A Study on Application of Lean Six Sigma Techniques to Reduce Manufacturing Cycle Time for an Industrial Ceramic Manufacturing Unit

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ABSTRACT

This paper explains the implementation of lean six sigma techniques to reduce manufacturing cycle time for an industrial ceramic manufacturing unit. The aim of the research is to reduce the cycle time of the production process by identifying the bottlenecks and eliminating the non-value added activities. Current state map was prepared to describe the present state and various problem areas. Future state map was prepared to show the proposed improvement plans. Reduction in lead time, cycle time and inventory level were achieved from value stream implementation. Line balancing was carried out to identify the idle time in the process and suggestions were given to reduce rework time which would also reduce DPMO.

Problem Definition

The time taken to manufacture a product is approximately seven days and the lead time is 13 days. The objective of the study is to identify the bottlenecks in the process and to reduce the cycle time, inventory and lead time by the application of suitable techniques.

Scope of the study

Process improvement is effected by identifying the non-value added activities and eliminating it. After implementing and attaining improvements, the process is mapped again for further enhancement of productivity. This was done until every process in production of the part was stabilised and the whole process became value streamed.

Review of Literature

William G. Sullivan, Thomas N. McDonald (2002),[1] explained the purpose of their paper as follows:

(a) To provide a roadmap to illustrate how value stream mapping (VSM) and its associated tools can be used to design a desired future state aligned with lean manufacturing principles

(b) To examine the economic aspects of replacement decisions created by lean manufacturing systems using information on anticipated cost savings from VSM.

[1] William G. Sullivan, Thomas N. McDonald, Eileen M. Van Aken, "Equipment replacement decisions and lean manufacturing" Robotics and Computer Integrated Manufacturing, Vol. 18 (2002), pp. 255– 265.

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VSM and its associated tools are explained in detail and the methodology adopted to map the present state and adopt a future state is elucidated. They begin with a discussion of VSM and its associated tools, how they are used to map a current state and design a future state.

Lean Thinking, a concept that is based on the Toyota Production System, extends continuous improvement efforts to reduce the costs of serving customer/s beyond the physical boundaries of a manufacturing facility, by including the suppliers, distributors and production system that support the manufacturing function **[Womack and Jones, 1996][2].** These improvements and cost reductions are achieved by eliminating the MUDA (wastes) associated with all activities performed to deliver an order to a customer. Wastes are defined as "all activities that consume resources (add costs to the product) but contribute zero value to the customer." According to Womack and Jones, there are five steps for implementing Lean Thinking in an enterprise:

1) Define Value from the perspective of the Customer

2) Identify the Value Streams

3) Achieve Flow

4) Schedule production using Pull

5) Seek Perfection through Continuous Improvement

Womack and Jones define a Value Stream as "the set of all the specific actions required to bring a specific product through three critical management tasks of any business: problem solving, information management and physical transformation".

Rother and Shook (1999)[3] define a Value Stream as "all the actions (both value-added and non-value-added) currently required to bring a product through the main flows essential to every product"

Shahrukh A. Irani and Jin Zhou[4] propose a computer-aided method for HVLV manufacturing facilities – Value Network Mapping (VNM) – that is an effective alternative to the manual method of Value Stream Mapping. Given the network of interacting value streams corresponding to an assembled product or a large sample of different parts, VNM can (a) retain the parent-child relationships in the assembly and (b) aggregate the value streams of components and sub-assemblies with identical, or similar,

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[2] Womack, J. P. & Jones, D. T. (1996). Lean Thinking: Banish Waste and Create Wealth in your Corporation. New York, NY: Simon & Schuster.

[3] Rother, M. & Shook, J. (1999), "Learning to See: Value Stream Mapping to Add Value and Eliminate Muda", Brookline, MA: Lean Enterprise Institute (www.lean.org).

[4] Shahrukh A. Irani and Jin Zhou "Value Stream Mapping of a *Complete* Product" Department of Industrial, Welding and Systems Engineering, the Ohio State University, Columbus.

manufacturing routings. In essence, when the process steps contained in different VSMs are not absolutely identical, VNM helps to aggregate similar value streams “in such a way that several products can pass through each step with some slight detours if required, as in a manufacturing cell”.

Ravindrakumar S. Agrahari, Priyanka A. Dangle (2015)[5], address the implementation of Lean manufacturing in the industry. Characteristics of an ideal manufacturing line include having a proper rhythm of assembly line, minimising wastages like bottleneck time, waiting time and material handling time. The lean tool - value stream mapping (VSM) methodology was adopted to improve process cycle efficiency. [5]

McDonald, Van Aken, and Rentes (2002) and Lian and Van Landeghem (2007)[6]**,** determined the required optimum level of work in progress (WIP) inventory using VSM. Optimum level of WIP is needed to support the desired takt time and to estimate the total takt time.

Braglia, Frosolini, and Zammori (2009)[7]**,** utilised variability analysis with VSM, to minimise uncertainty.

Research Methodology

Descriptive Research

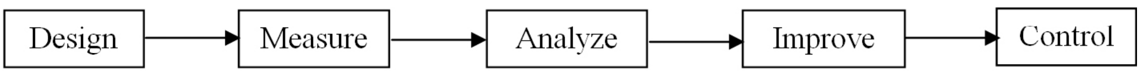
Descriptive research includes surveys and fact-finding enquiries of different kinds. The major purpose of descriptive research is to describe the current state of affairs.

Data collection method

Primary data (by observation and interview method) was used for the study.

DMAIC process

The methodology adopted to conduct the investigation were the first three steps of the Lean Six Sigma DMAIC process.



5 Ravindrakumar S. Agrahari, Priyanka A. Dangle, Prof. K.V. Chandratre, March 2015, Improvement of process cycle efficiency by implementing a lean practice: a case study, International journal of research in aeronautical and mechanical engineering, Vol.3 Issue.3,. Pg: 38-51

6 McDonald, T., E. M. Van Aken, and A. F. Rentes. 2002. Utilising Simulation to Enhance Value Stream Mapping: A Manufacturing Case Application.” International Journal of Logistics Research and Applications 5 (2): 213–232.

7 Braglia, M., M. Frosolini, and F. Zammori. 2009. “Uncertainty in Value Stream Mapping Analysis.” International Journal of Logistics Research and Applications 12 (6): 435–453.

Objectives of the Study

Primary Objective

The primary objective of the research work was to conduct a study on application of lean six sigma techniques to reduce the manufacturing cycle time for an industrial ceramic manufacturing unit.

Secondary Objectives

1. To study the manufacturing process of metalized cylinder.
2. To analyze and reduce the lead time of manufacture.
3. To study men and material movement and eliminate / reduce unnecessary movement.
4. To reduce / eliminate inventory between processes.

Tools used

- Value Stream Mapping
- Line Balancing
- DPMO

Analysis and Interpretation

DMAIC process

Define

The define step is the project goal which is reducing the cycle time by applying lean manufacturing tool for metalised cylinder.

Measure

This step involves measuring the time taken for each process and preparing the current state map.

Lead time

Table 1: Lead time between stations

Stations	Lead time (hrs)	Cumulative time (hrs)
Raw material storage	24	24
Green moulding	24	48
Green machining	24	72
Fire ware 1	72	144
Fire ware 2	48	192
Metz firing 1	72	264
Metz firing 2	48	312

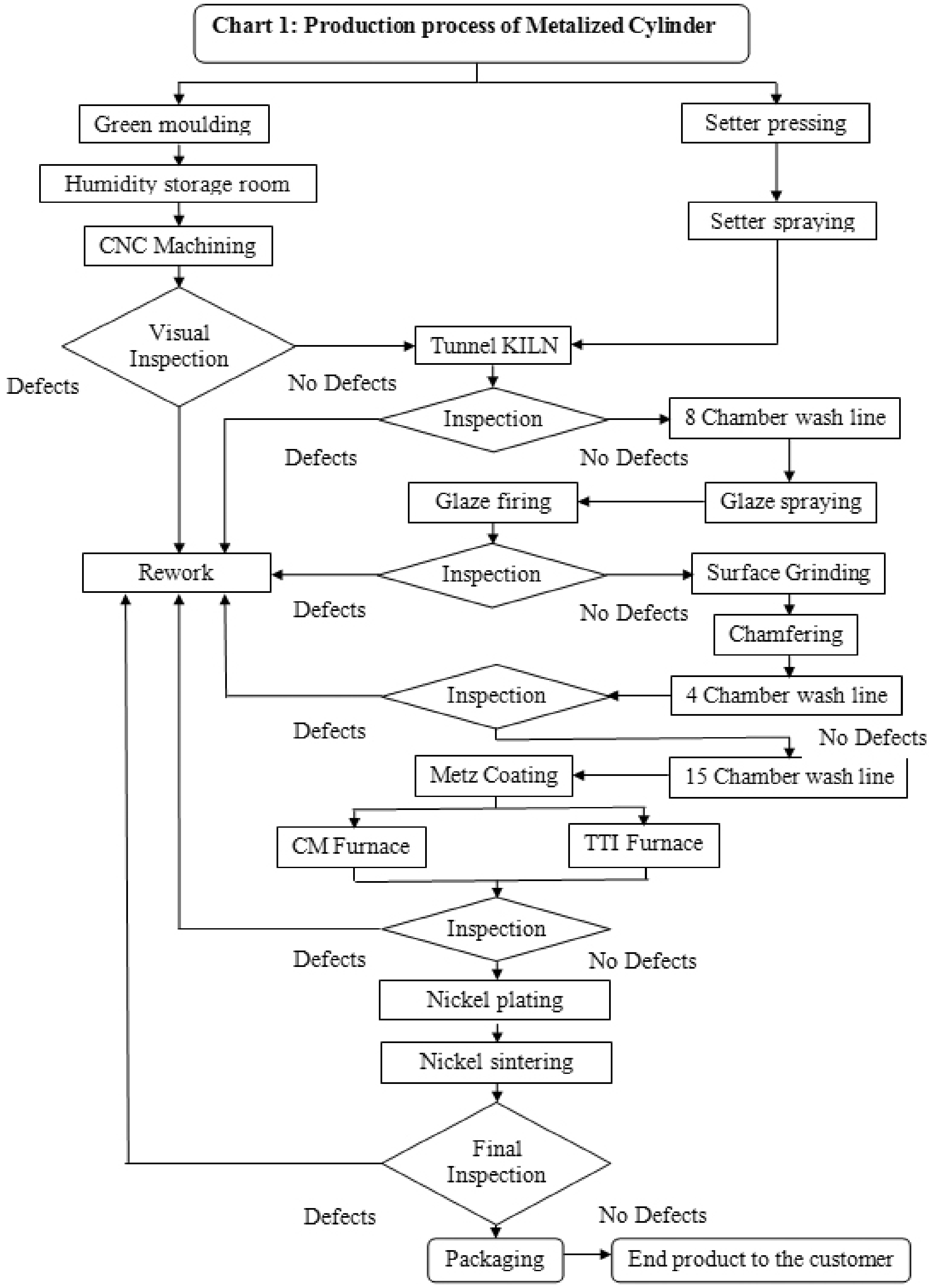


Chart 1: Production process of Metalized Cylinder
Green moulding
Setter pressing
Humidity storage room
Setter spraying
CNC Machining
Visual Inspection
Tunnel KILN
Defects
No Defects
Inspection
8 Chamber wash line
Defects
No Defects
Glaze firing
Glaze spraying
Rework
Inspection
Surface Grinding
Defects
No Defects
Chamfering
Inspection
4 Chamber wash line
Defects
No Defects
Metz Coating
15 Chamber wash line
CM Furnace
TTI Furnace
Inspection
Defects
No Defects
Nickel plating
Nickel sintering
Final Inspection
Defects
No Defects
Packaging
End product to the customer

Chart 2 : Lead Time between Stations

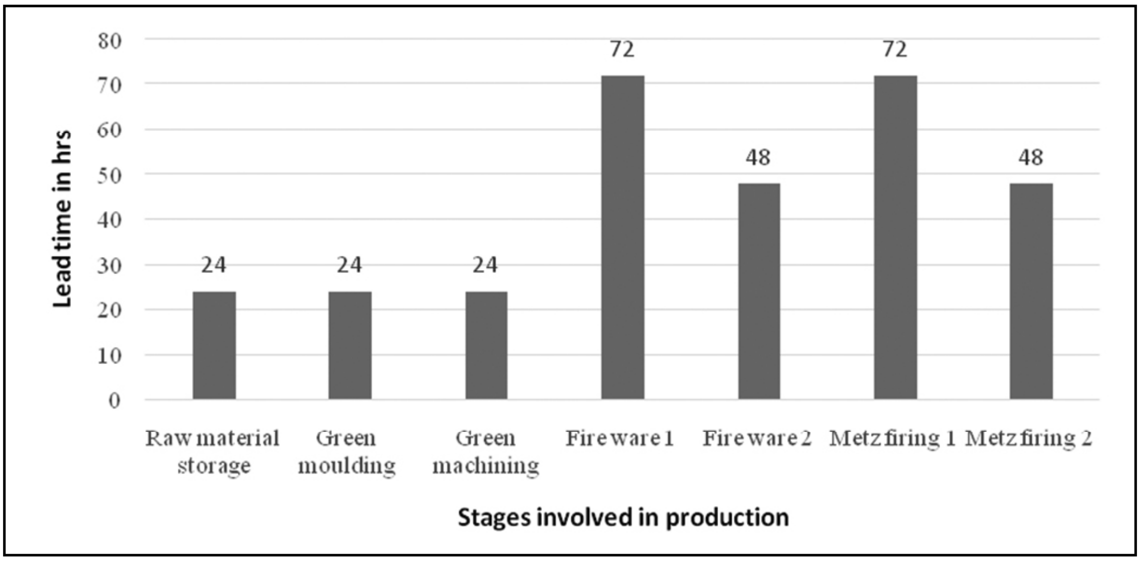
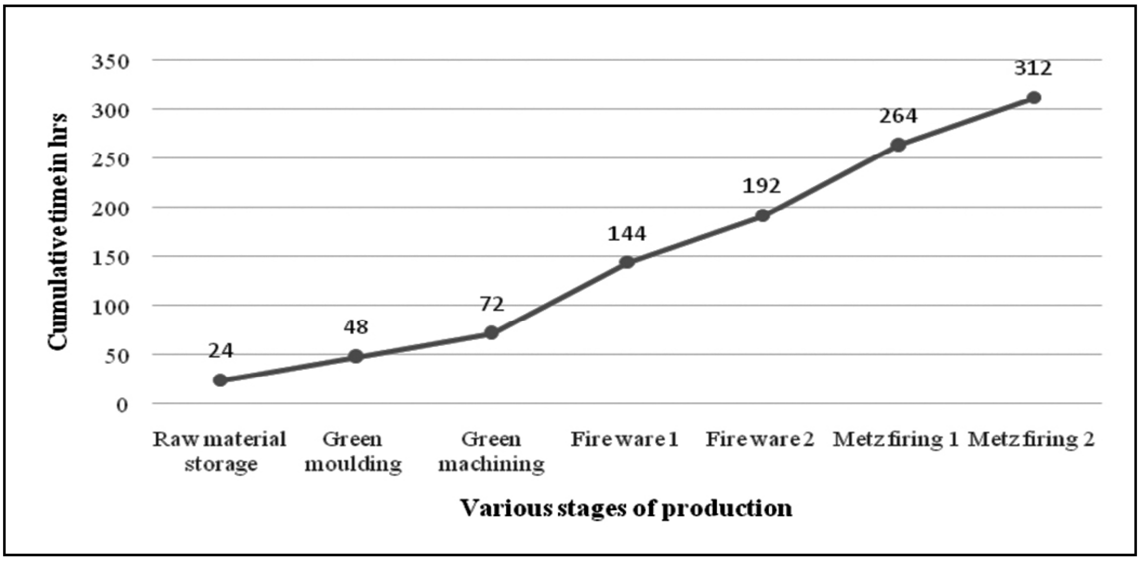


Chart 3 : Cumulative Lead Time



It can be inferred from above chart that Fireware 1 and Metz firing 1 are the two processes having higher lead time and the cumulative time taken for the cylinder to complete the process steps is 312 hours.

Cycle time

Table 2 : Cycle time for each process

Process	Cycle time (Seconds)
DBP 1	160
DBP 2	220
Setter presser 1	30
Tube Cutting	30
CNC 4 (three cylinders)	318
Setter spraying	15
Tunnel kiln	180000
8 Chamber washline	1320
Glaze spraying	80
Glaze firing	216000
Surface Grinding	3600
Chamfering	140
4 Chamber washline	300
15 Chamber washline	7200
Metz coating	120
Metz firing (CM furnace)	28800
Metz firing (TTI furnace)	43200
Nickel plating	4800
Nickel sintering	5400
Final inspection	180
Packing	600

It can be inferred from the table that the tunnel kiln and glaze firing processes recorded the highest cycle time.

Capacity

Table 3: Production and loading capacity of Metalised Cylinder

Process	Capacity / 21.5 hrs	Loading capacity
DBP 2	2463	-
Setter presser 1	2580	-
Setter spraying	5160	-
Tube Cutting	5160	-
CNC 4	1290	-
Tunnel KILN	86	240/car
8 Chamber wash line	1410	24/basket
Glaze spraying	968	-
Glaze firing	659	1840/car
Surface Grinding	1828	85/basket
Chamfering	554	-
4 Chamber wash line	2064	24/basket
15 Chamber wash line	194	18/basket
Metz coating	3351	-
Metz firing (CM furnace)	1290	10/boat
Metz firing (TTI furnace)	717	400/batch
Nickel plating	387	24/cycle
Nickel sintering	172	12/basket
Final inspection	430	-
Packing	2322	18/box
DBP 1	3606	-

Production capacity has been calculated using Value Stream Mapping data. Loading capacity has been observed and entered by interviewing operators. It can be inferred from the above table that production capacity is high for Setter spraying and Tube cutting processes because these machines have the lowest cycle time. Tunnel KILN and Nickel sintering processes have the lowest production capacity because of high cycle time and lower loading capacity.

Inventory

Table 4: Inventory Data

Stations	Inventory
Green moulding	362
Green machining	2289
Fire ware 1	5561
Fire ware 2	2986
Metz firing 1	232
Metz firing 2	0

It can be inferred from the above table that Fireware 1 station (includes machines such as Tunnel KILN, 8 chamber wash line, Glaze spraying and Glaze firing) has a higher inventory than other stations as the production capacity of Tunnel KILN is less (86 products/ 21.5 hours). It can also be inferred that the second highest inventory is in Fireware2 (includes machines such as Surface grinding, Chamfering and 4 chamber wash line) as the production capacity of 15 chamber wash line is less (194 products / 21.5 hours).

Transportation

Cnc Machining

Transporting material from humidity storage room to CNC machining area takes time as operators carry the tubes manually to the machining area.

Production capacity of CNC machining	=	1290 products per day
Number of tubes an operator can carry manually	=	8
Maximum number of products an operator can carry	=	32
Time taken to reach the machining area	=	30 seconds
Number of times an operator manually takes products from storage room to machining area	=	1290/8 = 161.25 = 162 times (approx)
MUDA due to motion	=	162 * 30 = 4860 seconds

Value Stream Mapping

Creating Current State VSM

Mapping the value stream always starts with the customer demand. To create the current state map the following steps are followed:

Understanding Customer Demand

In this study, customer demand is 65000 products / month or 2167 products / day assuming 3 shifts.

Calculating Takt Time

Takt time = Daily Available Production (seconds) / Daily customer demand

= 77400 / 2167 = 36 seconds

Takt Time for this process is 36 seconds

Mapping the Process Flow

This step involves various sequential processes to complete product manufacturing, calculation of cycle time, change over time and up time for each. In this research, twenty processes are given to complete the products.

Mapping Material Flow

The flow of material from raw material to finished goods is given by the supplier to customer.

Mapping Information Flow

Information flow is also incorporated to provide demand information, which is an essential parameter for determining the process in production system. It includes data regarding cycle time(C/T) change over time (C/O), inventory and Takt-time (TT).

Calculating Total Product Cycle Time

After both material and information flows have been mapped, a time-line is displayed at the bottom of the map showing the processing time for each operation and the transfer delay between operations. The time-line is used to identify the value-added steps, as well as the wastes. Production lead time for the process is 13 days.

Detailing Off-line Activities

Activities like placing of order, supply of material, daily schedule and monthly forecasts involved are executed by transportation, supplier icons and information flow lines.

Identifying Opportunities for Improvement

Opportunities for improvement are identified and to further improve throughput rate, a future state map is drawn which shows the changes in the process.

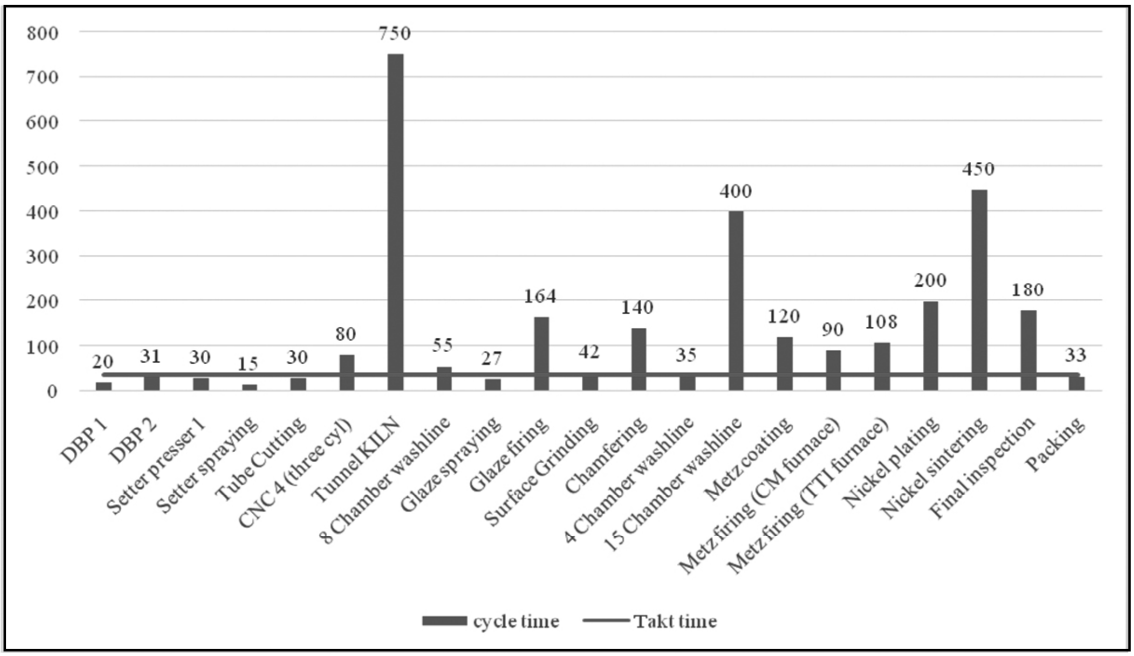
Creating Future State VSM

Creating Cycle Time v/s Takt Time Graph

This graph simply compares the individual cycle times to the overall takt time of the manufacturing process.

The presence of bottlenecks at any point is determined by checking in which operation the cycle time exceeds the takt time. It was found that the CNC Machining, Tunnel KILN, 8 Chamber wash line, Glaze firing, Surface grinding, Chamfering, 15 Chamber wash line, Metz coating, Metz firing, Nickel plating, Nickel sintering and Final inspection operations were the bottleneck machines.

Chart 4: Cycle time vs. Takt time



Calculating optimal workforce size

Optimal number of workers is equal to Total Cycle Time/ Takt Time i.e. 3000 seconds / 36 seconds = 84: Optimal work force size for the process is 84 nos.

Line Balancing

Calculations

Cycle time	= Production time / Production volume
	= ((21.5 * 60 * 60) / (65000/30))
	= 35.72
	= 36 seconds
Theoretical number of stations n	= ΣT / Cycle time
	= 3000 / 36
	= 84

Table 5: Kilbridge and Wester Heuristic Rule for Line Balancing

Station name	Cycle time (Seconds)	Actual no of stations	Idle time (Seconds)
A1	30	1	6
A2	15	1	1
B1	20		
B2	31	1	5
B3	30	1	6
B4	80	3	28
C	750	21	6
D	55	2	17
E1	27	1	9
E2	27	1	9
F1	164	5	16
F2	164	5	16
F3	164	5	16
G1	42	2	30
G2	42	2	30

G3	42	2	30
H1	140	4	4
H2	140	4	4
H3	140	4	4
I	35	1	1
J	300	9	24
K	120	4	24
L1	90	3	18
L2	108	3	0
M	200	6	16
N	450	13	18
O	180	5	0
P	33	1	3
	3619	110	341

Balance Efficiency = (©T/ (Cycle time*N))*100

= (3619 / (36*110))*100

= 91.38 %

Balance delay = 100 - Balance Efficiency

= 100 – 91.38

= 8.62%

Interpretation

Idle time between stations has been calculated using assembly line balancing. It can be inferred that the idle time is more for stations G1, G2 and G3 (Surface grinding) and the machine has to be kept idle for 30 seconds for a product. The total idle time is 341 seconds for the metallised cylinder.

Defects per million opportunities (DPMO)

	D	= Number of defects
	O	= Number of opportunities for a defect
	U	= Number of units
Defects per unit		= Total defects / Total units per day
		= 60 / 2167
		= 0.027
Defects per opportunities		= Total defects / (Number of units produced*Total opportunities)
		= 60/ (2167*7)
		= 0.00395543
DPMO		= Defects per opportunities * 1000000
		= 0.00395543 * 1000000
		= 3955.43

From Abridged Process Sigma conversion table

Long term yield = 99.5340%

Process sigma = 4.2

Hence the company is at the 4.2 Sigma level.

Findings

1. Cycle Time

It was found that the tunnel kiln and glaze firing processes recorded the highest cycle time to complete the process.

2. Lead Time

It was found that Fireware 1 and Metzfiring 1 are the two processes having high lead time and the cumulative time taken for metalised cylinder to complete the process is 312 hours.

3. Capacity

It was found that the production capacity is high for Setter spraying and Tube cutting processes because these machines have the lowest cycle time and Tunnel KILN and Nickel sintering has the lowest production capacity because they have the highest cycle time and their loading capacity is less compared to other machines.

4. Transportation

It was found that transporting material from Humidity storage room to CNC machining area takes time as operators carry the tubes manually to the machining area. Number of times the operator takes the product from storage room to machining area is 162 times which results in a wastage of 4860 seconds per day.

5. Idle time

It was found that the idle time is more for stations G1, G2 and G3 (Surface grinding) and the machine has to be kept idle for 30 seconds for a product. The total idle time is 341seconds for the metallised cylinder.

6. Inventory

It was found that Fireware1 station (includes machines such as Tunnel KILN, 8 chamber wash line, Glaze spraying and Glaze firing) have more inventory than other stations and the second highest inventory is in Fireware2 (includes machines such as Surface grinding, Chamfering and 4 chamber wash line).

7. Takt time vs. Cycle time

It was found that CNC Machining, Tunnel KILN, 8 Chamber wash line, Glaze firing, Surface grinding, Chamfering, 15 Chamber wash line, Metz coating, Metz firing, Nickel plating, Nickel sintering and Final inspection were the bottleneck machines as the cycle time of these machines is more compared to the takt time.

Suggestions

1. Implementing AGV system in Green machining area will reduce operator motion, cycle time and inventory. Increasing production capacity of surface grinding will reduce the inventory and also the idle time based on line balancing. Continuous inventory reduction analysis can be used to reduce the inventory level. (ABC analysis, Cycle counting, Safety stock, EOQ and product life cycle management)

2. Increasing the number of stations in Tunnel KILN will help to reduce the inventory and lead time and will also increase the production capacity.

3. Non value added activity can be reduced by reducing loading and unloading time in the processes and by implementing computerized inspection method or by online inspection method.

4. Loading capacity of Tunnel KILN car is 240 products per car. If we increase the capacity by 250 (by increasing the length of the car), the cycle time of a product will reduce to 720s from 750s.

5. Loading capacity of Glaze firing car is 1840 products per car. If we increase the capacity by 1850, the cycle time of a product will reduce to 117s from 164s.

6. Loading capacity of basket in 15 chamber wash line is 18 products per basket. If we increase the capacity by 24 like the same capacity in other two wash lines, the cycle time of a product will reduce to 300s from 400s.

7. Loading capacity of batt in Nickel sintering is 12 products per basket. If we increase the capacity by 14, the cycle time of a product will reduce to 337.5s from 450s.

8. Final inspection process is a bottleneck operation and to reduce the time taken it is suggested to carry out inspection after every critical stage of manufacture to reduce defects thereby reducing DPMO and rework time.

Conclusion

The production process was understood and explained by using a detailed process map. The current value stream map was drawn using the software Edraw Max 7.9. With the help of current value stream map, the future state was developed.

The biggest part of the current lead time is inventory time. Inventory levels directly affect the lead time. The more work in progress (WIP) there is, the longer the lead time will be. It is recommended to eliminate / reduce the inventory between processes so as to reduce the lead time by at least a day. To improve productivity, KANBAN is introduced in the Future State Map. By following these methods, non-value added time is reduced and productivity can be improved.

Value stream mapping has proven to be an effective way to analyse the current production state and point out the problematic areas. The visual nature of value stream mapping aids in combining the information and material flow on one map, thereby depicting its relationship to lead time.

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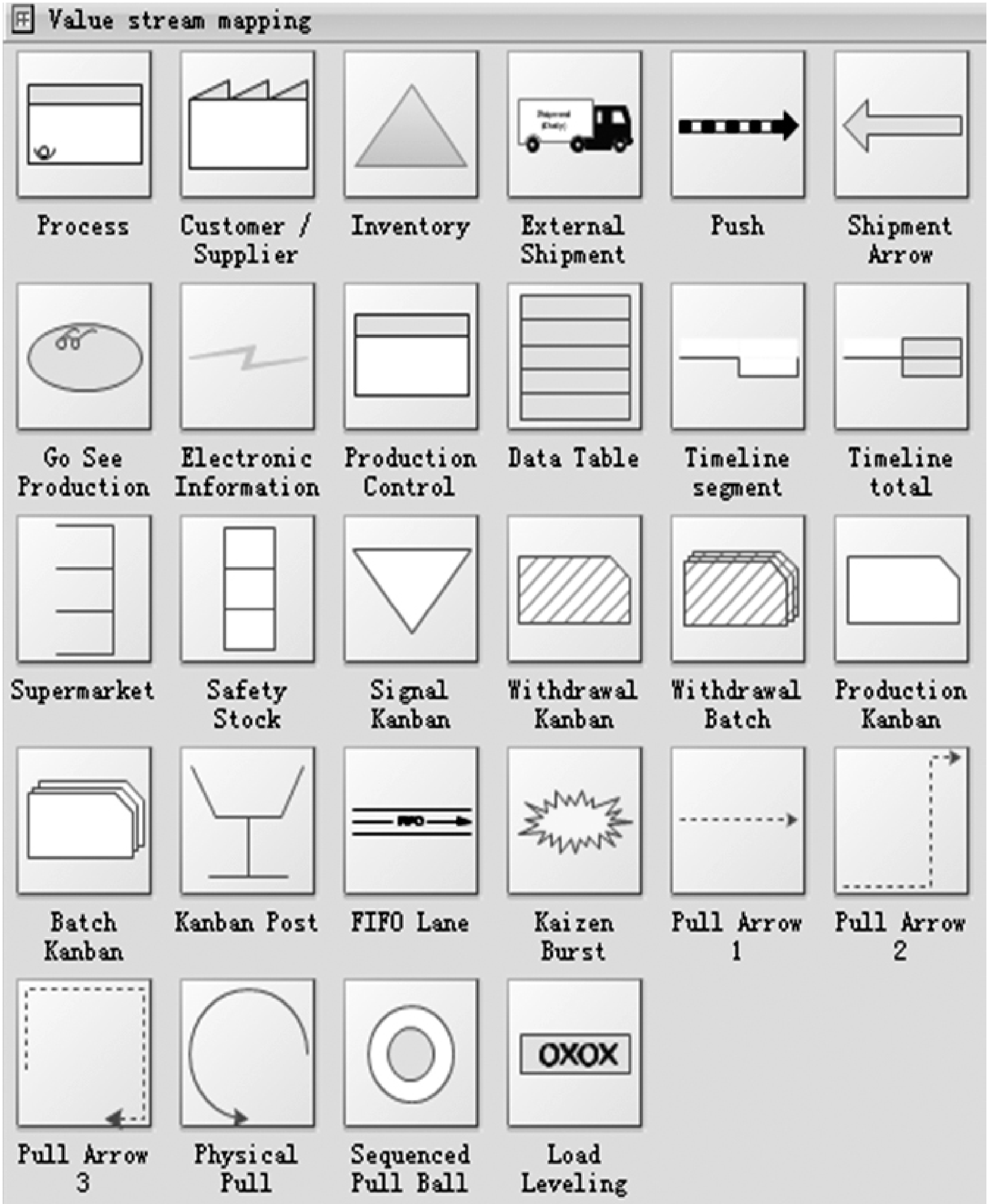
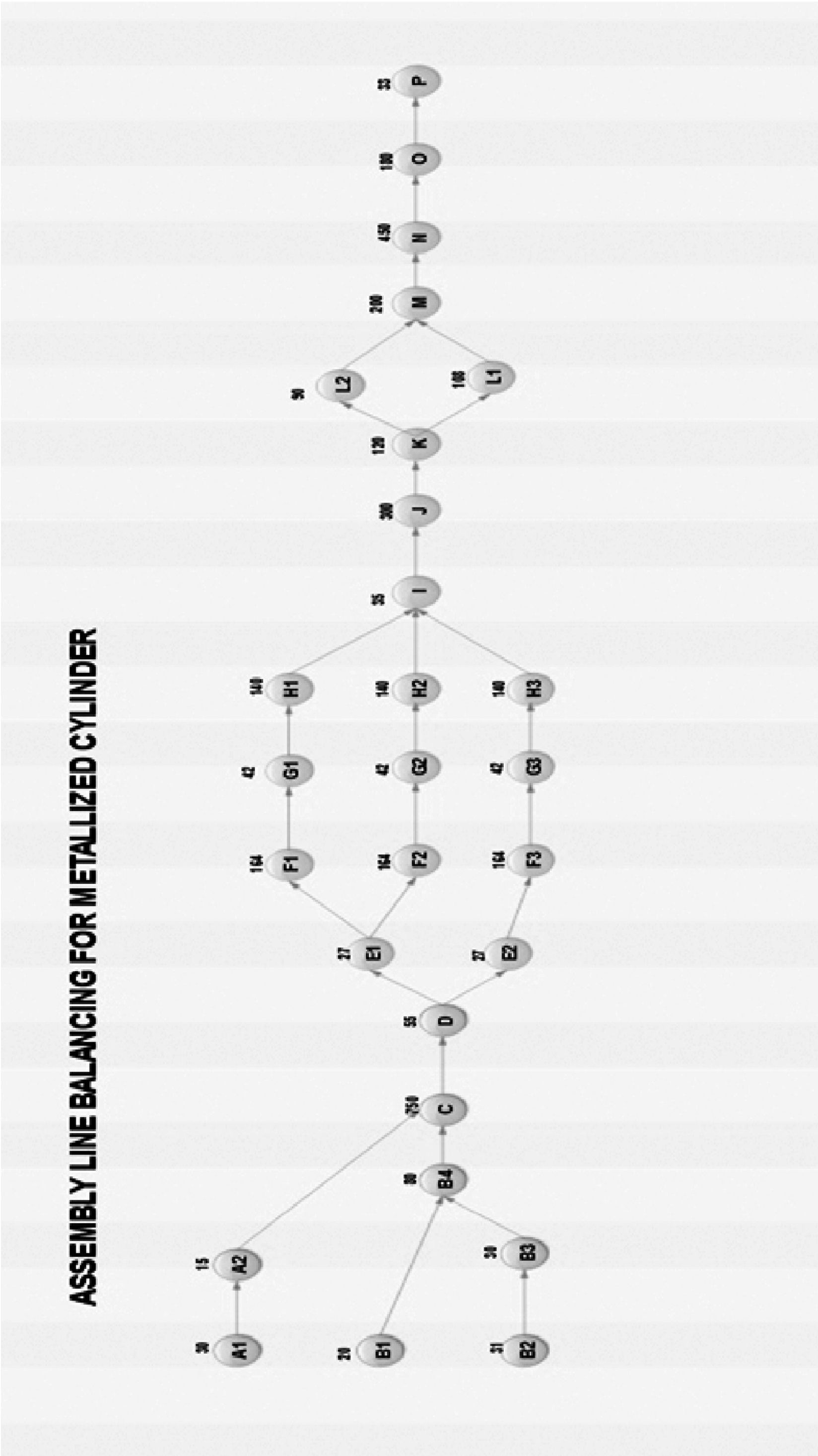
ANNEXURES:

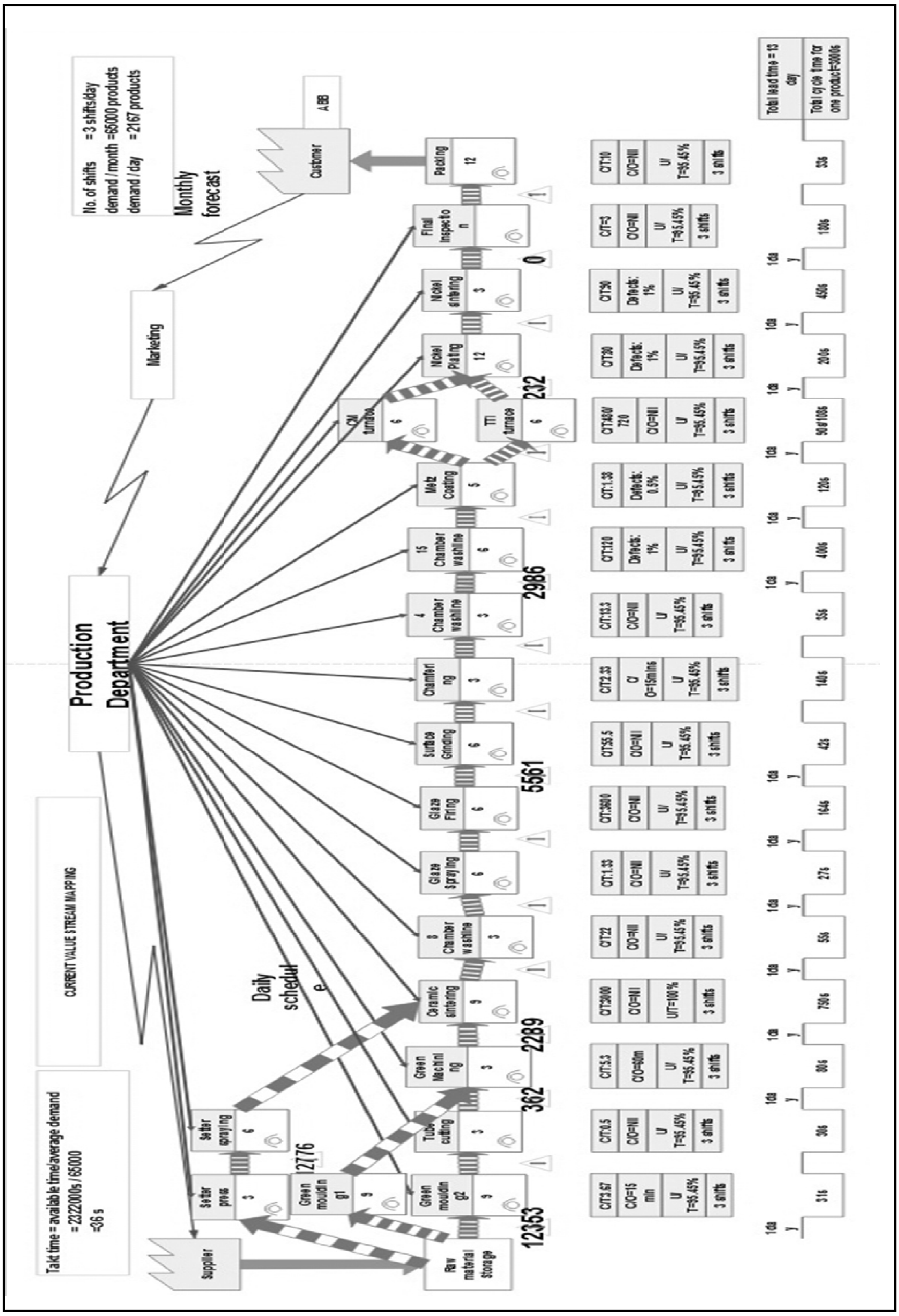
Annexure I: Symbols Used In Value Stream Mapping



Annexure II: Assembly Line Balancing for Metalised Cylinder



Annexure III: Current VSM



Annexure IV: Future VSM