Waste Assessment in an Indian Casting Industry: A step towards Lean Manufacturing

Abhyuday Singh Thakur, Sagarkumar Patel, Vivek Patel

Abstract*: *In today's era of globalization, it is essential to ensure that Indian manufacturing industries like casting and metal-working industries which work on stringent conditions of varying customer demands and constant adhering to excellent quality standards are able to flourish in the fiercely competitive environment while keeping the production as economical as possible. Hence, the need arises for continuous improvement in the manufacturing phase of the product by assessing, minimizing, and eliminating wastes of any kind. This study adopts and implements a waste assessment model in a casting industry with the purpose of assessment of wastes and hence, proceed towards a leaner manufacturing set-up. Initially, the quantification of direct relationships between the seven types of wastes was done by forming a waste relationship matrix (WRM). Next, a waste assessment questionnaire (WAQ) consisting of 68 questions, was introduced for the allocation of wastes in the industry. The results of WRM and WAQ were integrated to obtain the ranks of the seven types of wastes in the industry, and it was found that waste of defects was the highest-ranked waste followed by wastes of inventory and overproduction. Process Activity Mapping (PAM) received the highest score (482.79) in the analysis done by Value Stream Analysis Tool (VALSAT), thus, it was chosen as the preferred tool in the current situation. The results of Failure Mode and Effect Analysis (FMEA) of various defects of casting indicated sand inclusions (432) and slag inclusions (336) as the defects having the highest Risk Priority Numbers (RPN).

Keywords: Casting, Failure Mode, Lean Manufacturing, Risk Priority Number, VALSAT, Waste Assessment

I. INTRODUCTION

The Indian manufacturing organizations are facing enormous pressures due to international competition and customer demands, as a result of which they are forcing radical changes to reduce cost, improve quality and increase their importance in the global market. In the last decade of the twentieth century, older and more traditional methods/systems of manufacturing have been challenged and replaced with more innovative production systems. Indian manufacturing organizations' productivity growth rate still lags when compared to more developed nations such as China and Singapore [1]. Hence, as a necessity for survival, Indian manufacturing organizations have turned towards more 'leaner' principles, which aim at the elimination of such activities that fail to add any value to the product [2].

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Waste is defined as anything but the bare minimum amount of material, parts or equipment, machines, worker's time and effort, etc., which are an absolute necessity for adding value to the product or service being offered [3]. Taiichi Ohno and Sensei Shigeo Shingo were two employees of Toyota who laid the foundation of usage of waste elimination techniques inside organizations in order to gain a strategic advantage [4]. Their focus was primarily on productivity increase rather than quality improvement. According to them, systematic elimination of wastes would ultimately decrease elements underlying poor quality and fundamental managerial problems. The lean manufacturing principles have had such a positive impact on manufacturing systems that they have also been used in supply chain management, product development, and administration activities [5]. Several other sectors of industries like service, construction, process, and health-care have implemented lean manufacturing and have benefitted from the same.

There is an array of innovative lean manufacturing systems developed to improve productivity; one example of such a system is Just-in-time (JIT). In the JIT system, the primary focus is to eliminate all the wastes from the system [6]. It comprises of several techniques and methods to increase the production quality and reduce any waste or variability in the manufacturing cycle. There are seven categories of wastes, namely, overproduction, inventory, defects, motion, process, transportation, and waiting [7, 8, 9].

Waste elimination is regarded as a part & parcel of lean manufacturing. In order to reduce downtimes and increase efficiency, streamlining production is imperative. The use and importance of waste elimination techniques are manifold. The objective of this paper is to apply a waste assessment model on a casting industry to categorize the different kinds of waste and quantify it. This approach helps to differentiate and rank the wastes according to their significance and also plays a vital role in establishing the strength of interrelationships between different types of wastes. An analysis tool, namely VALSAT, is also used as a selection mechanism to find the most appropriate mapping method for value stream analysis [4]. Through the adoption of FMEA, Risk Priority Number is obtained which tells us the most common modes of failure in the industry.

II. METHODOLOGY

Investigation of wastes is done based on the waste assessment model adopted from Rawabdeh's waste assessment research [10]. The model is initiated by laying out the fundamental descriptions of the seven types of wastes and the relationships between them. The model adopted classifies the strength of the interrelationships according to a scale that ranges from weak to very strong and creates a waste relationship matrix. Next, a waste assessment questionnaire was circulated in the industry, the results of which combined with the waste relationship matrix make it practicable to rank the wastes according to their impact on the casting industry.

A. Seven Waste Relationships

The seven wastes mentioned before were used in sophisticated interrelationship testing. Each type of waste exerts a certain influence on others and is also influenced by each one of them. This influence can be direct or indirect. The types and nature of relationships between the wastes are not of equal weights. Hence, to know which kind of waste has more contribution to the shop floor, a questionnaire of six questions having answers carrying specific weights from zero to four was used. The summation of weights of all answers for a specific relationship was added, and this score represented the strength of that relationship.

B. Waste Relationship Matrix

WRM is obtained by organizing the waste relationship scores into a matrix. As by default, the relationship score of each type of waste will be highest with itself; the diagonal values in the matrix are found to be highest. The values in the matrix are also converted into percentage values to make it easier to understand. The results are shown in Table 2.

C. Waste Assessment Questionnaire

The comprehensive WAQ consisted of 68 questions which were further classified into four groups –

1. Man
2. Machine
3. Material
4. Method

The questions represented activities/conditions which led or caused a certain kind of waste. The questions allocated 'from' note indicated the relationship that led to a particular waste, whereas the questions allocated 'to' note indicated the relationship that caused a particular waste. Each question had three options having weights of zero, half, and one.

D. Industry Assessment Analysis

Depending on the answers given in the waste assessment questionnaire, each kind of waste had a specific type of relationship with the others. The final ranking of wastes is done by following an algorithm developed by Rawabdeh. The algorithm takes into account the weights of the answers and also the frequency of a particular situation. Mathematical results in terms of percentages are obtained by multiplying the probability of the occurrence of waste to the initial indication factor of the same waste.

E. Using VALSAT Approach

An industry's value stream involves both processes/activities that add value to the product and ones that don't, beginning from raw material sourcing to invoicing of the finished product. Difficulties like lack of visibility in supply chains and lack of right mapping tool selection to increase the visibility hinder the streamlining and waste reduction in them. The VALSAT method provides a decision mechanism to help us to choose between different mapping tools depending on the value chain of the industry and current scenario. A matrix representing the co-relationship between different waste types and value stream mapping tools is created. The tool which has the highest value in the matrix is considered the most effective for application.

F. Failure Mode and Effect Analysis

FMEA analyses the possibility of likely failure modes in a systematic manner so that failures can be prevented [11]. It is a recognized preventive action process to assure quality, durability & reliability of the product [12]. In this paper, we obtain the Risk Priority Number (RPN) with the help of an FMEA questionnaire. The defects or failure modes having higher RPN have a higher chance of occurring [13].

III. RESULTS AND DISCUSSION

The present research is carried out in a casting industry which is located in Gujarat, India. It is a large scale industry with over 400 employees. Its annual turnover is about $50M. Initially, the directors of the company were informed about the objectives of the research. After they accorded their approval, the general managers and production managers with their teams were briefed about the methodology of the research. Castings manufactured here were mainly of industrial valves like ball, gate, globe, butterfly, & non-return valves. The industry had in-house machining and testing facilities. Sand-casting and Investment casting are the two types of castings that were manufactured in the industry.

A. Waste Assessment Ranking

The questionnaire containing six questions about the interrelationships between the seven types of wastes were distributed to 16 managers and 6 senior engineers. The results are represented in Table 1. The score column of Table 1 indicates the degree of relationship a specific waste type has on another waste type.

Based on relationships and scores obtained in Table I, WRM is developed and presented in Table II. In this table, rows tell the extent of the effect of one waste on others, and columns tell us the extent by which one waste can be affected by others.

Table- I: Relationship scores of the seven types of wastes

Question Relationships	Score of Relationship	Final Relationship
O-I	18	A
O-D	10	I
O-M	6	O
O-T	14	E
O-W	17	A
I-O	14	E
I-D	13	E
I-M	11	I
I-T	7	O
D-O	13	E
D-I	8	O
D-M	11	I
D-T	17	A
D-W	13	E
M-I	10	I
M-D	15	E
M-P	13	E
M-W	18	A
T-O	4	U
T-I	6	O
T-D	8	I
T-M	4	U
T-W	13	E
P-O	8	O
P-I	3	U
P-D	18	A
P-M	10	I
P-W	14	E
W-O	6	O
W-I	14	E
W-D	9	I

The waster relationship matrix is one off the most critical aspects of this research study and thus, it has to be prepared with utmost care and attention.

Table- II: Waste relationship matrix (WRM)

From/To	O	I	D	M	T	P	W
O	A	A	I	O	E	X	A
I	E	A	E	I	O	X	X
D	E	O	A	I	A	X	E
M	X	I	E	A	X	E	A
T	U	O	I	U	A	X	E
P	O	U	A	I	X	A	E
W	O	E	I	X	X	X	A

After developing Table II, the Waste Matrix Values table is developed and presented in Table 3, which transforms the score of WRM into easy to understand percentages where A=10, E=8, I=6, O=4, U=2, and X=0.

Next, we validate our above results by using the outputs of the Waste Assessment Questionnaire (WAQ). The existence of the effect of each type of waste on others and vice versa is reflected in Table IV, where results of the validation are tabulated. After multiplying an indication factor with the probability of occurrence, we get the final indication factor, which is converted into a percentage, and rankings are allotted accordingly.

As indicated in Table IV, Defects (D), Inventory (I), and Overproduction (O) are the three highest-ranked wastes in the casting industry, respectively. In manufacturing processes like casting, several defects can occur like hard spots, mold swell, sand inclusions, misruns, porosity, shrinkage, cold shuts, blowholes, hot tears, etc. These defects can be a result of misalignment of molds, lack of fluidity of fluid, improper handling, lack of proper temperature regulation, etc. Inventory and Overproduction are closely related to each other. Raw materials for castings are procured in terms of weight. Metal is a commodity item with a very fluctuating market; hence, the company buys more extensive stocks of raw material when the prices in the market are down. This leads to more storage of material, which promotes the workers to produce more. Hence, increased levels of inventory lead to overproduction. Also, overproduction leads to an increased level of inventory of finished products.

B. Application of VALSAT method

The VALSAT methodology, which is a great lean manufacturing tool, involves multiplying the final indication factor with a VALSAT scale [4]. The VALSAT scale has three types of correlation, namely, high, medium and low. The tool with the highest multiplication result is deemed to be the best-suited tool. The results of the VALSAT method are given in Table V.

Process Activity Mapping (PAM) is found to be the one with the highest score (482.79). PAM involves preliminary analysis of the whole process and all the material required during the process. Activities like operations, transport, inspection, storage, delay, etc. are recorded and then analyzed whether these activities are needed, or whether we can combine them, or simplify them. These activities are further classified into three categories:

- Value-adding activities like machining, pouring molten metal, etc.
- Non-value adding activities like waiting between two processes, excess inventory, etc.
- Necessary but non-value adding activities like transportation between warehouses, etc.

Supply Chain Response Matrix tool is the next preferred mapping approach. This tool finds out the crucial time constraints of the manufacturing processes.

After this identification, we can work to improve individual areas of the process and also target unnecessary inventory amounts. This helps in identifying minute areas of improvement, which would otherwise be left unnoticed while looking at the bigger picture.

Table- III: Waste matrix value

From/To	O	I	D	M	T	P	W	Score	%
O	10	10	6	4	8	0	10	**48**	17.27
I	8	10	8	6	4	0	0	**36**	12.95
D	8	8	10	6	10	0	8	**50**	17.98
M	0	4	8	10	0	8	10	**40**	14.39
T	2	8	6	2	10	0	8	**36**	12.95
P	4	2	10	6	0	10	8	**40**	14.39
W	4	8	6	0	0	0	10	**28**	10.07
Score	**36**	**50**	**54**	**34**	**32**	**18**	**54**	**278**	100
%	12.95	17.98	19.42	12.23	11.51	6.47	19.42	100	

Table- IV: Company assessment analysis

	O	I	D	M	T	P	W
Score (Yj)	0.54	0.55	0.57	0.58	0.57	0.65	0.58
Pj Factor	226.84	236.29	354.44	159.63	151.23	94.52	198.49
Final Result (Yjfinal)	122.43	130.94	203.36	93.01	86.44	61.60	115.16
Final result (%)	15.06	16.11	25.02	11.44	10.63	7.58	14.17
Rank	**3**	**2**	**1**	**5**	**6**	**7**	**4**

Table- V: Outcome of applying VALSAT

Waste	Weight	Mapping Tools						
		Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure Mapping
Over-production	15.06	15.06	45.18	0	15.06	45.18	45.18	0
Inventory	16.11	48.33	144.99	48.33	0	144.99	48.33	16.11
Defect	25.02	25.02	0	0	225.18	0	0	0
Motion	11.44	102.96	11.44	0	0	0	0	0
Transport	10.63	95.67	0	0	0	0	0	10.63
Process	7.58	68.22	0	22.74	7.58	0	7.58	0
Waiting	14.17	127.53	127.53	14.17	0	42.51	42.51	0
TOTAL SUM		**482.79**	**329.14**	**85.24**	**247.82**	**232.68**	**143.60**	**26.74**

C. Application of FMEA

Any manufacturing system is prone to several failures, which can be analyzed by using FMEA [14, 15]. Defects (D), was the highest-ranked waste in the industry; hence, we chose to apply FMEA on the types of defects we got in the casting. A total of 19 different types of defects were chosen and confirmed by the quality control team. Risk Priority Number (RPN) was calculated with the help of a questionnaire of FMEA, which was submitted to the quality control team.

RPN is a number that is a result of multiplication of severity, occurrence, and detection of the defect [16]. Higher RPN indicates that the failure mode is more like to occur and cause damage to the process and reduce the productivity of the organization. The results of the RPN are presented in Figure 1. From the results, we can clearly see that sand and slag inclusion have the two highest RPN (432 & 336).

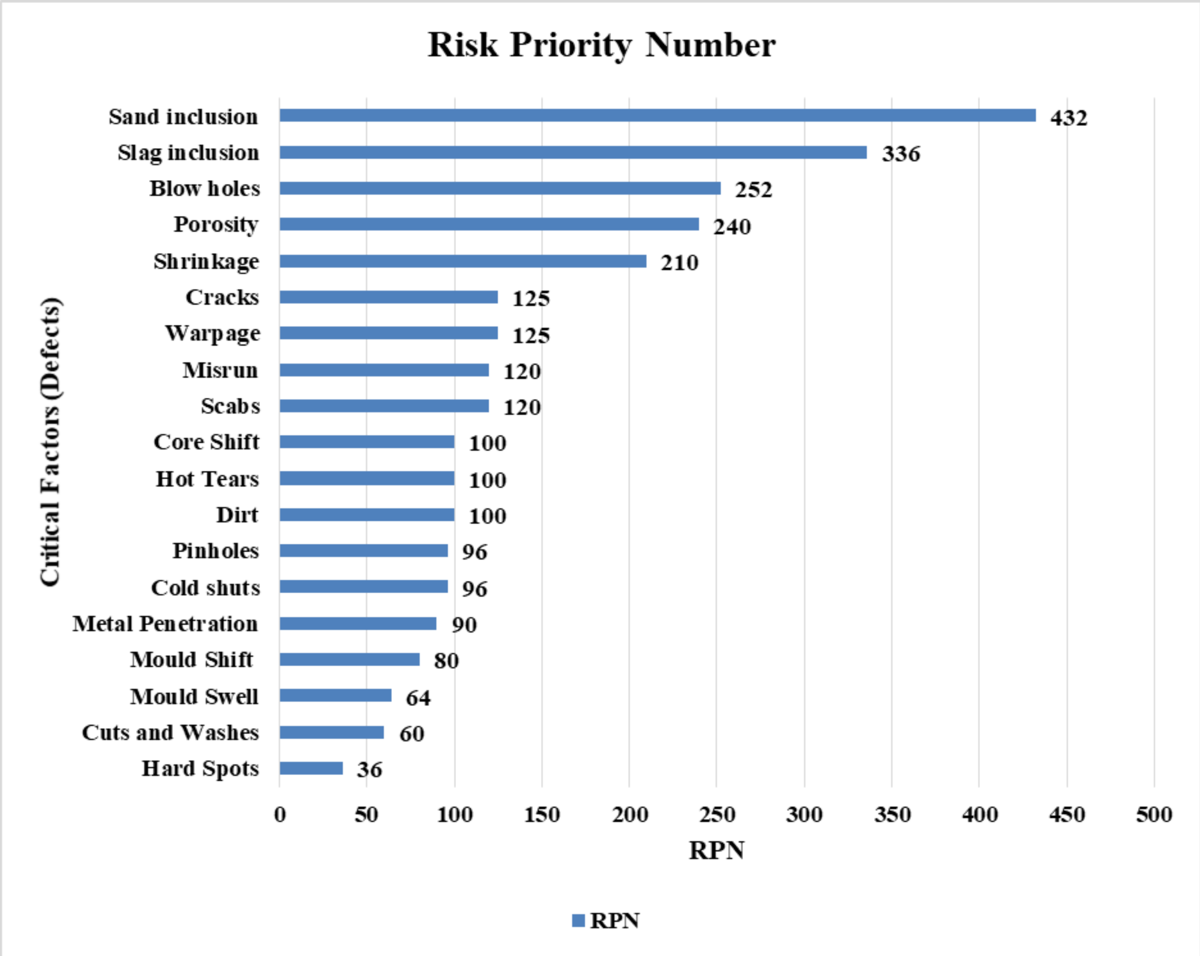

Figure-I Critical Factors Vs RPN

Therefore, we can conclude that the sand casting procedure requires urgent attention. Sand & slag inclusion in the castings can occur due to inefficient tools used during the manufacturing process and also if the operator is not competent enough. These loopholes can lead to significant dissatisfaction among the customers and lead to loss of money and time if reworking takes place or the material is replaced with a new casting. It is vital for the quality control team to monitor the material and the process at regular intervals so that the defects can be found at the early stages. The later a defect is detected, the more costly the remedy is going to be.

IV. CONCLUSION

This research study aimed to assess and minimize various wastes in the manufacturing process of the casting industry. The waste assessment model involved discussion on waste relationships, waste relationship matrix, and multiple waste assessment questionnaires. Quantification of the strength of relationships between the wastes is a crucial part of this research, which is rarely present in other assessment models. Defects, overproduction, and inventory wastes were to be found highest in the industry. Higher management of the casting industry will now put extra efforts to reduce these wastes and strive towards a leaner philosophy. With the help of this research, the elimination of wastes can be done by finding out which waste plays the most crucial role in the total generation of waste. Integrating WRM and WAQ can help any manufacturing organization to identify the root causes of the waste and further streamline their manufacturing processes by uprooting the causes and making their businesses more profitable. According to the VALSAT method, process activity mapping and supply chain response matrix are found to be the two most appropriate mapping tools. The application of these tools was not included in the scope of this research. Sand and slag inclusions had the highest RPN, which indicated an urgent need for improvement in the manufacturing process, improvement in the training of operators, and stricter inspection protocols. This research can be useful for casting industries to improve their production process and identify their areas of improvement. These industries can make an informed and focused decision to increase their productivity and work towards a better and leaner manufacturing environment.

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