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Ergonomic Value Stream Map Approach for Productivity Enhancement in Ductile Iron Pipe Industry

Abstract

Indian Ductile Iron (DI) Pipe Industry, being in its nascent stage, focuses to increase the production without thinking productivity. DI Pipe Industry, being Continuous Process Manufacturing with assembly lines operating throughout the year, has started adopting different methodologies like resource Optimization, Lean Manufacturing, and Six Sigma to increase its margins. But amid all these models, the Human Factor and Ergonomics (HFE) has gone somewhat overlooked as most DI Pipe plants are still labour-intensive. Most of these plants have very low levels of automation or almost no automation making them highly dependent on their existing manpower, and this push for higher productivity raises a serious question regarding the safety and well-being of the employees and workers. Hence, this study aims to probe into the HFE factor in the DI Pipe industry to improve the workers' life quality besides production and operation optimization by incorporating the HFE factor into the Value Stream Map (VSM) and creating a sustainable Ergo-VSM tool for the DI Pipe industry.

Keywords
Ergo-VSM; DI Pipe industry; HFE; Productivity

1. Introduction
The Ductile Iron (DI) Pipe Industry is practically very new as compared to other industries in the Iron and Steel sector with the Ductile Iron pipes being introduced to the marketplaces for the first time during 1950s. Ductile Iron Pipes are made of ductile cast iron and used for applications such as sanitary and water distribution and transmission purposes. This is very labour-intensive industry. So, productivity improvement is a major concern for top executives working in this sector. In past, many research studies have already applied to different lean tools for improving the productivity of DI Pipe manufacturing.

Value stream mapping (VSM) is one of the important lean techniques which is used for improving the productivity of processes. This can also be applied for DI Pipe manufacturing productivity improvement by analysing the whole DI pipe manufacturing from procurement of raw material to finished DI pipes. Additionally, VSM also helps to improve the quality of the product. Previous research studies suggest that the implementation of VSM may cause work intensification which leads to risk of musculoskeletal disorders (MSD) due to their works (Jarebrant et al., 2016). MSD is also due to work stress (Koukoulaki, 2014; Botti et al. 2017; Rathore et al., 2023). This is also applicable for DI pipe manufacturing. The manufacturing of DI pipes is associated with many challenges and issues. The critical issues are: (i) the nature of the manufacturing process is very much physically demanding, and it requires manual labour for lifting and moving heavy goods and materials; (ii) It requires to perform repetitive task like moulding, casting, and finishing processes. These challenges lead to Musculoskeletal disorders (MSD) and requires ergonomic intervention to reduce these risks.

MSD is the direct result of repetitive activities or restricted postures or working conditions that workers have to endure to apply the required productive improvements to the processes as per the lean manufacturing objectives (Botti et al., 2017). Elimination of unnecessary activities and movements or MUDA to increase productivity aggravates the ergonomic risks and deteriorates the well-being of the workers (André, Heldal and Edwards, 2015; Dombrowski et al., 2018; Koukoulaki, 2014).

This study tried to analyse the DI Pipe manufacturing plant with Human Factors and Ergonomics (HFE) approach by incorporating ergonomics concept it into a VSM technique. Basically, this study addresses the following research objectives:
RO1: To identify lean and HFE indicators to analyse the DI Pipe manufacturing.
RO2: To incorporate HFE indicators into VSM.
RO3: Identify the critical activities of DI Pipe manufacturing based on the calculated risk.

The rest of the research paper is organized as follows: Section 2 presents a literature review based on lean and HFE. Section 3 includes the overview of the DI pipe manufacturing. Section 4 presents a brief outline of research methodology. Section 5 briefly explains the case study. Section 6 includes the data collection. Section 7 presents the results and discussion on the findings. The last section highlights managerial implications and conclusion.

2. Literature Review

VSM is a lean management method that eliminates the non-value-added activities or processes and also reduces the waste for the manufacturing and service industries (Seth et al., 2017). It is also known as material and information flow mapping. First, this method develops current state map by observing the whole processes. Further, this current state map is analysed to identify the non-value-added activities. Finally, non-value-added processes/activities are minimized through lean tools and future state map is developed (Manos and Tony, 2006; Rother and Shook, 2003).

While going through the researches and studies for VSM (Manos, 2006; Rother and Shook, 2003; Wahab et al., 2013; dos Santos et al., 2015; Rathore et al., 2023), we came across a spurt of studies and researches pertaining to Ergo-VSM where the researchers and authors have actively incorporated the ergonomic factors in existing and working VSM models to emphasize the negative effects of Lean manufacturing like MSD and poor mental health of workers as well as positive effects of integration of HFE in process flows of various divergent sectors like IT industries, hospitals, textile mills, etc. Most significant of these studies are summarized in the Table 1.

Table 1. Summary of the literature on Ergo-VSM

S. No.	Study	Year	Lean Context	HFE Context	Industry	Type
1	ErgoVSM: A Tool for integrating Value Stream Mapping and Ergonomics in Manufacturing	2015	VSM	Posture, force, physical variation, porosity and ergonomic potential	Automobile Industry	Conceptual Application
2	Integration of human factors and ergonomics into lean implementation: ergonomic-value stream map approach in the textile industry	2019	VSM	Physical factors, Psycho-social factors, managerial factors and Work design factors	Textile Industry	Analytical study
3	ErgoVSM: A New Tool that Integrates Ergonomics and Productivity	2021	VSM	Ergonomic factors	Generalised	Review
4	Integrating ergonomics and lean manufacturing principles in a hybrid assembly line	2017	Lean Practices	Occupational Safety and ergonomics	Hybrid – manual with automated assembly lines	Conceptual
5	The impact of lean production on musculoskeletal and psychosocial risks: An examination of sociotechnical trends over 20 years	2014	JIT Producti on	Musculoskeletal and psychological effects	Generalised study	Conceptual

6	Ergonomic Value stream Mapping (ErgoVSM) – potential for integrating work environment issues in a Lean rationalization process at a Danish hospital	2013	VSM	Physical and Psychosocial factors	Danish Hospital	Conceptual and Application
7	Ergonomic Value Stream Mapping: A Novel Approach to Reduce Subjective Mental Workload	2018	VSM	Mental Workload	Electronic Industry	Conceptual
8	Implementation of the lean ergonomics approach to process performance improvement	2019	Lean systems	Ergonomics	Food Industry	Analytical study
9	Learning to see value stream mapping to add value and eliminate muda	2009	Lean Concepts	-	Generalized	Conceptual – Book
10	Value Stream Mapping – An Introduction	2006	VSM	-	Generalised	Conceptual Article
11	Waste Identification in a Pipe Manufacturing Through Lean Concept	2019	Lean Concepts -Time Base Mapping	-	Pipe Industry	Case Study
12	Development of fuzzy based ergonomic-value stream mapping (E-VSM) tool: a case study in Indian glass artware industry	2023	VSM	Physical factors, Psycho-social factors, managerial factors and Work design factors	Glass artware industry	Analytical study

3. Overview of the Ductile Iron (DI) Pipe Manufacturing

The manufacturing of DI pipes involves achieving a spheroidal or nodular nature of graphite structure within the cast iron. It is manufactured in metal or resin-lined moulds by centrifugal casting and a cement mortar layer (mostly and sometimes PUR) is used for internal lining while zinc, asphalt, bituminous, water-based paint, and sometimes polyethylene coatings (for extremely corrosive environments) are used for external protective coatings. An expected lifespan of DI pipes is likely 100 years based on the corrosiveness of the soil and installation practices as per 'evolving laying practices' (Rajani and Kleiner, 2003).

As it is evident from the Figure 1, DI Pipe Manufacturing is a Continuous Process Manufacturing. Continuous Process Manufacturing or just Process Manufacturing is a production line that operates 24/7, and the raw material gets perpetually processed through an uninterrupted process flow using chemical reactions or mechanical or heat treatments to produce large volumes of standardized products. Like, in DI plants, liquid iron goes in at one end of the factory for casting and then comes out as finished pipes from the other end to be shipped off.

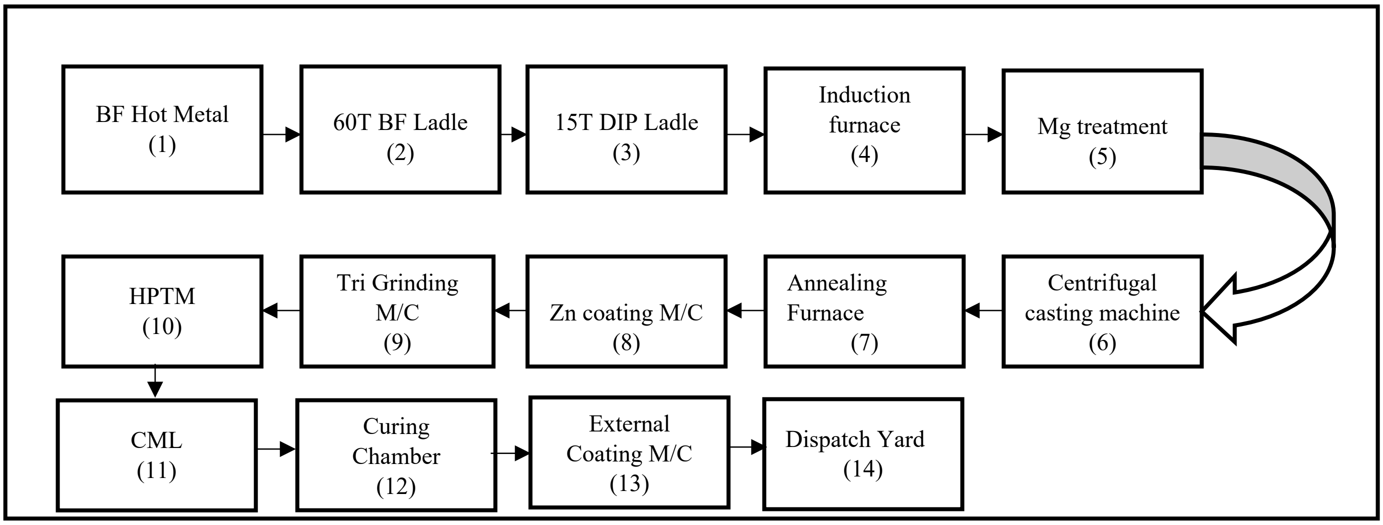

Figure 1. Detailed process of DI Pipe manufacturing

4. Methodology

In first stage, extensive literature review is done to identify lean performance and HFE indicators for DI pipe manufacturing. In second stage, workers' health and safety risk score is calculated with the help of data collected through HFE indicators questionnaire. In third stage, lean indicators data is for all processes. In fourth stage, HFE indicators categories are combined in VSM. In fifth stage, integrated tool i.e., HFE and VSM is used to develop the future state map for DI pipe manufacturing. In last stage, a comparison is performed between current state map and future state map through HFE and Lean indicators.

5. Case Study

The case study was conducted in the DI Pipe manufacturing Plant. This plant has a Hybrid type Continuous Manufacturing Process having both manual and automated processes. Hence this makes it a labour intensive and man-dependent and skill-dependent manufacturing process. The entire plant is divided into various zones based on the activities and operations carried out in the respective area. The activities of each area were mapped in detail for each area along with the waste involved, Lead Time (LT), Total Manpower involved etc. Each area has an amalgamation of various skill level Operations like Low skilled operation (LSO), Semi-skilled operation (SSO) and Skilled operation (SO) with engineers and supervisors being deputed for Skilled Operation while workers and workers being allocated to Semiskilled and Low skilled Operations. Most part of the Casting, Annealing and Finishing Operations are automated (Level -1 Automation) while the other areas are still in manual operation. A survey was conducted for HFE Risk Assessment in the ten stations of the DI Pipe manufacturing Plant.

6. Data Collection

6.1. Lean metrics and risk score for current state map

As evident from the Analysis of HFE Metrics, it can be seen that few zones namely Feeding HM, Pipe Curing, Pipe Repairing, and Yard Curing have attained High scores of risk for Physical Factors which elaborates the restricted postures, handling heavy weights facets, lack of independence for job scheduling and deficit of recovery space facets of the workers' jobs which might have detrimental effects on their health (Table 2a and Table 2b).

Table 2(a). Current State Map Lean Metrics

Lean Metrics	Feeding HM	Metal Preparation	Metal Treatment Station	Casting	Annealing	Zinc coating	Tri-Grinding Machine
CT (min)	10	61	14	17	88	4	92
SMV (min)	8	55	10	15	85	4	80
OP %	80%	90%	71%	88%	97%	100%	87%

Table 2(b). Current State Map Lean Metrics

Lean Metrics	HPTM	CML	Curing	Pipe repairing	External Coating	Yard Curing	Pick Up
CT (min)	4.5	9	960	35	70	720	5
SMV (min)	4.5	7	900	25	60	720	5
OP %	100%	78%	94%	71%	86%	100%	100%
Note: CT: Cycle Time; SMV: Standard Minute Value; OP: Operator Performance							

Table 3(a). Score of HFE Risk Level of current state map

Human Factor Metrics	Feeding HM	Metal Preparation	Metal Treatment Station	Casting	Annealing	Zinc coating	Tri-Grinding Machine
Physical Factors	4.0	3.4	3.6	3.8	3.4	3.8	4.7
Psychosocial Factors	3.8	3.3	3.6	3.6	3.4	3.5	3.8
Managerial Factors	2.3	2.2	2.1	2.1	1.8	2.0	2.1
Work Design Factors	3.6	3.6	3.3	3.7	3.9	3.7	3.4

Table 3(b). Score of HFE Risk Level of current state map

Human Factor Metrics	HPTM	CML	Curing	Pipe repairing	External Coating	Yard Curing	Pick Up
Physical Factors	3.7	3.9	4.3	4.1	3.7	4.0	3.1
Psychosocial Factors	3.7	3.5	3.7	3.5	3.2	3.7	3.4
Managerial Factors	2.1	2.0	2.3	2.1	2.1	2.2	1.9
Work Design Factors	3.6	3.6	3.1	3.4	3.1	3.3	3.6

Note: 0–1: very low (VL), 1–2: low (L), 2–3: medium (M), 3–4: high (H) and 4–5: very high (VH)

The Physical Factors, Psychosocial and Work Design scores for all zones are High which demonstrates that a large percentage of the workers are under huge mental and physical duress which might later result in MSD and mental ailments like hypertension, depression, etc Table 3 (a,,b)). These high scores demand serious remedy on behalf of the management and supervisors. This is a critical factor that needs to be taken care for successful implementation of Ergonomic VSM in the DI Pipe Plant.

6.2 Lean metrics and risk level for future state map (after intervention)

Ergonomic interventions were done based on the findings of current state map risk scores and value stream mapping method is also applied to eliminate the non-value-added activities. Intervention activities were kept on following for one month. After one month, again data is collected to establish future state map. The developed future state map with ergonomic intervention is illustrated in Table 4 (a, b) and Table 5 (a,b).

Table 4 (a). Future State Map Lean Metrics after Intervention

Lean Metrics	Feeding HM	Metal Preparation	Metal Treatment Station	Casting	Annealing	Zinc coating	Tri-Grinding Machine
CT (min)	9	58	12	16	86	4	85
SMV (min)	8	55	10	15	85	4	80
OP %	89%	95%	83%	94%	99%	100%	94%

Table 4(b) Future State Map Lean Metrics after Intervention

Lean Metrics	HPTM	CML	Curing	Pipe repairing	External Coating	Yard Curing	Pick Up
CT (min)	4.5	8	930	30	65	720	5
SMV (min)	4.5	7	900	25	60	720	5
OP %	100%	88%	97%	83%	92%	100%	100%

Table 5(a) Score of HFE Risk Level of future state map after intervention

Human Factor Metrics	Feeding HM	Metal Preparation	Metal Treatment Station	Casting	Annealing	Zinc coating	Tri-Grinding Machine
Physical Factors	VH	H	H	H	H	H	VH
Psychosocial Factors	H	H	H	H	H	H	H
Managerial Factors	M	M	M	M	L	L	M
Work Design Factors	H	H	H	H	H	H	H

Table 5(b) Score of HFE Risk Level of future state map after intervention

Human Factor Metrics	HPTM	CML	Curing	Pipe repairing	External Coating	Yard Curing	Pick Up
Physical Factors	H	H	VH	VH	H	VH	H
Psychosocial Factors	H	H	H	H	H	H	H
Managerial Factors	M	M	M	M	M	M	L
Work Design Factors	H	H	H	H	H	H	H
Note: 0–1:very low (VL), 1–2: low (L), 2–3: medium (M), 3–4: high (H) and 4–5: very high (VH)							

7. Results and Discussion

After implementation of Ergonomic VSM, there had been significant improvement in Operator Performance (OP%) in all the zones as evident from Table 4. This clearly indicates that ergonomics intervention in any workplace can significantly improve the well-being of the workers and can help to improve the overall performance. Significant reduction in risk score can be seen in all critical factors – Physical, Psychosocial, Managerial and work design. For the reduction of risk, new and sufficient workforce were hired and deputed for each station to reduce the workload and mental pressure. The workers have even been furbished with recovery rooms to rest in between their jobs to recover from fatigue and sheer exhaustion.

Significant improvements have been done in work design category and now workers are being provided requisite trainings and assessments to improve and upgrade their skills so that they have the opportunity and choice of multitasking and job rotation. Sufficient tools and have been made available for them so that they have all the necessary assets at their fingertips as per their needs to multi-task.

Table 4 (a) and (b) illustrates the overall improvement in CT and OP percentages after the ergonomics intervention which clearly demonstrates the effectiveness of Ergonomic VSM tool in a closed continuous manufacturing unit. This helps us to understand how the well-being of the workers improves the overall productivity of the workplace.

8. Conclusion

This study helps the managers to understand where the current methodologies and process practices are lacking in terms of ergonomics. Even though HFE factors are mostly overlooked in most manufacturing organizations and depending heavily on lean manufacturing and Production Optimization, but nonetheless HFE factors are not replaceable or unworthy in any sense in the long run. As evident from the study results, one can clearly see that despite the high companionship between co-workers and with their supervisors and excellent working environment, workers are still suffering due to the shortfalls in the Physical, Psychosocial and Work design HFE factors. Every day, they have to battle to physical stress, insurmountable mental stress, work overload and unrealistic deadlines which is affecting their wellbeing and mental health. In short, we can say that they are not happy or satisfied with their overall conditions and demands of their jobs.

So, it's very necessary for the managers to take this into mind and incorporate these into creating the Ergonomic VSM tool. For implementation of the new Ergonomic VSM, more employees should be hired and positioned at each station so that the existing workers don't have to battle with unattainable timelines, too much workload etc. Also, the level of automation for the plant (to minimise human intervention) has to upgraded so that the workers do not have to handle such heavy loads physically or have to be constricted in awkward working postures and positions.

Though these rapid improvements are surely eye-catching and encouraging for everyone but what's vital about these improvements are sustaining such improvements in the long run. As time passes, new demands and practices will come into being where these ergonomics factor cannot be retained as their initial state of implementation and can also be overlooked. Hence, it's totally up to the managers and supervisors to retain these ergonomics development and take care of the workers' well-being all the time while prioritising productivity, costs, and quality.

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