Reduction of lead time through curtailment of cycle time of a supplier-a case example

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Abstract — *This study demonstrates the methodology for reduction of cycle time in the finishing department of a manufacturing company in India. The DMAIC path of lean sigma has been followed. The process performance has been assessed through summary statistics, value stream mapping, PERT technique and sigma rating. Action plans to reduce cycle time have been chalked out through process FMEA. The application of Gnatt chart has helped effectively to reduce the replacement time of rejected material. The extent of improvement in cycle time is found to be 121 days to 69 days for Bitumen coated ductile iron pipes, and 129 days to 78 days for FBE coated ductile iron pipes. This paper will be valuable to many practitioners and researchers of lean sigma for understanding the systematic structured application of quality management tools in a real life situation through appropriate quantification.*

Keywords — *Lead time, PFMEA, PERT, Gnatt chart, sigma rating, value stream mapping.*

I. INTRODUCTION

Lead time is essentially the time lag between supply of a product or service and its requisition or demand. If the lead time gets inordinately increased in procurement, maintenance of equipment and machinery, production or logistics, it adversely affects the delivery performance of an organization. This, as a result, can turn out to be a potential cause for customer dissatisfaction (both internal and external) and associated tangible as well as intangible losses like loss of image, reputation etc. It may not always be easy to quantify the pertinent losses to understand the magnitude of the problem. But in today's highly competitive global market, driven predominantly by buyers, one can perceive as to how substantial a role 'consistently reduced lead time' plays in improving delivery performance and consequently gaining the competitive edge of a business organization. This study on reduction of lead time has technically tried to identify and reduce (if not eliminate) the causes of high lead time and thus helps delineate the diagnostic and remedial journeys undertaken in an Indian manufacturing organization in the context of implementation of lean six sigma. It may be relevant to mention here the more conceptual definition of lead time given by Rajaniemi. He mentions that in the absence of finished goods or intermediate (work in progress) inventory, it is the time taken to actually manufacture the order without any inventory other than raw materials [9].

Ductile iron pipe is a pipe made of ductile cast iron commonly used for potable water transmission and distribution [22]. A ductile iron pipe manufacturing company in India encountered a chronic problem to reduce the delay in order processing system of materials. Realizing the severity of the problem, this study was undertaken to explore the feasibility of reducing the delay in order processing of material. There are different stages in order processing system. Lead time is the algebraic sum of these stages.

Lead time(days) = days taken for [casting + casting movement from casting department to finishing department + shot blasting + fettling + Zn coating + cement lining +hydro testing + machining + coating+ third party inspection + waiting for accessories + di (Ductile iron pipe) send + packing].

The process baseline for lead time has been estimated to be 129 days for FBE (Fusion Bond Epoxy) coating and 121 days for Bitumen coating. FBE and Bitumen are the two coatings applied to ductile pipes based on customer requirement. This amount of lead time is considered to be very high as far as the delivery schedule of the customers is concerned.

II. OBJECTIVE

To reduce lead time from 129 days to 80 days for FBE coating and 121 days to 85 days for bitumen coating, this turns out to be a reduction to the tune of 30 percent approximately. The objective of the study was to understand and internalize the methodology and also to reduce the time taken by critical activities through a disciplined approach. Long time back W.E. Deming suggested a radical new definition of a company's role: a better way to make money is to stay in business and provide jobs through innovation, research, constant improvement and maintenance [21]. Firms can take advantage of the six sigma implementation to improve their capacity in innovation [23]. Lean Six sigma [12] is the methodology that has been used for the purpose of the study. The concept of combining the principles and tools of lean enterprise and six sigma in a more synergistic manner has occurred in the literature over the last several years [15]. Due to commercial competition, enterprise must focus on low cost, waste elimination and work force effectiveness to get high profit by satisfying end user lean six sigma programs, which comprise statistical approaches with a systematic and quantifiable project based improvement methodology [24]. It also focuses on eliminating non value-added activities such as producing defective product, excess inventory charges due to work in process and finished goods inventory, excess internal and external transportation of product, excessive inspection and idle time of equipment or workers due to poor balance of work steps in a sequential process [5]. It may be mentioned here that the study has been carried out by adopting five phases of Lean six sigma [2]. The phases and the activities carried out are described in the following.

A. Define: Define your business problem.

B. Measure: Measure the process performance. Identify all possible inputs related to outputs.

C. Analyze: Find the root causes (X's) of the problem

D. Improve: Improve, implement new solution.

E. Control : Deliver and maintain the output performance over time.

III. *Resources*

A team was formed to carry out the study with the Purchase Manager as the team leader. The General Manager of the finishing department was the champion responsible for providing guidance, support as well as the necessary impetus. The Stores Manager (deputy leader) was the process owner as well as the executive responsible for providing routine support and resources. A project team has been set up to go through stages such as forming, storming, norming, performing, adjourning and recognition for enhancing team work to achieve project milestones.

The role of the leader and the deputy leader in the study team are provided in Table I.

TABLE I.
Resources

Member	Role in project
Leader	Adherence to timelines, following proper DMAIC structure, coordinating meetings, following agenda
DY Leader	Conduct meeting in the absence of the leader, to be updated by the project team members from time to time, updating checklists.

A. Define

The primary objectives of the define phase are:

a) Developing a project charter. b) Developing a SIPOC model. c) Description of process. d) Team formation. e) Specifying the scope of the project. f) Developing a problem statement. g) Nomenclature for Unit, Defect etc. h) Developing a process flow diagram.

1) *Project Charter-*

The different activities and corresponding schedule as vital components in project charter are given in Table II. It may be worthwhile to mention here that a project charter in lean six sigma serves as an informal contract that helps the relevant improvement team stay on track with the goals set for the enterprise.

Table II. Project charter

Project charter			
General Project Information			
Project name	Reduction of lead time through curtailment of cycle time of a supplier- a case example.		
Project manager	Mr A.Raju	Start date: 13.03.15	End date: 30.09.2015
Project essentials			
Business case	Total lead time at the finishing department of the ductile iron pipe manufacturing company is not only substantially high but also quite unpredictable. This adversely affects the delivery performance to customer. Thereby it requires focus for identification of areas where time for process execution can be reduced and also identify areas of improvement.		
Problem statement	To identify the causes for discrepancies between the expected and the actual time taken for the relevant activities and to bridge the gap by eliminating the same to the greatest extent possible.		
Goal statement	Reduce cycle time of all individual activities for overall lead time reduction.		
Project Kpov	Overall Cycle Time in order execution process of ductile iron pipe.		
Assumption	Order execution time for the similar types of material is same.		
Project scope	Execution time of the different processes in the Finishing Department.		
	Timeline	Start date	End date
Project Schedule	Review	25.03.15	31.03.15
	Plan	01.04.15	05.04.15
	Define	06.04.15	22.04.15
	Measure	23.04.15	23.06.15
	Analyze	24.06.15	27.07.15
	Improve	28.07.15	20.08.15
	Control	21.08.15	22.09.15
	Summary and closure	23.09.15	30.09.15
Project team	Mr.A.Bose(Purchase Manager) , Mr.R. Agarwal (Champion),Mr.J Ghosh (Dy leader) , Dr. P Banerjee (Guide).		

2) SIPOC Model-

The supplier-customer relationship can best be described using a SIPOC diagram which is one of the most useful techniques of process management and improvement. It presents an "at a glance" view of work flows. SIPOC is an acronym for suppliers, input, process, outputs and customer. In Table III, we present a high level process map, established through a SIPOC model for this study.

Table III. Project charter

Supplier	I/P	Process	O/P	Customer
1.Casting department 2.Cement supplier 3.Zn Supplier 4.Bitumen suppliers 5.Fusion Bond Epoxy suppliers 6.Packing box supplier	1.Semi finished pipes 2.cement 3.Zn 4.Bitumen 5.FBE 6.Pipe accessories 7.Packing box	1.Shot blasting 2.Fettling 3.Hydro testing 4.Machinig 5.Zn coating 6.Cement lining 7.coating 8. Quality inspection 9.Assembly 10. Coding, segregation of ductile iron pipes.	1.Finished pipes 3.Material usage report 4. Leak test report at hydro testing	1.Ware house (internal) and end-users (external) 2.Production planning 3.Purchasing 4.Quality assurance

3) Process Description-

The operations in the finishing process are described in a nutshell in Table IV.

Table IV. Process description for different operation

Process	Process description
Shot blasting:	Cleaning of carbon dust from metal.
Fettling	Removal of unwanted metal projection.
Hydro testing	Leak proof test of metal.
Machining	Making the flat surface on the flange portion of metal.
Zinc coating	Well-suited corrosion protective coating for steel products.
Cement lining	Cement-mortar lined ductile iron pipe is a ductile iron pipe with cement lining on the inside surface, and is commonly used for water distribution.
FBE coating	Fusion-bond epoxy powder coating and commonly referred to as FBE coating, is an epoxy-based powder coating that is widely used to protect steel pipe used in pipeline construction, concrete reinforcing bars (rebar) and on a wide variety of piping connections, valves etc. [22].
Bitumen coating	Bitumen coating is a type of coating used to build a vapor-proof and flexible protective coat in accordance with its formulation and polymerization grade. Its flexibility and protection against vapor and water can be influenced by the polymer grade as well as reinforcement of fiber. Bitumen coating can be used both externally and internally on carbon steel pipes. It is usually black, and when applied properly, this coating offers outstanding cathodic protection (protection of a metal structure from corrosion under water by making it act as an electrical cathode) needed for almost all structural steel pipes situated underground [16].
DI(Ductile iron pipe)send	Send the ductile iron pipe in packing section for packing.
Packing	a box and dispatch.

4) Process Flow Diagram-

The process flow diagrams [13] for the Bitumen coating orders and for the Fusion Bonded Epoxy (FBE) coating orders are given respectively in Figure 1 and Figure 2. The process flow diagrams have graphically outlined the sequence of the processes showing how steps in respective processes relate to each other.

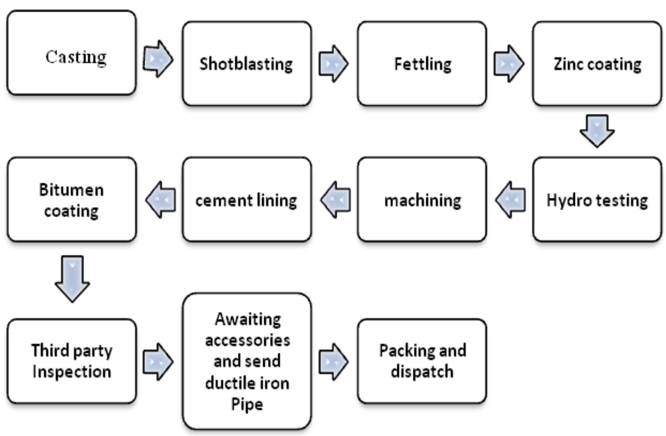


Fig1. Process flow diagram for bitumen coating order

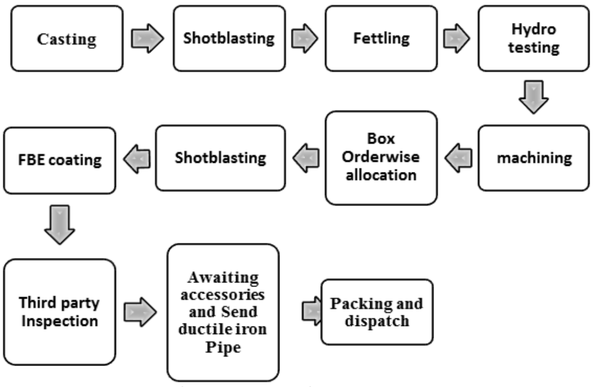


Fig 2. Process flow diagrams for FBE coating order

5) The Scope for the Study-

It is decided to carry out the study on the order processing activities of the ductile iron pipes fitted with accessories starting from the Shot Blasting to Despatch of the material for identifying bottlenecks, redundancies, value-added and non-valued activities.

6) Problem Statement-

The distilled version of the project rationale is to identify the causes for discrepancies between the expected and the actual time taken for the relevant activities and to bridge the gap by eliminating the causes thus identified to the greatest extent possible.

7) Nomenclature for unit, defect-

i) Unit: A finished or semi-finished ductile iron pipe.

ii) Defect: Any ductile iron pipe for which the actual operational time at any processing stage is more than the corresponding expected time.

iii) The expected time $t_e = \frac{t_o + 4t_m + t_p}{6}$.

Where to=optimistic time, tm=most likely time and t_p=pessimistic time.

iv) DPU: Defects per unit, i.e., the ratio of the excess operational times to the number finished or semi-finished ductile iron pipes.

v) KPIV: Key Process Input Variable. In this study, it is the individual component of cycle time at any stage of the order processing for the ductile iron pipes.

vi) KPOV: Key Process Output Variable. In this study, it is the sum total of the individual cycle times at different stages of the order processing for the ductile iron pipes.

vii) CTQ: Critical to quality characteristics. In this study, the time taken in completing an activity, which comes under the purview of direct control by the concerned organization, is identified as a CTQ related to every unit under consideration.

viii) Baseline measures: In a very general sense, it is the data signifying the level of process performance as it was operating at the initiation of an improvement project prior to solutions. In this study, the baseline sigma level has been measured as an indicator of the existing process performance.

B. Measure

The primary objectives of the measure phase in this study are:

(1) To identify the activities in the entire process, including the expected time of completion of those activities (both controllable and uncontrollable) through PERT techniques [10].

(2) To develop a data collection plan to capture the performance related to time of completion, thereby estimating the defect level.

(3) To estimate the baseline process performance through the sigma level, and fix the target completion time. Since external lead time was not within the control of management, the management felt interested in studying only the performance of internal lead time for the different activities.

There are two different types of 'order execution' after casting.

i) Bitumen Coating Orders. ii) FBE Coating Orders.

All components of Lead time for Both Bitumen and FBE Coating are furnished in Table V.

Table V. Theoretical cycle time for all different activities

Sl No	Activity description	Theoretical cycle time for Bitumen coated pipes (Days)	Theoretical cycle time for Bitumen coated pipes(Days)
1	Casting	02	02
2	Casting movement	05	05
3	Shot blasting	04	04
4	Fettling	42	42
5	Zn coating	02	xx
6	Hydro testing	07	07
7	Machining	10	10
8	Box order wise allocation	xx	10
9	Cement lining (CML)	02	xx
10	FBE Coating	xx	07
11	Coating	01	xx
12	Bitumen coating	04	xx
13	Third party inspection	07	07
14	Awaiting accessories	10	10
15	Packing	15	15
16	Di send	10	10
Total cycle time		121 Days	129 Days

1) Identification of Problem Areas of the Current Process-

Since external lead time related activity numbers 1,2,5,9 and13 for bitumen coating and 1, 2, 13 for FBE coating (Table V) are not within the direct control of the management of the finishing department, it is of interest in studying only the performance of internal lead time for the remaining concerned activities within the confine of the finishing department.

2) Data Collection Plan-

a) It was planned to put the date of receipt on every unit of ductile iron pipe by the concerned department prior to start of the activity.
b) An activity completion time (in days) was measured from the difference in receipt dates of two successive departments through which the unit travelled.
c) This exercise has been carried out for about one-month duration for each of the activities related to KPIVs (Table VI) and the respective departments /owners of the processes.
d)The cycle times of the process steps like Shot blasting, Fettling, Zinc coating, Cement lining, Machining, awaiting accessories, Ductile iron (DI) send, and Packing that have been measured, are described in Table VI. The process steps that are not within the control of the management of the finishing department, (external lead time) like casting, transition from casting department to finishing department are kept outside the purview or scope of this study. It is of interest to measure only the performance of internal lead time for the remaining concerned activities within the confine of the finishing department.
e) For any operation or activity in the finishing department, sample size varied. However, the sample of fixed order quantity with a consequent fixed order volume only has been chosen for this study.

3) Value Stream Mapping-

Value stream mapping requires a number of future-state maps, each a little leaner and closer to the ideal. It seeks a process that makes only what the next process needs, when it needs it [11]. The as-is value stream mappings for Bitumen coated pipes and Fusion Bond Epoxy (FBE) coated pipes are given in Figures 3 and 4 respectively. The value stream mappings have summarized the cycle time of each operation, change-over time from one item to another in an operation, in-process waiting time and operational time. It is to be noted that the in-process waiting time includes non-value-added but needed steps as well as absolutely non-value-added steps. Identification and reduction (if not elimination altogether) of these absolutely non-value-added steps are necessary for shortening the total lead time of the ductile iron pipe finishing operation. It can be seen from Figure 3 and Figure 4 that the total lead time in the finishing department for Bitumen coating is 121 days and that for Fusion Bond Epoxy (FBE) coating is 129 days.

4) Identification of KPIV, CTQ and KPOV-

For a description of KPIVs and CTQs,
i) KPOV: Y=f (X) =f (X1, X2, X3, X4, X5, X6, X7)

ii)KPOV is defined as the Overall Cycle Time in order execution process of ductile iron pipes. The delay alias defect is measured as the difference between the actual time and the expected time at any relevant stage of the process. Every KPIV (X) has its own defect rate. This defect rate represents the degree of non-performance D(X) of that KPIV. The degree of performance of that KPIV, P(X), is defined by: P(X) =1- D(X).

iii)Similarly, the degree of performance of KPOV, i.e. P(Y), is determined.

iv)On the basis of the collected information the KPIVs and the CTQs are described in Table VI.

Table VI. Description of KPIVs and related CTQs

KPIV	Activity description	Sample size	CTQ (Time/duration, in general)
X1	Shot blasting	67	Difference between date of Casting and Starting date of Fettling.
X2	Fettling	69	Difference between starting date of Fettling and starting date of hydro testing.
X3	Hydro testing	69	Difference between starting dates of Hydro Testing and Machining
X4	Machining	55	Difference between starting date of Machining and Cement Lining
X5B	Bitumen coating	30	Difference between starting date of Bitumen Coating and Third Party Inspection (TPI)
X5F	FBE coating	46	Difference between starting date of FBE Coating and Third Party Inspection (TPI)
X6	Awaiting accessories, Di send	56	Difference between TPI and Packing
X7	Packing	57	Difference between Starting dates of packing and Dispatch.

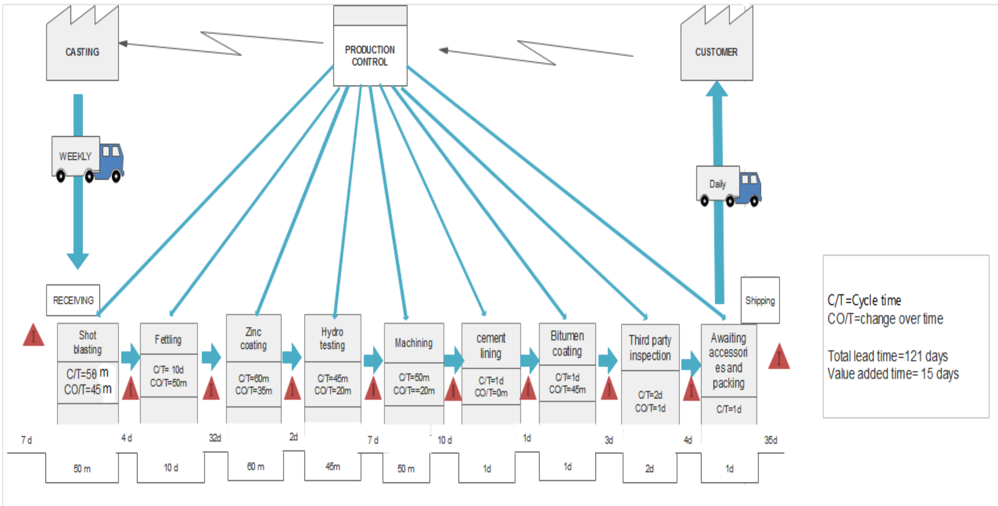


Fig3. Current value stream mapping for Bitumen coated pipes

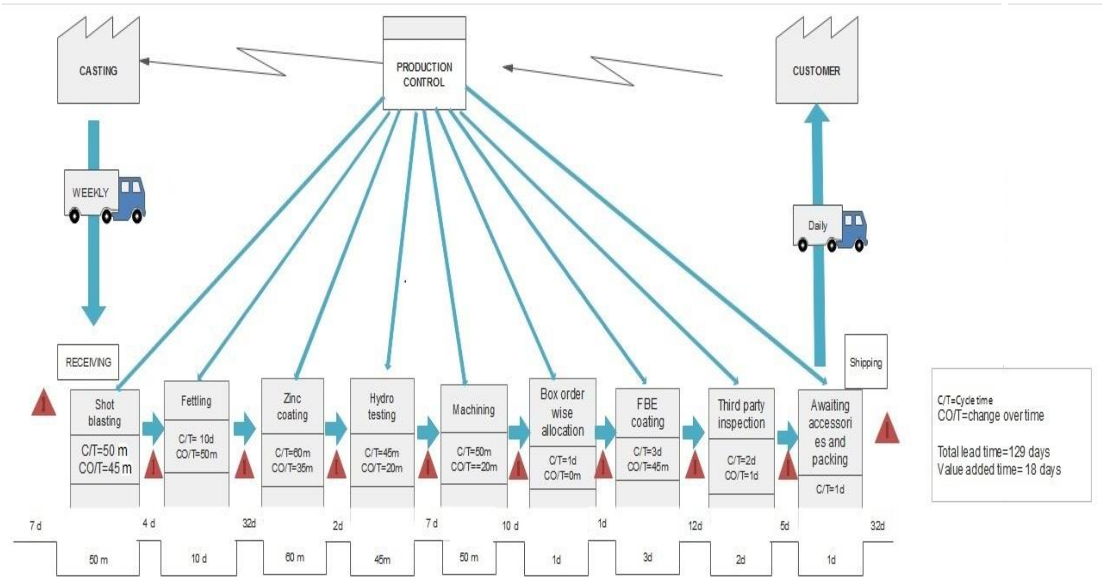


Fig4. Current value stream mapping for Fusion bond epoxy coated pipes

5) *Summary Statistics for Important KPIVs-*

To determine the distribution of lead-time, histogram has been constructed (Appendix 1) for the KPIVs for which the gap between two consecutive starting times is appreciably long. The corresponding KPIVs are Fettling, Hydro Testing, Machining, Bitumen Coating and FBE Coating. The pertinent summary statistics have also been computed and furnished in Table VII.

6) *Summary Statistics for Other KPIVs-*

In addition, histograms (Appendix 2) have been constructed to determine the distribution of lead time for other KPIVS as well for which the gap between two consecutive starting times is not appreciably long.

Based on the Anderson Darling statistic (Appendix 1 and 2) it has been found that the distributions of the cycle times of different activities do not follow Normal distribution. Consequently, median has been considered as the measure of central tendency instead of mean.

After estimation of central tendency (median), dispersion (standard deviation), 95% confidence interval of median and 95% confidence interval of standard deviation (Table 7), the expected time and the corresponding variation for any activity have been found using the Program Evaluation and Review Technique (PERT) [4]. Since the objective of the study is reduction of cycle time along with lead time, PERT is thought to be an appropriate statistical technique as a decision making tool to save time as time is a critical factor in this study. PERT is applied essentially to simplify planning and scheduling of large and complex activities of this study.

Table VII. Summary statistics for all KPIVs:

KPIV	No of observation	Median	95% lower confidence limit of median	95%upper confidence limit for median	Standard deviation (SD)	95% lower confidence limit (SD)	95% upper confidence limit (SD)
X1	67	5.00	5.00	5.01	2.79	2.39	3.37
X2	69	36.00	34.67	39.11	9.19	7.87	11.04
X3	69	6.00	6.00	7.00	1.23	1.05	1.48
X4	55	8.00	6.00	9.00	2.60	2.18	3.19
X5(Bitumen)	30	3.50	2.23	4.00	1.08	0.86	1.45
X6	56	14.00	13.24	15.00	4.68	3.95	5.74
X7	57	14.00	14.00	15.00	20.63	17.41	25.30
X5(FBE)	46	5.00	4.00	5.00	1.50	1.25	1.90
Note: The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.							

The PERT has been applied considering the summary statistics as an internal benchmark (Table VIII) as well as considering the feedback of the concerned management from Table IX based on their exposure at other plants as an external benchmark (Table X). It may be worthy to mention here that the PERT technique is based on Pessimistic (t_p), Optimistic (t_o), and most likely (t_m) times. Perceptions of the management as well as the findings based on the summary statistics are both used as separate inputs for carrying out two PERT studies.

Based on the feedback from the management from exposure in other plants, the following information (Table IX) have been made use of to evaluate the expected cycle time at the Finishing operation.

Table VIII. Estimation of expected time (t_e) and dispersion based on internal benchmark (bitumen and FBE coatings)

Process name	KPIV	To	t_m	t_p	t_e	Sd(standard deviation)
Shot blasting	X1	5.00	5.00	5.01	5.00	0.001
Fettling	X2	34.67	36.00	39.11	36.30	0.74
Hydro testing	X3	6.00	6.00	7.00	6.17	0.17
Machining	X4	6.00	8.00	9.00	7.83	0.50
Bitumen coating	X5B	2.23	3.50	4.00	3.37	0.30
DI send	X6	13.24	14.00	15.00	14.04	0.29
Packing	X7	14.00	14.00	15.00	14.17	0.16
FBE coating	X5F	4.00	5.00	5.00	4.83	0.17
Total for bitumen coating		81.15	86.50	94.12	86.87	
Total for FBE coating		82.92	88	95.12	88.33	
Note: to=Optimistic time, t_m=most likely time, t_p=pessimistic time, t_e=expected time, The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.						

Table IX. External benchmarks for optimistic, pessimistic and most likely times

Characteristic	Symbol	Bitumen Coating	FBE coating
Optimistic time	t_o	19.00	20.00
Pessimistic time	t_p	128.00	129.00
Most likely time	t_m	54.00	56.00

Table X. Estimationof expected time (t_e) and dispersion based on external benchmark

Process name	KPIV	t_o	t_m	t_p	t_e	St(standard deviation)
Shot blasting	X1	2.00	2.00	8.00	3.00	1.00
Fettling	X2	6.00	22.00	50.00	24.00	7.33
Hydro testing	X3	1.00	3.00	11.00	4.00	1.67
Machining	X4	2.00	4.00	18.00	6.00	2.67
Bitumen coating	X5B	1.00	2.00	6.00	2.50	0.83
DI send	X6	2.00	8.00	17.00	8.50	2.50
Packing	X7	5.00	13.00	18.00	12.50	2.17
FBE coating	X5F	2.00	4.50	7.00	4.50	0.83
Total for bitumen coating		19	53.50	128	60	
Total for FBE coating		20	56	129	62	

Note: to=Optimistic time, t_m=most likely time, t_p=pessimistic time, t_e=expected time, The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.

7) Expected Cycle Time Based on Internal and external Benchmark-

Based on summary statistics for cycle time of the KPIVs or the internal benchmark (Table VII) the expected cycle time has been computed to be 86.87 days for Bitumen coating and 88.33days for FBE coating for the finishing operation (Table IX).

Based on the feedback from the management from exposure in other plants (Table X) the expected cycle time has been computed to be 60 days for Bitumen coating and 62 days for FBE coating for the finishing operation (Table X).It may be worthwhile to mention here that cycle time being a lower-the-better type characteristic, external benchmark (Table X) has been given due consideration for target fixing than the corresponding internal benchmark (Table VIII) for any operation in the finishing department.

8) Target Completion Time-

Based on the findings from Table X on the performance of the identified activities with respect to time of completion and the overall expected time as perceived by the management, the target completion time for the combined seven KPIVs has been fixed at 60 days for Bitumen coating and 62 Days for FBE coating. To be more precise, the 62 days' target completion time for FBE coating and 60 days for bitumen coating is nothing but the sum total of the expected times for 7 pertinent KPIVs including FBE coating

and Bitumen coating as mentioned in Table X. Apart from these seven KPIVs, provision has to be kept for some process steps as per Tables V for activities that are of fixed duration of one day like Zinc coating, cement lining etc. and also for process steps that are beyond control of the finishing department like casting, transition from casting department to finishing department. Put together, these fixed-duration-activity and uncontrollable-activity cycle times have been worked out to be 10 days for Bitumen coating and 17 days for FBE coating. Therefore, the total expected cycle time turns out to be70 days for Bitumen coating and 79 days for FBE coating.

Table XI Sigma rating for different processes

BITUMEN COATING			FBE COATING		
Stage of rejection	Min days	Max days	Stage of rejection	Min days	Max days
Casting	42	137	Casting	42	145
Shot blasting	56	158	Shot blasting	56	173
Fettling	44	146	Fettling	44	154
Hydro testing	52	197	Hydro testing	51	203
Machining	54	207	Machining	53	213
			FBE Coating	57	230

9) Baseline Measures-

Thus Target completion time t_e is found to be 60.5 days for Bitumen coating and 62.5 days for FBE coating (based on external benchmark). The sigma rating for different processes for both Bitumen and FBE coating is computed in Table XI. The corresponding overall sigma rating is given in Table XII.

Table XII. Overall sigma rating

Process name	KPIV	No. of unit	No. of defect	DPU	Sigma rating
Shot blasting	X1	67	45	0.67	1.06
Fettling	X2	69	50	0.72	0.90
Hydro testing	X3	69	45	0.65	1.11
Machining	X4	55	29	0.52	1.43
Bitumen coating	X5B	30	20	0.66	1.07
DI send	X6	56	40	0.71	0.93
Packing	X7	57	30	0.52	1.43
FBE coating	X5F	46	23	0.50	1.50

The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.

Thus, the baseline sigma level for the exist process performance for Bitumen coating is

1.13 and FBE coating is 1.18.

10)Rework for Rejected Material-

At times, materials get rejected during testing at different stages in the finishing department. Extra times are required to replace these rejected materials with good materials that need to be re-produced. The actual additional or extra cycle time required for rejection, that can take place at different stages in the finishing department, is provided in Table XIII both for Bitumen and FBE coatings.

Table XIII. Actual extra cycle time for rejected material

Stage of rejection	Benchmark time(days)
Casting	55
Shot blasting	58
Fettling	65
Hydro testing	70
Machining	75
FBE coating	78

11)Benchmark for Cycle Time of Rejected Materials-

Considering the feedback from the concerned management based on their exposure in other plants, the target for the cycle time by means of replacement of the rejected materials through re-production has been set at different stages (Table XIV).

Table XIV. Benchmark for cycle time through replacing the rejected materials

Parameters	Bitumen Coating	FBE Coating
Number of unit checked	403	419
Defect	259	262
DPU	0.64	0.62
ZST	1.13	1.18

C. Analyze

From Table XIII it can be seen that the process baseline in terms of sigma level is 1.13 for Bitumen coating and 1.18 for Fusion Bonded Epoxy (FBE) coating, for the finishing operation. In the analysis phase, the root causes have been identified and their contributions in terms of the Risk Priority Numbers (RPN) have been computed through the application of the Process Failure Mode and Effect Analysis (PFMEA) [14].

The primary objectives of the analyze phase are:

(a) To identify all possible causes contributing to the system discrepancy,

(b) To estimate the contribution of each cause, and

(c) To segregate the most critical causes (vital few) for remedial measures.

1) Potential Causes for Long Lead Time-

There are several reasons for long lead time. By conducting brainstorming sessions, the reasons for long lead time have been identified for the stages (KPIVs) that are controllable within the confine of the finishing department. The reasons thus identified are furnished in Table XV.

2) Identification and Contribution of Causes through PFMEA Technique

The potential causes (reasons for delay) under each KPIV have been listed using the concept of PFMEA [1] and ranked on the basis of Occurrence [O], Severity [S] and Detect ability [D][17].After having discussion with the concerned management, the guideline that unanimously emerged for the scales of [O-S-D] is shown in Table XVI. By conducting a brainstorming session, the Risk Priority Number (RPN) which is the product of the likelihoods of occurrence, severity and detect ability, has been determined for each individual cause [18]. The RPN for a KPIV has been determined, in turn, by calculating the geometric mean of the RPN values of the respective causes of that KPIV (Table XVII). The geometric mean of RPNs for each KPIV has been calculated to realize the significance of them relating to the overall system discrepancy (delay). The higher the RPN value, the higher the likelihood of contribution of the particular cause for delay in the procurement of materials. Altogether 26 causes for delay have been identified considering all the 7 KPIVs.

Table XV. Causes for long lead time

Process Name	KPIV	Potential Causes
Shot blasting	X1	i) Longer change over time. ii) Shortage of space. iii) Delay in unloading of materials. iv) Lack of knowledge with respect to material specification.
Fettling	X2	i) Large number of steps required in fettling. ii) Lack of knowledge with respect to lead time. iii) Misunderstanding on schedule of work. iv) Shortage of space. v) Low manpower with lack of knowledge in mechanics. vi) Lack of knowledge on material specification. vii) Rework for poor quality product.
Hydro testing	X3	i)Too much difference (size, type etc.) in configuration of material. ii) Lack of knowledge on lead time. iii) Low manpower. iv) Lack of knowledge for handling the machine. v) Longer change over time.
Machining	X4	i) Too much difference (size, type etc.) in configuration of material. ii) Outsourcing.
Bitumen coating	X5B	i) Lack of knowledge on lead time. ii) Misconception on schedule of work i.e. prioritizing the fresh piece instead of the rejected and replaced piece.
Awaiting Accessories , Di Send	X6	i) Incomplete packing for material getting rejected after testing at various stages. ii) Lack of knowledge on lead time. iii) Stock mismatch (physical stock vs. excel sheet stock)
FBE Coating	X5F	i)Repetition of shot blasting operation. ii) Improper red& blue color scheduling in FBE. iii) Lack of knowledge on material specifications.
Note: The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.		

Table XVI. Guideline for [O-S-D] scale

Occurrence [O]	**Detect ability [D]**	**Severity [S]**
Estimates the probability that the failure mode will occur due to the cause given.	Estimates the ability to detect the failure mode before it reaches to the customer.	Estimates the effect of the failure experienced by the customer.
Remote (1) Low (2–4) Moderate (5–6) High (7–8) Very high (9)	Very high(1-2) High(3) Moderate(4-5) Low(6-7) Remote(8-10)	Minor(3) Major(6) Critical(9)

Table XVII. Contribution of causes for delay

KPIV	Process	Cause of failure	[O]	[S]	[D]	RPN	GM
X1	Shot blasting	i) Longer change over time.	3	4	3	36	69.63
		ii) Shortage of space.	4	3	6	72	
		iii) Delay in unloading of materials.	3	4	3	36	
		iv)Ambiguity on materials specification.	7	4	9	252	
X2	Fettling	i) Large number of steps required in fettling.	7	2	6	84	156.09
		ii) Lack of knowledge on lead time.	7	6	9	378	
		iii) Misunderstanding on schedule of work.	9	6	6	324	
		iv)Shortage of space.	7	2	6	084	
		v) Low manpower with lack of knowledge in mechanics.	8	4	3	096	
		vi) Ambiguity on materials specification.	7	3	6	126	
		vii) Rework for poor quality product.	6	4	9	216	

X3	Hydro testing	i)Too much difference (size, type etc.) in configuration of material. ii) Lack of knowledge on lead time. iii) Low manpower. iv) Lack of uniformity for handling the machine due to non-standardized operating procedure. v) Longer change over time.	8 8 8 7 7	1 6 2 3 8	3 9 3 6 6	24 432 48 126 336	116.07
X4	Machining	i) Too much difference (size, type etc.) in configuration of material. ii) Outsourcing.	6 7	6 8	6 6	216 336	269.40
X5B	Bitumen coating	i) Lack of knowledge on lead time. ii) Misconception on schedule of work i.e. prioritizing the fresh piece instead of the rejected and replaced piece.	8 8	6 4	7 6	336 192	254.00

Continued Table XVII

KPIV	Process	Cause of failure	[O]	[S]	[D]	RPN	GM
X6	Di send	i) Incomplete packing for material getting rejected after testing at various stages. ii) Lack of knowledge on lead time. iii) Stock mismatch (physical stock vs. excel sheet stock)	9 8 9	8 7 6	9 6 6	648 336 324	413.2
X5F	FBE coating	i)Repetition of shot blasting operation. ii) Improper red & blue color scheduling in FBE. iii) Lack of knowledge on materials specification.	5 5 8	3 2 8	3 3 6	45 30 384	80.33
RPN=Risk priority number, GM=Geometric mean. The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.							

3) Description of Root Causes-

The cut-off point for the RPN values corresponding to the causes for any KPIV has been considered as 100(Hsien, 1996). Accordingly, the causes for which RPN values are more than 100 have been identified as critical or root causes for the prolonged cycle time or delay in the finishing department. Out of 26 total causes 15 causes that turned out to be critical or root causes based on this cut-off RPN of 100 are mentioned in Table 18.

Table XVIII Description of Root Causes

KPIV	Operation	**Cause Of Failure(Delay)**	**RPN**
X1	Shot blasting	i) Ambiguity on materials specification.	252
X2	Fettling	ii) Lack of knowledge on lead time.	378
		iii) Misunderstanding on schedule of work.	324
		iii) Ambiguity on materials specification.	216
X3	Hydro testing	i) Lack of Knowledge on lead time.	432
		ii)Large Lot size.	336
		iii) Lack of uniformity for handling the machine due to non-standardized operating procedure.	326
X4	Machining	i) Out sourcing.	336
		ii) Too much difference (size, type etc.) in configuration of material.	216
X5B	Bitumen coating	i) Lack of knowledge on lead time.	336
		ii) Misconception on schedule of work i.e. prioritizing the fresh piece instead of the rejected and replaced piece.	192

D. Improve

The objective of this phase is to take appropriate remedial measure on the root causes identified in the Analyze phase to attain sustainable improvement.

The techniques that are thought to be useful for this purpose are:

a) JIT Management System
b) Single Minute Exchange of Dies (SMED)
c) Kan Ban System
d) Value Stream Mapping

To tide over the problems enlisted in Table XV, some action plans have been suggested. These action plans have been implemented by the company. The stage-wise action plans in this behalf are shown in Table XIX.

Table XIX. Stage-wise action plan to reduce lead time

KPIV	Operation	RPN	Action Plan
X1	Shot blasting	252	i) Implement Kanban system [19] to specify important material rejected at an intermediate stage for suitable replacement with good material. ii) Implement SMED [20] to reduce Change over time with appropriate production scheduling and its communication down the line.
X2	Fettling	378	i) Increasing awareness about the lead time of all materials by the relevant personnel. ii) Bringing in practice of the knowledge about the expected required time for each activity in the whole order processing. iii) Segregate all the materials with respect to high/low consumption, critical/noncritical and long lead time/short lead time to prioritize the vital, and essential items [3].
		324	iii) Strengthening the internal communication process along with the necessary reporting structures among the personnel/departments engaged in order processing of ductile iron pipe in the finishing department.
		216	iv) Prioritization of rejected products that are replaced with good products for reduction of lead time.
X3	Hydro testing	432	i) Bringing in practice of the knowledge about the expected required time for each activity in the whole order processing. ii) To comply with the schedule time for the allied activities.
		336	i) When the products are homogenous in nature then small lot size is the solution to reduce setup time. Implement Just in Time methodology [7].
		326	i) Evaluating the effectiveness of training provided to the inspectors on the handling of machine.
X4	Machining	336	i) Increasing awareness about the lead time of all materials by the relevant personnel. ii) Reducing (if not eliminating) the number of outsourcing material for difficulty in exercising control. iii) Vendor quality rating is important for evaluating vendors such that we can identify the best vendor for outsourcing.
X5B	Bitumen coating	336	i) Bringing in practice of the knowledge about the expected required time for each activity in the whole order processing. ii) Segregate all the materials with respect to high/low consumption, critical/noncritical and long lead time/short lead time to prioritize the vital, and essential items [3].
		326	i) Prioritization of rejected products that are replaced with good products for reduction of lead time. ii) Introduction of segregation of various products on the basis of size and type to get over traceability problem.

Continued Table XIX

X6	Di send	648	i) Implement Gantt chart to reduce the time for replacing the rejected material by new material. ii)Implement Kanban system [20] to specify the importance of the product with respect to lead time.
		336	i) Increasing awareness about the lead time of all materials by the relevant process owner. ii) Bringing in practice of the knowledge about the expected required time for each activity in the whole order processing.
		324	i) Stringent monitoring or follow up to get over the stock mismatch between excel and physical verification.
X5F	FBE coating	384	i) Prioritization of rejected products that are replaced with good products for reduction of lead time. ii) Implement Kanban system to specify the important material. iii) Reduce change over time applying SMED [19] with appropriate job scheduling to prevent colour mismatch through compatibility of colour wave length.

1) Remuneration System-

Last but certainly not the least, the remuneration system in the finishing department needs to be changed from the simple straight jacketed piece-rate system to time-rate system. In addition to a fixed wage based on the time rated system, the operators need to be inspired through introducing incentive based on their focusing attention on production of consignments that had been rejected earlier and awaiting arrival of good components or items for replacement.

2) Usefulness of Gantt Chart-

Appendix III depicts the Gantt chart considering all the operations or activities in the finishing department for both Bitumen and Fusion Bonded Epoxy (FBE) coatings [8]. At present, if a product gets rejected at any intermediate stage like Shot blasting, Fettling, Hydro testing etc., the shortage of the quantum of product due to rejection is noticed at the Machining stage of the Finishing department. Subsequently, the rejected product gets replaced by a good product. The remaining good items in the rejected consignment await the arrival of the good item(s) as a replacement of the rejected material. As a result, the cycle time increases enormously.

It is worthwhile to mention here that the extent of rejection is found to be 2%, 5% and 1% respectively at Shotblasting, Hydro testing, and Machining during this study. The total rejection thus turned out to be around 8%. Consequently, the remaining 92% good material wait at the Packing stage for replacement of this 8% rejected material with good material.

Instead of this present practice, it is recommended through the Gantt chart [6] to invigorate the monitoring system so that any rejected item or product is noticed right at the stage where rejection has taken place. Then and there order needs to be placed to replace the rejected item or product with a good item or product. The resultant savings in cycle time for rejections that may occur at different stages of the finishing department are shown in Table XX.

Table XX. Result from Gantt chart:

Stage of rejection	Present Cycle Time (Days)	Cycle Time After implementation (Days)	Reduction (Days)
Fettling	195	174	21
Hydro testing	195	184	11
Machining	195	188	7

3) Extent of Ongoing Improvement-

Subsequent to taking the appropriate remedial measures as per Table 19 and Appendix III for Gantt chart, the extent of improvement has been worked out from the data collected duringpost-improvement period [8]. Table XXI provides a comparison of the central tendency (median) and the dispersion (standard deviation) of the cycle time for different operations directly controllable in the finishing department.

Apart from the improvement measured through central tendency (median) and dispersion (standard deviation), the sigma rating has also been computed. While Table XXII gives comparison of stage-wise sigma rating,

Table XXI. Improvement in cycle time after remedial measure

KPIV	Operation	Expected time	Median		Standard deviation	
			Before improvement	After improvement	Before improvement	After improvement
X1	Shot blasting	3.00	5.00	3.00	2.79	1.34
X2	Fettling	24.00	36.00	24.00	9.19	7.02
X3	Hydro testing	4.00	6.00	4.00	1.23	0.11
X4	Machining	6.00	8.00	6.00	2.60	1.29
X5B	Bitumen Coating	3.00	3.50	3.00	1.08	0.51
X6	DI send	8.00	14.00	7.00	4.68	2.54
X7	Packing	12.50	14.00	12.00	20.63	2.76
X5F	FBE coating	5.00	5.00	4.00	1.50	0.56

Note: The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.
Median and standard deviation of cycle time after improvement has been taken from summary statistics in Appendix 2.

Table XXII. Stage-wise comparison of sigma rating after remedial measure

Parameters	Unit checked		Defective		DPU		ZST	
Improvement	Before	After	Before	After	Before	After	Before	After
Bitumen coating	403	760	259	74	0.64	0.10	1.13	2.80
FBE coating	419	732	262	55	0.63	0.08	1.18	2.94

Table XXIII. Comparison of overall sigma rating in the finishing department

Process name	KPIV	DPU		Sigma Level	
		Before improvement	After improvement	Before improvement	After improvement
Shot blasting	X1	0.67	0.15	1.06	2.54
Fettling	X2	0.72	0.09	0.90	2.84
Hydro testing	X3	0.65	0.06	1.11	3.05
Machining	X4	0.52	0.19	1.43	2.38
Bitumen coating	X5B	0.66	0.12	1.07	2.67
DI send	X6	0.71	0.08	0.93	2.90
Packing	X7	0.52	0.05	1.43	3.14
FBE coating	X5F	0.50	0.09	1.50	2.84

The KPIV X_5 only differs. Others are identical for both Bitumen and FBE Coatings.

Table XXIII compare overall sigma rating in the finishing department before and after taking appropriate remedial measure. It can be observed from Table XXIII that the overall sigma rating has improved from 1.13 to 2.80 for Bitumen coating and from 1.18 to 2.94 for Fusion Bonded Epoxy (FBE) coating based on the improvement initiative partially taken so far.

4)Value Stream Mapping after Improvement-
The value stream mappings after improvement for Bitumen coated pipes and FBE coated pipes are exhibited in Figures 5 and 6 respectively. It can be seen from Figure 5 that the total lead time has reduced to 74 days from 121 days before improvement for Bitumen coating. Figure 6 reveals that for FBE coating the total Lead time has reduced to 78 days from 129 days before improvement. These improvements have been attained within a short period of time of around 4 months. Further improvement can be realized after deriving the due benefits of the remedial measures for longer period of time.

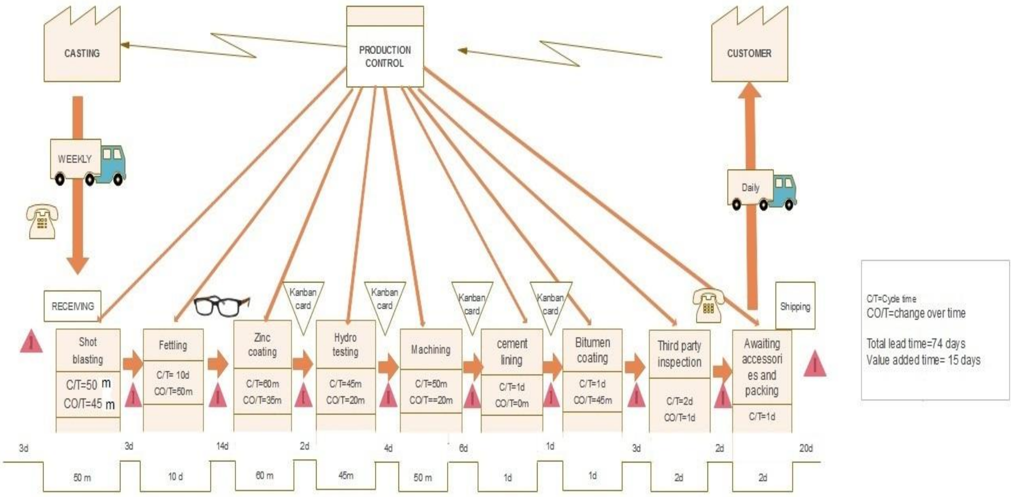


Fig 5. Value stream mapping for Bitumen coated pipes after improvement

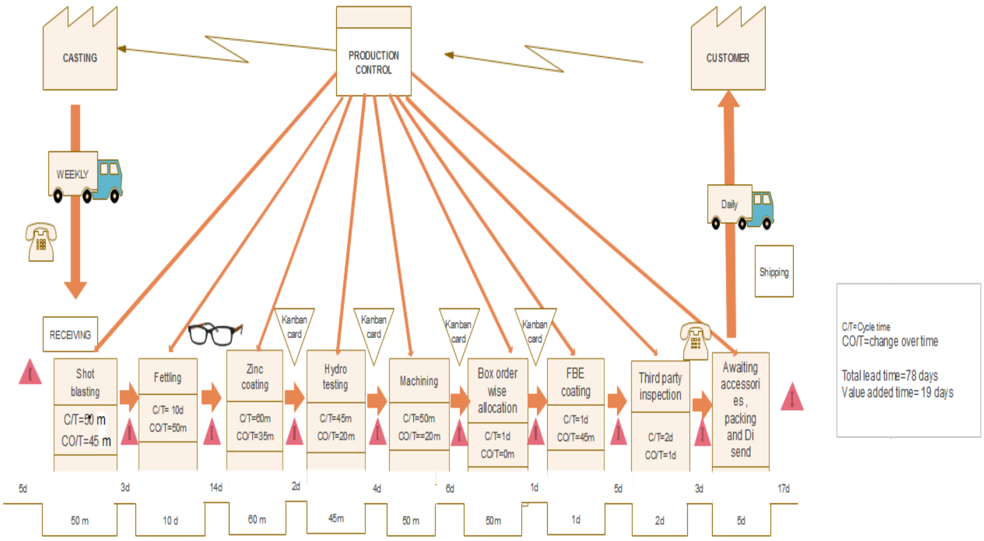


Fig 6. Value stream mapping for Fusion bond epoxy coated pipes after improvement

E. Control

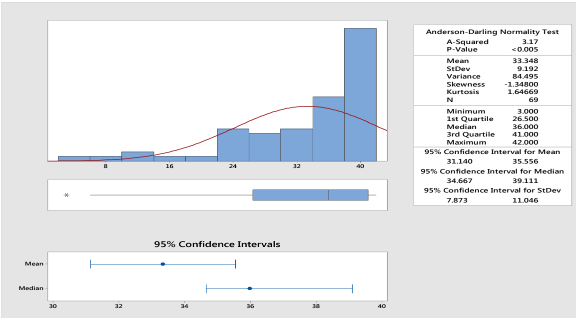
In order to ensure sustainability in the cycle time of the Finishing department considering separately the Bitumen coated and Fusion Bonded Epoxy (FBE) coated ductile iron pipes, the central line and the control limits have been suggested (Table XXIV) for exercising control over the cycle time. While the expected time primarily based on the external benchmark has been considered as the central line, the first and third quartiles have been considered as the lower and upper control limits based on the data collected during the post-improvement period.

Table XXIV. Central line, lower limit, and upper limit for cycle time

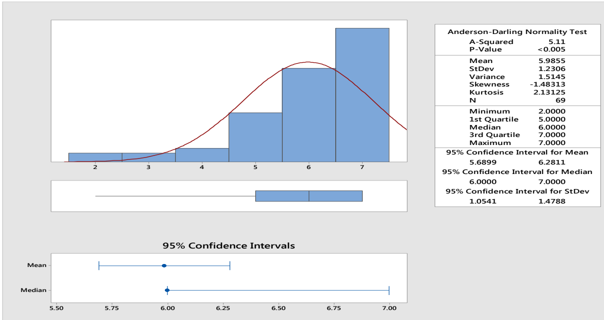
Operation	Central line	Lower limit	Upper limit
Shot blasting	3.00	2.00	5.00
Fettling	24.00	22.00	28.00
Hydro testing	4.00	2.00	6.00
Machining	6.00	4.00	8.00
Bitumen coating	3.00	2.00	4.00

Appendix-1

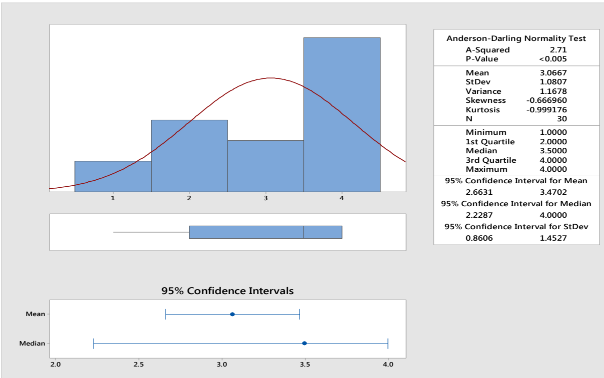
Distribution of cycle time in days for operations with relatively longer lead time



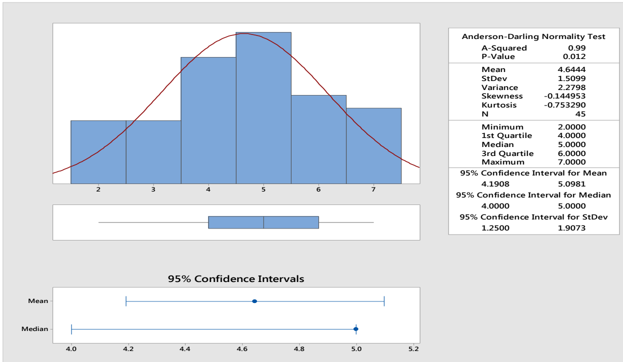
Fettling Operation



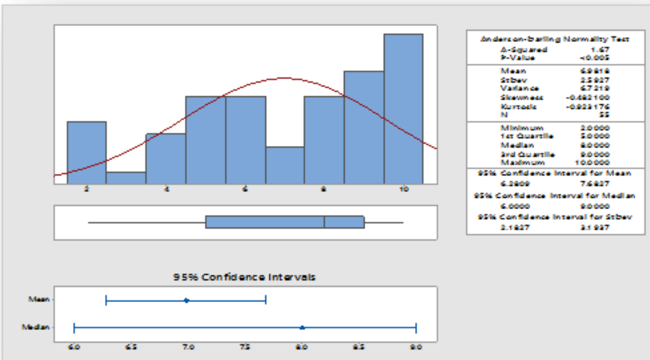
Hydro testing Operation



Bitumen Coating

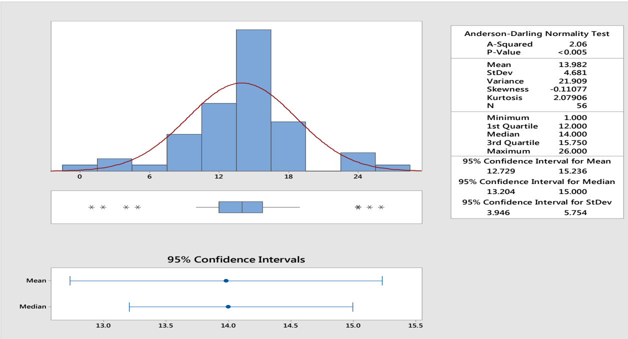


FBE Coating

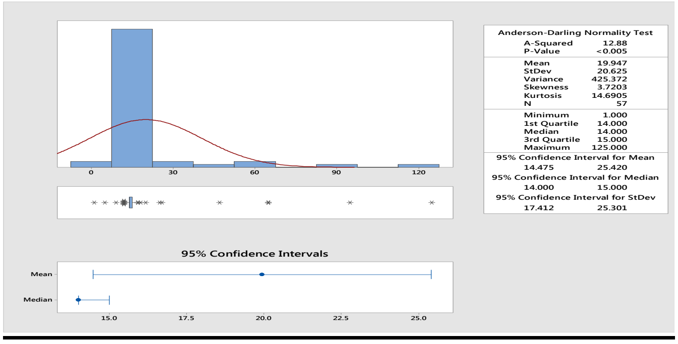


Machining operation

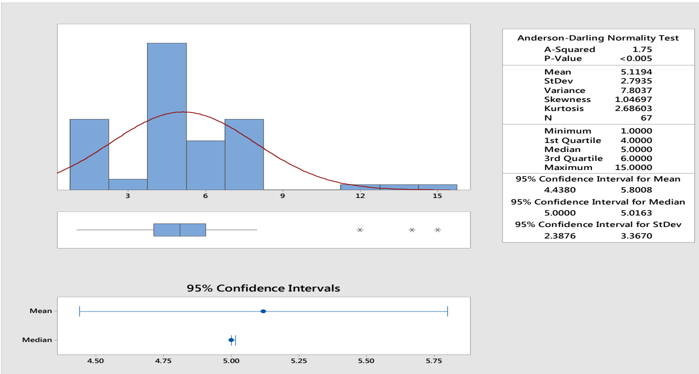
Appendix-II
Distribution of cycle time in days for other operations with relatively shorter lead time



Packing operation

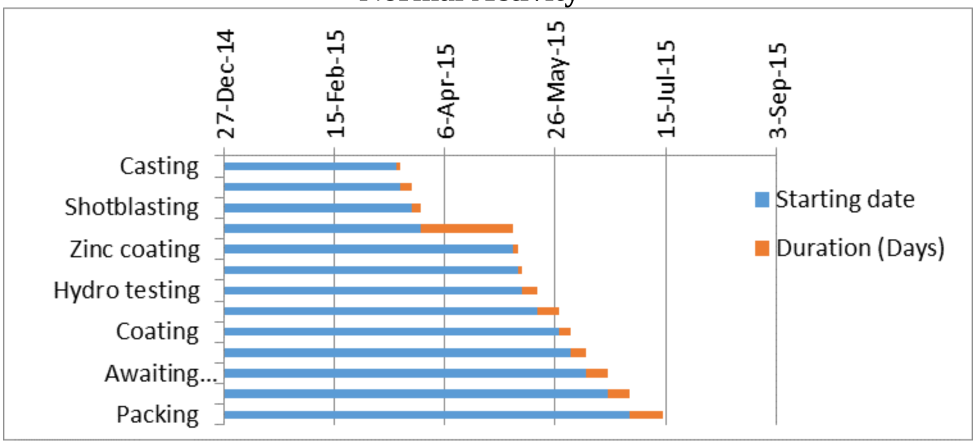


Awaiting accessories and DI send operation



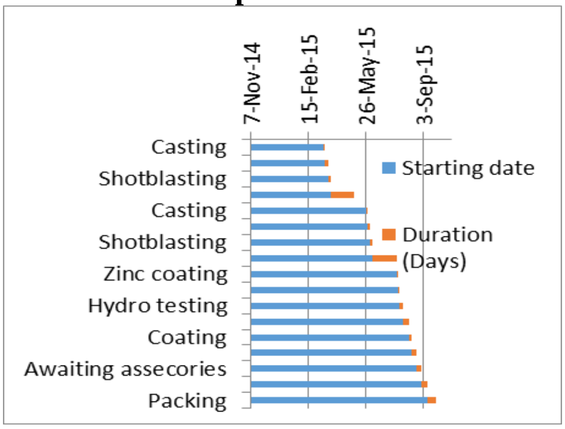
Shot blasting operation

Appendix-III
Gantt charts
Normal Activity

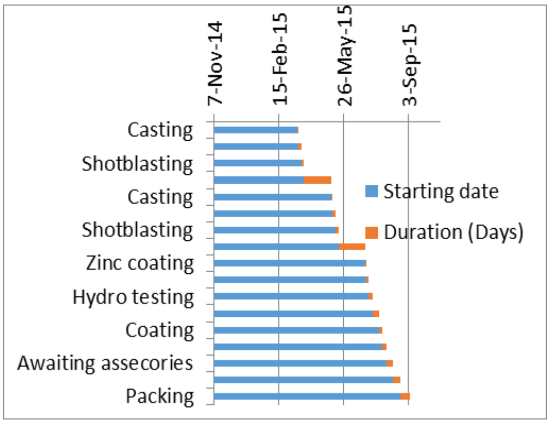


When the material gets rejected at Fettling operation and replaced by good material.

Before improvement

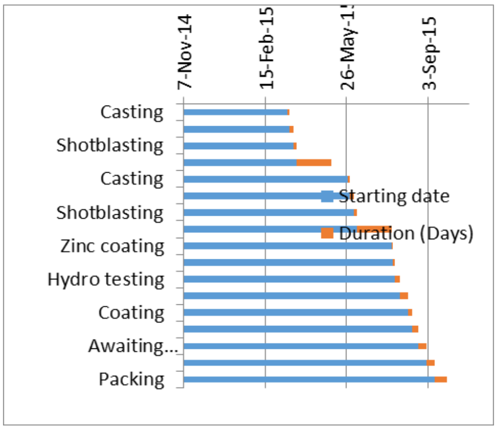


After improvement

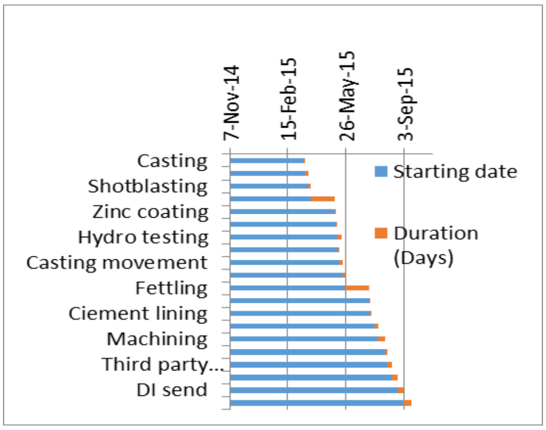


When the material gets rejected at Hydro testing operation and replaced by good material.

Before Improvement

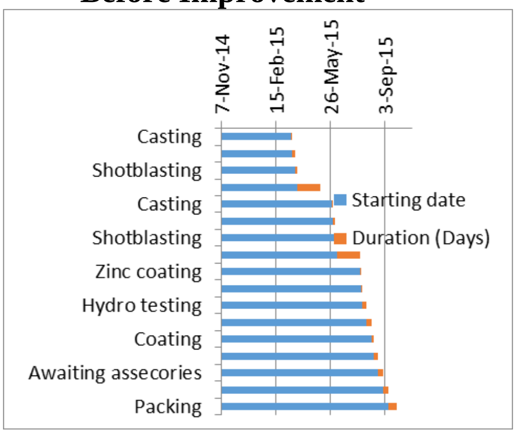


After improvement

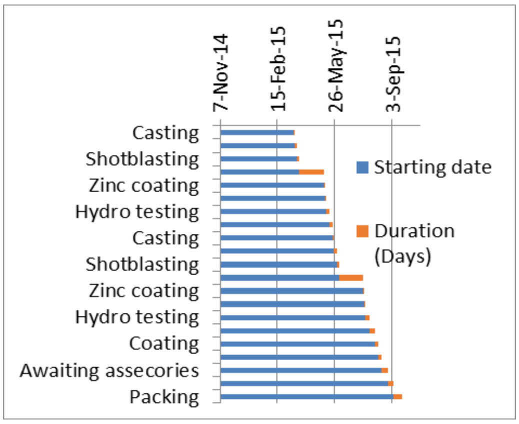


When the material gets rejected at Machining operation and replaced by good material.

Before Improvement



After improvement



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