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Parikh, Shriraj

**Value Stream
Analysis and
Overall Equipment
Effectiveness in an
Automated Valve
Production System**

September 2007

Value Stream Analysis and Overall Equipment Effectiveness in an
Automated Valve Production System

by

Shriraj Parikh

A Thesis
Presented to the Graduate and Research Committee
Of Lehigh University
in candidacy for the Degree of
Master of Science

in

Industrial and Systems Engineering

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This thesis is accepted and approved in partial fulfillment of the requirements for the Master of Science

May 16, 2007
Date

~~Thesis Advisor~~

Chairperson of Department

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Friends and Family

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This thesis is dedicated to those who have helped to shape its work, directly or indirectly.

*I've done it, I've done it!
Guess what I've done!
Invented a light that plugs into the sun.
The sun is bright enough,
The bulb is strong enough,
But, oh, there's only one thing wrong...
The cord ain't long enough.*

INVENTION by Shel Silverstein

Table of Contents

	<i>Page No.</i>
<i>Acknowledgement</i>	<i>iii</i>
<i>Table of Contents</i>	<i>v</i>
<i>List of tables</i>	<i>vii</i>
<i>List of figures</i>	<i>viii</i>
<i>Abstract</i>	<i>1</i>
<i>Chapter 1 Introduction and Executive Summary</i>	<i>2</i>
<i>1.1 Value stream Mapping</i>	<i>3</i>
<i>1.2 Overall Equipment Effectiveness</i>	<i>5</i>
<i>References</i>	<i>7</i>
<i>Chapter 2 Process Flow and capability analysis in the current state</i>	<i>8</i>
<i>2.1 Size 6 Valve Descriptions</i>	<i>8</i>
<i>2.2 Samag Cell Descriptions</i>	<i>10</i>
<i>2.3 Tool list for Samag MFZ I</i>	<i>12</i>
<i>2.4 Process Flow Chart</i>	<i>13</i>
<i>2.4.1 Size 6 valve body machining flow chart</i>	<i>14</i>
<i>2.5 Process Capability Analysis</i>	<i>17</i>
<i>References</i>	<i>22</i>
<i>Chapter 3 Value Stream mapping</i>	<i>23</i>
<i>3.1 Background for Value Stream Mapping</i>	<i>23</i>
<i>3.1.1 Value Stream Mapping</i>	<i>26</i>
<i>3.1.2 Value Stream Mapping Icons</i>	<i>27</i>

3.1.3 Current State	28
3.1.4 Future State	30
3.1.5 Implementation Plan	32
3.1.6 Value Stream Matrix	33
3.1.7 Advantages/Disadvantages of VSM	35
3.2 Value stream Mapping at the company	36
3.3 Recommendations	39
References	40
<i>Chapter 4 Overall Equipment Effectiveness (OEE)</i>	42
4.1 Overall Equipment Effectiveness Background	42
4.2 Calculation of OEE	45
4.3 Comparison of the OEE approaches at the company	49
4.4 Downtime Reason Codes	55
4.5 Suggested Action Plan	62
References	66
<i>Chapter 5 Conclusions and Recommendations</i>	67
5.1 Current state analysis	67
5.2 Overall Equipment Effectiveness	68
<i>Appendix A</i>	69
<i>Appendix B</i>	81
<i>Vita</i>	84

List of Tables

	<i>Page No.</i>
<i>Table 1.1: Five environmental Characteristic definitions</i>	4
<i>Table 2.1: Samag Tool list</i>	12
<i>Table 2.2: Ppk summary for parameters related to machining size 6 valve body</i>	20
<i>Table 2.3: Process capability Action Plan</i>	21
<i>Table 3.1: Typical Value Stream Metrics</i>	29
<i>Table 3.2 : Value Stream Mapping Matrix</i>	34
<i>Table 4.1: OEE factors review</i>	47
<i>Table 4.2: Comparison between Current Formulation and Proposed Formulation for OEE Calculation</i>	55
<i>Table 4.3 Defining the Six Big Losses</i>	58

List of Figures

	<i>Page No.</i>
<i>Fig1.1: The effects of environmental characteristics on implementation</i>	4
<i>Fig1.2: Value Stream Mapping Matrix</i>	4
<i>Fig 2.1: 2/2-, 3/2- and 4/2 Directional Poppet Type Valves with Solenoid Operation Model M-SEW 6 (Series 3X)</i>	9
<i>Fig 2.2: 3/2- Directional Poppet Type Valves with Solenoid Operation Model M-SEW 6 (Series 3X)</i>	10
<i>Fig 2.3: Flow chart Symbols</i>	14
<i>Fig 2.4: Flow chart for size 6 valve body machining</i>	16
<i>Fig 3.1: Steps of Lean Thinking</i>	24
<i>Fig 3.2: Icons for VSM</i>	27
<i>Fig 3.3: Current Value Stream Map</i>	29
<i>Fig 3.4: Future Value Stream Map</i>	31
<i>Fig 3.5: The effect of environment characteristics on Implementation</i>	32
<i>Fig 4.1: Pictorial representation of OEE Calculation</i>	48
<i>Fig 4.2: Current approach for OEE calculation</i>	49
<i>Fig 4.3: Proposed approach for OEE calculation</i>	50
<i>Fig 4.4: OEE report</i>	51
<i>Fig 4.5: Excel based template for OEE calculation</i>	52
<i>Fig 4.6: Current Downtime Reason codes</i>	60
<i>Fig 4.7: Current Downtime Reason codes</i>	61
<i>Fig 4.8: Proposed Planned Downtime reason codes</i>	63
<i>Fig 4.9: Proposed unplanned Downtimes reason codes</i>	64

<i>Fig 4.10: OEE Cockpit chart</i>	65
<i>Fig A1: Samag MFZI Axis Diagram</i>	70
<i>Fig B1: Value Stream Map, Size 6 Valve body machining</i>	81

Abstract

Currently, the production of size 6 valve body at a company is carried out on a Samag cell located in the valve focus factory (VFF). The cell consists of two robots, two CNC machines, workers, honing machine and inspection station. All these components are linked by various conveyers. Two aspects comprise the total study; the first uses a methodology to analyze the Samag Cell using process flow charts, process capability analysis and value stream mapping. The analysis found value stream mapping to be a critical exercise and suggests various means to eliminate muda (waste) from the current manufacturing system. In the second aspect of the thesis an Overall Equipment Effectiveness metric is studied. The principal result of the study was to deduct planned downtimes from the total available time for calculation purposes of Overall Equipment Effectiveness. A set of downtime reason codes are proposed to facilitate reliable data collection and subsequently obtain realistic OEE values.

Thesis Advisor: Dr. Nicholas G Odrey

Title: Professor of Industrial and Systems Engineering.

Chapter 1 Introduction and Executive Summary

Currently, the production of a size 6 valve body at the company is carried out on a Samag cell located in the valve focus factory (VFF). The work presented here studies the process of manufacturing through a manufacturing system redesign to gain insight into, primarily, the use of one design tool, value stream mapping. Also, an Overall Equipment Effectiveness (OEE) metric is studied and its importance is detailed in the lean culture being adopted via a Production Systems (BPS) initiative and Total Productive Maintenance (TPM).

This thesis is split into two parts. Part 1 focuses on the current state analysis of the production of size 6 valve bodies. This was done to better understand the problems and obstacles of manufacturing system design through an in-depth study. The analysis of the current system and the design of the future system are explored. As part of the analysis, the Samag machine is described and the tool list is investigated to get a clear idea of the machining process. A Process flow chart, process capability analysis and value stream mapping are the tools used to analyze the current state of the valve body machining process and provide an insight into improvements.

Part 2 focuses on the OEE metric. This metric has been chosen to be studied due to its growing importance in the lean culture at the company. OEE is a simple but a powerful metric which is the product of 3 factors, namely, availability, performance efficiency and quality rate. The OEE analysis serves as the base for studies which will lead to decisions on investments on the type of machines, and their maintenance schedules. The OEE analysis will potentially lead to improvements which will help achieve higher uptime and production, combined with a lesser defect rate. The current

approach of calculating OEE is discussed and problems with the current approach are explained. A new approach is proposed and its effects on achieving realistic numbers for an OEE metric are explained. A set of machine downtime reason codes are proposed against the current one to aid in reliable data collection.

1.1 Value stream Mapping

Value stream mapping (VSM) is an improvement tool that has been used as an integral part of lean transformations [1.3]. It has been shown to yield vast improvements in lead-time throughout manufacturing, including the aerospace industry, and beyond the factory floor. A value stream mapping exercise was performed at the company as a part of the investigation. The activity outlined possible improvement opportunities and helped identify the impact of the system being studied on both the upstream and downstream operations. It was also seen that in some cases VSM was being used in what were not considered its initial appropriate environments. Also, it was determined that the five environmental characteristics (Table 1.1): representative part, capability, complexity, type of organization, and investment, could be used to explain the appropriateness of value stream mapping. These five characteristics are organized in Figure 1.1 showing how they affect VSM. The first three characteristics, namely, representative part, capability and complexity affect the success of the event itself, while the remaining two characteristics, organization and investment affect the implementation of the new map.

Using this organization of the five characteristics, a VSM Matrix has been created [1.1] which is structured similar to Figure 1.1. The VSM Matrix, shown in Figure 1.2, can be used to determine how a company, or VSM area, fits into each category ranging from most appropriate to inappropriate. Under each of the five characteristics, there is a

description of levels at which each characteristic can be met. A company should be able, under each, to determine where the product being discussed fits and this will lead to a level of success that can be reached with VSM.

The value stream mapping for a particular company is based on the category it falls in. The company leadership can see how effective VSM will be by studying the tradeoffs of different categories. This matrix can be used in the future to decide if a manufacturing area or a particular focus factory is appropriate for Value stream mapping.

Table 1.1: Five environmental Characteristic definitions [1.1]

Representative	Product that has similar process steps to the majority of the products that go through the system. The category also includes the time to obsolescence of the map due to product or process changes.
Capability	Level of difficulty associated with the production of a part.
Complexity	Technological ability to repeatedly assemble something with minimal intervention and minimal disruptions (scrap, rework, shortages).
Organization	Level of innovativeness (change) supported on the factory floor.
Investment	Availability of money and labor to make change.

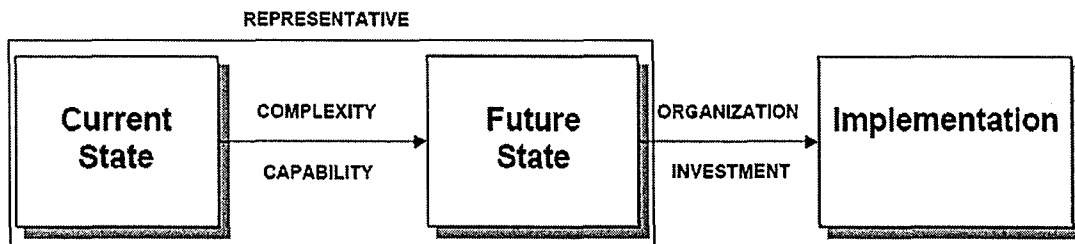


Fig 1.1: The effects of environmental characteristics on implementation of VSM [1.1]

Environmental Characteristics					Success
Pick a Representative Part	Product Complexity	System Capability	Type of Organization	Investment	
				➔	

↑
VSM appropriate

Fig 1.2: Value Stream Mapping Matrix [1.1]

1.2 Overall Equipment Effectiveness

OEE is a "best practices" way to monitor and improve the efficiency of manufacturing processes (i.e. machines, manufacturing cells, assembly lines). [1.2] OEE is simple and practical. It takes the most common and important sources of manufacturing productivity loss, places them into three primary categories and separates them into metrics that provide an excellent gauge for measuring equipment effectiveness. OEE is frequently used as a key metric in TPM (Total Productive Maintenance) and Lean Manufacturing programs and gives one a consistent way to measure the effectiveness of TPM and other initiatives by providing an overall framework for measuring production efficiency.

The 3 major factors affecting OEE are as follows [1.2]:

1. Availability

Availability takes into account Down Time Loss, which includes any events that stop planned production for an appreciable length of time (usually several minutes - long enough to log as a traceable event). Examples include equipment failures, material shortages, and changeover time. Changeover time is included in the OEE analysis, since it is a form of down time. While it may not be possible to eliminate changeover time, in most cases it can be reduced. The remaining available time is called Operating Time. As shown in the bar chart below, the downtime losses are to be reduced to increase operating time, and achieve maximum availability.



2. Performance Rate

Performance rate takes into account Speed Loss, which includes any factors that cause the process to operate at less than the maximum possible speed when running. Examples include machine wear, substandard materials, misfeeds, and operator inefficiency. The remaining available time is called Net Operating Time as depicted in the following bar chart.



3. Quality Rate

Quality rate takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. The remaining time is called Fully Productive Time. The goal is to maximize Fully Productive Time as depicted in the bar chart below.



The basic equation used for an OEE metric is given by [1.2]:

$$\text{OEE} = \text{Availability} * \text{Performance Rate} * \text{Quality rate. \%} \quad (1.1)$$

One of the major goals of TPM and OEE programs is to reduce and/or eliminate what are called the Six Big Losses – the most common causes of efficiency loss in manufacturing, which are as follows [1.2] :

1. Unplanned Downtime Loss
2. Changeover Time Loss

3. Cycle Time Loss
4. Minor Stoppages
5. Start-up Loss
6. Scrap/Rework Loss.

References (Chapter 1):

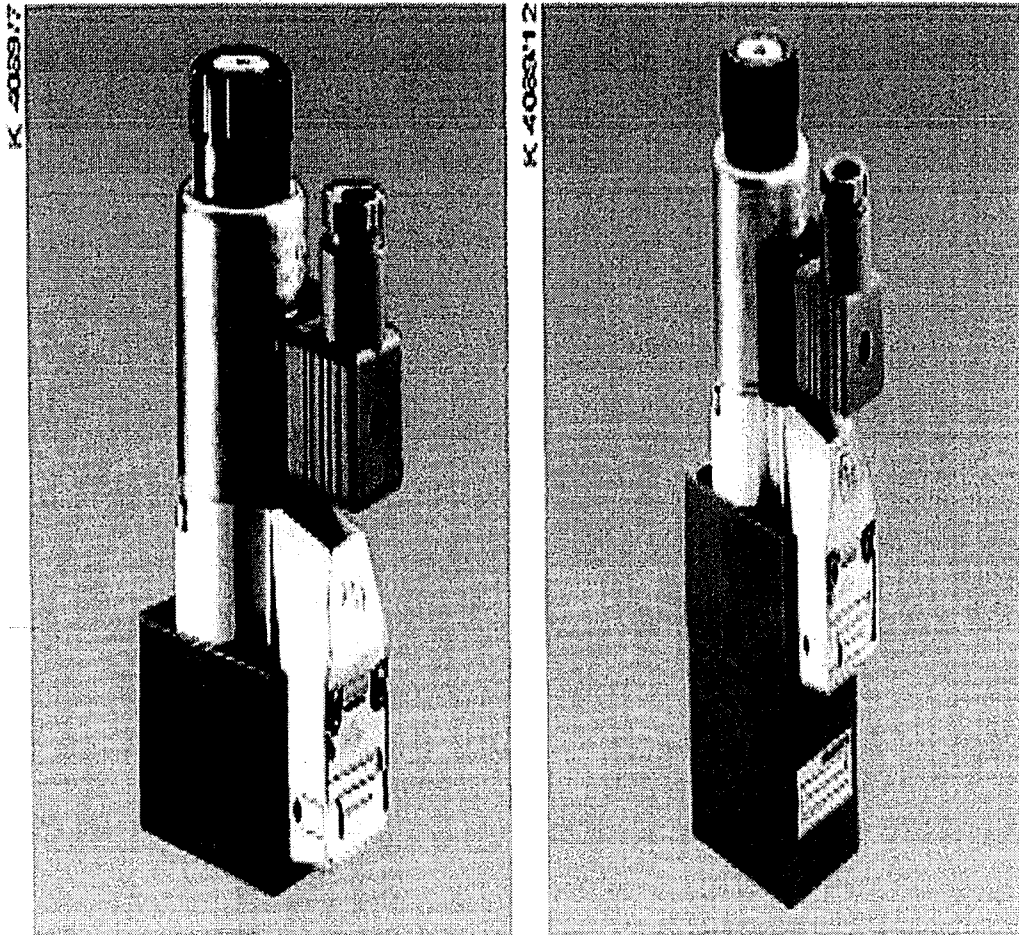
- 1.1 *Salzman, R.A. (2002), Manufacturing System Design: Flexible Manufacturing Systems and Value Stream mapping, Master's thesis, Department of Mechanical Engineering, MIT, USA*
- 1.2 *Source: - www.oee.com*
- 1.3 *Rother, M. and Shook. J, (2003), Learning to See, Version 1.3, The lean Enterprise Institute, Brookline, MA. (www.lean.org)*

Chapter 2 Process Flow and Capability Analysis in the current state

The purpose of this chapter is to analyze the current state of valve body machining for a Size 6 valve. This machining is carried out in the Samag cell located in area termed as the Valve Focus Factory work area at the company. A Process flow Diagram, Process capability analysis are the tools used to analyze the process. In the chapter the focus is on process flow diagram and process capability analysis. A subsequent chapter will discuss the value stream mapping exercise performed at the company. The intent of the analyses was to identify the process steps and define their need.

2.1 Size 6 Valve Descriptions

The final assembled and tested Size 6 valves are used as Check/ No return valves, Directional Control Valves, Servo valves and are also mounted on manifold blocks made by the company in the Manifold Focus Factory (MFF) located in the same plant. The size 6 valve is machined, painted, assembled and tested in the Valve Focus Factory (VFF) area at the company. The raw material for the valve body arrives from Germany in the form of raw castings which are then machined in the Samag cell to achieve specified dimensions. These machined valve housings are then painted and used in final assembly and testing of the valve. Figure 2.1 below, provides an example of 2/2-, 3/2- and 4/2 Directional Poppet Type Valves with a Solenoid Operation Model M-SEW 6 (Series 3X) size 6 valve.



*Fig 2.1: 2/2-, 3/2- and 4/2 Directional Poppet Type Valves with Solenoid Operation
Model M-SEW 6 (Series 3X), [2.1]*

The 3/2 way directional poppet valves consist of a steel housing (1), solenoid (2), hardened sleeve (3), and poppet (4), made of ball bearing steel. Solenoid force is applied upon angled lever (6), ball (7) and on operating pin (8). The operating pin has seals on both sides. The chamber between these two seals is connected to P port. This innovative design, allows operating forces (solenoid & spring forces) to be almost perfectly balanced, and permit high pressure applications to 9150 PSI (630 bar). In the de-energized position, ball (4) is held against the left seat (lever side) by a biasing spring (9).

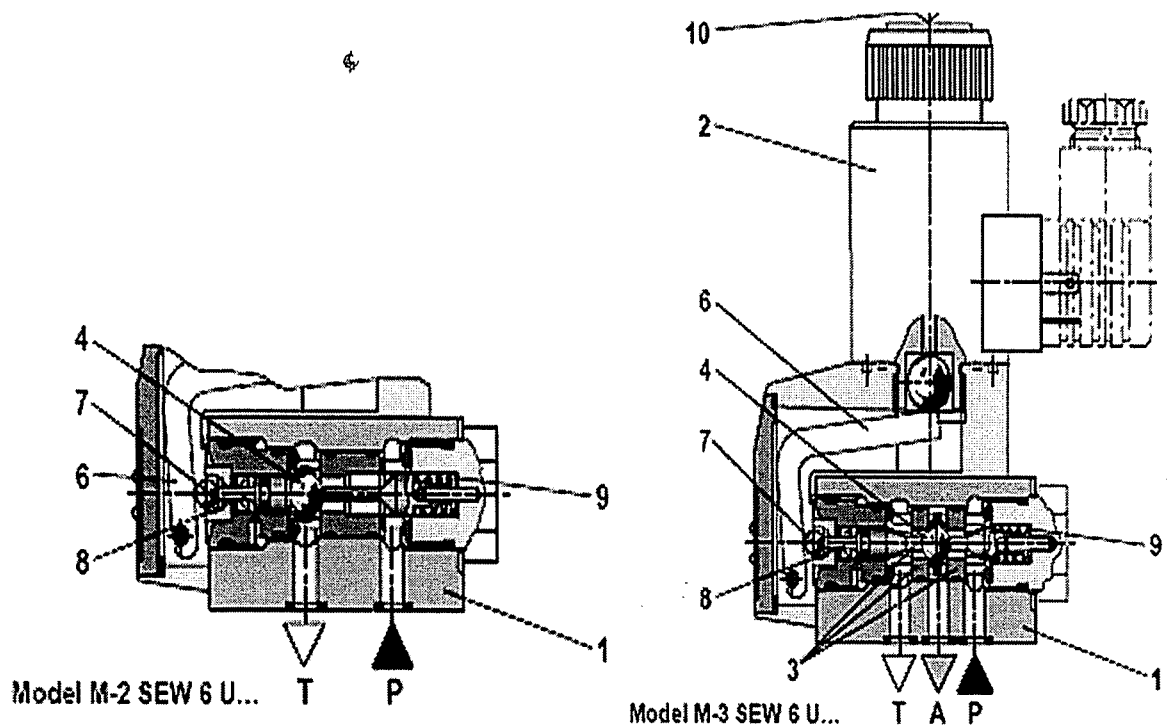


Fig 2.2: 3/2- Directional Poppet Type Valves with Solenoid Operation Model M-SEW 6 (Series 3X), [2.1]

2.2 Samag Cell Description

The Samag cell in the Valve focus factory area produces machined housings for size 6 valves. It machines 8 different types of housings. There are multiple Kanbans being used throughout the plant. One Kanban is used in the VFF area. The Kanban size for raw material (i.e. castings for housings is 1100 pieces). Castings are received from Germany and are stocked up at the Logistics Centre. The Samag cell is manned by 3 personnel on the shop floor. The entire cell works a on First in First out (FIFO) basis. The CNC machines are the bottleneck for the operation. The Samag cell has the following components:

- Belt type Conveyor feeding raw material
- Kuka Pick and Place Robot for machining cell
- 2 Samag MFZ1 CNC machining cells with 2 fixtures each, having 2 clamping on each fixture
- Unima Washer
- Pin printer
- Belt type Conveyor feeding the honing and washing cell
- Kuka Pick and Place Robot for honing cell
- Honing machine
- Inspection and measuring device
- Unima Washing machine
- Belt type Finished product conveyor

The number of parts being worked on in each segment of the cell at any given time during study state production for the valve body machining process run on a daily basis is as follows:

- | | |
|---|-----------------------------|
| • Raw material feeding conveyor --- 120 | CNC machining cell 1 --- 24 |
| • CNC machining cell 2 --- 24 | Washer 1 --- 12 |
| • Pin printer --- 6 | Washer 2 --- 1 |
| • Honing machine --- 5 | Inspection device --- 1 |
| • Washing machine --- 1 | |

The machine description, design and technical specifications for the Samag MFZ 1 CNC machine can be reviewed in Appendix A.

2.3 Tool list for Samag MFZ I

Table 2.1 below gives a short description and function of the tools used in machining of the Size 6 valve body. This description is important to understand the machining process for the size 6 valve body and the various steps during the process flow. The tools are listed in order of their use for each of the specific clampings.

Table 2.1: Samag Tool list and Operator work Instructions for Size 6 valve machining [2.3]

SAP No.	Tool Function	Tool Description
1 st Clamping		
T3	Rough Mill "A" side first "B" side second 3 rd Counter Bore Side	Rough Millhead (inserts)MRO MILL INSERT VOVO56266 Q6 CERAMIC
T21	Deburr Edges	Chamfer/ Deburring Tool
T5	Finish Mill Counter Bore Face	Finish Millhead (inserts)
T1	4 Bolt Holes	Stepdrill 5.3mm x 4mm x 8mm
T4	Rough out O ring pocket	Formdrill/ Endmill 4mm x 7.8mm
T19	O Rings	Stependmill 8.05mm x 12.34mm x 14 mm
T6	Pin location hole	Stepdrill 3mm x 5 mm
T30	Deburring brush	Wire brush P 6 L 8 x 0.15
2 nd Clamping		
T17	Top four holes with Chamfer at bottom of counter bore holes	Stepdrill 5.6mm x 8 mm
T16	Counterbore + Chamfer	Stependmill 9.4mm x 14mm
T15	Pinholes top "A" + "B" side	Stepdrill 2mm x 4mm x 8 mm
T18	Rough "A" + "B" Bores + Counter bore	Stepdrill 11, 30/12, 24/19, 05
T9	Threadmill "A" then "B"	Threadmill M20 x 1
T10	Rough in steps in lands	Rough undercut 10.1 x 11.2
T12	Maple reamer through "B" side	Maple reamer 11.96 mm
T13	Finish Steps in lands one at a time	Finish Undercut 11.7
T14	Flex hone brush	Flexhonbrush ½". 320 Grit

Note: T3 and T21 are also used in second clamping.

2.4 Process Flow Chart

A flowchart is a graphical representation of a process, depicting inputs, outputs and units of activity. It represents the entire process at a high or detailed (depending on your use) level of observation, allowing analysis and optimization of workflow. [2.5] Flow charts are easy-to-understand diagrams showing how steps in a process fit together. This makes them useful tools for communicating how processes work, and for clearly documenting how a particular job is done. Furthermore, the act of mapping a process out in flow chart format helps one clarify understanding of the process, and aids in deciding where the process can be improved. [2.5]

A flow chart can therefore be used to:

- Define and analyze processes;
- Build a step-by-step picture of the process for analysis, discussion, or communication; and
- Define, standardize or find areas for improvement in a process

In addition, by conveying the information or processes in a step-by-step flow, one can then concentrate more intently on each individual step without feeling overwhelmed by the bigger picture.

Four particular types of flow charts have proven useful when dealing with a process analysis: top-down flow chart, detailed flow chart, work flow diagrams, and a deployment chart. Each of the different types of flow charts tends to provide a different aspect to a process or a task. The top-down flow chart is used for the analysis of the size 6 valve body machining since it provides an detail examination of each step for the entire process flow. Flow charts provide an excellent form of documentation for a process, and

quite often are useful when examining how various steps in a process work together. When dealing with a process flow chart, two separate stages of the process should be considered: the finished product and the making of the product. In order to analyze the finished product or how to operate the process, flow charts tend to use simple and easily recognizable symbols. The basic flow chart symbols below are used when analyzing how to operate a process.

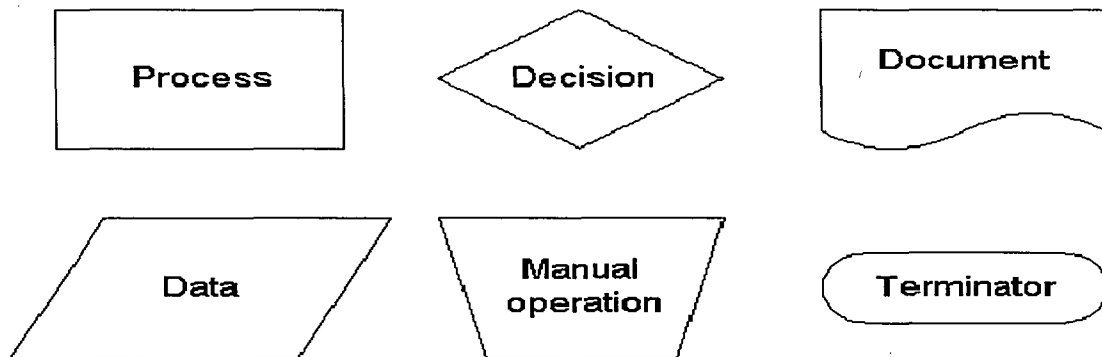


Fig 2.3: Flow chart Symbols [2.4]

In today's computer market, numerous software packages are available to produce process flow charts. The following is a listing of software packages designed specifically for flow charts. All of the packages listed are compatible with Microsoft Windows.

- ABC Flow charter
- Corel Flow
- VISIO

2.4.1 Size 6 valve machining flow chart:-

The size 6 valves machined on the Samag consist of 2 basic types:

- NG6 valves
- 5 channel valves

Each type has different operation numbers on the Bill of Materials, but they both go through a similar set of processes to reach assembly. The only difference between the NG6 and the 5 channel valve was that the NG6 was machined in the Samag Cell and the 5 channel was machined on the DMG machine. Also, the 5 channel went through one less step of geometric inspection. Thus, a common process flow chart for both types was prepared. Both these types of valve bodies first go through CNC machining in the Samag cell. The parts then go through a pin printing operation which helps to trace back the batch number used for manufacturing. Both valves bodies are then washed and honed before final inspection. These parts are then sent to paint after which they are prepped for final valve assembly.

Fig. 2.4 is the chart depicting the process flow of the size 6 valve body through its machining cycle. The numbers in the column for Samag operations for NG6 are the numbers corresponding to the ones in the bill of materials for each step. The “x” symbol in the Samag NG6 and 5 channel column denotes if the step was a part of the process flow or not. The steps with “x” symbol are a part of the process flow. The numbers in the column for the 5 channel valve are corresponding to the numbers in the bill of materials for each step. The inspection after the engraving operation is a poka yoke inspection carried out to check for width of the part and identify for excessive material on the back side. The geometric inspection after honing checks for the concentricity of the spool lands inside the valve body. The visual inspection (naked eye) after the final washing operation is performed by the operator to check for any visible defects to the surface finish of the machined housings.

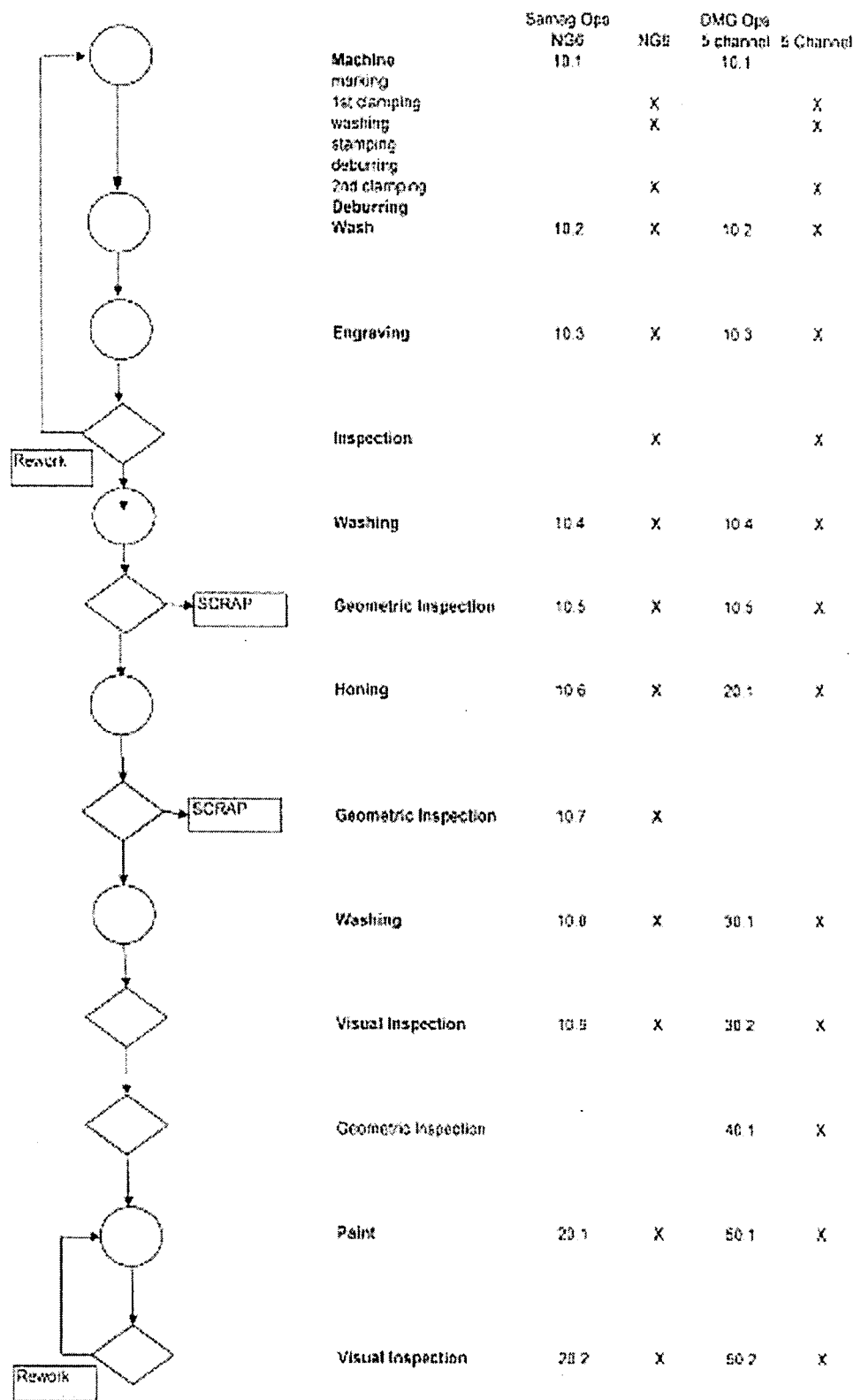


Fig 2.4: Flow chart for size 6 valve body machining [2.8]

2.5 Process Capability Analysis

A process capability index is a numerical summary that compares the behavior of a product or process characteristic to engineering specifications [2.7]. These measures are also often called capability or performance indices; here capability index is used as the generic term. A capability index relates the customer required specification limits to the specifications being achieved by the process. A large value of the index indicates that the current process is capable of producing parts that, in all likelihood, will meet or exceed the customer's requirement. A capability index is convenient because it reduces complex information about the process to a single number. The indices are used to communicate how well the process has performed. The effect of a process change can be assessed by comparing capability indices calculated before and after the change.

A capability index relates the engineering specification (determined by the customer) to the observed behavior of the process. The capability of a process is defined as the ratio of the distance from the process center to the nearest specification limit divided by a measure of the process variability.

Mathematically,

$$\text{Process capability} = \min (USL - \mu / 3\sigma, LSL - \mu / 3\sigma) \quad (2.5.1)$$

USL and LSL are the upper and lower specification limits, respectively, and μ and σ are the process mean and standard deviation, respectively, for the individual measurements of the characteristic of interest. Calculating the process capability requires knowledge of

the process mean and standard deviation, μ and σ . These values are estimated from data collected from the process.

Often the process data is collected in subgroups. Let X_{ij} , $i=1, \dots, m$ and $j=1, \dots, n$ represent the process data collected from the j^{th} unit in the i^{th} subgroup. Here m equals the total number of subgroups and n equals the subgroup sample size [2.6]. The most widely used capability indices are defined as:

$$P_{pk} = \min (USL - \mu / 3 \sigma_S, \mu - LSL / 3 \sigma_S) \quad (2.5.2)$$

$$C_{pk} = \min (USL - \mu / 3 \sigma_{r/d_2}, \mu - LSL / 3 \sigma_{r/d_2}) \quad (2.5.3)$$

Where μ , the overall average, is used to estimate the process mean μ and σ_S and σ_{r/d_2} are different estimates of the process standard deviation σ . The estimate σ_S is the sample standard deviation whereas σ_{r/d_2} is an estimate derived using the subgroup ranges R_i , $i=1, \dots, m$. The parameter d_2 is an adjustment factor needed to estimate the process standard deviation from the average sample range. Large values of P_{pk} and C_{pk} should correspond to a capable process that produces the vast majority of units within the specification limits. [2.6]

As shown in (2.5.2) and (2.5.3), the measures P_{pk} and C_{pk} differ only in the estimate of the process standard deviation used in the denominator. As a result, to compare the two capability measures we need to compare the two standard deviation estimates σ_S and σ_{r/d_2} . There is one important difference between the two. Since the range based estimate σ_{r/d_2} is calculated based on subgroup ranges, it uses only the variability within each subgroup to estimate the process standard deviation. The sample standard

deviation σ_s , on the other hand, combines all the data pooled, and thus uses both within subgroup and between subgroup variability. The total variation is the sum of the within subgroup and between subgroup variability. As a result, σ_s , estimates the total variation present in the process while $\sigma_{r/d2}$ estimates only the within subgroup variation.

The question of which estimate provides a more appropriate measure of process variability to use in process capability calculations can be answered by considering the customer perspective. Customers are concerned about all the variation in the process output, regardless of its source. As a result, the capability of a process should be based on the process total variation, i.e. one should use the capability index P_{pk} . C_{pk} underestimates the total variation if the between subgroup variability is substantial. In all cases of practical interests the estimate σ_s is larger than $\sigma_{r/d2}$, since σ_s includes the between subgroup variability in the calculation. Thus, P_{pk} , tends to be smaller than C_{pk} and thus using it makes the process “look worse”. However, it is beneficial for the manufacturer and the customer to obtain a realistic view of the capability of the process to produce parts within specification.

The standard deviation estimates also differ in a less fundamental, but also important way. The subgroup range-based approach yields estimates that are not as efficient as the sample standard deviation method even if the between subgroup variation is zero. This loss of efficiency results mostly from a loss of degrees of freedom, and means that when using the range method, process information is discarded needlessly. The less efficient range-based estimate is popular since it is used in control charts and can be calculated easily by hand.

Based on these observations, the P_{pk} index was used to calculate the capability of machining of size 6 valve bodies on the Samag cell.

Data Collection

In the study 48 data points were collected for each valve parameter to be studied. 6 data points were collected on each day i.e. 2 data points per shift, one at the start of the shift and the other data point at the end of the shift. The intent of the sampling procedure was to consider the variability occurring in the process throughout the day. Thus, it was hoped that variability affected by time, operator and raw material could be accounted for.

Analysis

Excel based calculations were done after collecting data from the floor. Table 2.2 below is the summary of results for P_{pk} values calculated using equation 2.5.2 for various parameters of the Size 6 valve housing measured by the quality assurance department.

Table 2.2: Ppk summary for parameters related to machining size 6 valve body

Valve body Parameter	Ppk Value
Overall Length	1.40
Overall length minus the counter bores	0.90
O ring Counter bore depth	2.00
B side to bolt hole distance	0.95
Concentricity A	0.70
Concentricity B	7.72
Spool bore diameter before Hone A	0.39
Spool bore Diameter before Hone B	0.26
Land Location 1	0.75
Land Location 2	1.03
Land Location 3	0.96
Land Location 4	0.98
Land Location 5	0.97
Land Location 6	1.04
Land Location 7	0.94
Land Location 8	0.97

Land Location 9	0.91
Land Location 10	1.51
Spool Bore surface before honing	0.50
B port O ring counter bore surface finish	0.72
A port O ring counter bore surface finish	0.63
P port O ring counter bore surface finish	0.73
T port O ring counter bore surface finish	0.61
A side (End) O ring surface finish	0.64
B side (End) O ring surface finish	0.75
Spool Bore Diameter	0.43
Spool Bore cylindricity after honing	0.09
Spool Bore Surface finish after Honing	0.78
Surface finish on bottom	1.04
Straightness of bottom along Spool bore axis	0.00

Action Plan

After calculation of the Ppk index for each of the parameters it was noticed that the values for most of the parameters were below 1.33 and thus the processes were sub standard. Table 2.3 provides a corrective action plan for all the parameters which have values below 1.33, i.e. they do not meet customer specifications.

Table 2.3: Process capability Action Plan

Results	Interpretation+ Action plan
Pp and Ppk > 1.67	The process probably meets customer requirements. After approval, begin production and follow the approved control plan.
1.33 <= Ppk >= 1.67	The process may not meet customer requirement. After part approval, begin production with additional attention to the characteristic until an ongoing Ppk >= 1.33 is achieved.
Ppk < 1.33	The process is substandard for meeting customer requirements. Process improvements must be given high priority and documented in a corrective action plan. Increased inspection or testing is normally required until an ongoing Ppk of 1.33 is demonstrated. A revised control plan for these interim actions must be reviewed with and approved by the customer.

References (Chapter 2):

- 2.1 *Industrial Hydraulics valve Catalogue, Bosch Rexroth.*
- 2.2 *Operating Instructions Manual, Samag MFZ1*
- 2.3 *Operator work Instructions, Valve Focus Factory, Bosch Rexroth – Internal Document*
- 2.4 *deming.eng.clemson.edu/pub/tutorials/qctools/flowm.htm - 9k*
- 2.5 *en.wikipedia.org/wiki/Flowchart*
- 2.6 *Steiner S, Bovas A and Jock M, Understanding Process capability Indices, Institute for Improvement of Quality and Productivity, Department of Statistics and Actuarial Science, University of Waterloo, Canada*
- 2.7 *K. Samuel and J. Norman, Process Capability Indices (1993), Chapman and Hall, USA*
- 2.8 *Personal Communication with technical personnel at the company*

Chapter 3 Value Stream Mapping

3.1 Background for value stream mapping

Lean manufacturing is the philosophy of eliminating muda (waste) within a process. It looks to isolate the value added activities and place them in a form of continuous flow to better meet customer demand. Many industry leaders, in order to improve their processes toward the ultimate lean production system, are using value stream mapping (VSM). VSM allows a simple two-dimensional representation that identifies the value added steps from the non-value added ones. Value stream mapping is a great tool to help determine wasted steps, reduce total lead-time, and provide a valuable door-to-door perspective on the entire process [3.1]. First the history of lean is reviewed in what follows, including the five key principles, and its implementation in the US. This will be followed by a detailed discussion of value stream mapping and the application of VSM to the company valve focus factory.

Lean is a term coined by The MIT International Motor Vehicle Program to describe the Toyota Production System (TPS) in their publication *The Machine That Changed the World* [3.1]. The goal of this publication was to characterize the performance differences between companies operating with traditional mass manufacturing systems and those using TPS [3.5]. This book was considered to revolutionize the way people thought about the automotive industry.

The Toyota Production System, now known also by the terms “lean” or *Just-in-Time (JIT)*, was developed based on the cultural, geographic and economic history of Japan in the 1950s. The Japanese believe strongly in conservation of material, making it easier to adapt tight material control policies. Due to a more systems-oriented culture,

policies that cut across individual workstations, such as cross training of floating workers and total quality management, were easier to adapt. The location of suppliers also made it feasible to have more frequent deliveries. The possible impending doom of the automotive industry in Japan without an increase in efficiency and productivity fueled the ability to make drastic changes [3.5] and the theories and principles of lean manufacturing were developed. Lean has been implemented in a diverse set of environments including aerospace, consumer products, metals processing, and industrial products [3.5]. Contrary to Toyota's open atmosphere about its practices, "few manufacturers have managed to imitate Toyota successfully" (Spear and Bowen, 1999).

Lean Principles

In *Lean Thinking*, Womack and Jones define lean thinking as "a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively." Womack and Jones noted that there are five key principles vital to lean thinking; these key principles are: specify *value*, identify the *value stream*, make value *flow*, organize customer *pull*, and pursue *perfection*. These principles are expected to be addressed in order, with each one building on the one before it as shown in fig 3.1. Within this framework of lean principles, this research concentrates on the identification of the value stream and the identification of the value adding action.

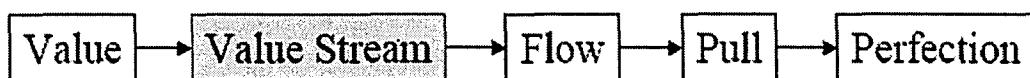


Fig 3.1: Steps of Lean Thinking

Each term in fig 3.1 is described as follows:

Specify Value - Value is expressed in terms of a specific product or service, delivered at a specific price at a specific time, which meets the needs defined by the customer. [3.2]

Identify the Value Stream – A Value stream is a look at the entire door-to-door perspective of a production, from raw materials to product delivery. It includes the determination of all actions necessary to produce a product, and the separation of these necessary activities from the identified non-value added steps. This includes, not only the physical transformation of the product from raw materials, but also the information system necessary to produce the right quantity at the right time.

Flow – Once waste has been eliminated, ‘flow’ can be accomplished. Flow, the opposite of batch production, requires the movement of products from one value-creating step to the next with no waiting or scrap.

Pull - The production of only what the customer wants when the customer wants it. Instead of pushing products from raw materials to the customer, information travels upstream from the customer signaling production only when a need is shown.

Perfection – This step is a reminder that there is no end to reducing waste. Continuous improvement of a system is vital to perfection, where waste is constantly being eliminated.

It is necessary to understand that lean is not a specific control tool, improvement tool, floor layout, or principle. It is the methodology or framework that focuses on the ideas of value, waste, and meeting customer demand. Value stream mapping came about

as a way of determining where the value and waste are located and aiding in the reduction of lead-time to help make the right product at the right time.

3.1.1 Value Stream Mapping

Identifying the value stream, the second principle in lean thinking, includes a study of the entire production process and separation of value added from non-value added process steps. This can be accomplished through the use of value stream mapping (VSM), where a highly complex real system can be represented in a simpler two-dimensional format. Value stream mapping is the process of compiling all actions that go into the design, order and production of a product into a “door-to-door diagram”. A future vision can be then created through the implementation of lean concepts such as flow and pull.

VSM allows the separation of actions into three categories: (1) value added, (2) non-value added but necessary, and (3) non-value added. The non-value added actions should be addressed first and be eliminated. It should be possible to complete this step in a short span of time under current operating procedures. This is followed by elimination of non-value added actions but necessary steps, which may require considerable restructuring of the system.

Rother and Shook [3.4] devised value stream mapping in its present form and recommended that value stream mapping be done in three phases; current value stream, future value stream, and determination of an implementation plan. In many cases, value stream mapping is done in a workshop type atmosphere which brings together engineering, manufacturing control, machinists, and maintenance personnel, where the current state, future state, and implementation plan are all created during a three to five

day period. This format brings together all of those people affected by changes to the system. It achieves a method for obtaining their collective buy-in for the changes, a sense of ownership of the improvements, and increased team camaraderie for all involved.

3.1.2 Value Stream Mapping Icons

The value stream approach to process mapping utilizes the icons shown in Figure

3.2. These icons are very useful to individuals familiar with lean manufacturing.

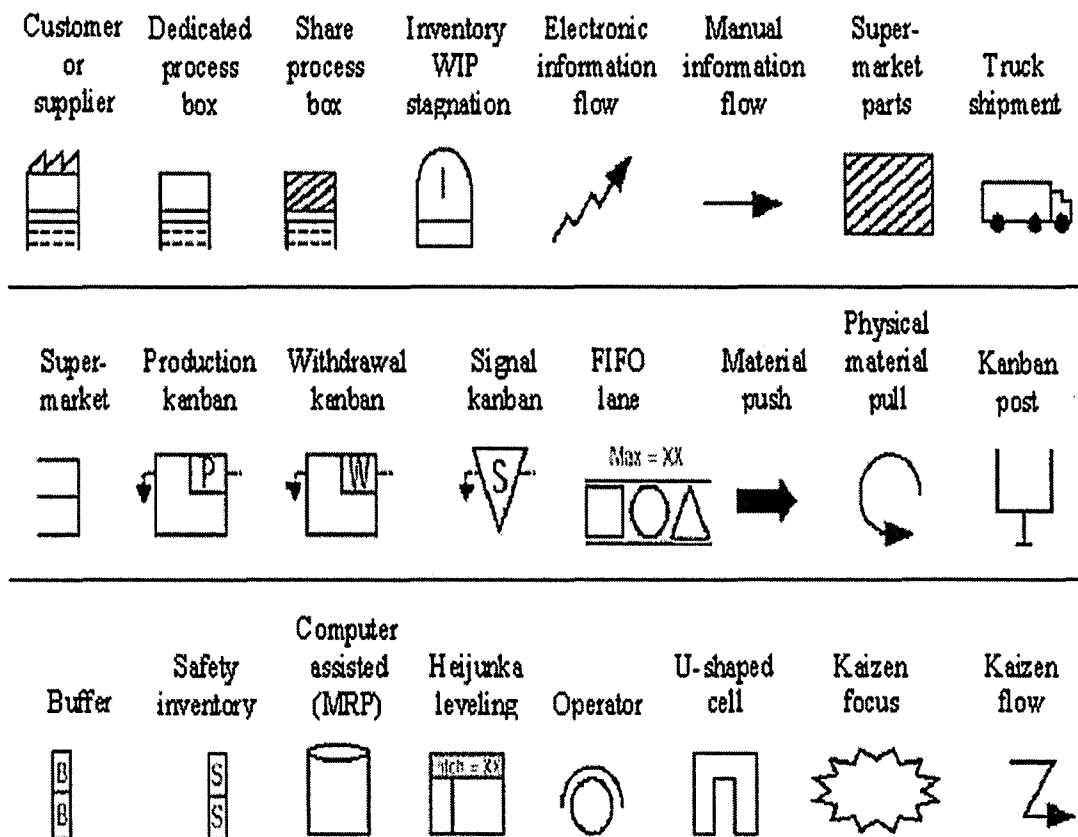


Fig 3.2: Icons for Value stream Mapping [3.7]

3.1.3 Current State

A current value stream map reproduced from the book *Learning to See*, [3.4] and given in Fig 3.3 is read from left to right with the first production step being placed in the bottom left corner. Shipping is usually placed in the bottom right corner. In the top left corner the supplier can be found, and the top right is the customer. The bottom of the chart is reserved for production steps, and the top for information flow between the company, the individual production steps, the customer, and the supplier.

Rother and Shook [3.4] stated that the current value stream should be made as a snapshot of current findings and include such information as inventory levels, total lead-time, machine uptime, and machine reliability. Table 3.1 shows the typical metrics included for a specific process box on a value stream map. A current value stream map allows someone to see the flow of the entire production process from supplier to customer. People can then understand how their job or function affects the critical path operation.

Referring to the value stream metrics on the value stream map gives a snapshot view of the current state of the machine or the system. The typical metrics are, cycle time, changeover time, uptime, available time, batch size and yield [3.4]. The example of the current state value stream map shown in Fig 3.3 shows the product and information flow across the value stream. For this example, it is seen that that the production lead time is 23.5 days and the value added time is a very small percentage of the lead time, amounting only to 184 secs.

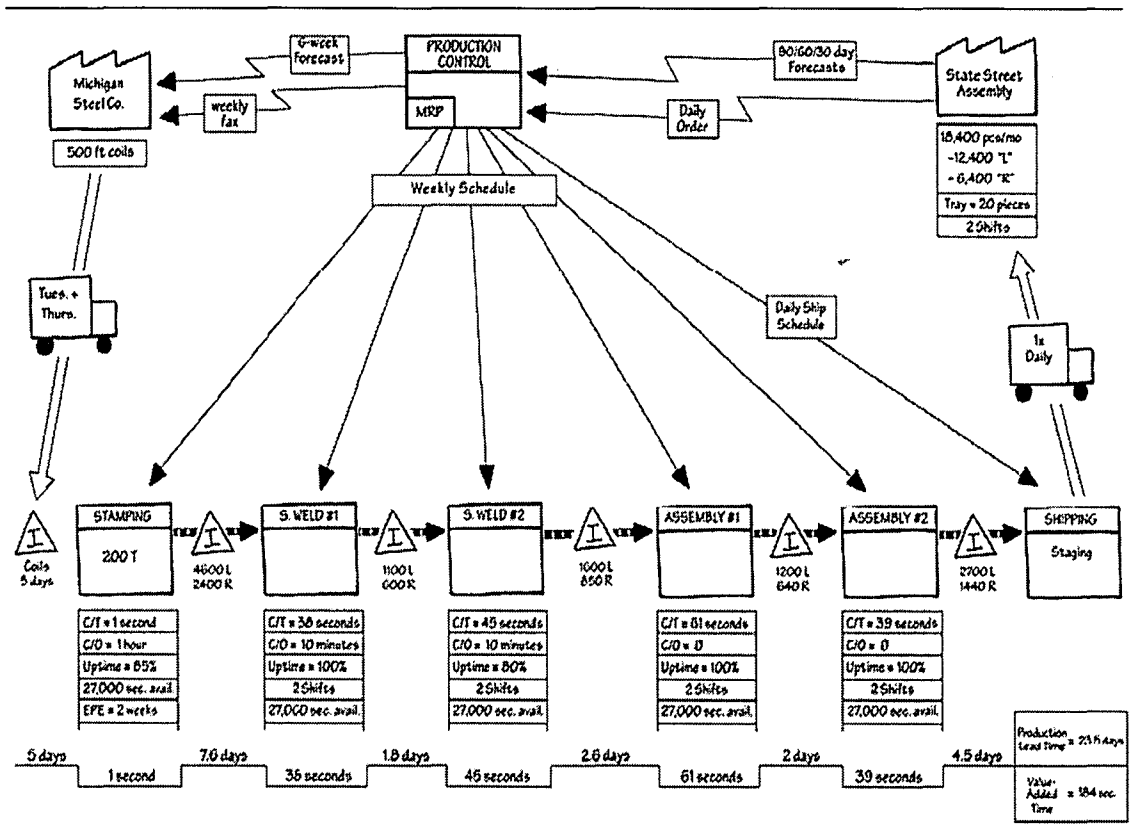


Fig 3.3: An example of a Current Value Stream Map [3.4]

Table 3.1: Typical Value Stream Metrics [3.4]

Metric	Description
Cycle time	Time required to complete a process
Changeover Time	Time required to change a process from one product to another
Uptime	Percentage of time station is processing parts
Available time	Amount of time machines and employees are free to work
Batch Size	Number of same part that goes through a process step at one time
Yield	Percentage of good parts produced in a process

3.1.4 Future State

After a current value stream is developed, the next phase is to develop a future value stream. Using the principles of lean manufacturing and a set of important questions vital to lean manufacturing a future state is drawn. Terms and concepts important to development of the future value stream are as follows [3.3]:

Takt Time: The available production time divided by customer demand.

Supermarket: The location where a predetermined standard inventory is kept to supply downstream process.

Pacemaker: Any process along a value stream that sets the pace for the entire stream. The pacemaker process should not be confused with a bottleneck process, which necessarily constrains downstream processes due to lack of capacity.

Eight questions developed by Rother and Shook [3.4], which can be seen below, should be answered in the following order to gain system perspective:

1. What is the takt time?
2. Will we ship directly to the customer, or to a finished goods warehouse?
3. Where can we use continuous flow?
4. Where will we need supermarket pull systems?
5. Where will our pacemaker be?
6. How will we level the production mix at the pacemaker?
7. What increments of work will you consistently release and take away at pacemaker?
8. What process improvements will we need to achieve our future state design?

It should be noted that these questions link to the ideas of flow and pull mentioned in lean principles, and show how making a value stream map is vital to

determining where processes can be improved. Figure 3.4 is an example of the future state corresponding to Fig 3.3 that has been developed using the principles of lean. A pull system from shipping has been implemented through the use of kanban cards and supermarkets. In this example the welding steps and assembly steps have been combined for a continuous flow cell. Through these identified improvements, there was a change in lead-time from 23.5 days to 4.5 days in this example.

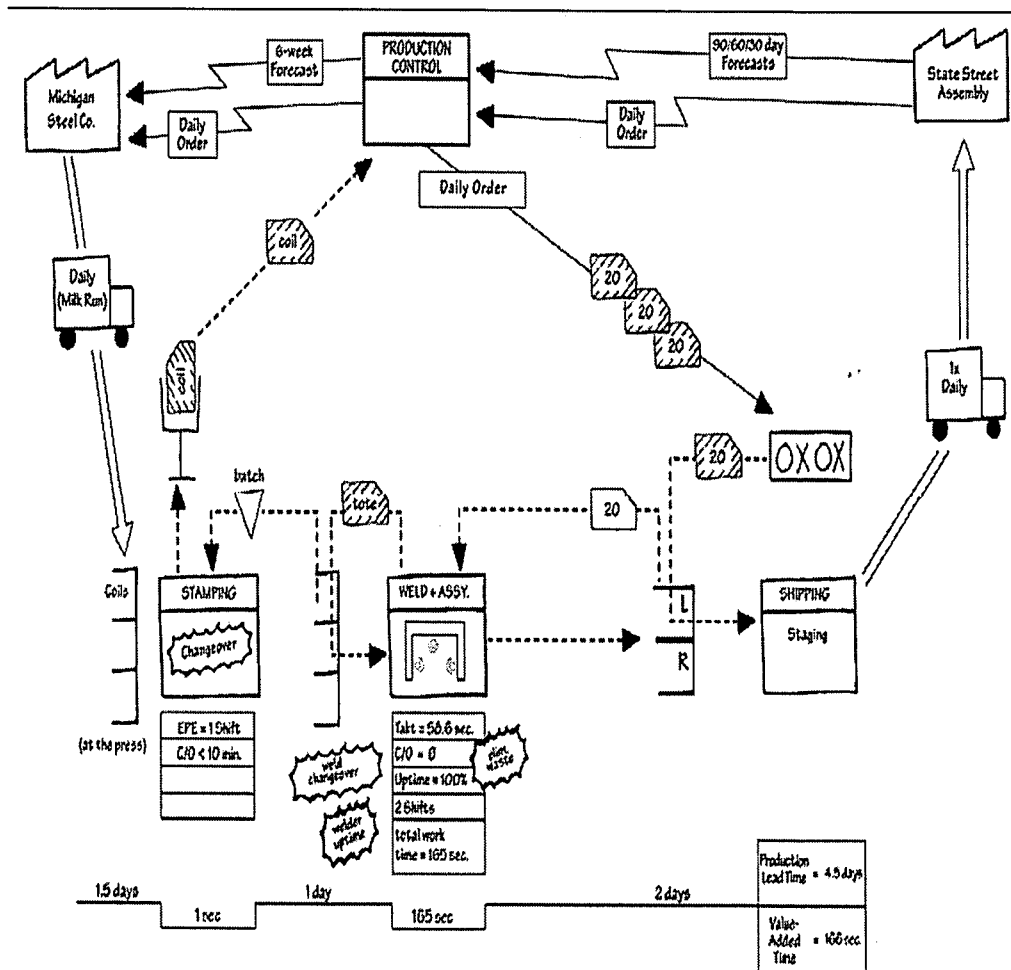


Fig 3.4: An example of a Future Value Stream Map (3.4)

3.1.5 Implementation Plan

The final step of value stream mapping is creating an Implementation Plan to help achieve the future state from the current state. Rother and Shook [3.4] suggest the use of a value stream plan worksheet and a review worksheet. It is recommended that follow up meetings, once every week to two weeks, are necessary to continue to update and make progress on the implementation plan. This regular meeting format stresses the importance of the initial value stream mapping event and the actions that were identified. Making people accountable for certain action items will also help speed along the process. Fig. 3.5 below indicates the environmental characteristics affecting value stream mapping. The first three characteristics, namely, representative part, capability and complexity affect the success of the event itself, while the remaining two characteristics, organization and investment affect the implementation of the new map.

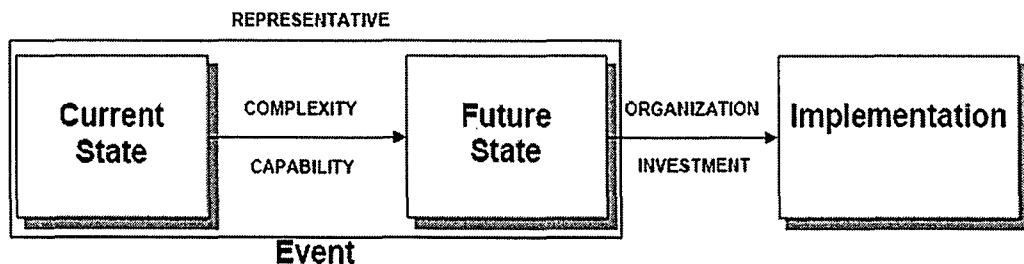


Fig 3.5: The effect of environment characteristics on Implementation of Value stream Mapping, (3.5)

3.1.6 Value Stream matrix

The matrix proposed by Rhonda A. Salzman, [3.5] and mentioned earlier in chapter 1 is shown in Table (3.2) and can be used to determine the appropriateness of a VSM event. The five environmental characteristics identified, namely, representative part, product complexity, system capability, type of organization, investments, are evaluated. A company can rank itself from 1 to 5, 1 being the best, and determine what factors need improvement in order to make value stream mapping more successful or to determine for what purpose it can be run. The matrix should be filled out in reference to an individual VSM event. The matrix is designed in a similar format as Figure 3.5 with the first three columns associated with the value stream mapping event. The next two columns pertain to implementing change. The last column (success) indicates the correlation between these factors and the success expected for value stream mapping and results from recording already known improvement opportunities to making a measurable change. An environmental characteristic score as discussed above can be developed from the matrix to determine whether value stream mapping will be a valuable tool. This matrix is organized in a proposed format that can be used by those determining improvement opportunities.

This value stream mapping matrix can be utilized at the company in the future to decide if a particular area or manufacturing system is eligible for the Value Stream mapping exercise. The five environmental characteristics identified should be taken into consideration to decide if value stream mapping would be a valuable tool.

<i>Value stream mapping</i>			<i>Implementation</i>	<i>Correlation</i>	
Pick a Representative Part¹	Product Complexity	System Capability	Type of Organization	Investment	Success⁷
All products go through the process depicted and the process drawn will not be changed ²	Tasks per process box is 10 steps or less and all processes are serial ⁴	Disruptions ⁶ almost never happen and variation in cycle time of a process box is negligible.	Senior leaders reinforce transition and foster improvement throughout the VSM.	Money and labor are in abundance	1 An improvement was seen in the performance of the mapped area
The majority of the products go through the process depicted and they will not change before improvements can be made (1 year)	Tasks per process box is greater than 10 steps and most processes are serial	Disruptions are low enough not to impede flow and variation does not impact flow	The organization promotes changes and improvements	Money, and labor are available but limited	2 Improvements were made using additional projects, but not enough were initiated to see an improvement
Half the products go through the process depicted and the process drawn might change in less than a year.	Tasks per process box is greater than 100 and the processes are a mixture of serial and parallel	Occasionally disruptions force out of sequence work and variation in cycle time impacts flow	Level of commitment among management is variable	Money and labor can be made available but an extensive justification process exists	3 The event helped to recognize new opportunities but no implementation occurred
A few of the products go through the process depicted and the process drawn might change in the next few months	Tasks per process box is greater than 1000 and most processes are parallel ⁵	Disruptions and variation in cycle time are barriers to continuous flow	VSM was initiated by upper management with no lower management support, or visa versa	Money and labor are hard to come by even if justified	4 The event was a good way to record improvements that have already been suggested
Only the product mapped goes through the process shown and the processes drawn might change next week, making the map obsolete. ³	Tasks per process box is too many to count and all processes are parallel	Disruptions are a fact of life and cycle time of a process box is nearly impossible to predict	The VSM event was perceived as a check the box exercise	Money and labor are impossible to get	5 The VSM event did not help surface any issues

¹ Ability to pick a Representative Part- within the products that go through the mapped area

² Assuming no process improvements are initiated

³ Assumes multiple products go through the area, if only one product goes through assume answer of all.

⁴ Serial- only one task is occurring on the product at one time

⁵ Parallel- multiple items of the product are being worked on at one time

⁶ Disruptions – scrap, rework, shortages

⁷ Improvements are seen in reference to the customer

Table 3.2: Value Stream Mapping Matrix, [3.5]

3.1.7 Advantages/Disadvantages of VSM

Value stream mapping as a technique has its advantages and disadvantages. They are listed as follows [3.8]:

Advantages of value stream Mapping:

- Relates the manufacturing process steps to other components of the supply chain viz. distributors, suppliers and production control.
- Integrates material and information flows.
- Links Production Control and Scheduling (PCS) functions to Shop floor Control.
- Integrates various IE techniques for material and information flow analysis.

Disadvantages of value stream Mapping:

- Fails to map multiple products that do not have identical routings.
- Fails to relate plant layout and/or material handling to process and equipment parameters.
- Lacks any economic measure for “value”.
- Lacks the spatial structure of the facility layout.
- Biased towards high-volume low-variety manufacturing systems.
- Fails to capture the time value (in \$) of the flow delays due to setup, processing, queuing (at each process step), material handling, etc. delays due to capacity constraints and order sequencing at each process step.

It is recommended that value stream mapping exercise be carried out for any manufacturing area or focus factory after checking for the appropriateness of the exercise by using the value stream matrix.

3.2 Value stream mapping at the company

A value stream mapping exercise was performed at the company to obtain a better understanding of where the currently discussed cell fits into the bigger production system and to identify muda (waste) in the system and eliminate it. (*Refer to appendix B for the value stream map*). The value stream mapping exercise was done to improve the flow and the lead time for machined housings of the size 6 valve body through out the VFF area. The size 6 valve body was chosen because it has high volume, with a large number of steps and large lead time. The exercise found many opportunities for improvement of the system including improvement in the supplier delivery of castings. For the purpose of this value stream mapping exercise, the assembly area of the VFF was considered as the customer for the machining cell.

The typical process data collected from the shop floor was as follows [3.4]:

C/T (Cycle time)

C/O (Change over time)

Uptime

Number of operators

Number of Product Variations

Scrap rate

Working Time

The approach taken at the company was to consider all the components of the Samag cell as different steps of the value stream and provide a detailed analysis for each. This approach enabled one to look at each step critically and eliminate any visible waste. The cycle time for each operation in the corresponding component was recorded. This

exercise helped filter out non-value added times from the value creating ones. It was noted that the external suppliers for Size 6 valve body castings were notified of the demand through electronic communication by the Production Control SAP system. Castings are shipped from Germany and other external suppliers to the company where they were stored as inventory for 50 days at the Logistics Centre. There is a Kanban system between the machining cell and Logistics Centre. Only 1 kanban exists between the machining cell and the logistics centre. The Kanban value is 1100 castings. A pull based supermarket is created on the shop floor as per the demand for the machining Samag Cell. The waiting time on the shop floor for the castings is recorded to be 3 days. The Samag Cell operators receive production orders through the SAP system. The castings are then loaded by the operator on to the raw material feeding conveyor on the Samag Cell. There is a very small variation in the cycle times recorded, since it is a CNC based machining process.

The average cycle times for each component were obtained for the cell and are listed below:

- Conveyor feeding raw material ---- 6 hours
- 2 CNC machining cells with 2 fixtures each, having 2 clamping on each fixture
 - 1st Clamping: - 8 min 50 sec / 12 parts
 - 2nd Clamping :- 7mins / 12 parts
- Washer ---- 1min / 12 parts
- Washing machine 1 --- 37 secs
- Pin printer ---- 1 min 43 sec / 6 parts
- Conveyor feeding the honing and washing cell --- 2min

- Honing machine --- 5 mins
- Inspection and measuring device +Washing machine --- 5mins
- Finished product conveyor ---- 20mins

These machined valve housings are then packed and sent to painting. These parts are staged as inventory for 2 days before being painted. There is no Kanban system between machining and painting. The variation in the cycle times for steps related to painting is +/- 3 σ . The average cycle times for various steps in painting are as follows,

- Prepped for paint --- 30secs +/- 5secs
- Painting --- 20 mins / 216 parts = 6 secs / part +/- 2 secs / part
- Cured --- 12 hrs +/- 30mins
- Packed into boxes -- 30 mins/ 216 parts = 14 secs/ part. +/- 5secs/ part

These painted valve bodies are then sent to the assembly area for final assembly and testing on the valve.

There is one operator working at the Samag Cell and two operators working at the paint booth. The Samag Cell is operational for all 3 shifts while the Paint booth is operational for only for 2 shifts. The batch size for the Samag cell is 34 pieces and that for the paint booth is 216 pieces. The assembly area in the VFF receives production order through SAP system for finished size 6 valves. It then uses the valve housings staged as post paint inventory. The average time for housings to be staged as post paint inventory is around 5 days.

It was noticed that the parts go through a poka yoke inspection before entering washing machine 1. This poka yoke inspection is carried out so that the parts which are wider than the washing machine rail don't pass through. It was observed that the

dimension being checked is not a quality critical dimension, and the surface creating that dimension is not even worked upon by the CNC during the machining process. As such, the, supplier quality of the castings is very critical. Also, there is no means to indicate to the operator if a part is stuck at the poka yoke. This leads to parts machined within specifications waiting behind the parts which have excess material that is required to be machined off. This increases cycle time and lowers production rate. The parts which fail to pass through the poka yoke are collected on a weekly basis and reworked on the weekend. This leads to lesser machine availability on the weekend for production of new parts.

The quantity of scrap can only be recorded at the end of the honing step after the measurement and inspection. As discussed earlier, the parts which fail to pass through the poka yoke are considered as rework and not scrap. This leads to very low scrap values. The data below shows the scrap rate values for the first three months of 2007.

January 2007 --- 9208 ppm

February 2007 – 6310 ppm

March 2007 – 537 ppm

3.3 Recommendations

It was recommended that the rails of the washer be widened so the dimension which is not quality critical can stop affecting the production. Also, the poka yoke width should be regularly checked with a GO/ NO-GO gauge. A buzzer or a flash light is recommended to be installed to notify the operator if a part is stuck at the poka yoke. This will lead to quick removal of the part allowing the good parts behind it to go through, and minimize cycle time. In addition it is recommended that the parts which are needed to be

reworked be considered as a part of scrap data so as to obtain realistic values of quality losses.

Castings arriving from Germany and external suppliers are held as inventory in the blue building and Logistics centre for 50 days. An approach to deliver castings directly to the shop floor is recommended. This will lead to minimizing inventory storage cost and time. It is also recommended that all the steps in the machining cycle be critically evaluated and the ones unnecessary be eliminated. This will lead to shortening of cycle time and thus an increase in production rate. It is further recommended that kanban be used between machining and paint and also paint and assembly to diminish inventory levels on the shop floor. The paint booth is located in the opposite direction from the flow of material and leads to unnecessary transportation of the machined castings to the paint booth. This results in increasing the lead time of the entire process. It is recommended that the cells are redesigned and arranged in line with product flow.

References (Chapter 3):

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3.2 www.lean.org

3.3 *Lean Lexicon a graphical glossary for Lean Thinkers*, 2nd Edition, (2003), Lean Enterprise Institute, Brookfield, MA, USA. (www.lean.org)

3.4 Rother, M. and Shook. J, (2003), *Learning to See, Version 1.3, The lean* Enterprise Institute, Brookline, MA. (www.lean.org)

- 3.5 Salzman, R.A. (2002), *Manufacturing System Design: Flexible Manufacturing Systems and Value Stream mapping*, Master's thesis, Department of Mechanical Engineering, MIT, USA
- 3.6 Bosch Production Systems Literature, Bosch Rexroth
- 3.7 http://csob.berry.edu/faculty/jgrout/processmapping/Value_Stream/value_stream.html
- 3.8 Khaswala Z. N. , Irani S.A. , *Value Network Mapping: Visualization and Analysis of Multiple Flows in Value Stream Maps*, Dept. of Industrial, Welding and Systems Engineering, The Ohio State University, Columbus, Ohio, USA.

Chapter 4 Overall Equipment Effectiveness (OEE)

The purpose of this chapter is to understand the Overall Equipment Effectiveness (OEE) metric. This metric has been chosen to be studied due its growing importance in the lean culture at Bosch. The OEE analysis in the future will lead to decisions on investments on the type of machines, their maintenance schedules and finally leading to improvements which will help achieve higher uptime and production, combined with a lower defect rate. The current approach of calculating OEE is discussed and what is deemed incorrect with the current approach is explained. A new approach is proposed and its effect on achieving realistic numbers for OEE metric is explained. A set of machine downtime reason codes are proposed against the current one, with the objective of aiding in reliable data collection.

4.1 Overall Equipment Effectiveness Background

OEE is a total productive maintenance (TPM) measure of how effectively equipment is being used. OEE is a "best practices" way to monitor and improve the efficiency of our manufacturing processes (i.e. machines, manufacturing cells, assembly lines). OEE is simple and practical. It takes the most common and important sources of manufacturing productivity loss, places them into three primary categories and provides an excellent indicator for measuring "where we are - and how we can improve" [4.5].

Overall Equipment Effectiveness (OEE) is fast becoming a widely used measure in manufacturing industries, but it is also one of the more misunderstood and misused measures and causes much confusion [4.2]. OEE is an improvement measure and is used as part of the improvement cycle. Unfortunately, much is made of the 85% 'World Class

Standard' [4.5], a target found in the original Total Productive Maintenance literature.

OEE is an internal measure, which relates to your efficiency and costs.

OEE developed out of the need for improvement groups to have a way of measuring and analyzing equipment problems as part of their Define, Measure, Analyze, Improve, and Control cycle [4.2]. OEE defines the expected performance of a machine, measures it and provides a loss structure for analysis, which leads to improvement. It can then be used as a tracking measure to see if improvement is being sustained i.e. if control is sufficient.

OEE typically focuses on what are termed the six major losses: Unplanned Downtime Loss, Changeover Time Loss, Cycle Time Loss, Minor Stoppage, Start-up Loss, and Scrap/Rework Loss. The primary factors affecting OEE are:

- Availability Rate ---- Affected by Downtime (Availability) Loss

Availability rate is related to unplanned downtime losses, changeover time loss and cycle time loss.

- Performance Rate ---- Affected by Speed (Performance) Loss

Performance rate is related to minor stoppages and start up losses.

- Quality Rate ---- Affected by Quality Loss

Quality rate is related to scrap/rework losses/

A machine is available if it is ready to produce, as opposed to being offline: i.e., "broken down" or having some changes or adjustments made. The definition of availability allows for planned maintenance (when the machine is not meant to be available to production) but makes no allowance for changeovers etc. A machine with

changeovers can never be 100% available. The reason for taking this approach is that changeovers are a major loss to both efficiency and flexibility.

Performance efficiency measures the output during available time compared to a standard. A good rule of thumb is to make the performance efficiency calculation based on best known performance [4.2]. If a machine does not reach its design speed performance it is not helpful to measure against the design speed. On the other hand, if it has consistently out performed the design specifications one can have performance figures which can hide poor availability. One purpose of OEE is to indicate if the equipment has the capacity meet customer demand.

Output Quality is a First Time Through (FTT) measure i.e., determining what percentage of the output was right the first time without any rework. The issue in OEE is that the quality feedback may not be immediate. In these cases it is best not to include quality in the OEE calculation and use a more customer focused measure for quality, e.g. number of complaints etc. At a gross level all OEE indicates the amount of active production that can be compared to planned production. OEE is a specific measure for use in specific improvement projects such as total productive maintenance [4.2]. A misuse of OEE is to compare different processes, plants or machines. OEE is not considered a useful executive Key Performance Index [4.2]. Still, it is an improvement measure that can be used to improve equipment performance.

4.2 Calculation of OEE

The calculation of OEE can be carried out by finding 3 major factors, namely availability, performance rate and quality rate. The product of these three factors leads to an OEE value.

Availability

Total Available Time is the amount of time a facility is open and available for equipment operation. For the company considered in the study, total time = 24 Hrs/day. Planned Downtimes includes all events that should be excluded from an efficiency analysis since there is no production (e.g. breaks, lunch, scheduled maintenance, etc). The remaining available time is our Planned Production Time and can be expressed by the following equation:

$$\text{Planned Production Time} = \text{Total Available Time} - \text{Planned Downtimes} \quad (4.1)$$

Availability takes into account Down Time Loss, which is not a part of the planned downtime and includes any events that stop planned production for an appreciable length of time (usually several minutes - long enough to log as a traceable event). Examples include equipment failures, material shortages, and changeover time. The remaining available time is obtained after subtracting the unplanned downtime from the planned production time and is called Net Operating Time. Availability is then defined by the ratio:

$$\text{Availability} = \text{Net Operating Time} / \text{Planned Production Time} \quad (4.2)$$

Performance Rate

Performance rate takes into account Speed Loss, which includes any factors that cause the process to operate at less than the maximum possible speed, when in operation. Examples contributing to speed loss include machine wear, substandard materials, misfeeds, and operator inefficiency.

$$\text{Performance rate} = \text{Ideal Cycle Time} / (\text{Net Operating Time} / \text{Total Pieces}) \quad (4.3)$$

Quality Rate

Quality rate takes into account the defect rate, which accounts for produced pieces that do not meet quality standards, including pieces that require rework.

$$\text{Quality Rate} = 1 - \text{Defect Rate} = \text{Good Pieces} / \text{Total Pieces} \quad (4.4)$$

OEE takes into account all three OEE factors, and is calculated as [4.2]

$$\text{OEE} = \text{Availability Rate} \times \text{Performance Rate} \times \text{Quality Rate} \quad (4.5)$$

The OEE value is typically expressed as a percentage.

The factors that contribute to OEE losses have been developed and table 4.1 shows a review of the key points.

Table 4.1: OEE factors review [4.5]

Loss	OEE Factor
Planned Shutdown	Not part of the OEE calculation
Down Time Loss	$\text{Availability} = \text{Net Operating time} / \text{Planned production time}$ $= (\text{Planned production time} - \text{Downtime losses}) / \text{Downtime Losses}$ $= 1 - (\text{Downtime losses} / \text{Planned production time})$ <ul style="list-style-type: none"> • 100% <i>Availability</i> means the process has been running without any recorded stops. (no downtime losses)
Quality Loss	<p><i>Quality rate</i> is the ratio of Fully Productive Time to Net Operating Time</p> $\text{Fully Productive time} = \text{Net operating time} - \text{Quality loss}$ <ul style="list-style-type: none"> • Quality Rate = Good Pieces / Total Pieces. • 100% <i>Quality rate</i> means there have been no reject or rework pieces.

Figure 4.1 is a pictorial representation of the OEE calculation shown in the TPM literature at the company [4.4]. The figure indicates the losses being identified at each stage and explains the necessity of considering planned maintenance and other planned downtimes such as breaks and daily meetings as a part of productive time and not as a component of availability losses. OEE can be calculated by two formulations, namely the one given in equation 4.5 and the other one indicated in figure 4.1. Both these formulations are used in the industry to calculate OEE. The formulation in equation 4.5 calculates the factors affecting OEE separately and derives at the OEE value by their product. Whereas, the formulation shown in fig. 4.1 takes into account the various and arrives at the OEE value.

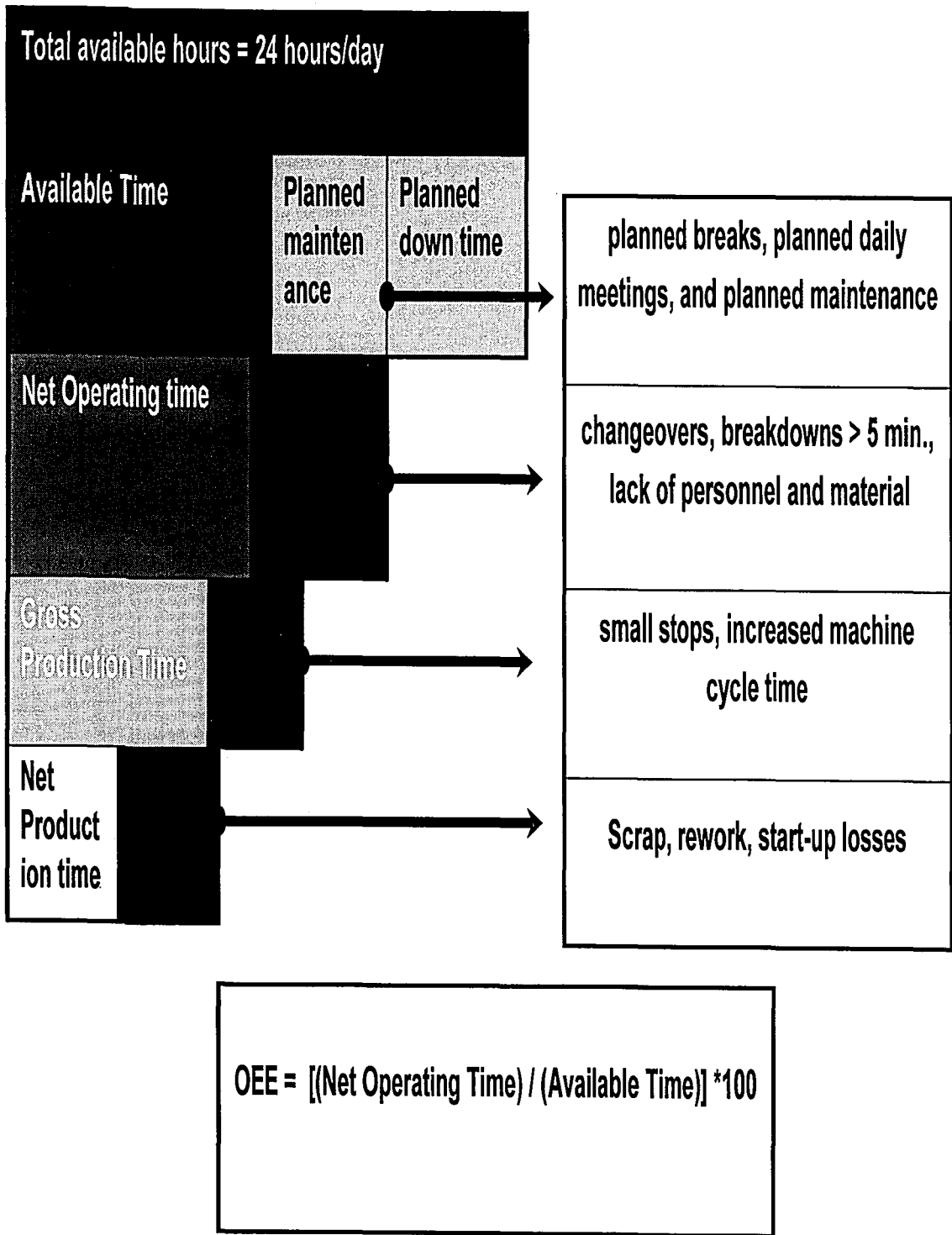


Fig 4.1: Pictorial representation of OEE Calculation [4.4]

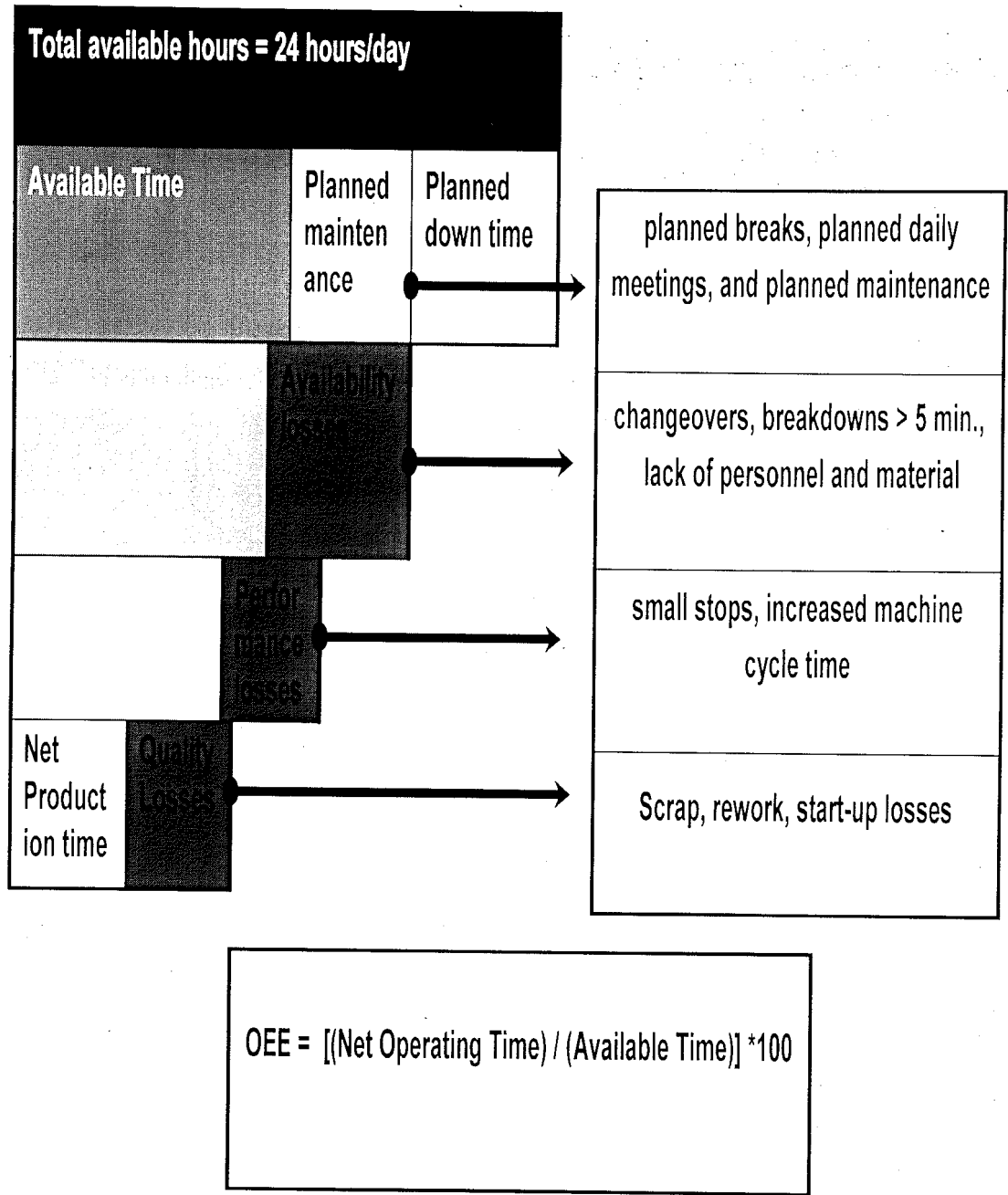


Fig 4.1: Pictorial representation of OEE Calculation [4.4]

4.3 Comparison of the OEE approaches at the company

Current OEE Calculation Approach

In the current approach at the company the calculation of OEE as shown in fig. 4.2, the total available time of 24 hrs is considered as production time. The planned downtime is not subtracted to obtain the available time. Planned downtime, like daily planned meetings, planned maintenance, breaks etc. is considered as an availability loss. The gross production time is obtained by subtracting the performance losses and the net production time is achieved by subtracting the time related to scrap, rework and start up losses.

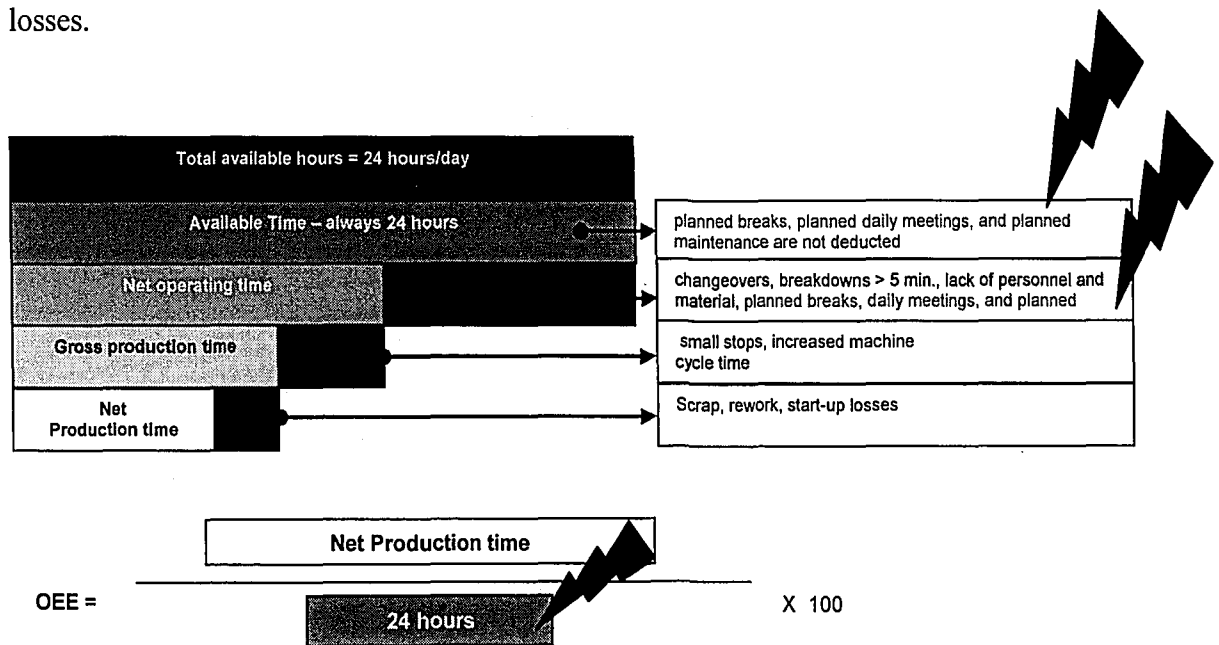


Fig 4.2: Current approach for OEE calculation [4.6]

Proposed OEE Calculation Approach

Fig. 4.3 illustrates the proposed company approach for calculation of the OEE. The available time in the proposed approach does not include planned downtimes like daily planned meetings, planned maintenance, breaks etc. Thus, they are not considered as availability losses.

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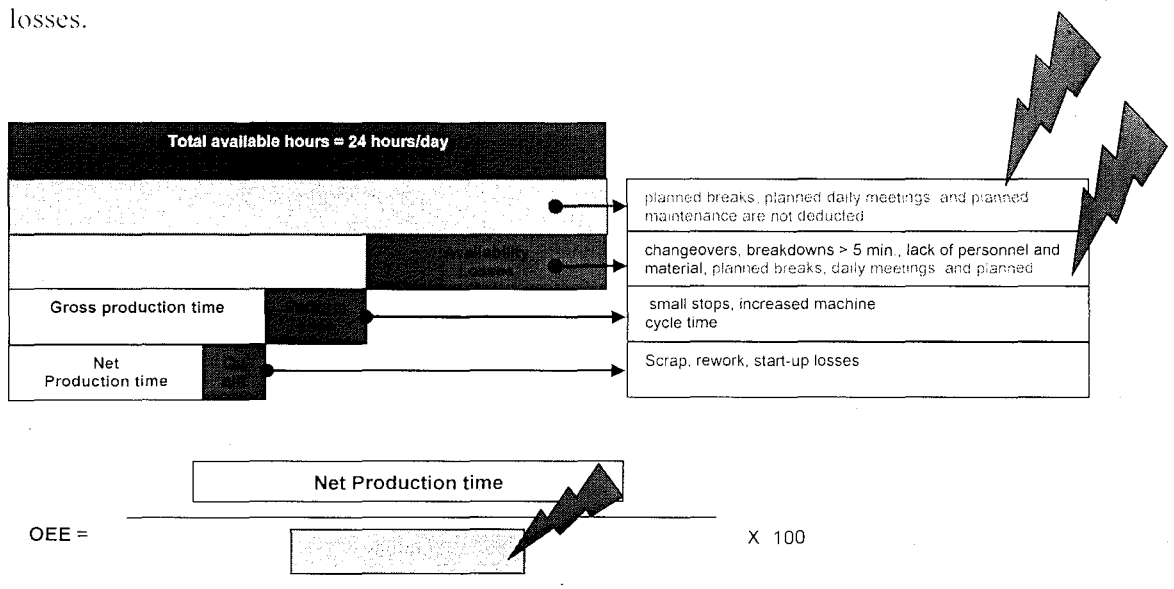


Fig 4.2: Current approach for OEE calculation [4.6]

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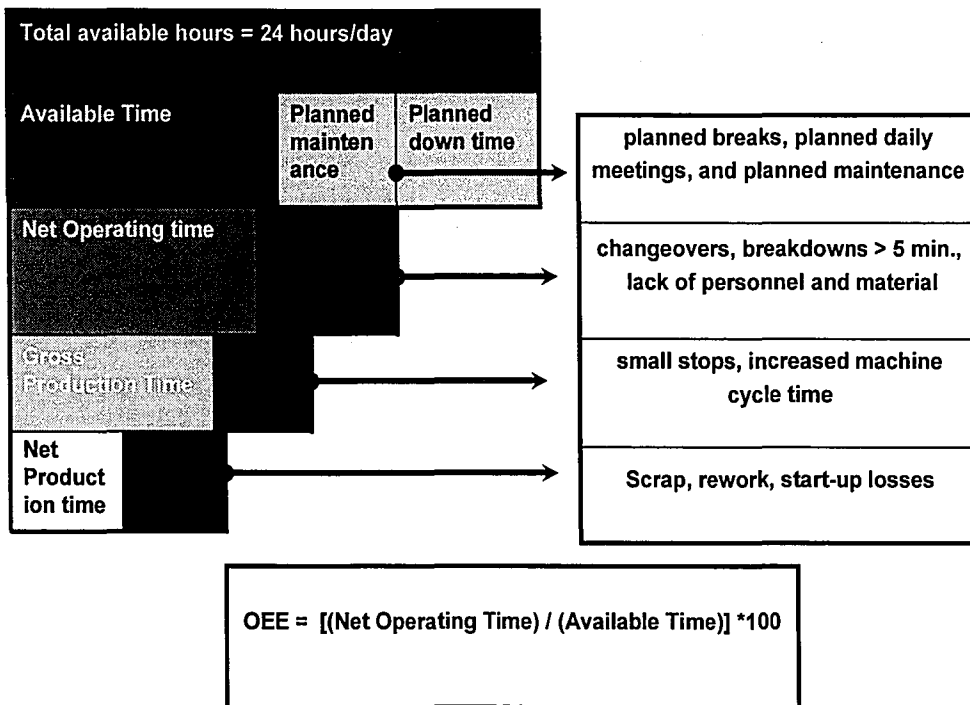


Fig 4.3: Proposed company approach for OEE calculation, [4.4]

The report shown in Fig 4.4 is a seven day report generated using the current formulation of OEE based on equation shown in fig 4.2. It can be noted that planned downtime is not tracked separately and as a result all downtimes are treated as unplanned. Planned downtimes are not deducted from the total available time for calculation purposes. As a result, the equipment availability is lower than the real rate. As seen in the report the total available time and net available time have the same value of 168 hours. Planned downtimes are not recorded separately leading to the value for net available time being same as total available time. All downtimes are treated as unplanned and thus equipment availability rate achieved is 92.9%, which is lower than the real rate.

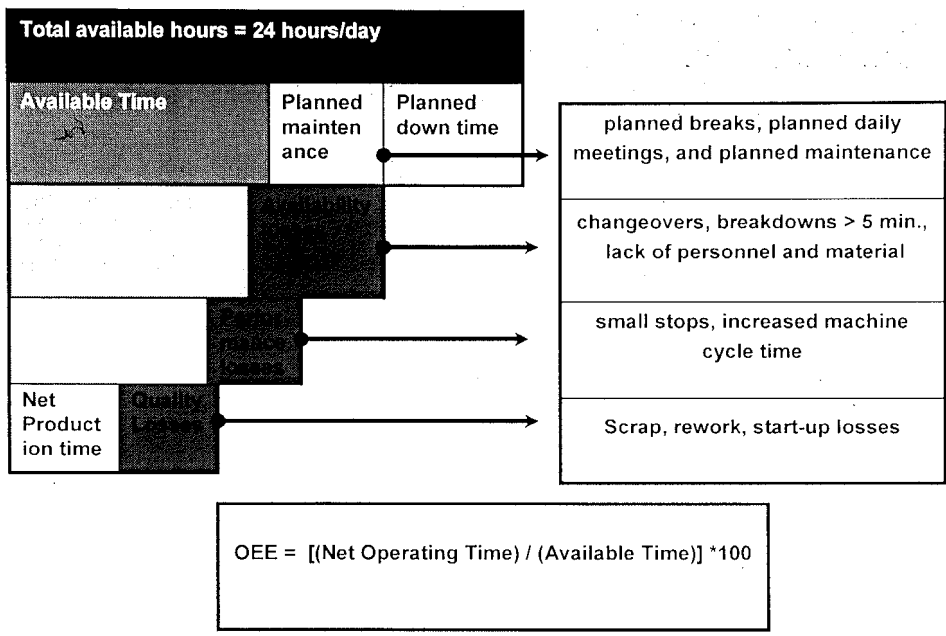


Fig 4.3: Proposed company approach for OEE calculation. [4.4]

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Overall Equipment Effectiveness (OEE)

W.C. MFF15 500 #3 359005 SEVEN DAY REPORT ENDING
 Sunday 11/19/2006

Planned downtimes are not calculated separately.

Availability (Utilization)

A. Total Available Time: 168.00 hrs
 B. Planned Downtime: []
 C. Not Available Time: (Total Available Time - Planned Downtime) (A - B) 168.00 hrs

D. Downtime: (From Downtime Reports)

BRKDN	0	35
CLEAN	0	0
REPAIR	7	30
SETUP	0	0

hours lost 11.92 hrs

As a result all downtimes are considered as unplanned regardless of their nature

E. Operating Time: (Not Available Time - Downtime) (C - D) 156.08 hrs

F. Equipment Availability (E/C) x 100%
 (Operating Time / Not Available Time) 92.90 %

Equipment availability rate appears to be lower than the real rate

Performance Efficiency

G. Total Parts Run: (Good and Bad Parts) 85 Parts
 H. Completed Parts times Standard Values 80.25 hrs
 I. Performance Efficiency: 51.42 %
 (Standard Value x Total Completed Parts / Operating Time)

Quality Rate

J. Total Defects: 6 Parts
 (Bad)
 Total Parts Run 85 Parts
 K. Quality Rate: ((G - J) / G) x 100 94.12 %
 (Total Parts Run - Total Defects) / Total Parts Run

As a result OEE appears to be lower than the real rate

Overall Equipment Effectiveness

OEE: (Equipment Availability) x (Performance Efficiency) x (Quality Rate) (F x I x K) x 100 44.78 %

Fig 4.4: OEE report, MFF area [4.4]

OEE Calculation Example: No unplanned downtimes, performance losses, quality losses

Fig. 4.5 represents an Excel based template developed as a part of the investigation for an OEE calculation. It identifies the various downtime losses and separates them into their root causes. For example, it separates the unplanned downtimes into breakdowns, changeover, power/ air loss, and start up losses. These losses are classified into further detail to facilitate data collection from the shop floor. The entries shown in the figure 4.5 indicate the gross production amount to be 800 pieces. The machine was not scheduled to run for 960 minutes, making it a planned downtime. All other data can be entered and subtracted accordingly during the calculation of OEE using equation 4.5. This excel based template can be used for recording data and calculating OEE values.

Machine: A	DAY	1	1
Ct (min): 0.6	GROSS PRODUCTION AMOUNT	800	800
	SCRAP		
	REWORK		
	NET PRODUCTION AMOUNT	800	800
BREAKDOWNS	MECHANICAL		
	ELECTRICAL/ELECTRONICAL		
	PNEUMATIC		
	HYDRAULIC		
	SOFTWARE		
CHANGEOVER	CHANGEOVER		
POWER/AIR LOSS	POWER LOSS		
	AIR LOSS		
LACK OF MAT.	LACK OF MATERIAL		
START UP LOSS	STABILITY MEASUREMENTS		
	WARM UP LOSS		
PLANNED DOWNTIMES	TESTING		
	TRAINING		
	BREAKS		
	AM ACTIVITIES		
	PM ACTIVITIES		
	MACHINE NOT SCHEDULED	960	960
	PLANNED DOWNTIMES	960	960
	UNPLANNED DOWNTIMES	0	0
	AVAILABLE TIME:24h-Planned Downtimes	480	1440
	NET OPERATING TIME:Available time-Unplanned Downtimes	480	480
	OEE (%)	100.00	33.33
	Availability Rate (%)	100.00	33.33
	Performance Rate (%)	100.00	100.00
	Quality Rate (%)	100.00	100.00
		WITH PROPOSED FORMULATION	WITH CURRENT FORMULATION

Fig 4.5: Excel based template for OEE calculation, [4.6]

As seen in *Fig 4.5* the proposed calculation gives an OEE of 100% since planned downtimes are subtracted for calculating the availability. The current method considers planned downtimes as a loss, penalizes the machine for the parts that were not intended to be produced and generates a significant error. The following calculations indicate the difference between the current approach and proposed approach for calculation of OEE using the data from the example shown in *Fig. 4.5*.

Current Approach for OEE Calculation

$$\text{Availability Rate} = \{(24 \text{ h} - \text{total Downtimes}) / 24 \text{ h}\} * 100$$

$$\text{Availability Rate} = \{(1440 \text{ min} - 960 \text{ min}) / 1440 \text{ min}\} * 100$$

$$\text{Availability Rate} = \{(480 \text{ min}) / 1440 \text{ min}\} * 100$$

$$\text{Availability Rate} = 33.00\%$$

$$\text{Performance rate} = 100\%$$

$$\text{Quality rate} = 100\%$$

Thus using equation 4.5, **OEE = 33%**

Proposed Approach for OEE Calculation

$$\text{Availability Rate} = \{(\text{Planned operating time} - \text{Unplanned downtime}) / \text{Planned operating time}\} * 100$$

$$\text{Availability Rate} = \{(480 - 0 \text{ min}) / 480 \text{ min}\} * 100$$

$$\text{Availability Rate} = \{(480 \text{ min}) / 480 \text{ min}\} * 100$$

$$\text{Availability Rate} = 100.00\%$$

$$\text{Performance rate} = 100\%$$

$$\text{Quality rate} = 100\%$$

Thus using equation 4.5, **OEE = 100%**

With the current calculation method, a machine can not reach an OEE of 100%. The OEE rate could fluctuate enormously as customer demand increases or decreases due to the change in planned production time. According to equation 4.6 with the increase or decrease of customer demand the planned production time varies, thus affecting the OEE rate.

For the current approach the best way to increase OEE is:

- To move more customer orders which would result in decreased NOT SCHEDULED times.
- To cancel planned maintenance activities to decrease PM times
- To cancel planned trainings, meetings and breaks

An approach such as the current approach which would incorporate the actions in the above list would decrease planned maintenance activities. This would result in the shortening of machine life and also the increase of unplanned downtimes due to stoppages. Canceling training sessions for the work force would hinder work force education. The proposed OEE formulation approach was created to capture unexpected downtimes, performance losses and quality losses which can be eliminated.

The following table 4.2 indicates the differences between the current formulation for OEE calculation used at the company and the proposed formulation.

Table 4.2: Comparison between Current Formulation and Proposed Formulation for OEE Calculation

	Current Formulation	Proposed Formulation
1	Penalizes the machine for the downtimes that are scheduled. Assumes an available time of 24 hours regardless of the planned downtimes.	Calculation is based on available time after the planned downtimes are deducted. Planned downtimes are clearly defined and are not taken into consideration during the calculation of availability rate.
2	Theoretically it is not possible to reach an OEE of 100%	Theoretically a machine can reach an OEE of 100%
3	Is not an indicator of efficiency or performance losses in the machinery	Clearly indicates real losses that can be improved
4	OEE fluctuates significantly although nothing has been changed in the equipment	OEE metric changes only with efficient technical countermeasures such as elimination of breakdowns, process optimization, cycle time improvement, quality improvement, etc.

4.4 Downtime Reason Codes.

The downtime reason codes can be used to capture data from the shop floor related to the losses affecting the OEE calculation. The downtime reason codes are proposed to capture the six big losses affecting the OEE calculation.

Principles of Selecting Appropriate Reason Codes

Downtime Reason Codes should be determined such that 6 big losses or OEE Components can be captured.

6 Big Losses [4.5]:

- 1) Breakdowns
- 2) Set up and adjustments
- 3) Small stops

- 4) Reduced Speed
- 5) Start-up Rejects
- 6) Production Rejects

Addressing the 6 Big Losses

By categorizing the data the Six Big Losses can be addressed much easily. The key goal should be fast and efficient data collection, with data put to use throughout the day in real-time. The following issues which address the losses are considered in the proposed approach.

Breakdowns: Eliminating unplanned Down Time is critical to improving OEE. Other OEE Factors cannot be addressed if the process is down. It is not only important to know how much Down Time the process is experiencing (and when) but also to be able to attribute the lost time to the specific source or reason for the loss (tabulated through Reason Codes). With Down Time and Reason Code data tabulated, Root Cause Analysis is applied starting with the most severe loss categories.

Setup and Adjustments: Setup and Adjustment time is generally measured as the time between the last good part produced before Setup to the first consistent good parts produced after Setup. This often includes substantial adjustment and/or warm-up time in order to consistently produce parts that meet quality standards. Tracking Setup Time is critical to reducing this loss, together with an active program to reduce this time (such as an SMED – Single Minute Exchange of Dies program). Many companies use creative methods of reducing Setup Time including assembling changeover carts with all tools and supplies necessary for the changeover in one place, pinned or marked settings so that coarse adjustments are no longer necessary, and use of prefabricated setup gauges.

Small Stops and Reduced Speed: Small Stops and Reduced Speed are the most difficult of the Six Big Losses to monitor and record. Cycle Time Analysis should be utilized to pinpoint these loss types. In most processes recording data for Cycle Time Analysis needs to be automated since cycles are quick and repetitive events that do not leave adequate time for manual data-logging. By comparing all completed cycles to the Ideal Cycle Time and filtering the data through a Small Stop Threshold and Reduced Speed Threshold the errant cycles can be automatically categorized for analysis.

Startup Rejects and Production Rejects: Startup Rejects and Production Rejects are differentiated, since often the root causes are different between startup and steady-state production. Parts that require rework of any kind should be considered rejects. Tracking when rejects occur during a shift and/or job run can help pinpoint potential causes, and in many cases patterns will be discovered. Often a Six Sigma program, where a common metric is achieving a defect rate of less than 3.4 defects per million “opportunities”, is used to focus attention on a goal of achieving “near perfect” quality.

Table 4.3 defines the six big losses giving the event examples for each loss category. The first two columns, namely, Six Big loss category and OEE loss category show the OEE loss corresponding to the six big losses. For example, the availability loss corresponds to the breakdowns and setup and adjustments.

Table 4.3: Defining the Six Big Losses [4.5]

Six Big Loss Category	OEE Loss Category	Event Examples	Comment
Breakdowns	Avail. Loss	<ul style="list-style-type: none"> • Tooling Failures • Unplanned Maintenance • General Breakdowns • Equipment Failure 	There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss).
Setup and Adjustments	Avail. Loss	<ul style="list-style-type: none"> • Setup/Changeover • Material Shortages • Operator Shortages • Major Adjustments • Warm-Up Time 	This loss is often addressed through setup time reduction programs.
Small Stops	Perform. Loss	<ul style="list-style-type: none"> • Obstructed Product Flow • Component Jams • Misfeeds • Sensor Blocked • Delivery Blocked • Cleaning/Checking 	Typically only includes stops that are under five minutes and that do not require maintenance personnel.
Reduced Speed	Perform. Loss	<ul style="list-style-type: none"> • Rough Running • Under Nameplate Capacity • Under Design Capacity • Equipment Wear • Operator Inefficiency 	Anything that keeps the process from running at its theoretical maximum speed (a.k.a. Ideal Run Rate or Nameplate Capacity).
Startup Rejects	Quality Loss	<ul style="list-style-type: none"> • Scrap • Rework • In-Process Damage • In-Process Expiration • Incorrect Assembly 	Rejects during warm-up, startup or other early production. May be due to improper setup, warm-up period, etc.

<p>Production Rejects</p>	<p>Quality Loss</p>	<ul style="list-style-type: none"> • Scrap • Rework • In-Process Damage • In-Process Expiration • Incorrect Assembly 	<p>Rejects during steady-state production.</p>
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4.4.1 Bar Coding System for collecting downtimes

A Reason code list for capturing machine downtimes should be as simple as possible. The downtime reason codes lists are not the tools to capture every single downtime reason. A more appropriate approach would be to capture the six big losses first and then to address them on a project basis.

Current Coding system: The current coding system consists of two levels. The two levels pertain to the primary reason for the downtime and the secondary or more specific reason for downtime. (Refer to Fig 4.6, 4.7 for the reason codes). For example, the primary reason code could be “machine broke” and the secondary reason code could be “power outage”. This procedure leads to the operator skipping to scan the second level code, thus not capturing the root cause of the downtime. This can result into unreliable data collection and result in misleading OEE metrics. In addition, the codes are not self explanatory leaving the operator in ambiguity of choosing the right code. There are a total of 25 top level and second level codes making it confusing for the operator to scan the right code corresponding to the occurred downtime. Moreover, the planned and unplanned downtime codes are not separate, thus leading to the failure of capturing planned downtimes and hence cannot be deducted from the total availability of 24hrs, resulting in skewed OEE values.

The operator has a sheet of downtime reason codes corresponding to each machine in the focus factory. The operator scans the bar code off the sheet to record the cause of the downtime.

Current Downtime reason codes

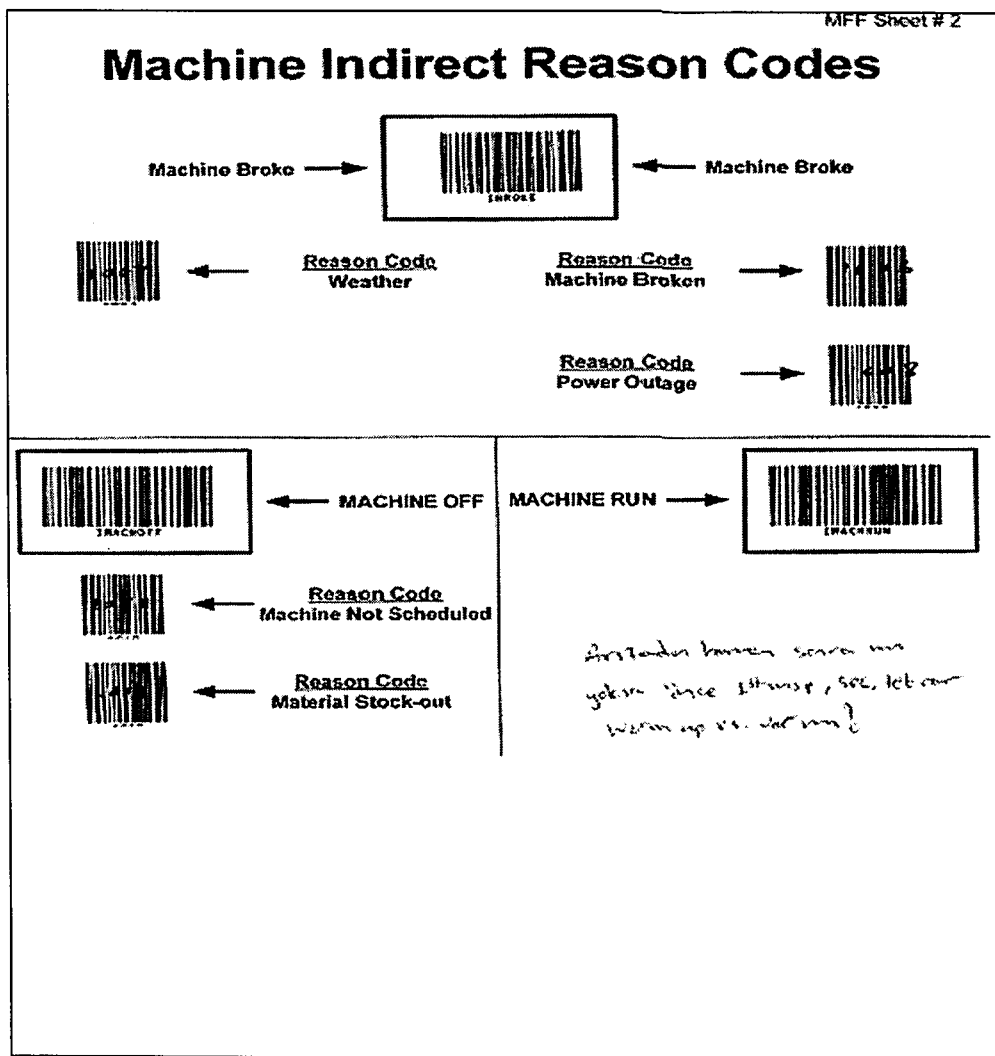


Fig 4.6: Current Downtime Reason codes, Manifold Focus Factory area. [4.4]

Machine Indirect Reason Codes

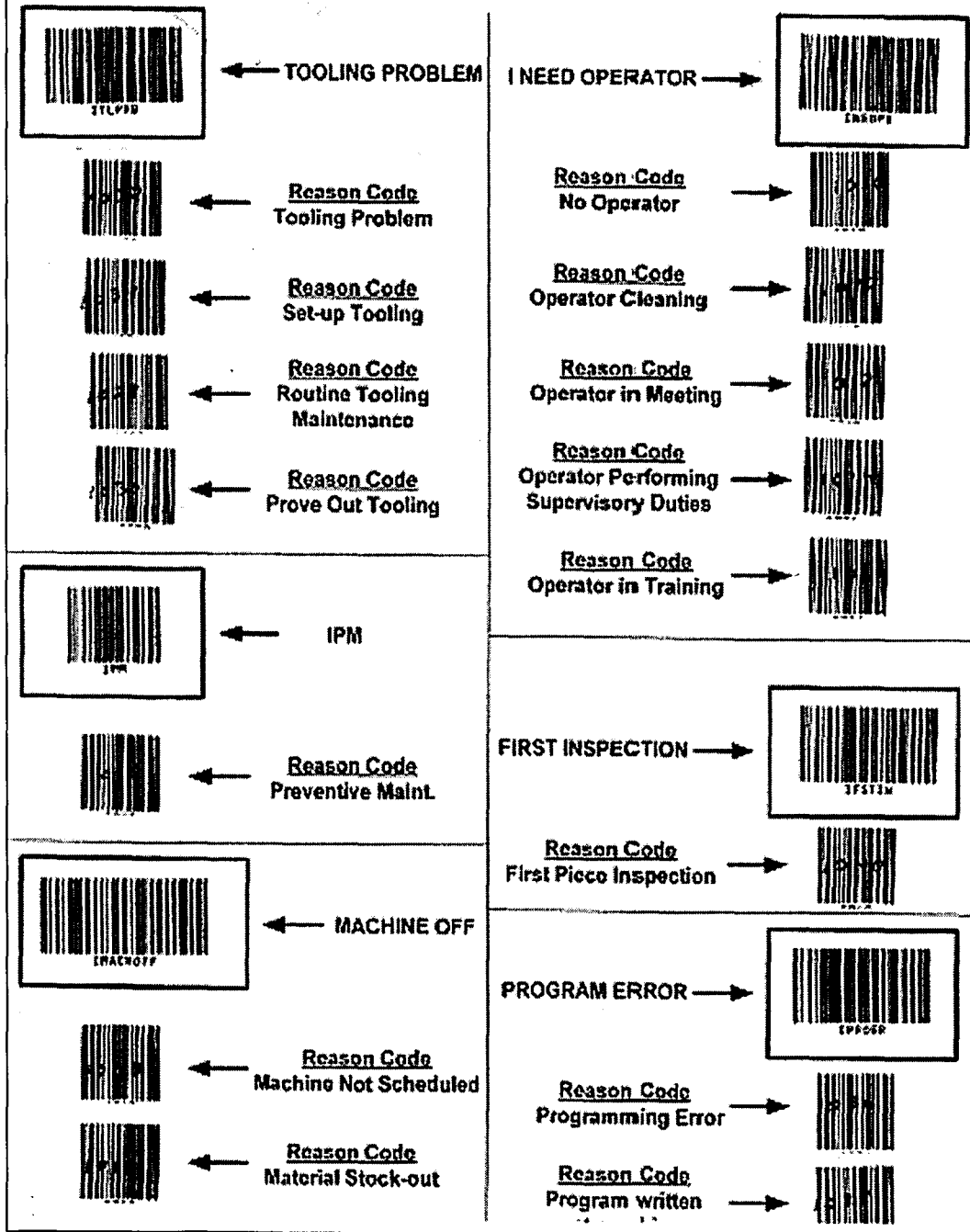


Fig 4.7: Current Downtime Reason codes, Manifold Focus Factory area [4.4]

Proposed Coding System: The proposed coding system has just one level (*Refer to Fig 4.8 and 4.9 for the reason codes*). Each code corresponds to a root cause for a downtime and thus there is no ambiguity for the operator on which code to scan. This leads to more reliable data collection and thus OEE values are more realistic and improvements can be targeted. The proposed system has only 15 codes, as indicated in the figures 4.8 and 4.9, making it simpler for the operator. Note that the planned and unplanned downtime codes have been separated. Thus, the planned downtime can be easily deducted from the total availability resulting in truer OEE values.

4.5 Suggested Action Plan

- Proposed reason bar codes should be reviewed and the final decision should be given by the management.
- Current OEE formulation should be corrected and based on the new bar codes. (Planned and unplanned downtimes should be treated differently).
- New bar code systematic should be communicated to the shop floor.
- In addition to the current reporting format, a new reporting format (preferably an Excel based OEE cockpit chart, see fig.4.10) should be generated. New reporting should be capable of providing information about the OEE and components of OEE (availability, performance and quality rates) based on the working cycle of the factory. i.e. one shift (8 hours or 480 minutes)
- Targets for OEE and its components should be determined.

Proposed down time reason Codes







REASON CODES (PLANNED DOWNTIME)		
REASON CODE	BARCODE	EXPLANATION
Testing		All kinds of production activity other than normal series production (e.g. testing of a new product / tool / program, or capability analysis, etc)
PM-Planned Maintenance		Scheduled maintenance activities performed by the operator or maintenance personnel according to PM plans
AM-Cleaning / Lubricating / Routine Equip. Checks		Routine autonomous maintenance checks on the equipment according to related AM checklists and guides
Training / Meeting / Breaks / Lunch		All kinds of planned breaks, trainings and meetings. Operator and/or setter at the plant but not available for production
Machine Not Planned		Machine not scheduled because it is not needed.
Machine Run		Machine starts operation after every kind of planned or unplanned stoppage

Fig 4.8: Proposed Planned Down time reason codes [4.6]

REASON CODES (UNPLANNED DOWNTIME)










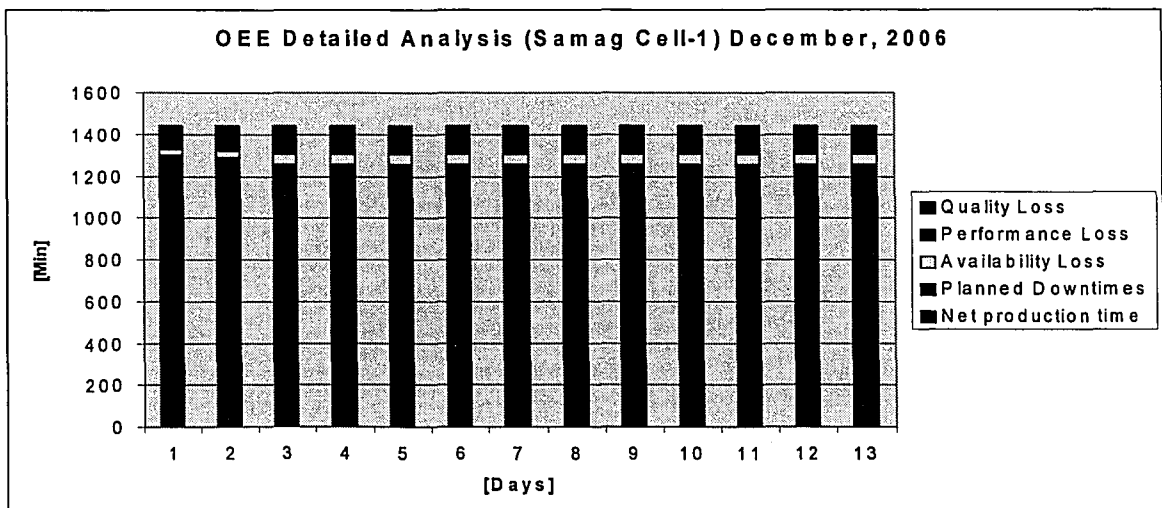
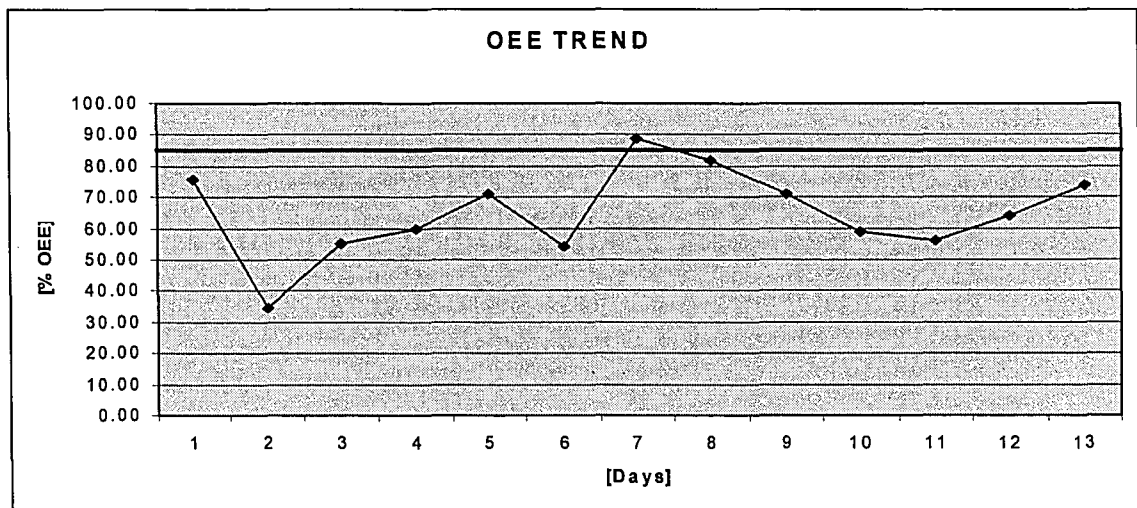
REASON CODE	BARCODE	EXPLANATION
Lack of Raw Material		Machine/Line can not continue production because of lack of raw material possibly due to one of the following reasons: logistics problem; upstream process can not produce parts; faulty incoming material, etc.
Lack of Setter / Operator		Machine/Line can not continue production because of lack of setter/operator. Possible reasons might be sickness, accident, etc.
Lack of Tooling		Machine/Line can not continue production because of lack of tooling. TOOLING: Manufacturing components that are in direct contact with the work piece and components that hold them (tool holders).
Lack of Manufacturing Components Other Than Tooling		Machine/Line can not continue production because of lack of manufacturing components other than tooling (e.g. coolant, lubricant, etc.)
Changeover		Machine/Line can not continue production because of changeover to a new product type.
Tool change		Machine/Line can not continue production because of: - tool change due to normal wear or - tool breakage
Machine Breakdown		Machine/Line can not continue production because of mechanical / electrical / electronical / hydraulic / pneumatic / software (NOT PART PROGRAM) problems
Power / Air Loss		Sudden loss of electric power or plant air pressure because of facilities problems
Other		All other unplanned downtimes

Fig 4.9: Proposed unplanned Downtimes reason code [4.6]

Proposed OEE Cockpit Chart (Samag Cell -1)

The pictorial representation of OEE and its related components shown below in *Fig 4.10* will provide an indication of the causes of downtimes and the areas in which improvements can be targeted on project basis. The chart below indicates the OEE values achieved for each day of the month. 85 % OEE is considered as a standard performance for a machine. The bar chart also indicates the break up of downtimes in minutes categorizing the downtimes in various losses. The pie chart shows the ratio of planned to unplanned downtime. The last bar chart gives a pictorial representation of the activities causing downtime on a daily basis.



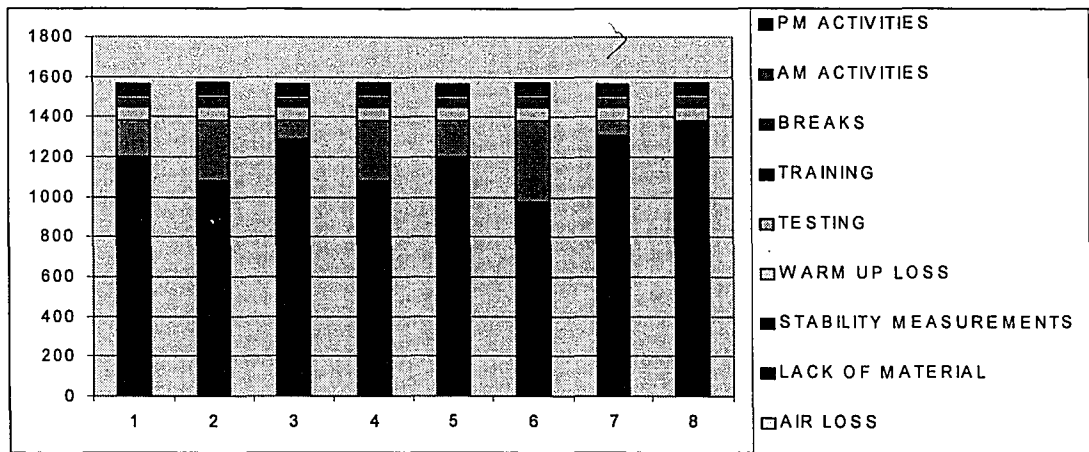
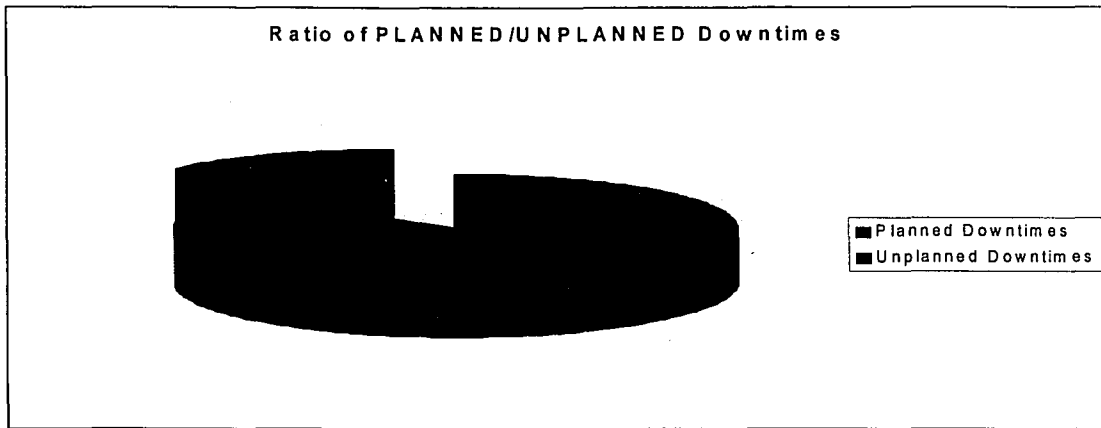


Fig 4.10: OEE Cockpit chart [4.6]

References (Chapter 4):

4.1 *Lean Lexicon a graphical glossary for Lean Thinkers, 2nd Edition, (2003), Lean Enterprise Institute, Brookfield, MA, USA. (www.lean.org)*

4.2 [www.plant-maintenance.com/articles/The Use and Abuse of OEE.pdf](http://www.plant-maintenance.com/articles/The_Use_and_Abuse_of_OEE.pdf)

(Source:www.google.com)

4.3 *N Seiichi, Introduction to TPM (1988), Productivity Press, Cambridge, MA, USA*

4.4 *TPM Literature (2004), Bosch Production Systems.*

4.5 www.oeec.com

4.6 *Personal Communication with technical personnel at the company*

Chapter 5 Conclusions and Recommendations

This thesis studied the current state of the manufacturing system for size 6 valve bodies at the company. It utilized tools such as process flow charts, process capability analysis and value stream mapping to analyze the current state. It also made an in-depth analysis on an Overall Equipment Effectiveness (OEE) metric, which is core to the Total Productive Maintenance (TPM) project and lean initiative at the company.

5.1 Current state analysis

A current state analysis of the size 6 valve body machining at the company was performed. The goal of this research was to understand the problems and obstacles of manufacturing system. An in-depth analysis was performed at each step of the process and was presented with reference to the methodology and tools used. In the first step it was found that the system in place was not meeting company needs. The number of rework parts was high and the lead time for parts and inventory holding time was also high. A process flow diagram was drawn to clearly identify each step in the process and determine the inspection steps. A process capability analysis was performed to determine the valve parameters not meeting the expected P_{pk} values.

Finally, a Value stream mapping exercise was performed to identify and eliminate muda from the Samag cell in question. It is recommended that process variables affecting the parameters with P_{pk} values less than 1.33 be investigated thoroughly on a project basis to target the root causes of the problems. Also, actions are recommended to eliminate muda during the machining of size 6 valve body. A Kanban Set up is also recommended between the machining process and paint and also between painting and assembly to eliminate work in-process (WIP) inventory on the shop floor. It is also

recommended that cycle times be re-evaluated after careful consideration of improvements in efficiency.

5.2 Overall Equipment Effectiveness

Overall equipment effectiveness is a key metric for TPM projects and the lean culture at the company. It gives an insight into 3 critical factors, namely, availability, performance efficiency, and quality rate. The current approach at the company is to consider 24 hr availability for the machines. In the approach there is a penalty in the calculation for availability since planned downtimes are not deducted from the total available time of 24 hrs. This leads to lower OEE values. Also, the existing reason codes used to capture downtimes does not distinguish planned downtimes from unplanned downtimes. These leads to unreliable data being captured, further leading to skewed OEE values.

It is recommended that planned downtimes start being deducted from total available time for OEE calculation purposes. It is also recommended that the proposed downtime reason codes based on the 6 big losses be reviewed by the management and be used to capture reliable data. This would lead to realistic OEE values. Also, it is recommended that the Proposed OEE cockpit chart be adopted and displayed on machines so that operators are aware of the downtimes and the trend. This approval will aid in targeting identified downtime causes and effect improvements.

Appendix A

The appendix describes the Samag MFZ 1 CNC machine used for machining the size 6 valve body in the Samag cell. It discusses the design, axis orientation and technical specifications for the machine.

CNC Machine description

The MFZ I CNC horizontal, twin-spindle machining centre automatically processes two identical work pieces simultaneously using rotating, chip producing tools, in line with the program produced by the user. The separation of work piece and tool loading from the actual machining operations enhances both operational safety (no manual control operations in the work area) and the machine productivity as both operations are performed parallel to one another. The tool magazine accommodates 2 x 48 tools enabling up to 24 different tools to be used in a single program. Tool changing on the work spindles is based on the pick-up principle. The work spindles of the X, Y and Z axes are positioned appropriate to the program. All work spindles comprise compact, motor spindles. Positioning of the work pieces in the work area is effected by the B1 and B2 rotating axes. Fig A.1 pictorially presents the axis position for the work piece and the related processes carried out on the Samag MFZ 1 CNC machine. *(Refer to Fig. A 1)*

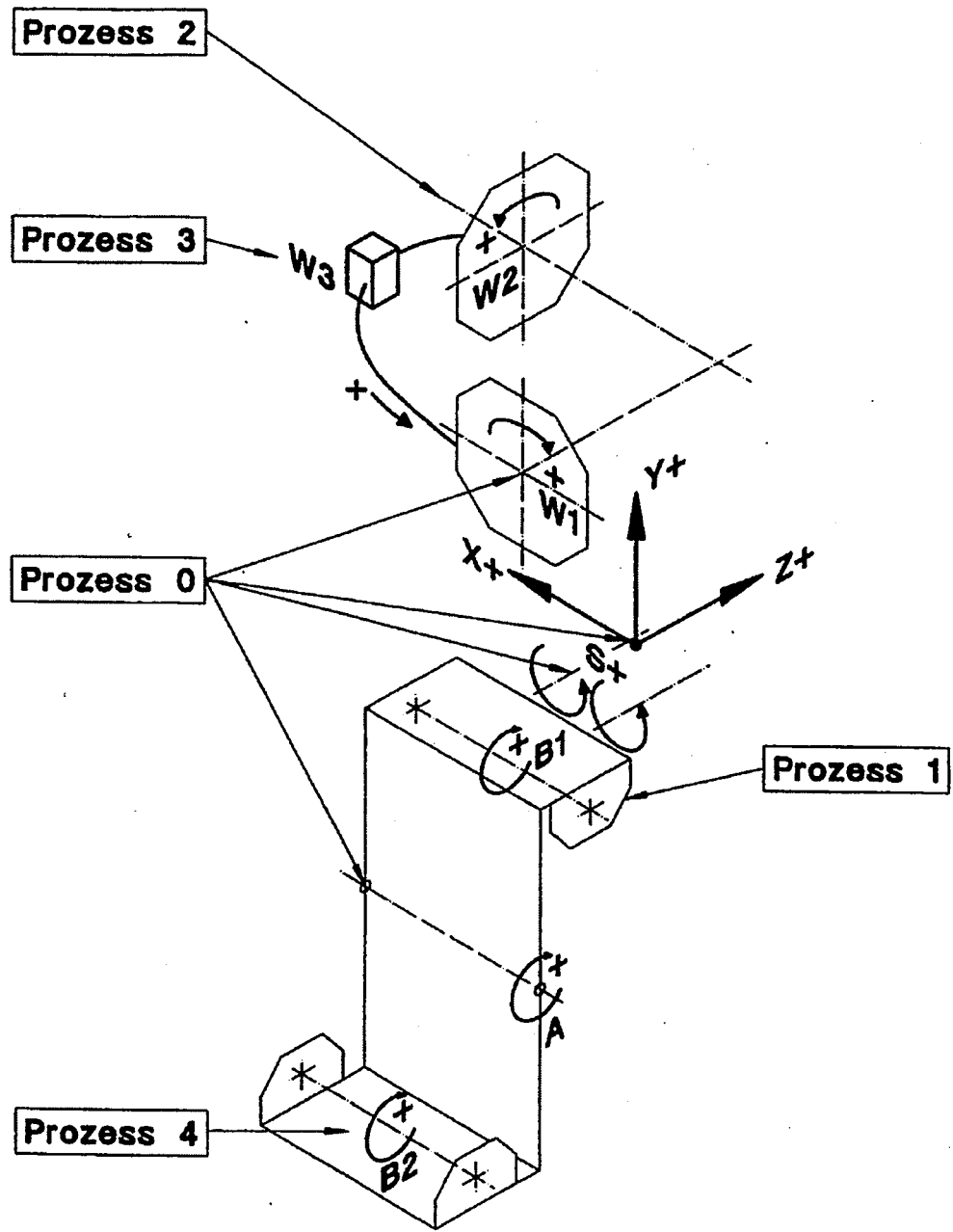


Fig A 1: Samag MFZ1 Axis Diagram, [A1]

Design

The machine consists of the following main assemblies:

- Processing module with tool magazine and secondary magazine. The tool loading and extraction equipment as well as the feeder also form part of this assembly.
- Work piece carrier module
- Chip conveyor
- Electrical equipment: control, switch cabinet
- Hydraulic power pack
- Energy and supply lines
- Enclosure (cabin)

The machining and work piece carrier modules are connected to one another and the ancillary equipment – with the exception of the chip conveyor and the cooling lubricant system – is also arranged in this compact unit. The dividing wall on the work piece carrier unit separates the loading area from the work area during the loading operations. Observation doors enable the work pieces to be viewed from both sides during machining operations. The tool magazine, with an additional safety door, is located in the upper area of the work area. This prevents chips from collecting on the tools. The main control console is arranged next to the work area such that the execution of the programmed commands can be visually monitored.

The actual processing module incorporates the motor spindle, the X, Y and Z axes with their drives, the Y-axis weight counterbalance and the machine frame in the form of a tunnel. The work area and the area in the tunnel are separated by strip curtains which permit the movement of the motor spindles and simultaneously protect against chips and

cooling lubricant. The X, Y and Z axes are guided by compact elements running on roller bearings and the drive is provided by ball lead screws. Safety couplings protect the X, Y and Z axis ball lead screws against over loading. Spindle no. 1 is the reference spindle. This applies to the measuring sensors for controlling the zero point/ zero point shifts and to measuring operation checks which use the spindle as a reference. The secondary tool magazine and the tool feeder to the main magazine are mounted on the processing module. These are used to load the main magazine. In the event of tool breakage or wear, sister tools are inserted.

Loading of the secondary magazine is effected by the manually operated tool loading and extraction device. The write/read head of the tool identification system records the current tool data which is then imported into the control's tool management system. The switch cabinet is located on the right-hand side of the processing station. The cooling unit for the motor spindle as well as the hydraulic power-pack, the cooling lubricant supply and the discharge of the chip conveyor are all located outside the enclosure at the back of the machine. The chip conveyor runs from the work area underneath the machine to the discharge station. The compressed air conditioning and central lubrication units are to be found on the left-hand side under the cooling unit.

Technical Specifications for Samag MFZ 1

Weights

Machine complete, ready for operation	11,000 kilos
Basic Machine	9500 kilos
Chip conveyor	795 kilos

Required Floor space

Machine with coolant tank and chip conveyor but not including chip container

(WXDXH) Approx. 3.2 x 5.5 x 3.2 m

Machine during maintenance Approx. 4.0 x 7.65x 3.2 m

(Space required for pulling out the chip conveyor to the rear, swinging out the cooling unit and opening the switch cabinet doors)

Conditions for storage

Temperature -10 ... + 50° C

Relative humidity, non-condensating max 80%

Operating Conditions

Temperature 15...35° C

The temperature fluctuations must not exceed +/- 2°/12 hours and 2°/ hour

Relative humidity, non-condensating max 80%

Dust content on site 1 mg/m³

Installation in enclosed, draught free room. Protect from the influence of direct sources of heat (sunrays).

Conditions for installation

Floor load capacity 3 Mpa

Evenness 2 mm

Securing Anchoring with 2 anchor bolts/machine

Installed on AirLoc elements.

Water protection regulations in accordance with environmental regulations (VAWS)

Classified in the WGK 3 water hazard class at category “A” danger level in accordance with the valid version of water management act.

Hook-up data

Electrical Hook up:

Power requirement (connected load)	96Kva
Mains voltage	3 x 460 +- 10% V
Frequency	60 Hz
Network Structure	TN-C-S//ground
Connection cross section	90mm ²
Power fuse rating (supplied by user)	160 Amps
Control Voltages	230 V AC 24 V DC

Compressed Air Supply:

Operating Pressure	6 bar
Volume of Air required	30Nm ³ /h

Quality of compressed air as per DIN ISO 8573-1:

Solids	5
Water	4
Oil	5

Processing Module

No. of work spindles	2
Spindle Unit	High frequency spindle HCS 232 – 15000/28 – Fa. GMN
Pitch	240 mm
Tool Holder	HSK A63 as per DIN 69063-1
Tool clamps	OTT System with hydraulic release unit
Tool insertion	18000 N
RPM range	50..... 15,000 min-1
Drive power	
at 100%ED (DUTY CYCLE)(SI)	28kw
at 53% ED (DUTY CYCLE)(S6; 5 min)	39kw
Maximum torque	
at 100%ED (DUTY CYCLE)(SI)	90Nm
at 53% ED (DUTY CYCLE)(S6; 5 min)	124Nm
Cooling unit spindle motor	Type K1-4
Max. ambient temperature	43°C
Water exit temperature	20°C
Positioning distances	
X axis	240mm
Y axis	
Working Stroke	400mm
Overall stroke including tool change	630mm
Z axis	350mm

Rate of feed

X,Y,Z axes, staging 1 mm min-1 1... 10,000 mm.min-1

Rapid traverse speeds

X axis 40,000 mm.min-1

Y axis 40,000 mm.min-1

Z axis 40,000 mm.min-1

Feed Forces

X axis 4,000 N

Y axis 4,000 N

Z axis 8,000 N

Positioning accuracy in accordance with VDI/DGQ 3441

Positioning tolerance (X,Y,Z) $T_p = 0.012 \text{ mm}$

Medium positioning range (X,Y,Z) $P_s = 0.008 \text{ mm}$

Work piece carrier module

Swiveling unit (A axis)

Swiveling range $0^\circ - 180^\circ$

Indexing steps $120 \times 3^\circ$

Repetitive accuracy $\pm 3^\circ$

Swiveling time 180° 3.5 seconds

Face plate/counter support dia. 345mm

Transport load max 600 kilos

Permissible axial load including transport load 10,500 N

Permissible radial load including transport load 10,500 N

Work piece holder B1/B2 axes

Positioning	72 x 5°
Indexing accuracy	+/-3°
Swiveling time 180°	3.5 seconds
Face plate/counter support dia	195 mm
Max table r.p.m.	25 min-1
Face plate/ counter support with pattern of holes for clamping device holder rail	
Permissible transport load when using counter support	250 kilos
Permissible axial load including transport load	8000 N
Permissible radial load including transport load	8000 N
Permissible tangential moment when table plate clamped	1600 Nm
Work piece clamping area (including clamping beams) 2 x 430x 510 mm dia.	

Tool magazine and tool changing

Tool magazine

Type:

2X disc magazine mounted on machine frame

Number of storage slots/disc magazine	48 (2x24)
Max tool weight	5 kilos
Max tool length	300 mm
Max tool diameter	75 mm
Max tool diameter with free neighboring slots	120 mm
Tool change on the spindle	Pick up principle
Average chip to chip time; no disc rotation	6 s

Tool change between the main machine magazine and the secondary magazine is accomplished by means of a Double gripper tool changer. Loading of a secondary magazine operation is possible. The appropriate tool data are recorded by the writing/reading head.

Electrical Equipment

Switch cabinet with cooling unit and temperature regulator

Desired Temperature 45° C

Numerical Control Manufacturer INDRAMART

Type MTC 200 multi axis control

Control Consoles:

Main operating panel

Work piece holding station

Tool loading station

Hydraulic power pack

Pressure 63 to 240 bar

Type of oil Mineral oil HLP 46 as per DIN 51 524 T2

Filtering Bypab filter with electric contamination display

Lubrication system

Central lubrication system, no manual lubrication required

Lubrication interval: distance of axis travel (X/Y/Z) 25 m

Type of oil Mineral oil HLP 46 as per DIN 51 524 T2

Pneumatics

Quality of compressed air as per DIN ISO 8573 -1 to be provided by user:

Solids 5

Water 4

Oil 5

Air serving by lubricator/water separator

Pressure reduction

Filtering of the air curtain

Chip Conveyor

Type: Dredging conveyor

Discharge height 1000 mm

Automatic operation after each tool change fro 3-5 secs

Otherwise operation controlled by M commands and sensors.

Cooling lubricant system

Dirty water section (Chip conveyor) approx 330 liters

Clean water section approx 1000 liters

Internal cooling (High pressure pump)

Delivery volume at 60 bar approx 30 l/min

External cooling (low pressure pump)

Delivery volume at 3.5 bar approx 80 l/min

Inclined bed filter SB 200 with fleece Filter band double changeover filter.

Filter fineness 60um

Immersion return cooling system TRK 50

Flange heater make: Helios

Enclosure

Closed protective cabin with interlocked doors and observation windows.

Work piece loading door operated pneumatically and secured by switch rail.

Connection points for central extraction.

Moveable guard on secondary magazine.

Ancillary equipment

Laser controlled drill breakage monitoring system make: Blum

Controllable tools:

Length 200 mm

Diameter 2 mm

Tool identification system:

Make: Balluff with evaluation unit/wiring and reading head/code carrier

Measuring sensors: Reinshaw MT 12 system

Flush pistol

Noise emission values

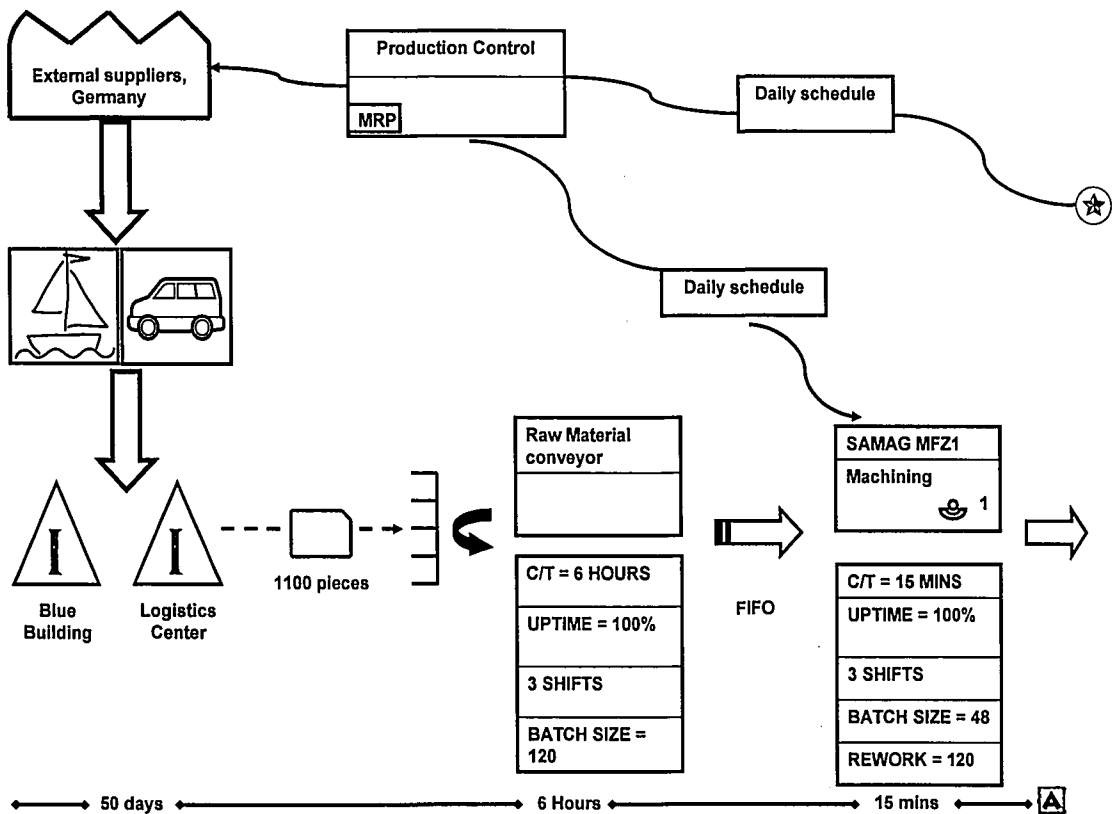
As per machine noise regulations – 3. GSGV and DIN EN 12417.

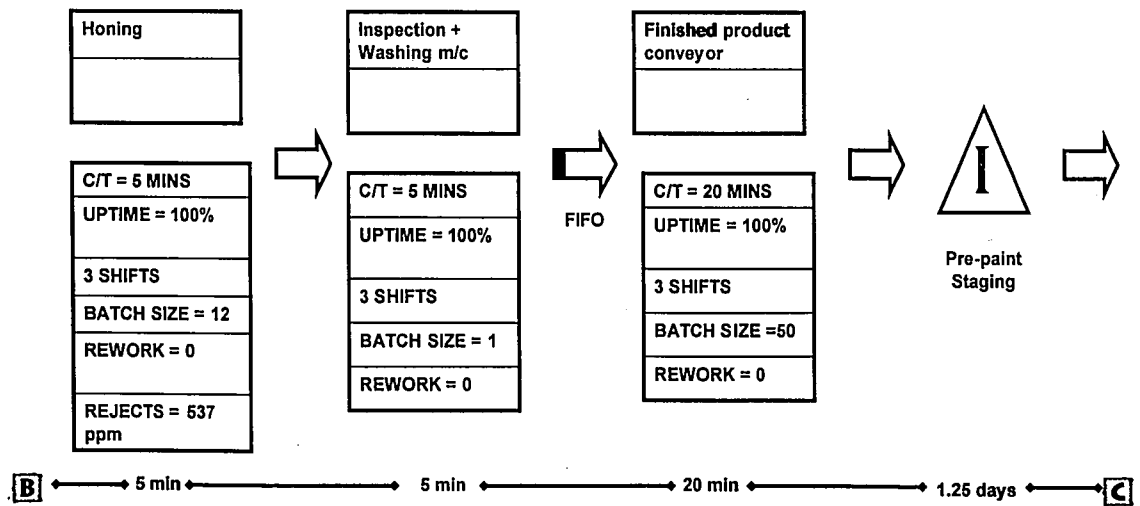
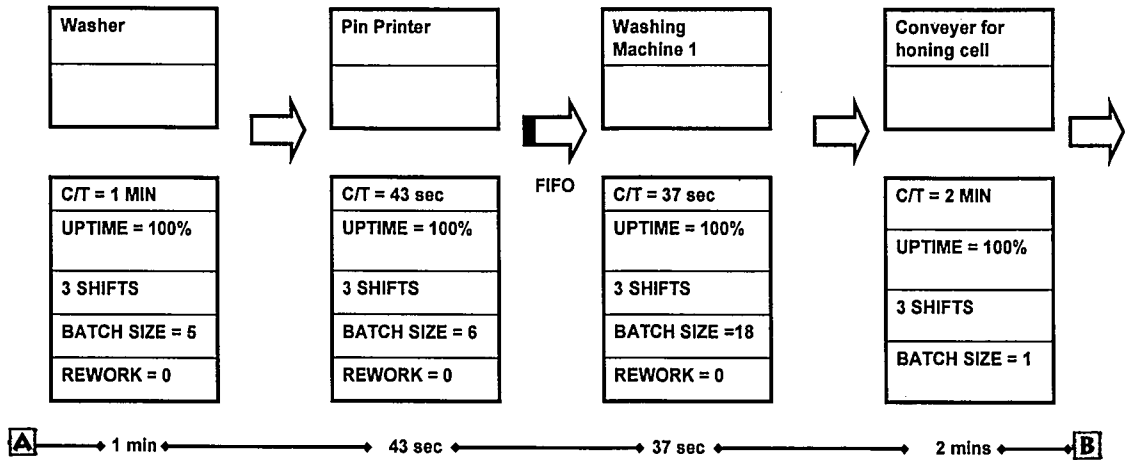
References (Appendix A):

A 1. Operating Instructions Manual, Samag MFZ 1

Appendix B

The appendix shows the current value stream map for the machining of size 6 valve body is performed in the Valve Focus Factory of the plant. Each figure has been divided in four parts. The parts have been labeled in continuation at the bottom of the figure. The figure can be read from the left to the right and it is connected from 'A' to 'B', 'B' to 'C' and 'C' to the end. The Uptime is considered always as 100% because reliable data is not available on the same.





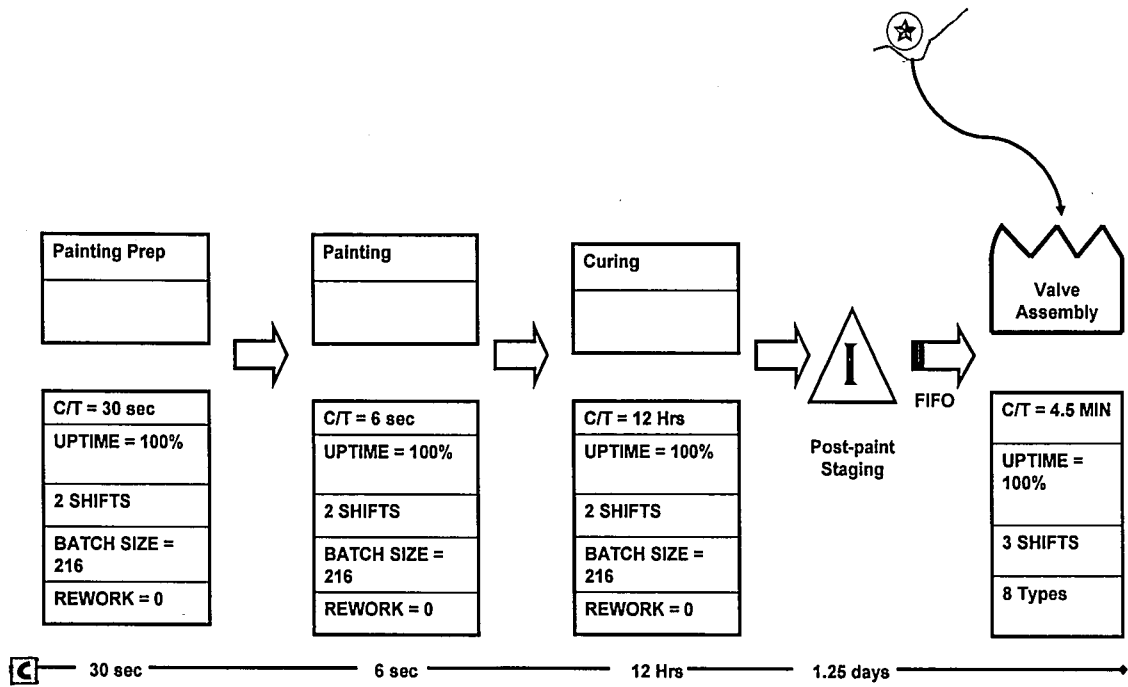


Fig B1: Value stream Map, Size 6 valve body machining

Vita

Name: Shriraj Parikh

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Fathers Name: Amit Parikh

Institutions Attended:

- St. Xavier's Loyola Hall, India, Higher Secondary Education (June 1999 – May 2001)
- Nirma Institute of Technology, India , Bachelor of Engineering, Mechanical Engineering (Oct. 2001 – May 2005)

Professional Experience:

- Bosch Rexroth, Bethlehem, USA (May 2006 – August 2006)

Worked in the Manufacturing Engineering department on Process Failure Mode and Effect Analysis, Control Plans, Flow Charts for assembly, testing and machining of valves and manifolds. Helped with spare part and tool inventory. Carried out Statistical Process Control analyzing defect causes using Control Charts.

- Bosch Rexroth, Bethlehem, USA (Oct. 2006 – April 2007)

Development of OEE metric in harmony with Bosch Standards, taking into consideration machine availability and utilization. Analysis of current state of valve body machining and value stream analysis.

END OF TITLE