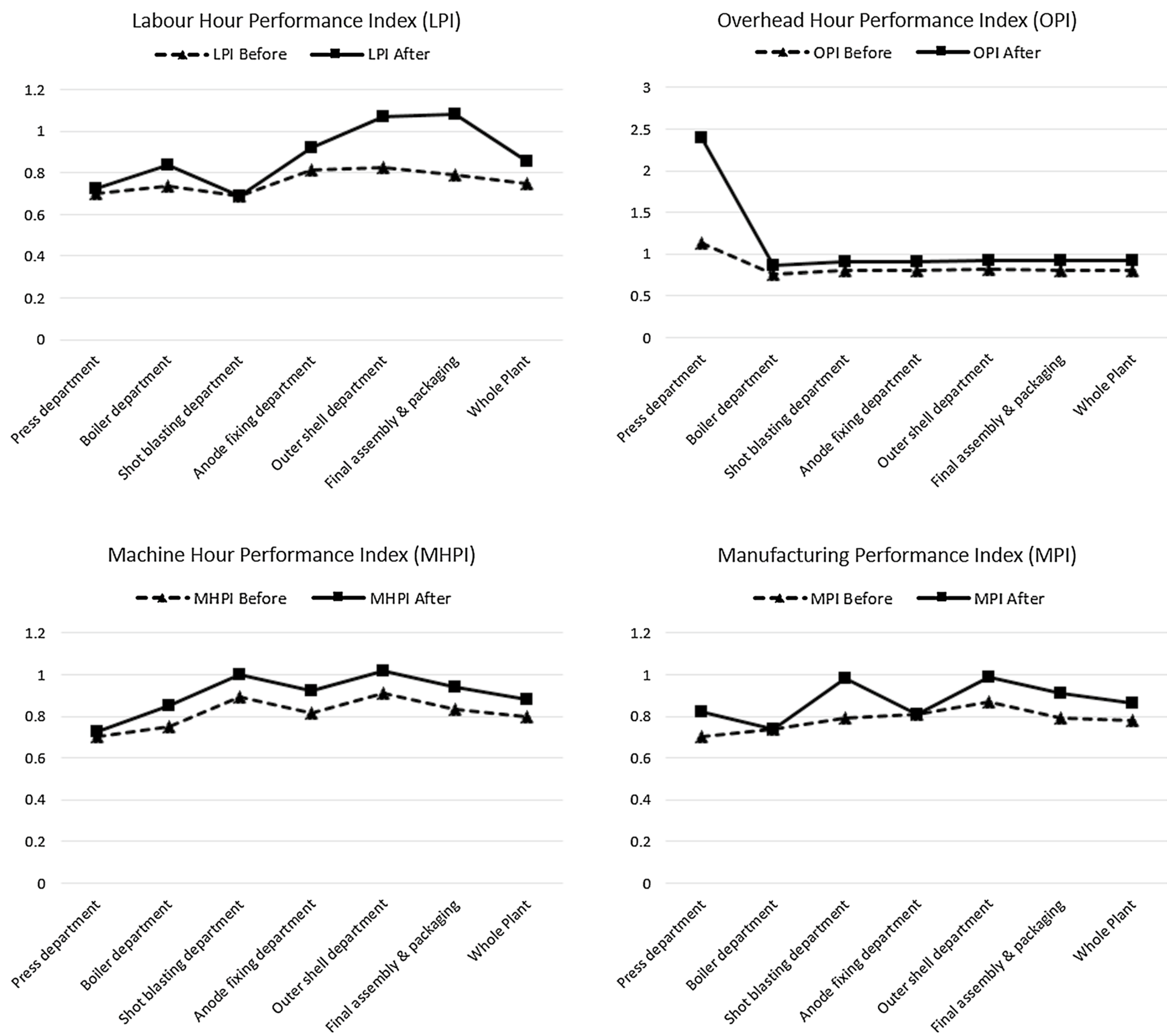


Fig. 7 Various performance indexes before and after improvement

As future scope, one can include correlations among performance measures, based on degree of implementation and assessment of leanness achieved. The adopted approach is new to Saudi Arabian industries. So there is a lot of scope for the implementation, it can be concluded that the lean manufacturing is an acceptable operation management tool. However, more attention and effort, training and operating teams are required for the success of the lean implementation in Saudi Arabia.

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References

1. Pakdil, F.; Leonard, K.M.: Criteria for a lean organisation: development of a lean assessment tool. Int. J. Prod. Res. **52**, 4587–4607 (2014). https://doi.org/10.1080/00207543.2013.879614
2. Azadeh, A.; Zarrin, M.; Abdollahi, M.; Noury, S.; Farahmand, S.: Leanness assessment and optimization by fuzzy cognitive map and multivariate analysis. Expert Syst. Appl. **42**, 6050–6064 (2015). https://doi.org/10.1016/j.eswa.2015.04.007
3. Haq, A.N.; Boddu, V.: An integrated fuzzy QFD and TOPSIS approach to enhance leanness in supply chain. Int. J. Bus. Perform. Supply Chain Model. **7**, 171–188 (2015). https://doi.org/10.1504/IJBPSCM.2015.069924
4. Henao, R.; Sarache, W.; Gómez, I.: Lean manufacturing and sustainable performance: trends and future challenges. J. Clean. Prod. **208**, 99–116 (2019). https://doi.org/10.1016/j.jclepro.2018.10.116
5. Saravanan, V.; Nallusamy, S.; George, A.: Efficiency enhancement in a medium scale gearbox manufacturing company through

different lean tools—a case study. https://www.scientific.net/JERA.34.128
6. Dhiravidamani, P.; Ramkumar, A.S.; Ponnambalam, S.G.; Subramanian, N.: Implementation of lean manufacturing and lean audit system in an auto parts manufacturing industry—an industrial case study. Int. J. Comput. Integr. Manuf. **31**, 579–594 (2018). https://doi.org/10.1080/0951192X.2017.1356473
7. Muñoz-Villamizar, A.; Santos, J.; Garcia-Sabater, J.J.; Lleo, A.; Grau, P.: Green value stream mapping approach to improving productivity and environmental performance. Int. J. Prod. Perform. Manag. (2019). https://doi.org/10.1108/IJPPM-06-2018-0216
8. Coffey, D.; Thornley, C.: Automation, motivation and lean production reconsidered. Assem. Autom. **26**, 98–103 (2006)
9. Biotto, C.; Mota, B.; Araújo, L.; Barbosa, G.; Andrade, F.: Adapted use of andon in a horizontal residential construction project. In: Proceedings of the 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, pp. 1295–1305 (2014)
10. Lam, N.T.; Toi, L.M.; Tuyen, V.T.T.: Lean line balancing for an electronics assembly line. Procedia CIRP **40**, 437–442 (2016)
11. Overboom, M.; Small, J.; Naus, F.: Applying lean principles to achieve continuous flow in 3PLs outbound processes. J. Econ. Manag. **11**, 65–79 (2013)
12. Haider, A.; Mirza, J.; Ahmad, W.: Lean capacity planning for tool room: an iterative system improvement approach. Adv. Prod. Eng. Manag. **10**, 169–184 (2015)
13. Imai, M.: Gemba Kaizen: A Commonsense Approach to a Continuous Improvement Strategy. McGraw Hill Professional, New York (2012)
14. Ward, P.; Zhou, H.: Impact of information technology integration and lean/just-in-time practices on lead-time performance. Decis. Sci. **37**, 177–203 (2006)
15. Modarress, B.; Ansari, A.; Lockwood, D.L.: Kaizen costing for lean manufacturing: a case study. Int. J. Prod. Res. **43**, 1751–1760 (2005)
16. Ciemnoczolowski, D.D.; Bozer, Y.A.: Performance evaluation of small-batch container delivery systems used in lean manufacturing–Part 2: number of Kanban and workstation starvation. Int. J. Prod. Res. **51**, 568–581 (2013)
17. Alaskari, O.; Ahmad, M.M.; Pinedo-Cuenca, R.: Development of a methodology to assist manufacturing SMEs in the selection of appropriate lean tools. Int. J. Lean Six Sigma. **7**, 62–84 (2016)
18. Mohamad, E.; Ito, T.; Yuniawan, D.; Ibrahim, M.A.; Saptari, A.; Kasim, M.S.; Izamshah, R.; Shibghatullah, A.S.; Ali, M.M.: A proposal of MUDA indicator agent to estimate lean manufacturing verification. J. Adv. Manuf. Technol. (JAMT) **8**, 71–82 (2014)
19. Jauregui Becker, J.M.; Borst, J.; van der Veen, A.: Improving the overall equipment effectiveness in high-mix-low-volume manufacturing environments. CIRP Ann. **64**, 419–422 (2015). https://doi.org/10.1016/j.cirp.2015.04.126
20. Saurin, T.A.; Ribeiro, J.L.D.; Vidor, G.: A framework for assessing poka-yoke devices. J. Manuf. Syst. **31**, 358–366 (2012). https://doi.org/10.1016/j.jmsy.2012.04.001
21. Cakmakci, M.: Process improvement: performance analysis of the setup time reduction-SMED in the automobile industry. Int. J. Adv. Manuf. Technol. **41**, 168–179 (2009). https://doi.org/10.1007/s00170-008-1434-4
22. Drohomeretski, E.; da Costa, S.E.G.; de Lima, E.P.; Garbuio, P.A.D.R.: Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. Int. J. Prod. Res. **52**, 804–824 (2014). https://doi.org/10.1080/00207543.2013.842015
23. Robinson, S.; Radnor, Z.J.; Burgess, N.; Worthington, C.: SimLean: utilising simulation in the implementation of lean in healthcare. Eur. J. Oper. Res. **219**, 188–197 (2012). https://doi.org/10.1016/j.ejor.2011.12.029
24. Ahuja, I.P.S.; Khamba, J.S.: Total productive maintenance: literature review and directions. Int. J. Qual. Reliab. Manag. **25**, 709–756 (2008). https://doi.org/10.1108/02656710810890890
25. Abdulmalek, F.A.; Rajgopal, J.: Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. Int. J. Prod. Econ. **107**, 223–236 (2007). https://doi.org/10.1016/j.ijpe.2006.09.009
26. Gapp, R.; Fisher, R.; Kobayashi, K.: Implementing 5S within a Japanese context: an integrated management system. Manag. Decis. **46**, 565–579 (2008). https://doi.org/10.1108/00251740810865067
27. Taj, S.: Lean manufacturing performance in China: assessment of 65 manufacturing plants. J. Manuf. Technol. Manag. **19**, 217–234 (2008). https://doi.org/10.1108/17410380810847927
28. Ferdousi, F.: An investigation of manufacturing performance improvement through lean production: a study on Bangladeshi garment firms. Int. J. Bus. Manag. **4**, 106 (2009). https://doi.org/10.5539/ijbm.v4n9p106
29. Singh, B.; Garg, S.K.; Sharma, S.K.; Grewal, C.: Lean implementation and its benefits to production industry. Int. J. Lean Six Sigma **1**, 157–168 (2010). https://doi.org/10.1108/20401461011049520
30. Vinodh, S.; Arvind, K.R.; Somanaathan, M.: Application of value stream mapping in an Indian camshaft manufacturing organisation. J. Manuf. Technol. Manag. **21**, 888–900 (2010). https://doi.org/10.1108/17410381011077973
31. Singh, G.; Belokar, R.M.: Lean manufacturing implementation in the assembly shop of tractor manufacturing company. Int. J. Innov. Technol. and Explor. Eng. **1**, 71–74 (2012)
32. Hemanand, K.; Amuthuselvan, D.: Improving productivity of manufacturing division using lean concepts and development of material gravity feeder–a case study. Int. J. Lean Think. **3**, 117–134 (2012)
33. Rohani, J.M.; Zahraee, S.M.: Production line analysis via value stream mapping: a lean manufacturing process of color industry. Procedia Manuf. **2**, 6–10 (2015). https://doi.org/10.1016/j.promfg.2015.07.002
34. Singh, B.; Garg, S.K.; Sharma, S.K.; Grewal, C.: Lean implementation and its benefits to production industry. Lean Six Sigma J. **1**, 157–168 (2010). https://doi.org/10.1108/20401461011049520
35. Chen, J.C.; Cheng, C.-H.; Huang, P.B.: Supply chain management with lean production and RFID application: a case study. Expert Syst. Appl. **40**, 3389–3397 (2013). https://doi.org/10.1016/j.eswa.2012.12.047
36. Hicks, C.; McGovern, T.; Prior, G.; Smith, I.: Applying lean principles to the design of healthcare facilities. Int. J. Prod. Econ. **170**, 677–686 (2015). https://doi.org/10.1016/j.ijpe.2015.05.029
37. Saraswat, P.; Sain, M.K.; Kumar, D.: Reduction of Work in Process Inventory and Production Lead Time in a Bearing Industry Using Value Stream Mapping Tool. AIRCC Publication (2015)
38. Choomlucksana, J.; Ongsaranakorn, M.; Suksabai, P.: Improving the productivity of sheet metal stamping subassembly area using the application of lean manufacturing principles. Procedia Manuf. **2**, 102–107 (2015). https://doi.org/10.1016/j.promfg.2015.07.090
39. Bortolotti, T.; Romano, P.; Martínez-Jurado, P.J.; Moyano-Fuentes, J.: Towards a theory for lean implementation in supply networks. Int. J. Prod. Econ. **175**, 182–196 (2016). https://doi.org/10.1016/j.ijpe.2016.02.020
40. Deldar, R.; Soleimani, T.; Harmon, C.; Stevens, L.H.; Sood, R.; Tholpady, S.S.; Chu, M.W.: Improving first case start times using Lean in an academic medical center. Am. J. Surg. **213**, 991–995 (2017). https://doi.org/10.1016/j.amjsurg.2016.08.025
41. Chan, C.O.; Tay, H.L.: Combining lean tools application in kaizen: a field study on the printing industry. Int. J. Prod. Perform. Manag. **67**, 45–65 (2017). https://doi.org/10.1108/IJPPM-09-2016-0197

42. Mahendran, S.; Senthilkumar, A.; Jeyapaul, R.: Analysis of lean manufacturing in an automobile industry - a case study. Int. J. Enterp. Netw. Manag. **9**, 129–142 (2018). https://doi.org/10.1504/IJENM.2018.093708
43. Dave, Y.; Sohani, N.: Improving productivity through lean practices in central India-based manufacturing industries. Lean Six Sigma J. (2019). https://doi.org/10.1108/IJLSS-10-2017-0115
44. Silva, C.D.C.M.; Arouche, M.N.M.; Lima, Z.M.; Vieira, A.C.S.; Pinheiro, E.M.: Application of lean manufacturing tools: a case study in a mattress factory. J. Lean Syst. **4**, 89–106 (2019)
45. Thomas, H.R.; Maloney, W.F.; Horner, R.M.W.; Smith, G.R.; Handa, V.K.; Sanders, S.R.: Modeling construction labor productivity. J. Constr. Eng. Manag. **116**, 705–726 (1990). https://doi.org/10.1061/(ASCE)0733-9364(1990)116:4(705)
46. Rehman, A.U.; Alkhatani, M.; Umer, U.: Multi criteria approach to measure leanness of a manufacturing organization. IEEE Access **6**, 20987–20994 (2018). https://doi.org/10.1109/ACCESS.2018.2825344
47. Thomas, H.R.; Završki, I.: Construction baseline productivity: theory and practice. J. Constr. Eng. Manag. **125**, 295–303 (1999). https://doi.org/10.1061/(ASCE)0733-9364(1999)125:5(295)
48. Harris, R.; Harris, C.; Wilson, E.; Womack, J.; Jones, D.; Shook, J.; Ferro, J.: Making materials flow: a lean material-handling guide for operations, production-control, and engineering professionals. Lean Enterprises Inst Inc, Brookline (2003)