

Dissertation
On
**PLANT CAPABILITY ASSESSMENT USING OEE AND TEEP WITH
GAUGE R&R**

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the award of degree of*

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IN
PRODUCTION & INDUSTRIAL ENGINEERING**

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DECLARATION

I hereby declare that the thesis entitled "**PLANT CAPABILITY ASSESSMENT USING OEE AND TEEP WITH GAUGE R&R**", is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering (Production and Industrial engineering)** under the guidance of Dr. Ajay Batish, Professor and Head, Department of Mechanical Engineering, Thapar University, Patiala and Sh. Anirban Bhattacharya, Assistant Professor, Department of Mechanical Engineering, Thapar University, Patiala during July 2010 to June 2011. This matter embodied in this report has not been submitted in part or full to any other University or Institute for the award of any degree.



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ABSTRACT

Overall Equipment Efficiency (OEE) metrics are used since a long time to measure the performance of machines. OEE metrics also help to improve the performance of machines by detecting bottleneck areas of the manufacturing lines or machine. The improvement in the productivity in small/medium scale industry where technology used is not so high is a difficult task. The main objective of the present study is to identify the bottlenecks operations find their root causes and implement possible solution to the problems. OEE metrics are used for this purpose. Time and motion study and method study are also done on different machines to reduce the operator fatigue and simplify method. Process study and material flow also studied to improve the material flow and for the purpose of line balancing. Capability assessments of different machines are done by using OEE data and Gage R&R and its relationship also shown with capability index Cp/Cpk.

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ABBREVIATION

OEE	Overall Equipment Effectiveness
TEEP	Total Effective Equipment Performance
PC	Process Capability
OTE	Overall Throughput Effectiveness
GR&R	Gauge Repeatability and Reproducibility
M/C	Machine
EV	Equipment Variation
OV	Operator Variation
EOV	Equipment and Operator Variation
OEEV	Overall Equipment Effectiveness Variation
CV	Combined Variation
PNA	Personal Need Allowence

1.1 OVERALL EQUIPMENT EFFECTIVENESS (OEE)

Initially the term (OEE) was used by Seiichi Nakajima in 1998s. He gave a quantitative metric for measuring the productivity of individual production equipment in a factory. The term has gained popularity in the recent past. The OEE measure attempts to reveal hidden costs associated with a piece of equipment. OEE is a "best practices" way to monitor and improve the effectiveness of our manufacturing processes (i.e. machines, manufacturing cells, assembly lines).

1.2 NEED OF OEE

In this evolutionary world the global economy has expanded the base of competition for all business. Every organization is focusing on more sales and increased profit. In order to survive (for an organization) in this competitive world, it is necessary to meet customer's expectations. So the total elimination of waste is necessary for the survival of the organization. The waste generated due to the failure or shutdown of facilities or the waste such as defective products, should be completely eliminated [1,2].

In the manufacturing industry, the utilization of installed capacity is rather low for various reasons. According to Ahlmann the overall utilization of installed capacity is around 60 per cent in a number of Swedish industries.

Huang et al. [3] also state that due to intense global competition, companies are continuously trying to improve and optimize their productivity in order to remain competitive. This would be possible if the production losses were identified and eliminated so that the manufacturers could bring their products to the market at a minimum cost. This situation has led to a need for a rigorously defined performance measurement system that is able to take into account different important elements of productivity in a manufacturing process.

The industrial application of OEE varies from one industry to another but the basic concept of measuring effectiveness is derived from the original OEE concept. OEE can be best illustrated by the six metrics that comprise the system. The hierarchy consists of two top-level measures and four underlying measures.

1.2.1 The Two Top-Level Metrics

Overall Equipment Effectiveness (OEE) and Total Effective Equipment Performance (TEEP) are two closely related measurements that report the overall utilization of facilities. These two metrics directly indicate the gap between actual and ideal performance.

1.2.1.1 Overall Equipment Effectiveness (OEE)

OEE quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run.

OEE is a multiplication of availability (actual run time vs. scheduled time), speed rate (actual rate vs. ideal speed rate) and quality rate (good product vs. total product) and is given by equation (1.1).

$$OEE = Availability\% \times Performance\% \times Quality\% \quad \dots\dots\dots eq. (1.1)$$

1.2.1.2 Total Effective Equipment Performance (TEEP)

TEEP proposed by Ivancic, is very similar to OEE. The main difference lies in the inclusion of planned downtime in the total planned time horizon. With the help of TEEP, planned and unplanned downtime can be measured. TEEP examines how effectively do factories run their processes relative to the calendar time. TEEP is given by equation (1.2).

$$TEEP = Loading\% \times Availability\% \times Performance\% \times Quality\% \quad \dots\dots\dots eq. (1.2)$$

1.2.2 The Four Underlying Metrics

OEE metric is a multiplication of availability, speed rate and quality rate. TEEP adds a fourth metric 'Loading'.

1.2.2.1 Availability

Availability is defined as the ratio between the total available time (uptime) and the scheduled production time. An availability of 85% implies that the equipment/process was actively producing product for 85% of the scheduled production time and for the remaining for 15% of scheduled production time the equipment/process was not available to produce (for example equipment failures, material shortages etc.). Availability can be calculated by using equation (1.3).

$$Availability\% = Total\ Available\ Time / Scheduled\ Production\ Time\% \quad \dots\dots\dots eq. (1.3)$$

1.2.2.2 Performance

Performance is defined as the ratio between the theoretical production time for the total product produced during available time (uptime) and the available time (uptime). A Performance of 90% implies a Speed Loss of 10%. Performance can be calculated by using equation (1.4).

$$\text{Performance}\% = \text{Theoretical Production Time} / \text{Available Time}\% \quad \text{.....eq. (1.4)}$$

1.2.2.3 Quality

Quality is defined as the ratio between the good units produced and the total Production. A Quality score of 95% implies a Yield Loss of 5% due to scrapping and/or reworking of product (this reworking consumes capacity in the equipment/process). Quality can be calculated by using equation (1.5).

$$\text{Quality}\% = \text{Good Units Produces} / \text{Total Production}\% \quad \text{.....eq. (1.5)}$$

1.2.2.4 Loading

Loading is the portion of the TEEP Metric that represents the percentage of total calendar time that is actually scheduled for operation. Loading Time can be calculated by using equation (1.6).

$$\text{Loading Time}\% = \frac{\text{Calendar Time} - \text{Planned Down Time}}{\text{Calendar Time}} \times 100\% \quad \text{.....eq. (1.6)}$$

The metrics used to calculate OEE are summarised on figure 1.1

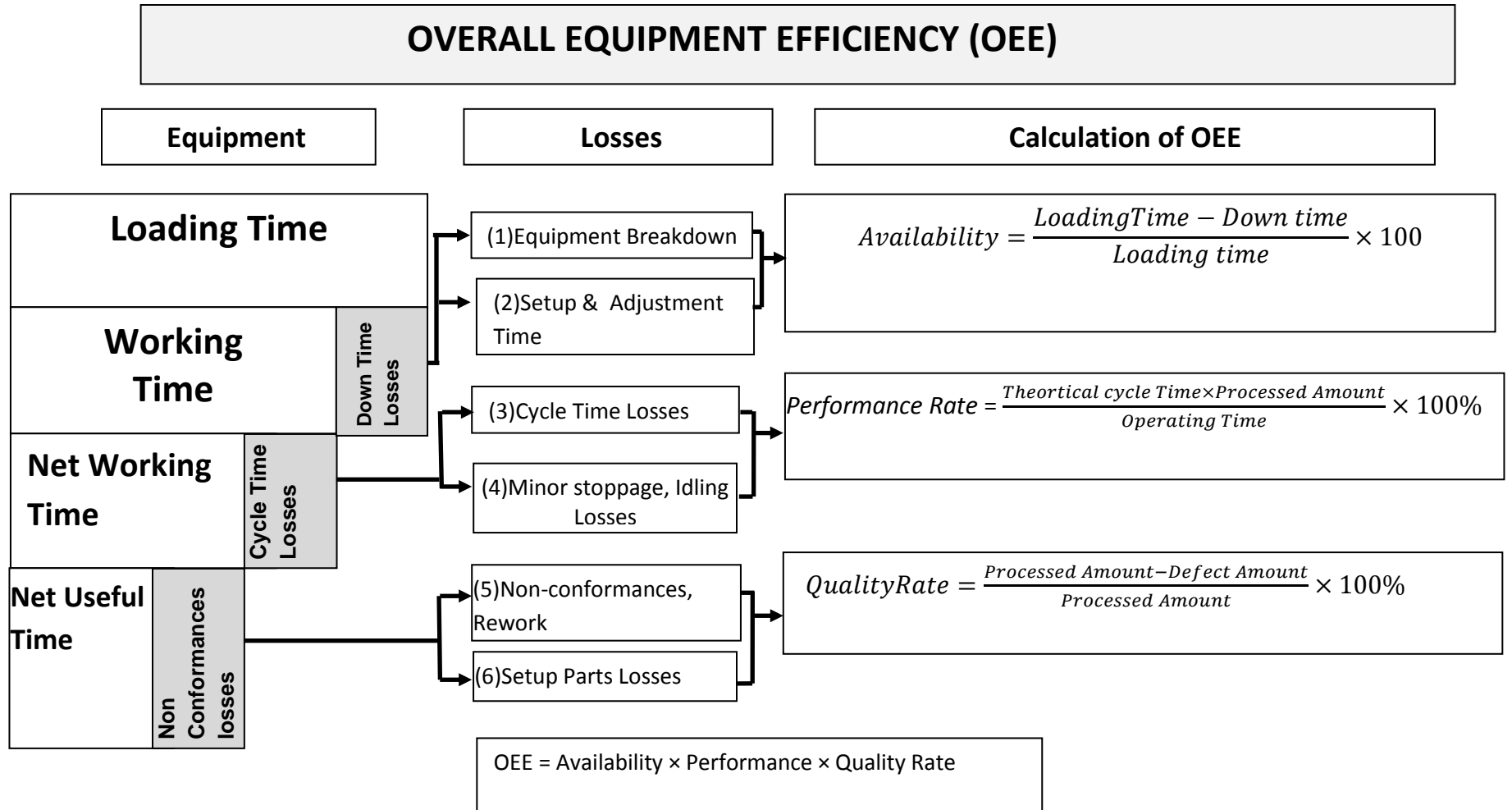


Figure 1.1: Overall Equipment Efficiency- Three metrics Combined

Metrics used to calculate TEEP are combined in figure 1.2

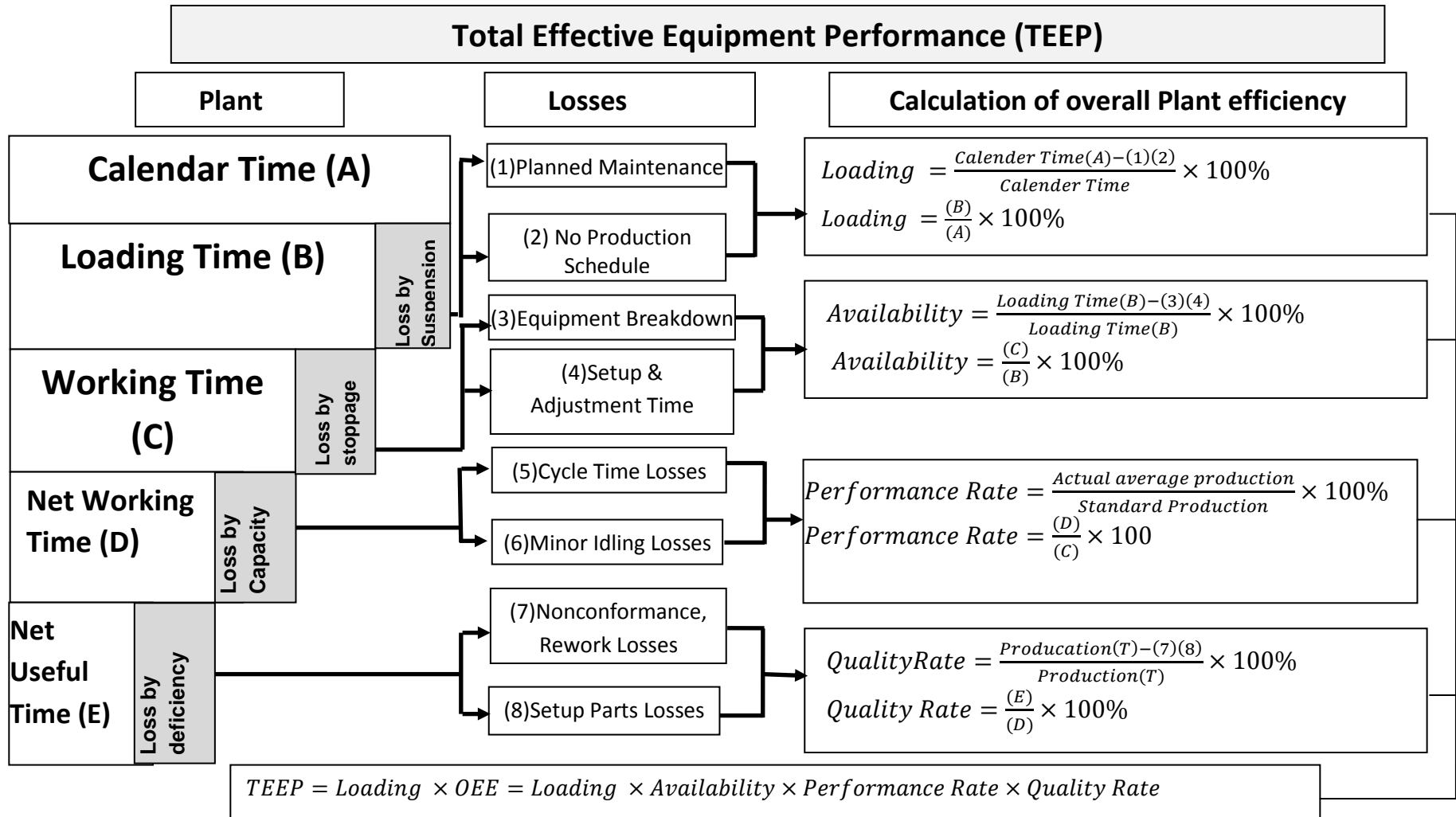


Figure 1.2: Total Effective Equipment Performance

1.3 SIX BIG LOSSES

One of the major goals of OEE programs is to reduce and/or eliminate the losses (which happened during manufacturing) and improve the efficiency of the manufacturing system. These losses are known as Six Big Losses in OEE. The following table lists the Six Big Losses, and shows how they relate to the OEE Loss categories.

Six Big Loss Category	OEE Loss Category	Examples
Equipment Breakdown	Down Time Loss	<ul style="list-style-type: none"> • Tooling Failures • Unplanned Maintenance • General Breakdowns • Equipment Failure
Setup & Adjustment Time	Down Time Loss	<ul style="list-style-type: none"> • Setup/Changeover • Material Shortages • Operator Shortages • Major Adjustments • Warm-Up Time
Minor Idling Losses	Speed Loss	<ul style="list-style-type: none"> • Obstructed Product Flow • Component Jams • Misfeeds • Sensor Blocked • Delivery Blocked • Cleaning/Checking
Cycle Time Losses	Speed Loss	<ul style="list-style-type: none"> • Under Design Capacity • Equipment Wear • Operator Inefficiency
Setup Parts Losses	Quality Loss	<ul style="list-style-type: none"> • Scrap • Rework • In-Process rejection • Assembly Rejection
Nonconformance, Rework Losses	Quality Loss	<ul style="list-style-type: none"> • Scrap • Rework • In-Process rejection • Assembly rejection

Table 1.1: Six big losses of OEE [4]

1.4 COMPILING OF OEE

OEE used in industry to measure and improve the productivity, but still OEE having some short coming. OEE measured by the availability, performance and quality rate, but the effect of performance loss due to worker inefficiency/skill and complexity of the part design are not shown in the OEE metrics.

1.5 PROCESS CAPABILITY

The process capability indices Cp, Cpk used in Statistical Process Control which was initially started by U.S and Japanese companies and are now used mostly all over the world. These tools are used as a decision making tool to assess the capability of the machine or manufacturing process.

Once the process is brought under statistical control by detecting and eliminating special cause of variation, its performance is predictable; its capability to meet customers' expectations can then be assessed.

Process capability study can be used to know how a machine or tool is performing. These indices tell us whether the process has low or high variability. Cp & Cpk helps to know about the initial variability of the machine or process as well as these are can also be use to predict any quality related problem even the product is older.

1.5.1 Capability Index (C_p)

C_p simply measures the spread of the specifications relative to the six-sigma spread in the process regardless of the location. C_p can be calculated by using equation (1.7).

$$C_p = \frac{\text{Tolerance}}{6\sigma} = \frac{USL-LSL}{6\sigma} \quad \dots\dots\dots\text{eq. (1.7)}$$

The equation provides an indication of how capable the process is, despite its inherent variability, of meeting the specifications expected by the customer.

1.5.2 Capability Index (C_{pk})

C_{pk} measures how well a given process is generating a specific characteristic with respect to specification limits. C_{pk} can be calculated by using either equation (1.8) or (1.9).

$$C_{pk} = \frac{USL-\bar{X}}{3\sigma} \quad \text{when } \bar{X} \text{ is above nominal} \quad \dots\dots\dots\text{eq. (1.8)}$$

$$C_{pk} = \frac{\bar{X} - LSL}{3\sigma} \quad \text{when } \bar{X} \text{ is below nominal} \quad \dots\dots\dots\text{eq. (1.9)}$$

Note that when process is running nominal, then $C_{pk} = C_p$. For the process to be capable, values of both measures have to be larger than one [5][6].

1.6 LIMITIATION OF C_p & C_{pk}

Many case studies are published in literature that explains the usefulness of the C_p & C_{pk} indices. But if the performance of a machine or a manufacturing line/assembly line is to measure over a long period of time and to find actually they are capable of making product profitably or not, C_p & C_{pk} study may not be sufficient. Because C_p and C_{pk} study is a short term study and not a continuous study which can continuously measure the performance of a machine or manufacturing line for a period of time. These PC indices only check the quality of the product and tells about the manufacturing system is able to manufacture quality product or not. But the OEE studies also include the machine availability and performance with quality which gives us better picture about the manufacturing process as well as its supporting activity like material handling, operator performance, part design complexity.

1.7 ABOUT THE CASE STUDY

A medium scale part manufacturing company was selected for study. Company is manufacturing plastic moulded and plated parts for the major OEM automobile companies. The cycle time and manufacturing method for all the machines and manufacturing/assembly lines and material flow in the plant are recorded. Time and Motion study and Method study was also done on different machines. OEE is calculated for all machines and manufacturing lines and also the bottleneck areas are find out to improve OEE. Suggestions are also given to company to minimise material handling on machine and also in between different departments which will improve quality of the product as well as OEE of the manufacturing lines.

2.1 OEE MEASUREMENT

OEE was created by Seiichi Nakajima at Nippondenso in 1988 and it is a very powerful tool that can be used to measure productivity at the equipment level. It was further developed by Japan Institute for Plant Maintenance (JIPM) and forms part of TPM method [7].

Honda stated that OEE is a measure of how well equipment or lines are utilized in relation to their full potential. OEE is based on the product of three individual factors, Availability, Performance efficiency and Quality rate. The main objective to measure OEE is to make constraint or “bottleneck” equipment run more effectively.

OEE identifies and measures losses of important aspects of manufacturing namely availability, performance, and quality rate. This supports the improvement of equipment effectiveness and productivity [8].

2.2 EVOLUATION OF OEE

OEE is a very powerful tool that can be used to measure productivity at the equipment level. OEE was recognized as a fundamental method for measuring equipment performance beginning in the late 1980s and early 1990s. Now it is accepted as a primary performance metric . The OEE measure attempts to reveal the hidden costs associated with a piece of equipment [3].

Fleischer et al. [9] stated that the competitiveness of manufacturing companies depends on the availability and productivity of their production facilities. In a manufacturing scenario, the desirable productivity, cost, inventory, quality and delivery all depend on the efficient functioning of the company’s facilities.

According to **Jonsson and Lesshammar [10]**, the OEE tool is designed to identify losses that reduce the equipment effectiveness. These losses are due to manufacturing disturbances that are either chronic or sporadic. Chronic disturbances are small and hidden, and are a result of several concurrent causes. Sporadic disturbances on the other hand are more obvious since they occur quickly and have large deviations from the normal state. It is a bottom-up approach to eliminate six large losses stated by Nakajima in 1988).

Huang et al. [11] stated that although the OEE tool has become increasingly popular and has been widely used as a quantitative tool essential for measurement of productivity, it is only limited to productivity behavior of individual equipments.

Scott and Pisa [12] pointed out that the gains made in OEE, while important and ongoing, are insufficient. It is necessary to focus one's attention beyond the performance of individual tools towards the performance of the whole factory. The ultimate objective is a highly efficient integrated system, not brilliant individual tools. The authors coined the term overall factory effectiveness (OFE), which is about combining activities and relationships between different machines and processes, and integrating information, decisions, and actions across many independent systems and subsystems.

Garza-Reyes et al. [13] developed overall resource effectiveness, which also considers material efficiency and variations in material and process cost as part of the evaluation of overall effectiveness.

Dal et al. [14] suggested that the role of OEE goes far beyond the task of just monitoring and controlling. This is because OEE takes into account process improvement initiatives, prevents the sub-optimisation of individual machines or production lines, provides a systematic method for establishing production targets, and incorporates practical management tools and techniques in order to achieve balanced view of process availability, performance and quality. Moreover, OEE can be used as an indicator of process improvement and as an approach to achieve it.

Jeong and Phillips [15] says that the standard definition of OEE given by Nakajima is not appropriate for capital intensive industry because, in this case, there is the need to account for additional causes of losses such as preventive maintenance, off-shifts and holidays.

Bonal et al. [16] noted that, with the exception of the bottleneck of the plant, selecting machines for a TPM program and evaluating the potential impact on the global efficiency is not a trivial task. OEE alone does not provide enough information and, to get the right decision, financial parameters too should be taken into account. To this scope, the authors proposed a new metric called overall fab efficiency, which combines OEE and the substitution capital of the machines installed in a plant.

An operative approach to get a rough evaluation of the efficiency of a line is presented by **Robinson (2004)**. According to the author, since the pace of the line is determined by the constraining operation, both the availability (A) and the performance rate (P) of the bottleneck machine must coincide with that of the line. In addition, quality defects upstream (US) from the constraining operation, affect the output of the line only if they result in the starvation of the bottleneck, whereas quality defects downstream (DS) from the bottleneck do affect the potential output of the line and should be counted against the quality rate. For these reasons the author suggested to evaluate the process OEE by mean of equations (2.1) and (2.2), respectively:

$$Process\ OEE = A_{BN} \times P_{BN} \times Q_{Tot} \quad \dots\dots\dots eq. (2.1)$$

$$Q_{Tot} = (TI_{BN} - DSD)/TI_{BN} \quad \dots\dots\dots eq. (2.2)$$

where, A_{BN} and P_{BN} are the availability and the performance rate of the bottleneck machine; TI_{BN} is the total number of items processed by the constraining operation; DSD is the total number of defects and reruns DS of the constraining operation[17].

Nachiappan and Anantharaman [18] proposed the overall line effectiveness (OLE) as an alternative metric to evaluate the efficiency of a continuous product flow manufacturing system. As shown in equation (5), OLE is obtained as the product of two independent terms, namely the line availability (LA) and the line production quality performance (LPQP) as given in equation (2.3).

$$OLA = LA \times LPQP \quad \dots\dots\dots eq. (2.3)$$

In an effort to simplify the nature of the problem **Muthiah and Huang [19]** have proposed a well-defined modular approach. The basic component of a manufacturing system is a Unit Production Process (UPP). Any factory can be decomposed into architectural combinations of these UPP's, and by doing this the equipment level metrics can be protracted to the system level. The interconnectivity of these subsystems has been represented as a directed graph, and an algorithm has been developed to automatically recognize the subsystems.

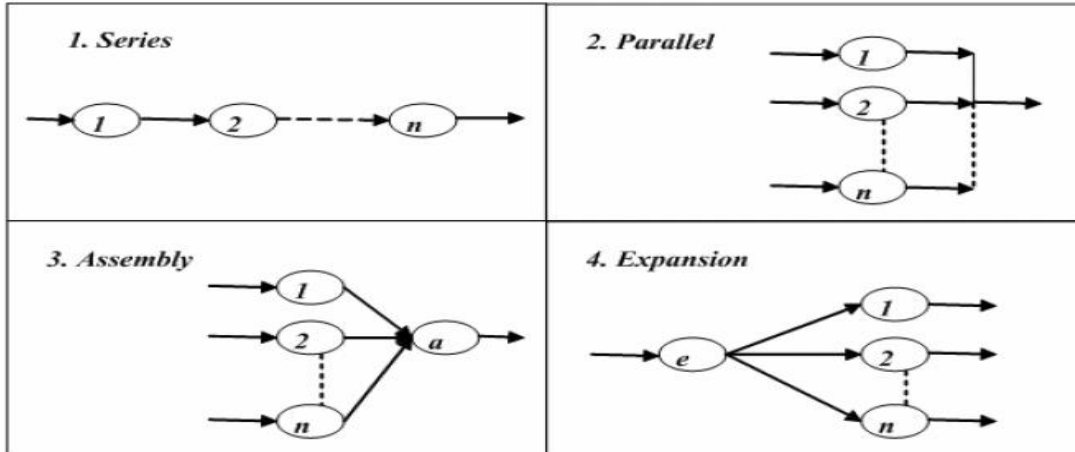


Fig.2.1 Manufacturing Subsystem [20]

The figure 2.1 shows the major combinations of UPP’s that have been proposed by Muthiah and Huang, 2004: “Series”, “Parallel”, “Assembly” and “Expansion”.

The Overall Throughput Effectiveness (OTE) metrics for these four unique subsystems are derived based on a “system constraint” approach that accounts for equipment idle time. The idea is as follows. If a part needs to be processed by Equipment A before it can be processed by Equipment B (e.g., A and B are connected in series), then the amount of good product output from Equipment B is constrained by those from Equipment A. If Equipment B does not experience idle time due to the lack of output from Equipment A, then good product output from Equipment B depends on its TEE, its theoretical processing rate, and the total time of production; otherwise, good product output is constrained by what Equipment A can produce and the quality efficiency of Equipment B. The derived OTE metrics are shown in Table 2.1, where $TEE(i)$ denotes Throughput Equipment Effectiveness of equipment i , $Rth(i)$ denotes theoretical processing rate of equipment i , $Qeff(i)$ denotes quality efficiency of equipment i , $kA(i)$ denotes number of parts needed from equipment i to make a final assembly, suffix “(a)” denotes assembly station, $kE(i)$ denotes number of parts proceeding to equipment i from the expansion station, suffix “(e)” denotes the expansion station and TT is the total time of observation, n denotes the number of equipments in the subsystem and N denotes the total number of parts resulted from processing one part in the expansion station. Table 2.2 shows the bottleneck indicator used for diagnostics.

Subsystem	<i>OTE</i>
Series	$\frac{\min \left\{ \min_{i=1,2,\dots,n-1} \left\{ TEE_{(i)} \times R_{th(i)} \times \prod_{j=i+1}^n Q_{eff(j)} \right\}, TEE_{(n)} \times R_{th(n)} \right\}}{\min_{i=1,2,\dots,n} \{R_{th(i)}\}}$
Parallel	$\frac{\sum_{i=1}^n (TEE_{(i)} \times R_{th(i)})}{\sum_{i=1}^n R_{th(i)}}$
Assembly	$\frac{\min \left\{ \min_{i=1,2,\dots,n} \left\{ TEE_{(i)} \times \frac{R_{th(i)}}{k_{A(i)}} \times Q_{eff(a)} \right\}, R_{th(a)} \times TEE_{(a)} \right\}}{\min \left\{ \min_{i=1,2,\dots,n} \left\{ \frac{R_{th(i)}}{k_{A(i)}} \right\}, R_{th(a)} \right\}}$
Expansion	$\frac{\sum_{i=1}^n \min \{R_{th(e)} \times TEE_{(e)} \times k_{E(i)} \times Q_{eff(i)}, R_{th(i)} \times TEE_{(i)}\}}{\sum_{i=1}^n \min \{R_{th(e)} \times k_{E(i)}, R_{th(i)}\}}$

Table 2.1 OTE Matrices [20]

Subsystem	Subsystem Bottleneck Indicator
Series	$\min \left\{ \min_{i=1,2,\dots,n-1} \left\{ TEE_{(i)} \times R_{th(i)} \times \prod_{j=i+1}^n Q_{eff(j)} \right\}, TEE_{(n)} \times R_{th(n)} \right\}$

Parallel	$\min_{i=1,\dots,n}(TEE_{(i)} \times R_{th(i)})$
Assembly	$\min \left\{ \min_{i=1,2,\dots,n} \left\{ TEE_{(i)} \times \frac{R_{th(i)}}{k_{A(i)}} \times Q_{eff(a)} \right\}, R_{th(a)} \times TEE_{(a)} \right\}$
Expansion	$\min_{i=1,\dots,n} \{ R_{th(e)} \times TEE_{(e)} \times k_{E(i)} \times Q_{eff(i)}, R_{th(i)} \times TEE_{(i)} \}$

Table 2.2 OTE Bottleneck Indicator [20]

Ron and Rooda [21] stated OEE is impacted by factors beyond the equipment itself, including the operator, recipe, facilities, material (input items) availability, scheduling requirements, etc. As this may result in OEE values influenced by factors beyond the equipment itself, a distinction can be made between stand-alone equipment and integrated equipment. OEE is directed towards equipment integrated in a manufacturing environment, so that OEE includes of this environment. As a metric lacking towards stand-alone equipment, Ron and Rooda proposed the equipment effective E. This performance measure was derived to monitor the effectiveness of stand-alone equipment, independent of the environment.

Abbas Al-Refaie and Bata, N. [22] proposes a procedure for assessing a measurement system and manufacturing process capabilities using Gage Repeatability and Reproducibility (GR&R) designed experiments with four quality measures. GR&R designed experiments helps to improve quality and also helps in assessing the capability of a measurement system and manufacturing process and it also help in deciding required action for improving performance.

Garza-Reyes, J. A. et al. [23] demonstrates the relationship between OEE and PC and suggests the existence of a “cut-off point” beyond which improvements in PC have little impact on OEE. Although statistically a C_p/C_{pk} equal to 1.0 indicates a capable process, the generally accepted minimum value in manufacturing industry is 1.33. This investigation challenges the traditional and prevailing knowledge of considering this value as the best PC target in terms of OEE. In terms of OEE, this suggests a C_p/C_{pk} of 0.8 as the ideal value and challenges the idea of considering the C_p/C_{pk} value of 1.33 as the “ideal” target in terms of OEE.

2.3 PROCESS CAPABILITY LITERATURE

Process Capability (PC) helps to determine the suitability of a process to meet the required quality standards. According to **Deleryd [24]**, after the development of this measure in the 1980s its use has increased considerably. The factor that has contributed to increase the application of PC is its request by quality systems and improvement methodologies like ISO9000 and Six Sigma.

In addition, **Jagadeesh and Babu [25]** mention that nowadays it is not quite logical to proceed with full-scale production without conducting a PC analysis.

Kane [26] developed C_p and C_{pk} indices, which are mostly used in industry to evaluate single quality characteristics in mass production. C_p and C_{pk} indices assume that the quality characteristic is normally distributed, and can be expressed as given in equation (2.4) and (2.5).

$$C_p = \frac{USL-LSL}{6\sigma} \dots\dots\dots\text{eq. (2.4)}$$

$$C_{pk} = \min \left\{ \frac{USL-m}{3\sigma}, \frac{m-LSL}{3\sigma} \right\} \dots\dots\dots\text{eq. (2.5)}$$

USL and LSL represent the upper and lower specification limits, respectively; m represents the process mean, and σ is the process standard deviation. Sometimes, a customer will provide a one-sided specification. The indices C_{pu} and C_{pl} were developed for these situations. For processes with upper specification limit only C_{pk} calculated by equation (2.6) and for process with lower specification limit only C_{pk} calculated by equation (2.7).

$$C_{pu} = \frac{USL-m}{3S} \dots\dots\dots\text{eq. (2.6)}$$

$$C_{pl} = \frac{m-LSL}{3S} \dots\dots\dots\text{eq. (2.7)}$$

The index C_{pu} compares the distance between the process mean and the upper specification limit to the upper half width of the distribution. Similarly, C_{pl} compares the distance between the process mean and the lower specification limit to the lower half-width of the distribution. The

indices show the relative size of the working margin, i.e. the closeness of the distribution to the specification limit.

Since C_p and C_{pk} indices does not account for the difference between the processes mean and its target value, **Chan et al [27] and Pearn [28]** considered this difference to develop C_{pm} and C_{pmk} indices as given in equation (2.8) and (2.9).

$$C_{pm} = \frac{USL-LSL}{6\sqrt{\sigma^2+(m-T)^2}} \dots\dots\dots\text{eq. (2.8)}$$

$$C_{pmk} = \min \left\{ \frac{USL-m}{3\sqrt{\sigma^2+(m-T)^2}} , \frac{m-LSL}{3\sqrt{\sigma^2+(m-T)^2}} \right\} \dots\dots\dots\text{eq. (2.9)}$$

where T represents the target value of a quality characteristic.

2.4 OEE AND PROCESS CAPABILITY INDICES

Since a long time overall equipment effectiveness and Process Capability(C_p and C_{pk} index) are commonly used and well-accepted measures of performance in industry. PC is a measure of quality performance that occupies an important place within online quality control as it helps to determine the suitability of a process to meet the required quality standards. Process Capability studies are done when new line or machine is setup in plant and when all random error are under control to check the machine capability to make the product under specified quality limit. Process Capability are also done when there is any quality related problem. PC indices study the quality of the product but the OEE also studies the effect of other parameter with quality which affects the process or product. OEE studies are done to check the overall performance of the machine or manufacturing lines on the base of its availability, performance and quality rate. OEE is a long term measure of machine or manufacturing line. OEE studies are done for a period of time like one month or more and we can check that our manufacturing setup is actually able to make the product profitably or not. C_p and C_{pk} check only the quality of the product but OEE measure the actual performance of the manufacturing setup.

2.5 GAPS IN LITERATURE

OEE and PC are used since a long time as a well accepted measure of performance in industry, but the OEE and PC are used for different measures. OEE is used as a quantitative metric tool for

controlling and monitoring the productivity of production lines or machines. OEE also helps to find the bottleneck in the process and so help to improve the overall productivity.

PC is a measure of quality performance helps to measure the online quality control. It helps to measure the suitability of the process or machine to meet the required quality standard.

OEE can also be used as a measure of Process capability. OEE data can be use to find the Process Capability by GR&R quality measure. Al-Refaie A. and Bata N. in 2010 evaluate the PC with GR&R method but they not used the OEE data in their study. Garza-Reyes J.A. et al. in 2009 also did a relationship analysis of OEE and Process Capability but they not used the GR&R method.

Through the literature it concluded that the metrics developed to calculate OEE includes process utilization (availability), operational rate (performance) and quality rate. Ron and Rooda says OEE is impacted by factors beyond the equipment itself, including the operator, recipe, facilities, material (input items) availability, scheduling requirements, etc. Ron and Rooda proposed the equipment effective E. This performance measure was derived to monitor the effectiveness of stand-alone equipment, independent of the environment. But Ron and Rooda not explain how we can include the factor like operator skill and product design complexity to find the OEE.

2.6 PROBLEM FORMULATION AND OBJECTIVES

To find the Process capability by the use of OEE data and by using GR&R method is still a scope to study. Product design complexity and operator skill also influence the OEE, to find the effect of these parameter and to use them in OEE metrics is still a challenge. The objectives of the study are to

- a) find the process capability by using the OEE data and GR&R method.
- b) improve productivity of the production lines.

3.1 INTRODUCTION OF COMPANY

To collect the data for our study of OEE and Process Capability a medium scale part manufacturing company from North-West India. The company is a leading manufacturer of Automotive Components and Assemblies for OEM's including Emblems (Electroplated, Painted, Gold Plated & Hot stamped), Automotive Plastic moulded components, Wheel Trims & Wheel Covers, Electroplated Bigger Parts (Radiator Grills, License Plate Garnish, Hood Strips), Decorative Body side moulding, Assemblies Control Brackets, Dash Board Components, Auto Electricals Assemblies, Door Handle, Ash Trays, Fuse Box Assemblies, Diesel Water Separator etc. The company is supported by in-house design and development facilities like modern tool room for manufacturing of moulds, dies, jigs and fixtures, and design facility is supported with leading 3D modeling software like Pro Engineer, Catia & Unigraphics.

3.2 SCOPE OF PRESENT STUDIES

The studies conducted in December 2010 - March 2011 provide for the following:

- Manpower requirement in each shop
- OEE studies on various work stations and the line.
- Process Capability study if required.
- Cycle time studies on each station (including the manual tasks which are currently on piece rate basis).
- Method studies on critical stations to improve productivity.
- Identification of jobs, that is critical to quality and plant efficiency. Skill requirement for these jobs.
- Stations on each line where multi-skilling will help improve the plant productivity.

3.3 METHODOLOGY

Following methodology was used based on the type of product and the processes employed:

- i. Detailed study and understanding of all production lines of the plant
- ii. Continuous time and motion study depicting the activities and time duration of operators on a common time scale
- iii. Cycle time study, product wise as well as machine/operator wise
- iv. Method study of manual operations
- v. Detailed time study during all shift changeovers
- vi. Layout and facility plan
- vii. Set up time study on the molding line was carried using observational techniques where in each activity was detailed into number of small elements and then 'Why-Why' technique was used to either convert internal times to external times or suggesting method modifications on the setup process.

CHAPTER 4

MEASUREMENT OF MOULDING SHOPS

4.1 TEEP STUDY OF DIFFERENT MACHINES

4.1.1 Moulding Machine ‘M1’

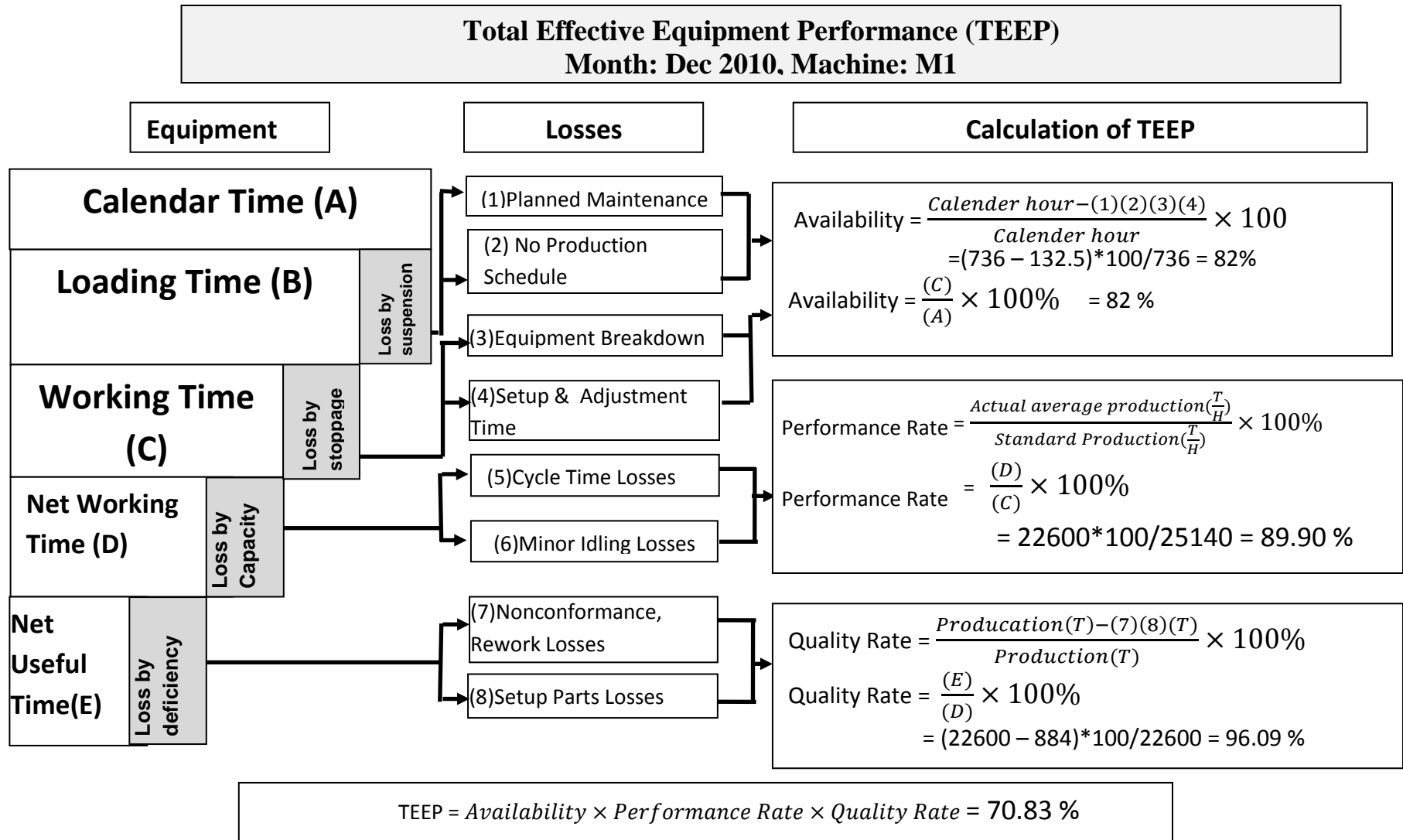


Fig 4.1: Total Effective Equipment Performance of M/C M1

4.1.1 Moulding Machine ‘M2’

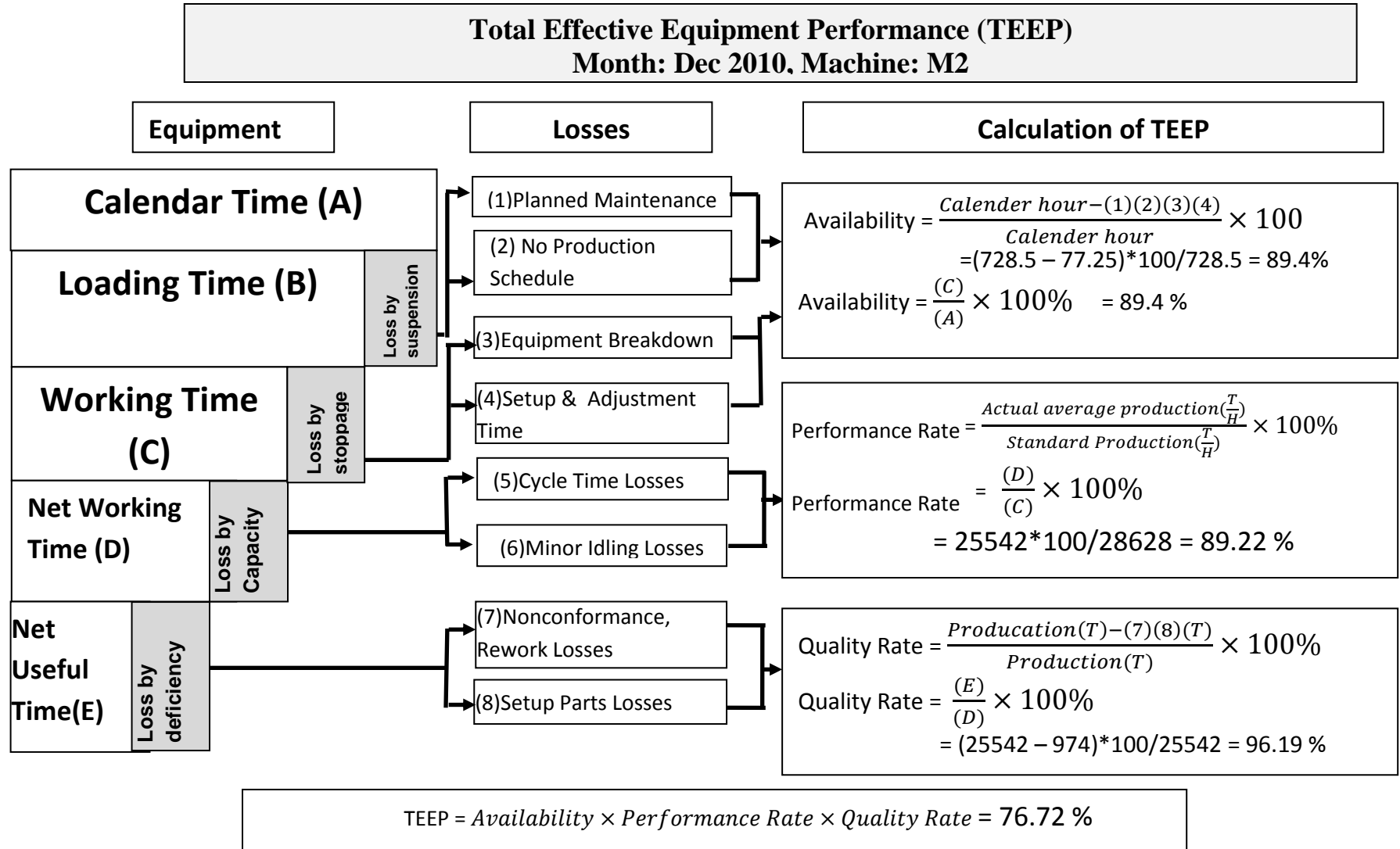


Fig 4.2: Total Effective Equipment Performance of M/C M2

4.1.3 Moulding Machine ‘M3’

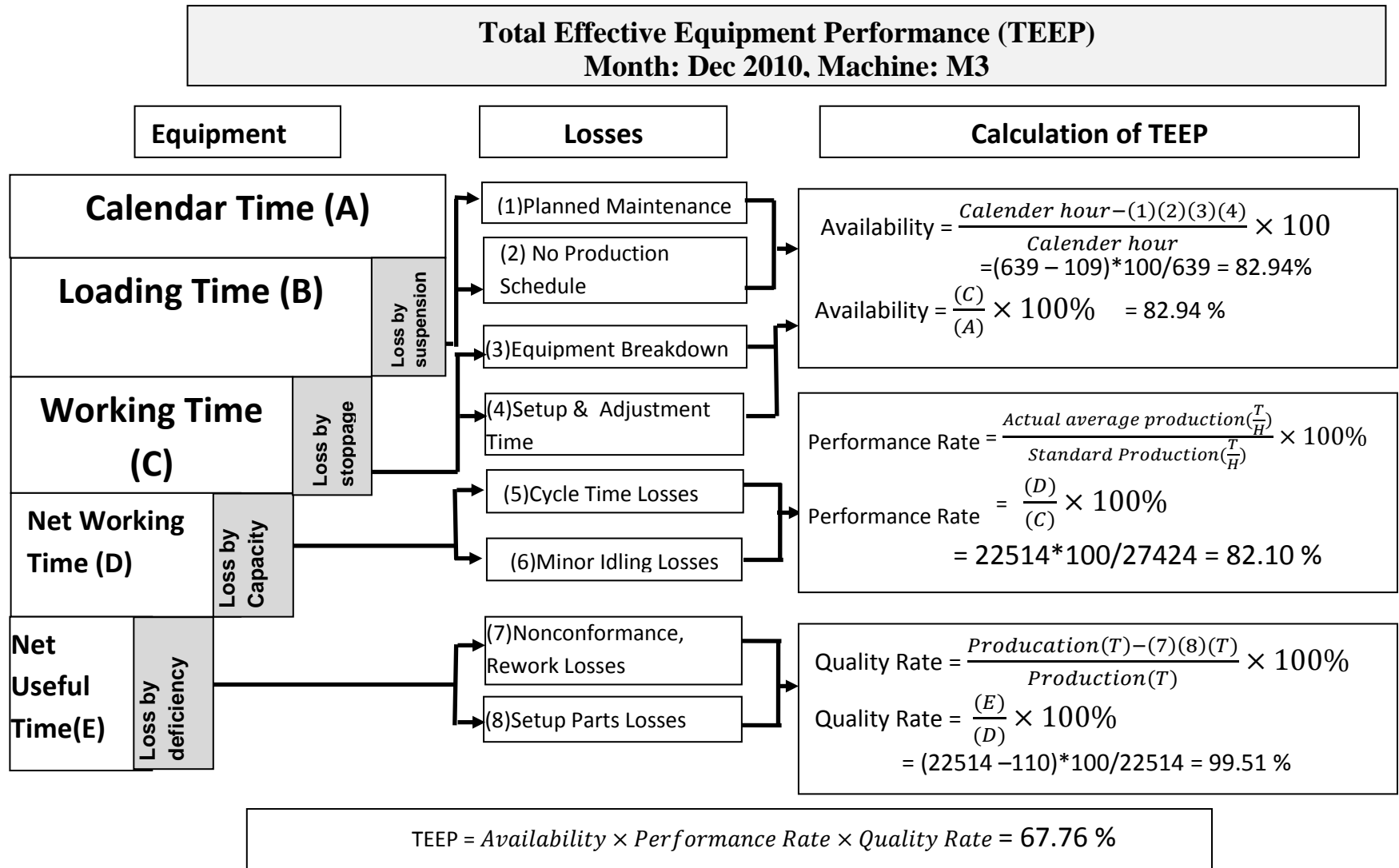


Fig 4.3: Total Effective Equipment Performance of M/C M3

4.1.4 Moulding Machine ‘M4’

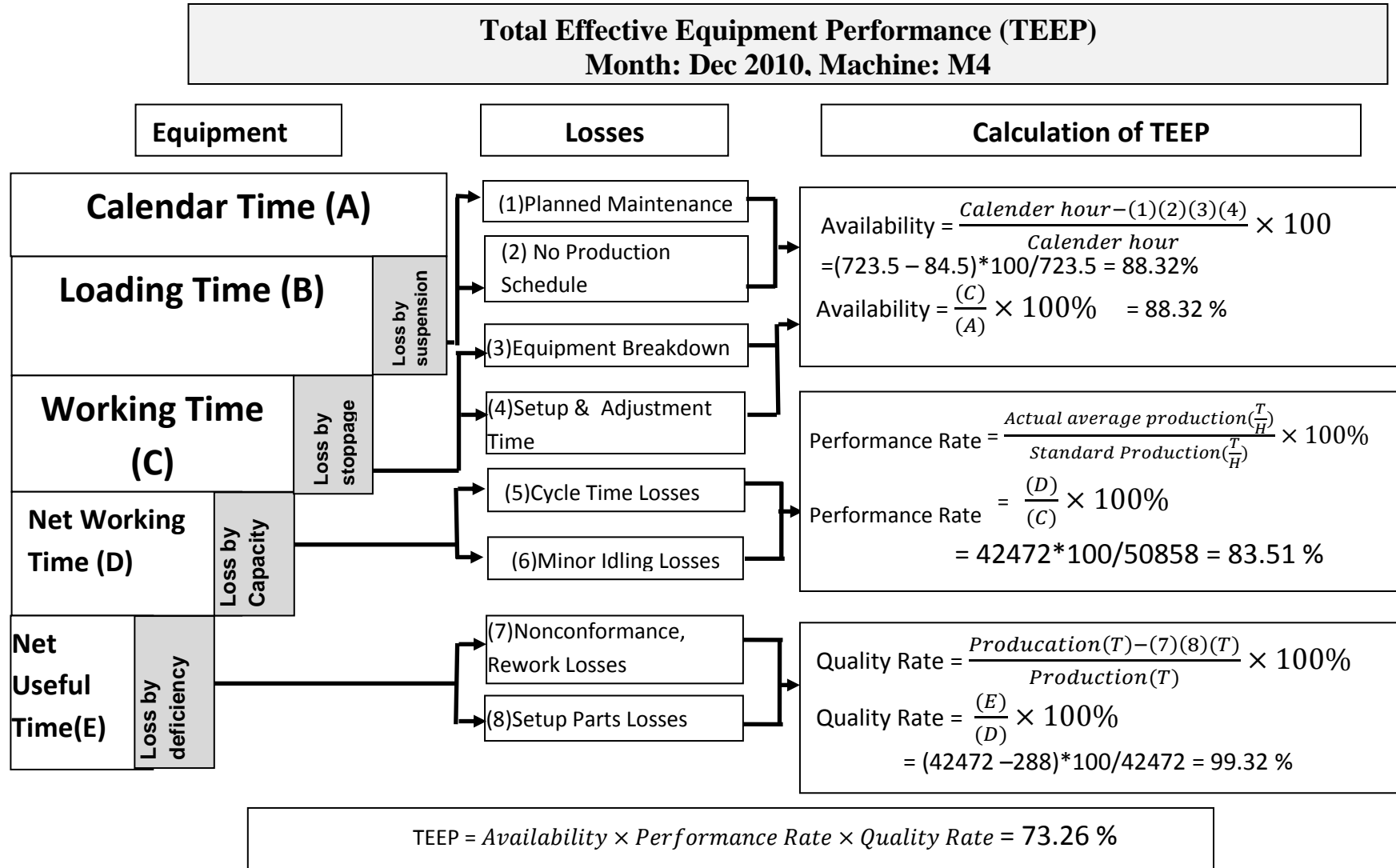


Fig 4.4: Total Effective Equipment Performance of M/C M4

- 4.1.5 Moulding Machine ‘M5’** see Appendix 1
- 4.1.6 Moulding Machine ‘M6’** see Appendix 2
- 4.1.7 Moulding Machine ‘M7’** see Appendix 3
- 4.1.8 Moulding Machine ‘M8’** see Appendix 4
- 4.1.9 Moulding Machine ‘M9’** see Appendix 5
- 4.1.10 Moulding Machine ‘M10’** see Appendix 6
- 4.1.11 Moulding Machine ‘M11’** see Appendix 7
- 4.1.12 Moulding Machine ‘M12’** see Appendix 8
- 4.1.13 Moulding Machine ‘M13’** see Appendix 9
- 4.1.14 Moulding Machine ‘M14’** see Appendix 10
- 4.1.15 Moulding Machine ‘M15’** see Appendix 11
- 4.1.16 Moulding Machine ‘M16’** see Appendix 12
- 4.1.17 Moulding Machine ‘M17’** see Appendix 13
- 4.1.18 Moulding Machine ‘M18’** see Appendix 14
- 4.1.19 Moulding Machine ‘M19’** see Appendix 15

4.2 TEEP ANALYSIS MACHINE WISE

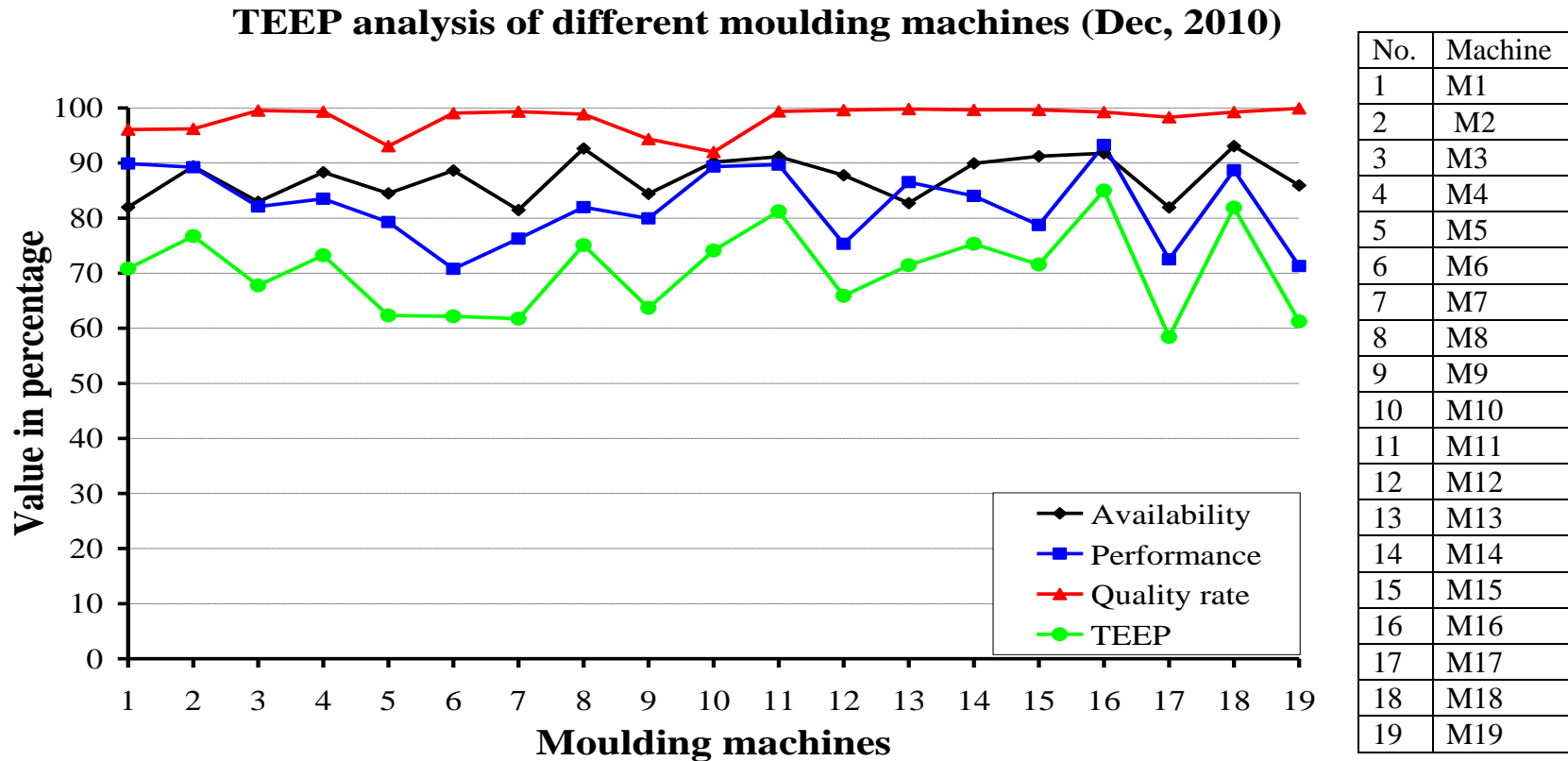


Fig 4.5: TEEP Analysis of different moulding machines

TEEP analysis of different moulding machines for a month shows machine M16 having largest TEEP and machine M17 having lowest TEEP. The major factor here which affects the OEE is the performance of the machine. Machine M15 also having nearly same quality rate and availability as machine M16 having but the TEEP of machine M15 is much lower than machine M16 just because of the differences in performance.

4.3 TEEP ANALYSIS OF MACHINE 'M1' DAYWISE

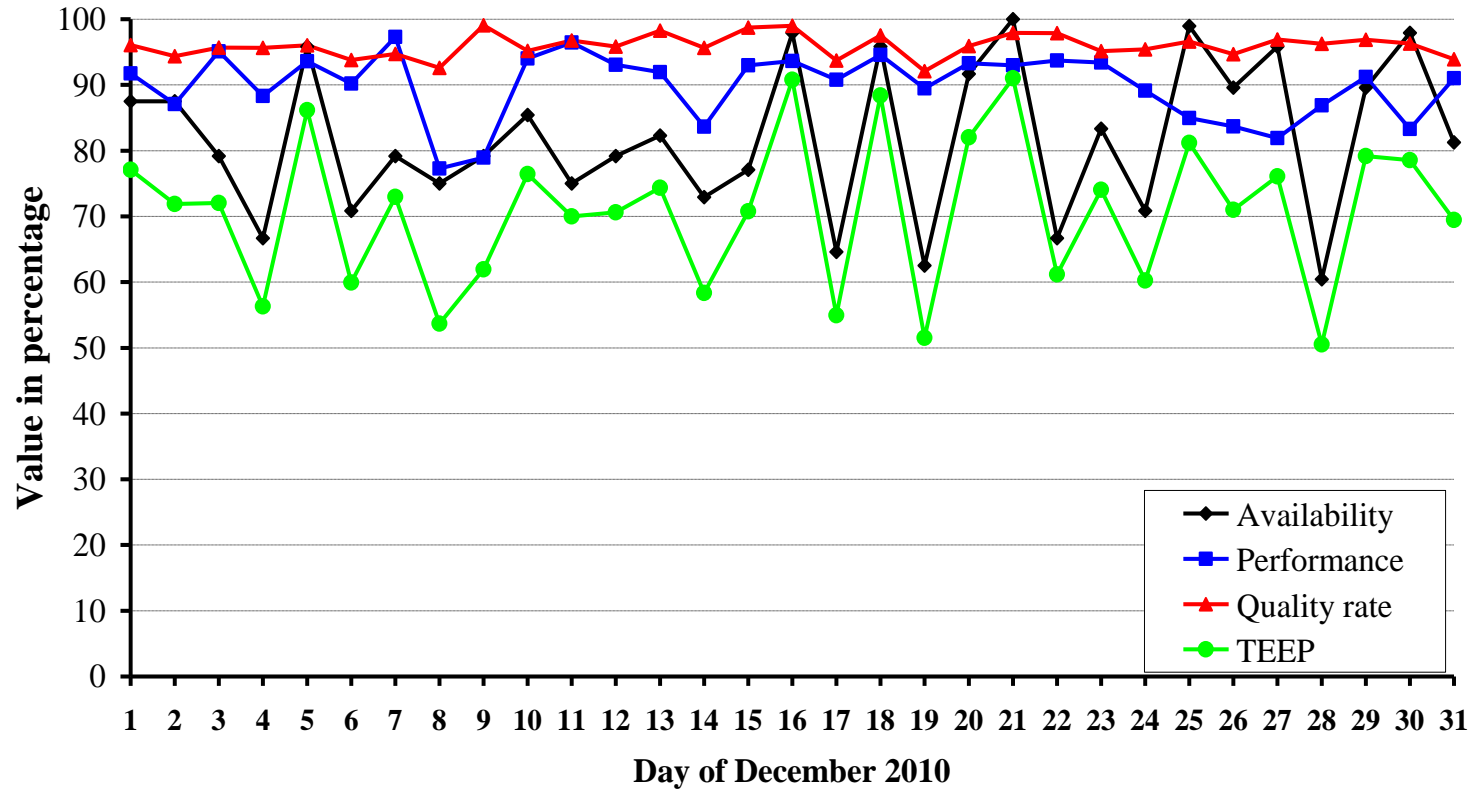


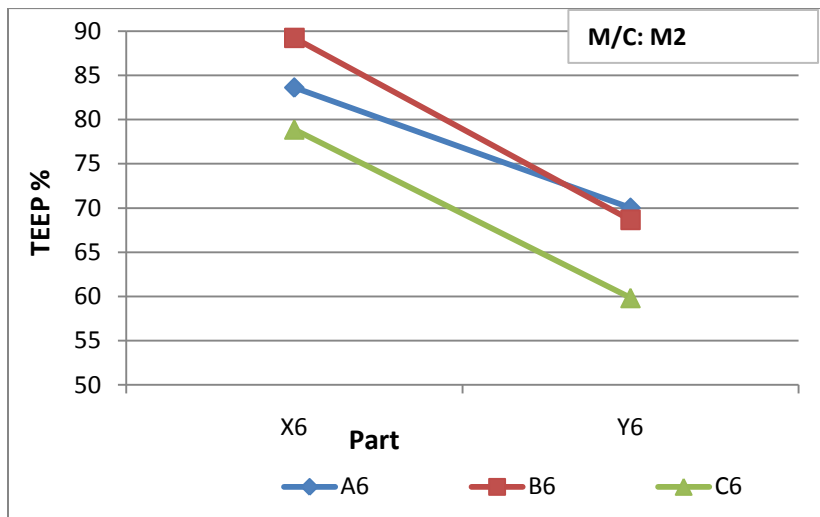
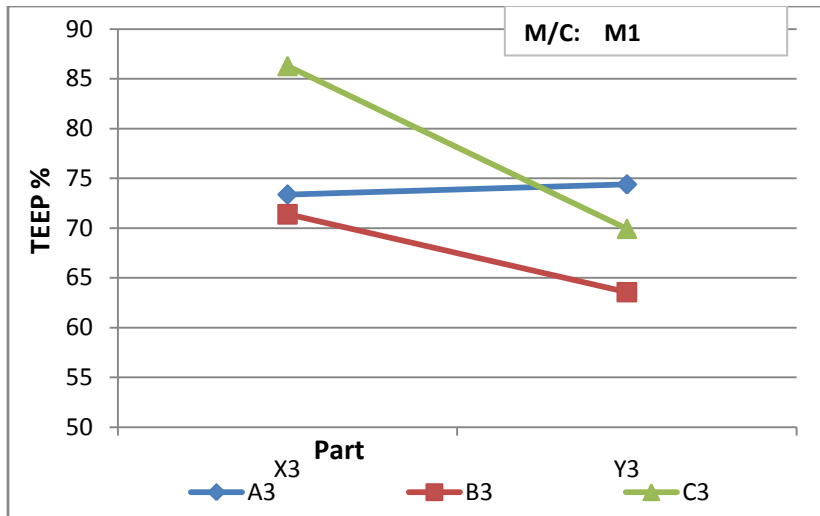
Fig 4.6: TEEP analysis of machine 'M1' during a month

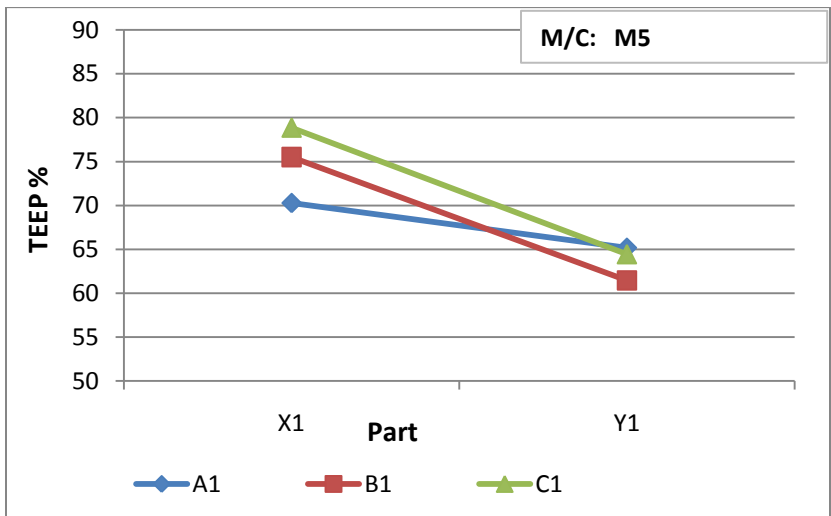
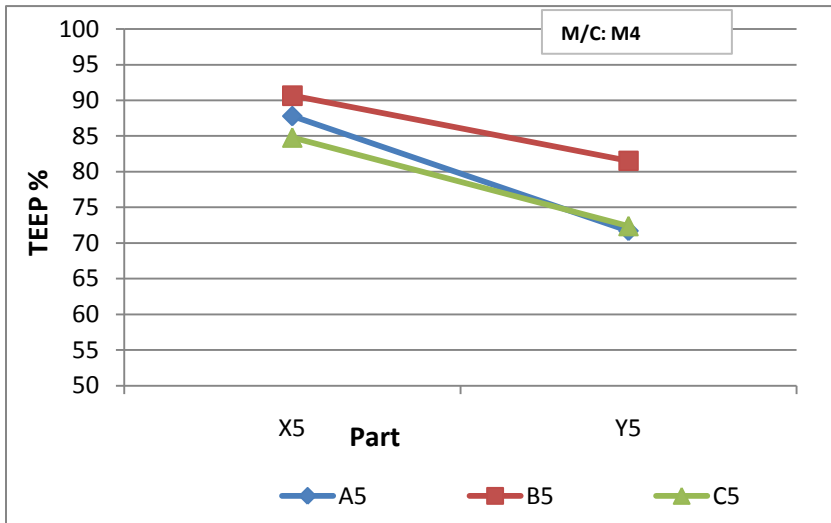
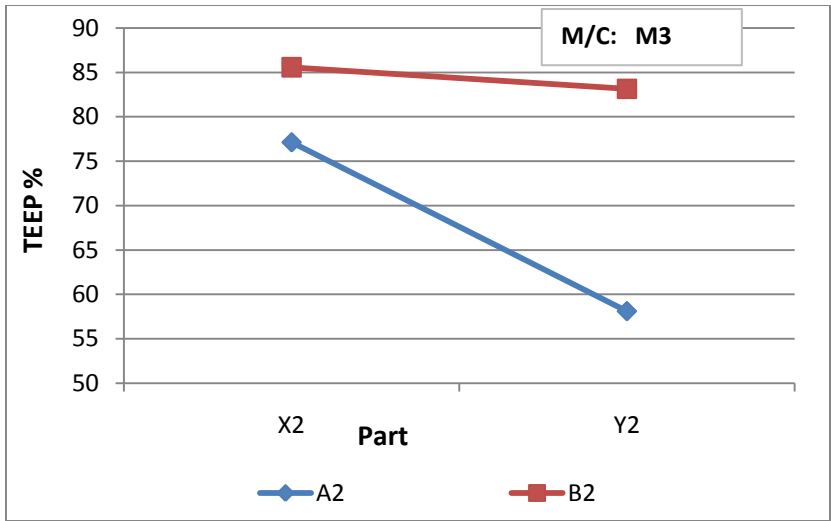
RESULTS

Through the figure it is clear that there is a lot of variation in the daywise availability of the machine which affect the TEEP most. Here the availability of the machine is the major reason for low TEEP. To improve the TEEP of machine first it is necessary to increase the availability of the machine.

4.4 TEEP OF PART AGAINST OPERATOR

TEEP study of different parts and operator are done to see the affect of these factors over TEEP.





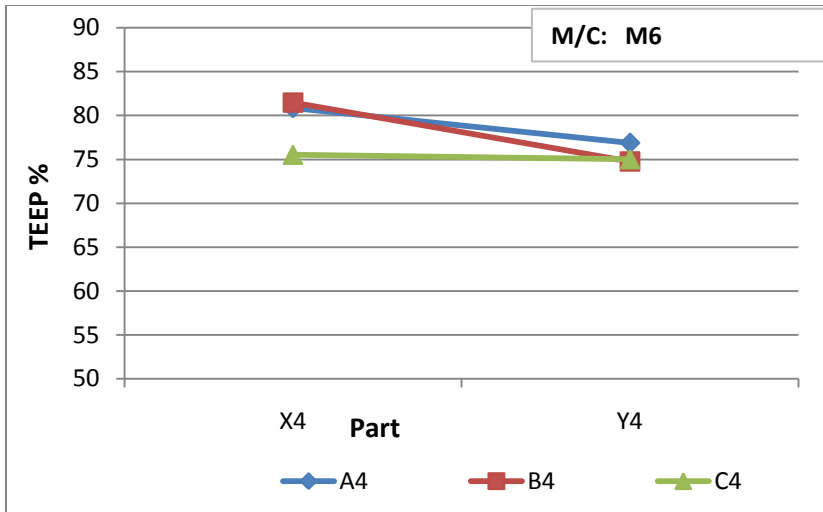
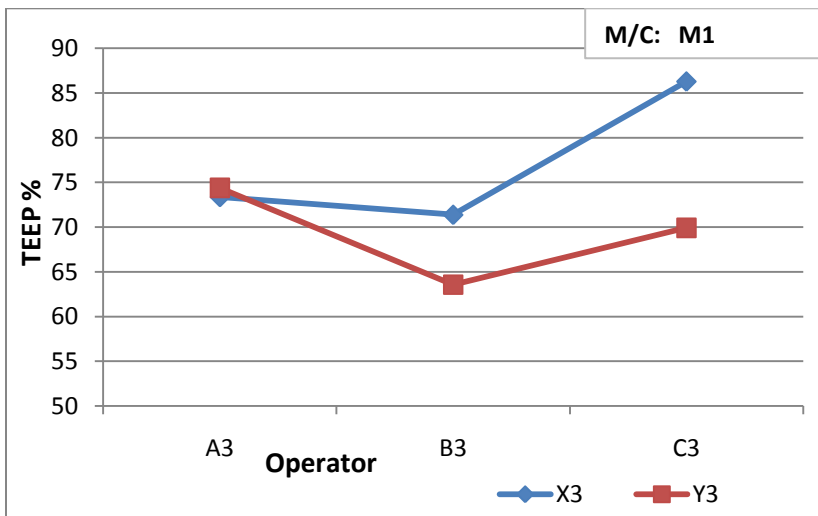
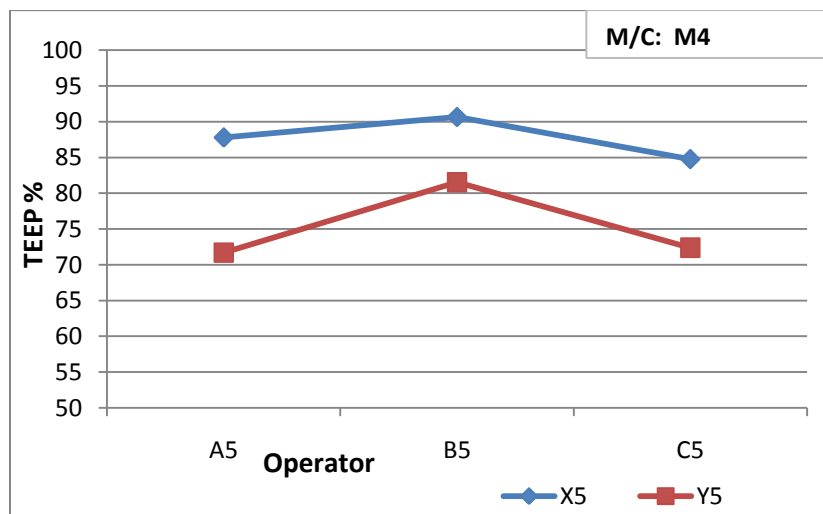
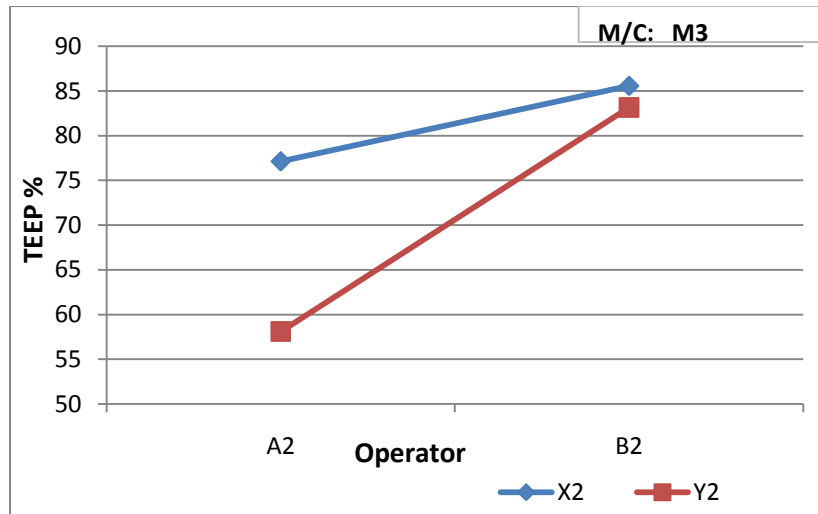
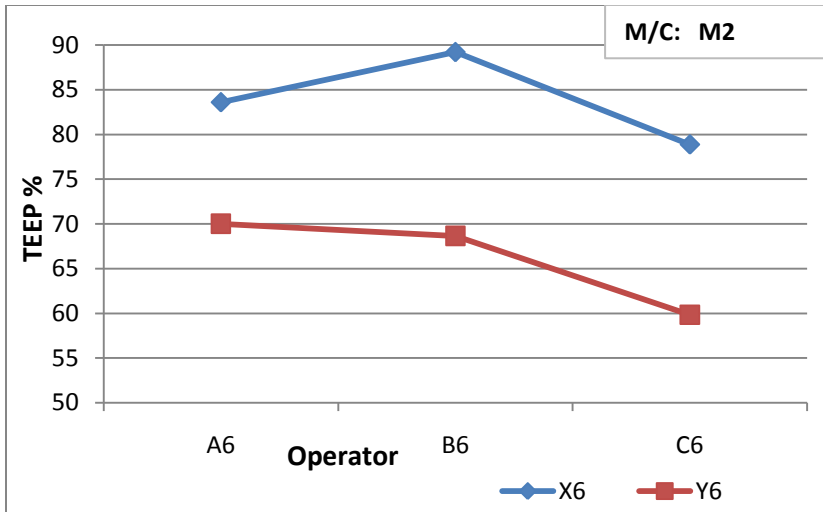


Fig 4.7: TEEP of Part against Operator

4.5 TEEP OF OPERATOR AGAINST PART





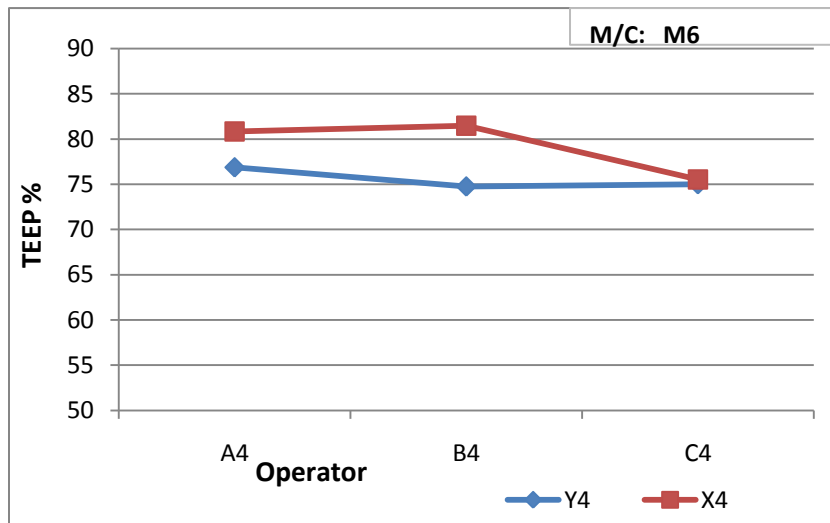
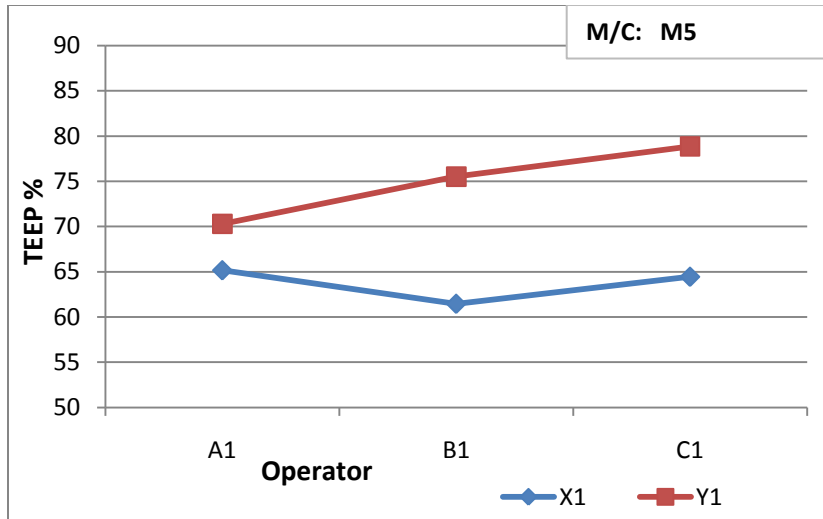


Fig 4.8: TEEP of Operator against Part

4.6 RESULTS

After the study of TEEP of part against operator and TEEP of operator against part it is concluded that there is considerable effect of both part type/design and skill of the operator over the TEEP. Same part is produced by different operator at same machine and same condition and it is observed that there is considerable change on TEEP. Similarly the different part having different TEEP even they are operated by same operator. This shows that TEEP is affected by both one the skill of the operator and secondly design complexity of the part.

5.1 WHAT IS PRODUCTIVITY IMPROVEMENT ?

Productivity improvement is a process of increasing the output with the help of same resources (input) or keeps the output constant and reduces the resources. Resources may be manpower, machine utilization, material etc. Productivity can also be increase by improving the quality of the product (by reducing rejection). Here the study of moulding and deflashing shop is done to improve the productivity of the shop floor.

5.1.1 Moulding machine ‘M1’ – As Is Process

One operator has been deployed for this machine. The total cycle time is 78 seconds. This includes the machine running time as well as part unloading time. The operator performs the following tasks which:

- Unloading of part
- Die Cleaning with compressed air
- Close machine door
- Remove gate by hand/cutter
- General Inspection and emery polishing
- Marking with pen
- Wrap in blue cloth cover
- Place in tray

The activity chart and man-machine chart of the operator viz a viz the machine is shown in Figure 5.1 (a) and 5.1 (b). The activity chart shows machine and the operator loading against time in one cycle. As can be observed from this figure, the operator is loaded for an average of 34 seconds in each machine cycle. The remaining 46 seconds is idle during each cycle.

To fill this idle time it was decided to review the next operation of deflashing to see the possibility of combining the two operations together. The deflashing operation was studied to divide the task into smaller elements and is given in the next section.

	M/C: M1	Component: 1001
Time	Machine	Machine Operator
0	Door open	Door Open + Taking component out
5		Spraying the compressed air
10	Machine Running	Pushing button to close door + Remove gates by hand/cutter/ Inspection
15		
20		Emery polishing
25		Marking by pen
30		Putting into blue cloth cover
35		
40		
45		
55		
60		
65		
70		
75		

Figure 5.1 (a): Activity chart for man of machine ‘M1’

Cycle Time Chart:

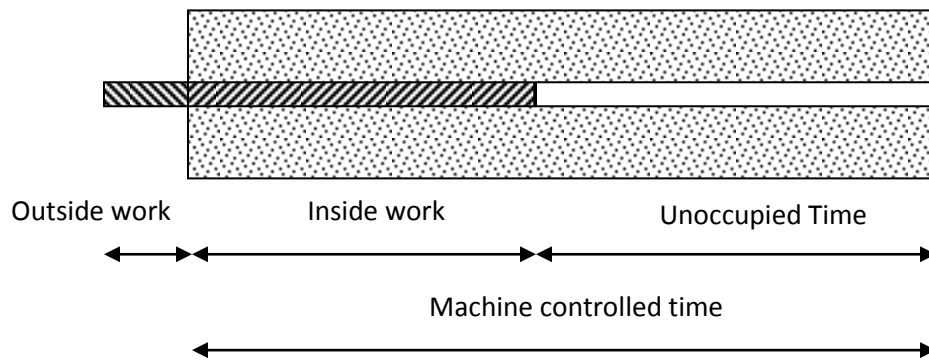


Figure 5.1(b): Task analysis for machine ‘M1’

5.1.1.1 Deburring / De-flashing of parts produced on Machine ‘M1’

All the parts made on machine ‘M1’ are then transferred to another location for removing flash. The deflashing for the parts produced on machine ‘M1’ was completed by a team of two operators who divided the work elements amongst themselves. The two operators work in tandem to complete deburring. The cycle time of the two operators was calculated over 10 cycles and averaged. The average cycle time of the operation was observed to be 139 seconds (for two

working in tandem). The activity chart and man-machine chart of the operator viz a viz the machine is shown in Figure 5.2 (a) and 5.2 (b).

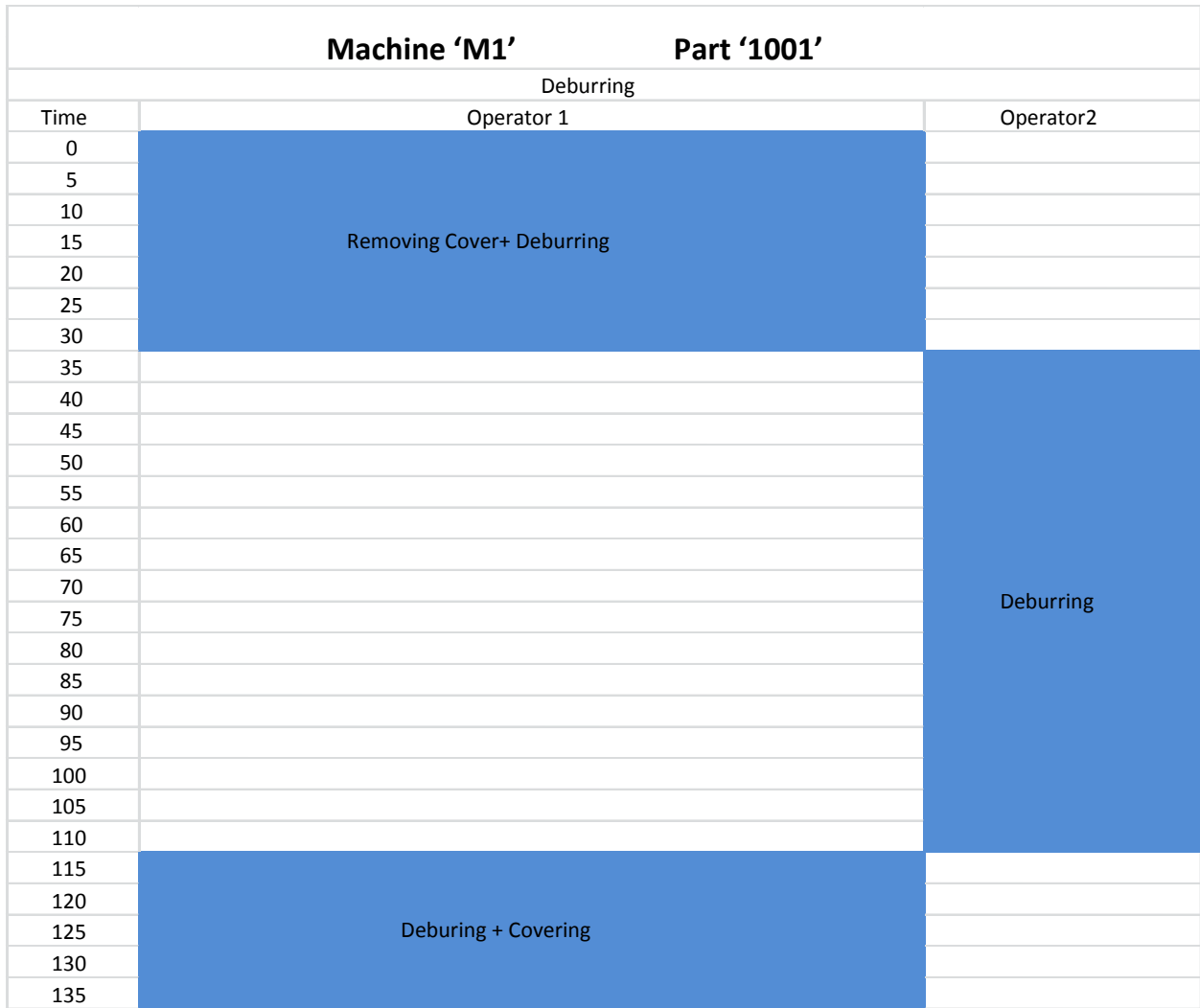


Figure 5.2 (a): Activity chart for Deflashing of Machine 'M1' Parts

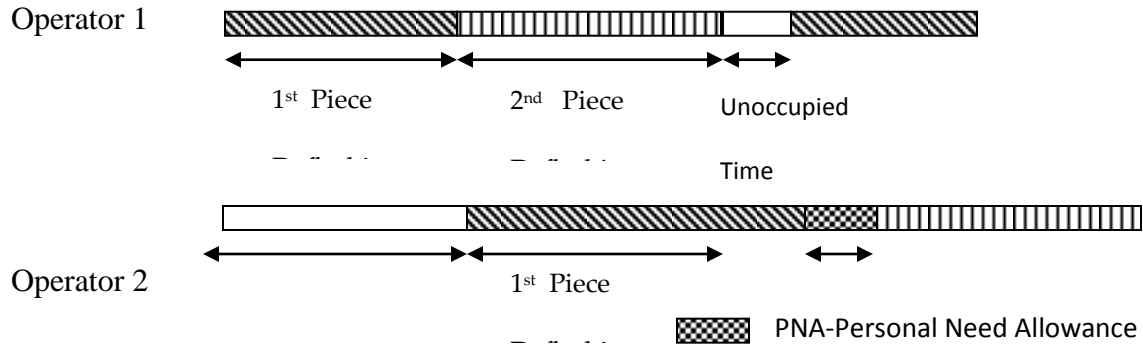


Figure 5.2 (b): Task Analysis for Deflashing of machine ‘M1’ parts

A review of the activity chart for deflashing of these parts indicates an opportunity for moving the deflashing operation on the machine itself wherein the idle time of the operator can be utilized to replace at least one of the two deflashing operators. The combined manufacturing and the deflashing operation on the machine is explained in Section 5.3.

5.1.1.2 Machine ‘M1’ – Proposed Scenario (To-Be Process)

In the ‘To- Be’ process, it is proposed to combine the molding and deburring operations, to be completed on the machine. Instead of 1 (machine) + 2 (deflashing) operators in the ‘As-Is’ method, the proposed method will require a manning of 1+1, thus saving one man. Also, the machine operator will not be required to wrap each part in cloth bag and will save an additional 10 secs in each cycle. Similarly, the deflashing operator will not need to unwrap the part. This would result in eliminate one potentially damaging handling operation preventing scratches, cuts or other handling and transportation defects. The combined process of manufacturing and deflashing is shown in Figure 5.3 (a) and 5.3 (b).

	M/C: 'M1'	Part: '1001'		
Time	Machine	Machine Operator	Deburring Operator	
0	Door open	Door Open + Taking component out		
5		Spraying the compressed air		
10	Machine Running	Pushing button to close door + Remove gates by hand/cutter/ Inspection		
15				
20		Emery polishing		
25		Marking by pen		
30		Deburring on one side (50sec)		
35				
40				
45				
50				
55				
60				
65				
70				
75				
0	Door open	Door Open + Taking component out	Deburring on other side + putting into cover (78 sec)	
5		Spraying the compressed air		
10	Machine Running	Pushing button to close door + Remove gates by hand/cutter/ Inspection		
15				
20		Emery polishing		
25		Marking by pen		
30		Deburring on one side		
35				
40				
45				
50				
55				
60				
65				
70				
75				

Figure 5.3 (a): Activity chart for manufacturing and deflashing of machine 'M1' parts

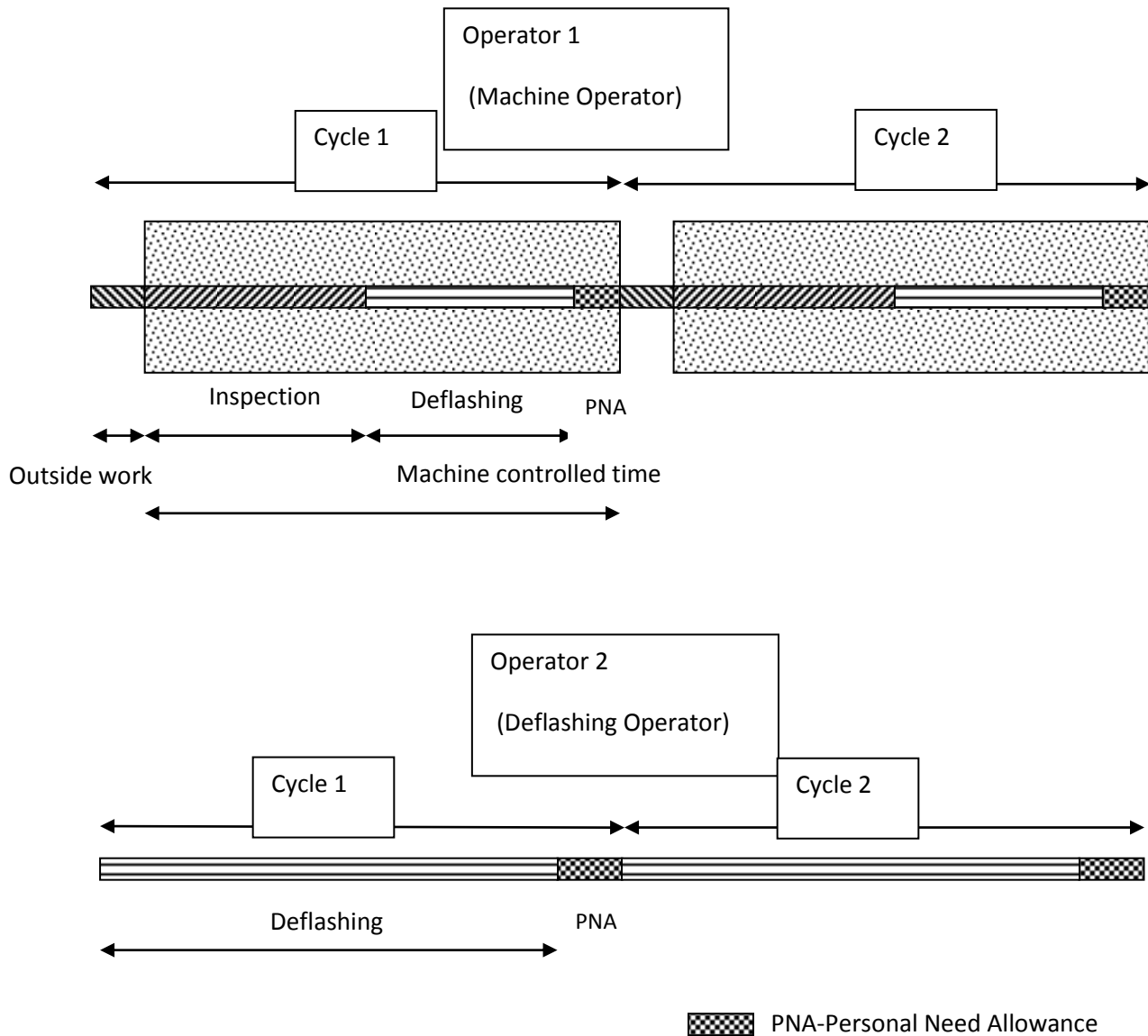


Figure 5.3 (b): Task Analysis for manufacturing and deflashing m/c 'M1' parts

Benefits Summarized:

- Combining the molding and deflashing operation reduces material handling.
- Saving of one manpower.
- Saving of an additional 10 secs in each cycle for wrapping by the machine operator in each cycle and unwrapping by the deflashing operator.
- Reduced handling will improve quality.
- Single piece flow also reduces rejections due to quick feedback.

5.1.2 Moulding Machine ‘M2’ – As Is Process

One operator has been deployed for this machine. The total cycle time is 64 seconds. This includes the machine running time as well as part unloading time. The operator performs the following tasks:

- Unloading of part
- Cleaning with compressed air
- Close door
- Remove gate by hand/cutter
- General Inspection and emery polishing
- Marking with pen
- Wrap in blue cloth cover
- Place in Tray

The operator is loaded for an average of 52 seconds in each machine cycle. The remaining time of 12 seconds is idle in each cycle. If molding and deburring are combined, it will save the operator 14 secs of wrapping in cloth and will also not require the deburring operator to unwrap saving him 8 secs. The ‘As-Is’ process is shown in Figure 5.4.

Machine ‘M2’ – Current Scenario

	M/C: M2	Part: 1002
Time	Machine	Machine Operator
0	Door Open	Door Open + Taking component out
5		Taking the compressed air nozzle
10		Spraying the compressed air
15	Machine Running	Closing the door
20		Visual inspection of the component
25		Remove gates by hand and throwing to bin
30		Cutting pinned part by cutter
35		Marking by pen + Placing it in paper (blue) packet
40		
45		
50		
55		
60		

Figure 5.4 (a): Activity chart for man machine of machine ‘M2’

Cycle Time Chart:

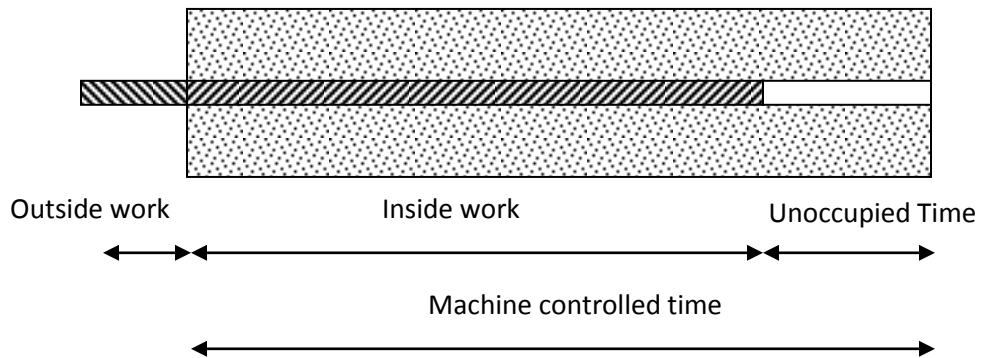


Figure 5.4 (b): Cycle time chart for man machine of machine ‘M2’

Like in machine ‘M1’ parts, the deflashing of these parts currently being done separately was also studied for cycle time. The observations for the deflashing of parts produced on machine ‘M2’ are given in Section 5.1.2.1.

5.1.2.1 Deflashing of Parts Made on Machine ‘M2’

M/C : ‘M2’		Part: 1002
	Deburring operator 1	
Time		
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		
60	Removing Cover+ Deburring+Putting into cover	
65		
70		
75		
80		
85		
90		
95		
100		
105		
110		
115		

Figure 5.5 (a): Activity chart for deflashing of parts made in machine ‘M2’

Cycle Time Chart:



Figure 5.5 (b): Cycle time chart for deflashing of parts made in machine ‘M2’

One operator takes 115 seconds to deflash one part produced on the 450T. Although the cycle time is relatively large compared to the machine cycle time, it would still be beneficial to see if the two processes can be combined to fill the idle time of the machine operator and also reduce the part handling which routinely cause rejections of up to 10%.

5.1.2.2 Machine ‘M2’ – To-Be Process (Proposed)

In the ‘To-be’ process, the deflashing station is proposed alongside the machine. However, there will be an accumulation as the total time for molding and deburring exceeds the cycle time of the machine by 15 secs, thus no manpower saving seems possible. The machine operator has an idle time of nearly 20 seconds per cycle. Such short period of unoccupied time can be used for recovery from fatigue. It is generally considered that any period of 30 seconds can be counted as available for relaxation. This idle time of the operator would thus be disregarded for cycle time improvement. Thus, to prevent accumulation of inventory at the machine in the event of deflashing station is moved next to the machine, two deflashing operators would be required at the machine. This would reduce unnecessary movement of parts from machine to the current deflashing station as well as also reduce handling. The machine operator, however, will wrap the part in the cloth bag after deflashing before it leaves the machine. The proposed method will require 1 (machine operator) + 2 (deflashing operator) manning.

Man Machine Chart:

	M/C: M2	COMPONENT: 1002				
Time	Machine	Machine Operator	Deburring Operator 1	Deburring Operator 2		
0	Door Open	Door Open + Taking Component Out	Deburring	Deburring		
5		Taking the compressed air nozzle				
10		Spraying the compressed air				
15	Machine Running	Closing the door				
20		Visual insp. Of the component				
25		Remove gates by hand and throwing to bin				
30		cutting pinned part by cutter				
35		Marking by pen				
40		Putting parts in cover				
45						
50						
55	Personal need allowance	PNA			PNA	
60						
0	Door Open	Door Open + Taking Component Out			Deburring	Deburring
5		Taking the compressed air nozzle				
10		Spraying the compressed air				
15	Machine Running	Closing the door				
20		Visual insp. Of the component				
25		Remove gates by hand and				

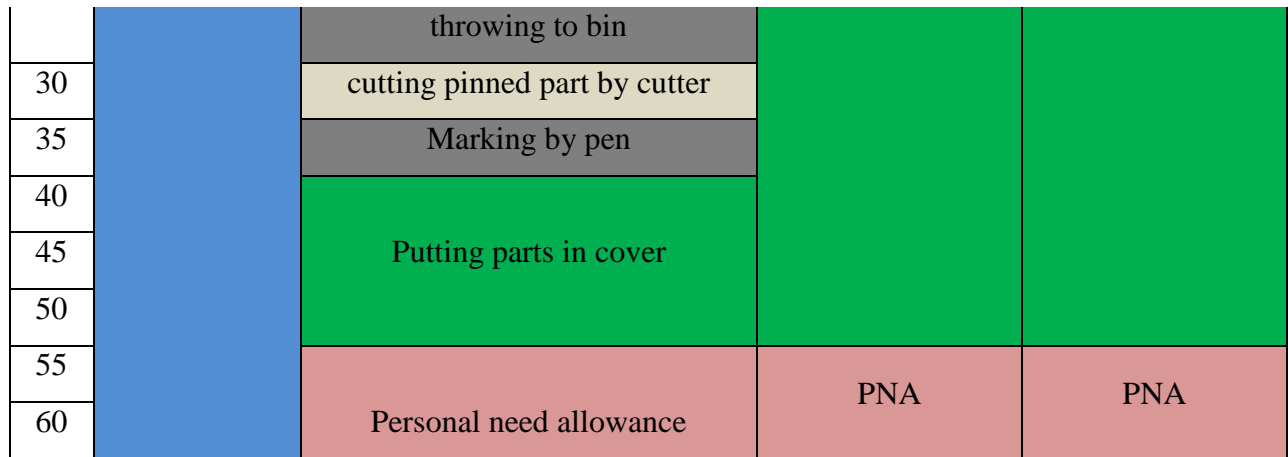


Figure 5.6 (a): Activity chart for parts manufacturing (on m/c 'M2') and deflashing
Cycle Time Chart:

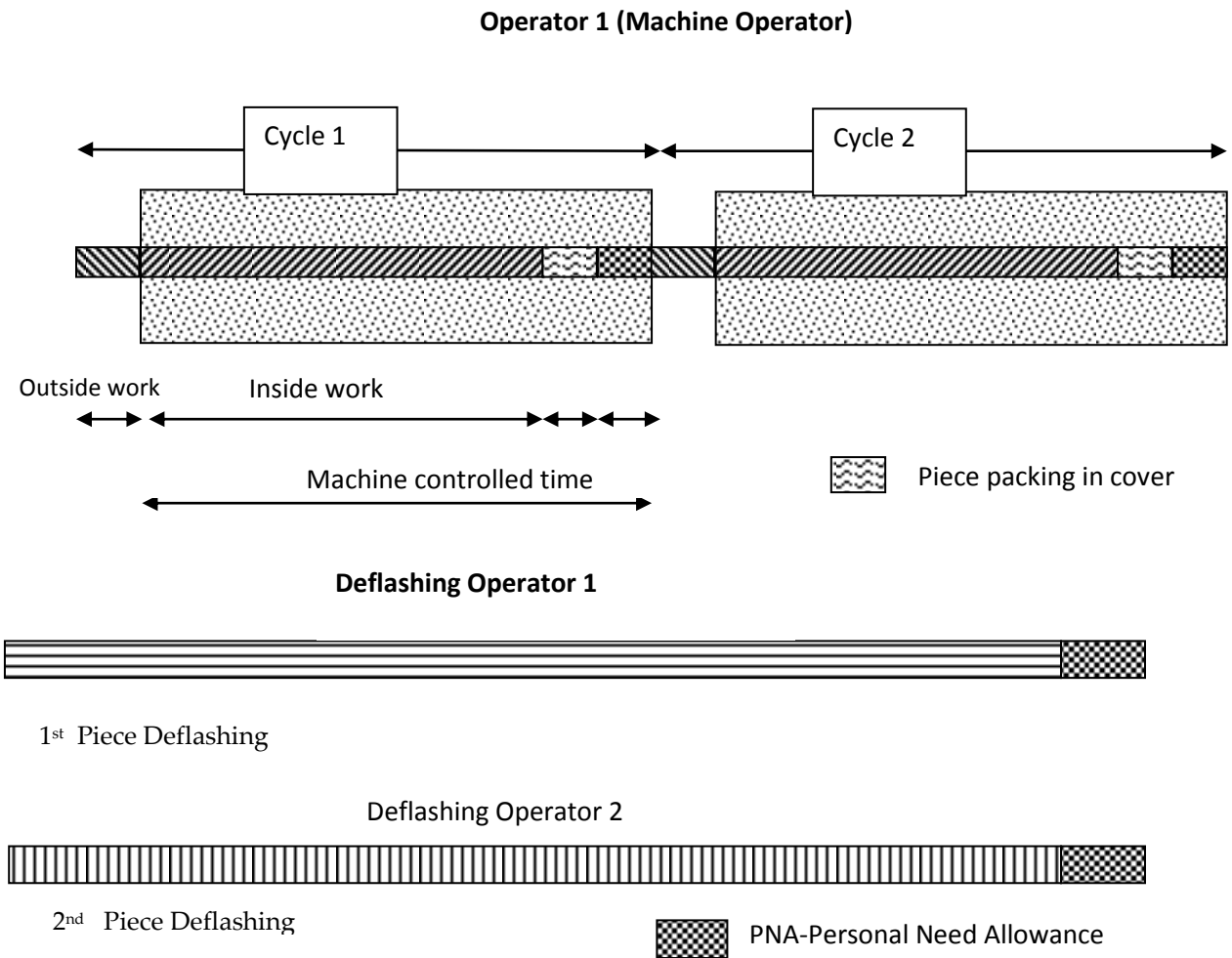


Figure 5.6 (b): Cycle time chart for parts manufacturing (on m/c 'M2') and deflashing

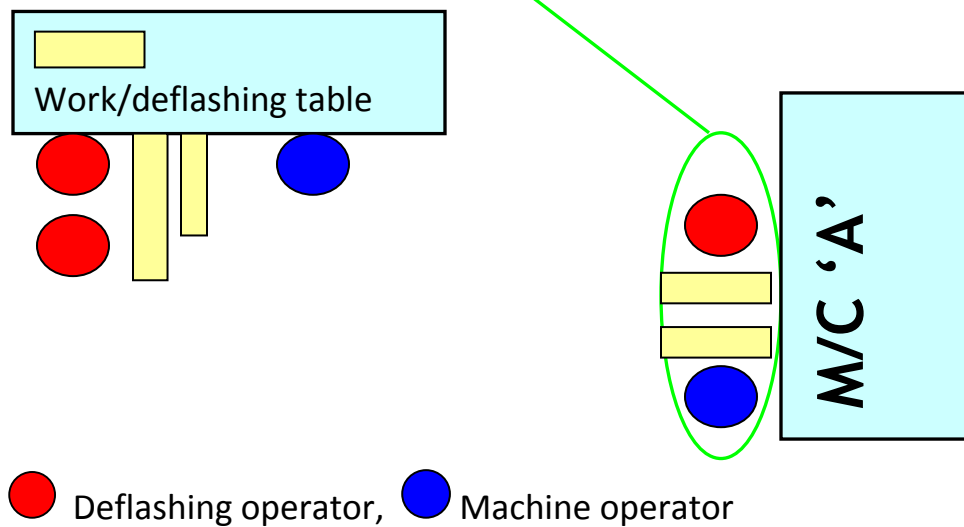
5.1.3 New Layout for Machine 'M1' and 'M2'

Existing Layout of M/C: 'M1'



Figure 5.7: Existing location/ layout of m/c 'A'

Proposed Layout of Machine 'M1' and 'M2'



● Deflashing operator, ● Machine operator

Figure 5.8: Proposed layout of Machine 'M1' and 'M2'

Benefits:

- Deburring on line will reduce unnecessary handling and prevent scratches and dents on surface.
- Will save additional 10 secs in each cycle for wrapping by the machine operator in each cycle and unwrapping by the deburring operator.
- Single piece flow help to reduce rejection.

5.1.4 Machine ‘M3’ – As Is Process

One operator has been deployed for this machine. The total cycle time is 45 seconds. This includes the machine running time as well as part unloading time. The operator performs the following jobs:

- Machine door opening
- Unloading of part
- Cleaning with compressed air
- Close door
- Remove gate by hand/cutter
- Putting it into individual packet

Machine: ‘M3’		
Time	Machine	Machine Operator
0	Door Open	Door Open + Taking component out
5	Machine running	Closing door + Remove gate by hand/separating component
10		Putting it into individual packet
15		
20		
25		
30		
35		
40		

Figure 5.9(a): Activity chart for man-machine of Machine ‘M3’

Cycle Time Chart:

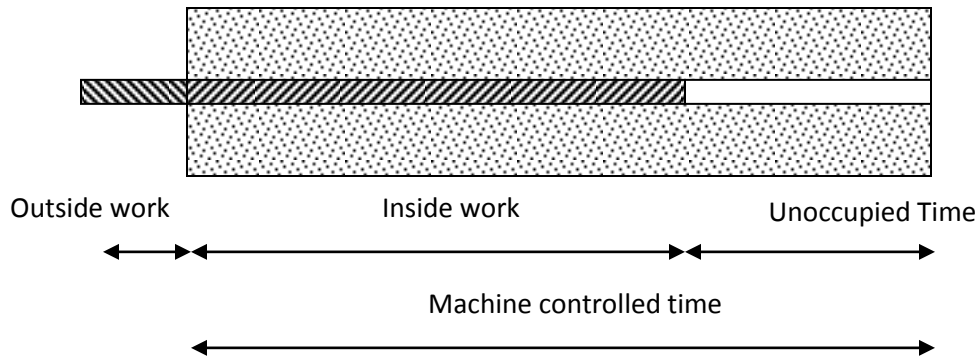


Figure 5.9(b): Cycle time chart for man-machine of m/c 'M3'

Like the other machines discussed above the operator has an idle time of 15 secs in each cycle. The deflashing is done in tandem by two operators at a separate station like in other cases. A review of the deflashing activity and its cycle time given in figure below shows that deflashing takes 15 secs when two operators do one side each. As discussed in earlier sections, the benefits of doing it on the production line are large and the company should consider doing it despite the fact that there is lack of adequate space in the molding section. A new layout of the molding shop is necessary to avoid cramped work space. The company may consider including the administrative space (a small room adjoining the molding section) in the molding section and move one of these machines into that area.

5.1.4.1 Deflashing of Parts Made on Machine 'M3'

M/C: M3		Part: 1003	
Deburring			
Time	operator 1	operator 2	
0	Deburring left part	Deburring Right Part	
5			
10			

Figure 5.9(c): Cycle time chart for man-machine for deflashing of m/c 'M3'

In the event the above recommendations are implemented, the revised man-machine chart with an additional deflashing operator is given below.

Time	Machine	Machine Operator	Deburring Operator	
0	Door Open	Door Open + Taking component out		
5	Machine running	Closing door + Remove gate by hand/separating component		
10		Deburring both left and right cover		
15				
20				
25				
30				
35		Putting left part in polyCovers		
40				
0		Door Open	Door Open + Taking component out	putting right part in poly cover
5		Machine running	Closing door + Remove gate by hand/separating component	
10	Deburring both left and right cover			
15				
20				
25				
30				
35	Putting into individual poly Covers			
40				

Figure 5.10: Activity chart for parts manufacturing (on m/c ‘M3’) and deflashing

Benefits to the company:

1. Reduced material handling
2. Reduced rejection due to scratches and dents
3. Improved utilization of machine operator time
4. Saving of one manpower

5.1.5 Other Molding Machines for Smaller Parts

The cycle time of parts made on these machines vary from part to part depending on size, complexity and material. The cycle time of some sample components manufactured on these machines is given in the Table 5.1.





Part No.	Cycle Time (Std.)	Work	Idle	
P-100	30 secs	28.5	1.5	
P-101	54 secs	34	20	
P-102	48 secs	39	9	
P-103	22 secs	16	6	

Table 5.1: Sample Cycle Time for Small Parts

The detailed break-up of cycle time for P-101 is as under:

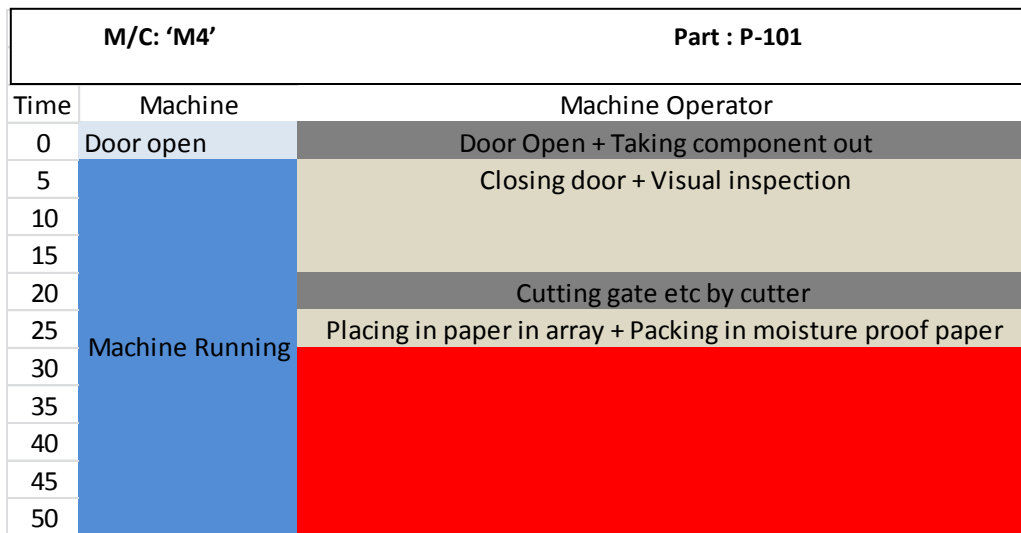


Figure 5.11: Activity chart for man-machine of P-101 parts on m/c 'M4'

Observations:

- Operator is idle for 24 secs in each cycle
- The operator cannot be used for any other work because of the existing layout which is cramped. The orientation of machines in the case of the smaller machines constraint the movement of the operators.

5.1.6 Improvement Proposal

In order to utilize the idle time of the operators (not for all types of parts) the molding machines may be re-oriented as shown to enable the operator to run two machines simultaneously. For this to happen, the unloading must run on auto-cycle mode and the unloading of parts need to be automated. The machine has a provision for the part to drop after molding. For collecting the parts, a bin filled with lukewarm water may be placed at the floor level. The individual parts may be allowed to drop into the bin filled with water to prevent damages caused by part to part contact. The parts will settle at the bottom of the water bin and can be collected as a batch of 30 nos for gate cutting or removal. The operator will operate two machines simultaneously and utilize his time alternatively for handling parts on two machines located as shown in figure below.

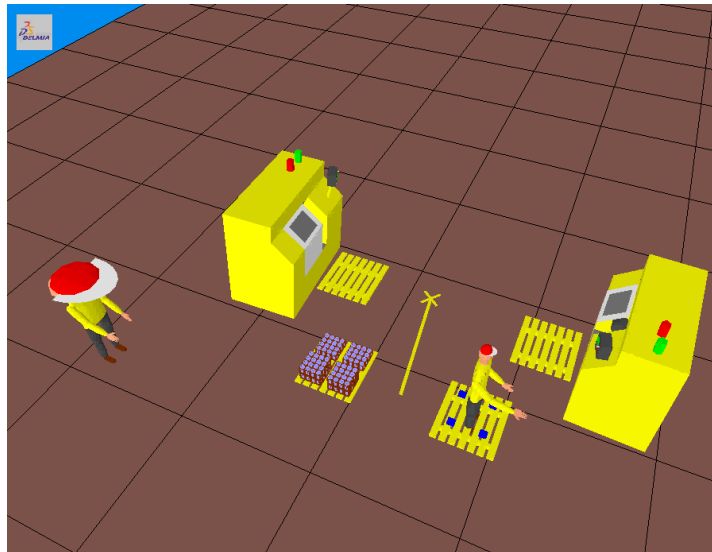


Figure 5.12: Schematic representation of simultaneous attending two small moulding machines

5.1.7 Set-up Time Reduction

The setup time study on small machines was carried out on all machines. The set up activity was broken into smaller sub-activities. These activities were then identified as internal or external. The average time taken is about 45 mins to 60 mins. The emphasis of the study has been to reduce the internal time so as to reduce the setup time.

Sr no	Time	Activity	
1.	7:55	Searching for Required Mould.	
2.	7:58	Screwing I Bolts.	
3.	8:03	Finding endless chain(String to lift)	
4.	8:04	Close the Pressure Hydraulic valves	
5.	8:05	Fixing the chain in I bolts of Mold to be removed	
6.	8:06	Operate OH Crain	
7.	8:07	Adjust the OH Crain position	
8.	8:08	Lift the mold	
9.	8:09	Remove clamping bolts	
10.	8:10	Adjust and open the mold(m/c)	
11.	8:11	Lift mould with the help of OH Crain	
12.	8:12	Move the mould to the rack	
13.	8:13		
14.	8:14	Removing chain and go to new mould	
15.	8:15	Removing eye bolts from old mould and Screwing eye bolts to new mould	
16.	8:16	Lift the mould with the help of OH Crain	
17.	8:17	Travel the OH Crain to the molding machine	
18.	8:18	Placing mould in the machine	
19.	8:19	Adjusting the mould placement in jaws	
20.	8:20	Aligning the mould(injection hole)	
21.	8:21		
22.	8:22	Adjusting the injection nozzle position in the mould	
23.	8:23	Re-adjusting	
24.	8:24	Adjusting the injection hole centering by hit and trail method	
25.	8:25	Tightening the front clamping nut bolts	
26.	8:26		
27.	8:27	Tightening the back clamping nut bolts	
28.	8:28		
29.	8:29		
30.	8:30	Screwing the water coolant pipes and Open pressure valves	
31.	8:31	Adjusting stroke length	
32.	8:32	Checking mould operation	
33.	8:33	Adjust the extrusion length (material to be injected)	
34.	8:34		
35.	8:35		
36.	8:36		
37.	8:46	First piece out put	

Table 5.2: Cycle Time for the activities during setup (mould) changing

5.1.7.1 Setup time study for Part-1001 Die

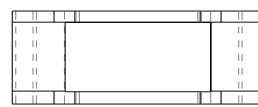
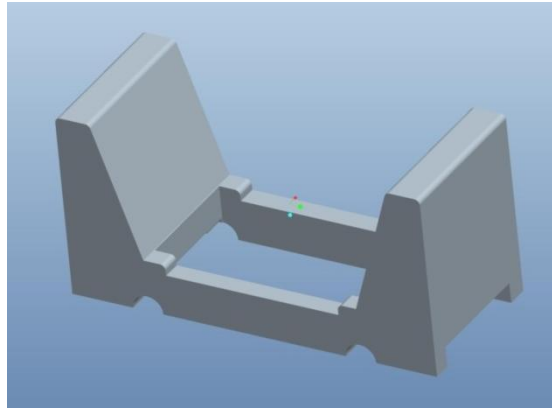
Sr no	Time	Activity
1.	9:44	Stop the Mouding machine.
2.	9:45	Operate OH Crain
3.	9:46	Adjust the OH Crain position and Lift the mold small amount
4.	9:47	Un screwing clamping nuts.
5.	9:48	Open the cooling water pipes
6.	9:49	Open extractor bolts
7.	9:50	
8.	9:51	Finding endless chain(String to lift) and Fixing in the eye bolts of Mold to be removed
9.	9:52	Operate OH Crain to lift mould
10.	9:53	Unscrew front clamping bolts
11.	9:54	Unscrew backside clamping bolts
12.	9:55	
13.	9:56	Removing two clamping bolts
14.	9:57	Removing another two clamping bolts
15.	9:58	Lifting mould with the help of OH Crain
16.	9:59	
17.	10:00	
18.	10:01	Move the mould to the rack
19.	10:02	Loose the chain bolt
20.	10:03	Removing chain and go to new mould
21.	10:04	Removing eye bolts from old mould and Screwing eye bolts to new mould
22.	10:05	Tight the chain bolt
23.	10:06	
24.	10:07	Operate OH Crain
25.	10:08	Lift the mould
26.	10:09	Travel the OH Crain to the molding machine
27.	10:10	Cleaning the mould extrusion hole
28.	10:11	Placing mould in the machine jaws
29.	10:12	Aligning the mould by hit and trail method
30.	10:13	Operate machine jaws
31.	10:14	Mould setup on the machine panel
32.	10:15	Feeding the values by hit and trail
33.	10:16	
34.	10:17	Call the other operator for setting parameter
35.	10:18	
36.	10:19	Remove old ejector pin and place new pin
37.	10:20	Adjusting the height of the mould to align the extrusion hole to extrusion nozzle

10:21		
10:22		
10:23		
10:24	Tightening the front clamping nut bolts	
10:25	Pressing T-bolts in the slot (Slot may be very tight)	
10:26		
10:27	Tightening the back clamping nut bolts	
10:28		
10:29		
10:30		
10:31		
10:32		
10:33	Screwing the water coolant pipes	
10:34		
10:35	Loose the OH Crain and remove the chain from eye bolts	
10:36	Operate OH Crain and move to the safe side	
10:37	Setting the data on the machine	Data Sheet according to mold should be made available
10:38		
10:39		
10:40		
10:41		
10:42	Problem in the mould	
10:43		
10:44		
10:45		
10:46	Problem find (one eye bolt is fallen in the mould)	
10:47	Try to remove the bolt from mould	
10:48		
10:49		
10:51		
10:52		
10:53		
10:54		
10:55		
10:56		
10:57	The injection is not fill the mould	
10:58		
10:59		
11:00		
11:01		
11:02	Plan to change new mould	

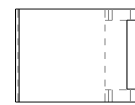
Table 5.3: Cycle Time for the activities during setup (mould) changing of Part-1001

Set-up time Reduction

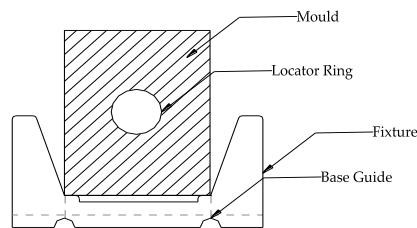
- 1) Design Jig for mold alignment will save 7 mins



Top View



Side View



Front View

Figure 5.13: Proposed jig design for quicker mould changing (low setup time)

To reduce the setup time for mould change operation a mould guide can be developed for quick alignment of locator ring with the hole in the machine jaw (injecting hole). The guide is to be placed on the bed of the machine and thereafter the mould can be aligned directly on the guide as shown in figure above which locates the locator ring to the injector hole in the machine automatically. The manual adjustment by this method will not be necessary and would save up to 7 minutes.

- 2) Data sheet for the machine to be made available to the operator – will save up to 5 mins
- 3) I-Bolt on each mold for handling

5.1.8 Proposed Layout of Moulding Shop

The proposed layout of the moulding shop incorporating the amendments discussed in previous sections of this unit is given below. The proposed layout is expected to reduce material handling, eliminate un-necessary movements of operators and parts and facilitate running of multiple machines by one or a group of operators. The proposed layout will de-cramp the space and also includes space for deflashing operators who are expected to work online resulting in a single piece flow to the plating section.

Existing & Proposed Layout

MOULDING SHOP

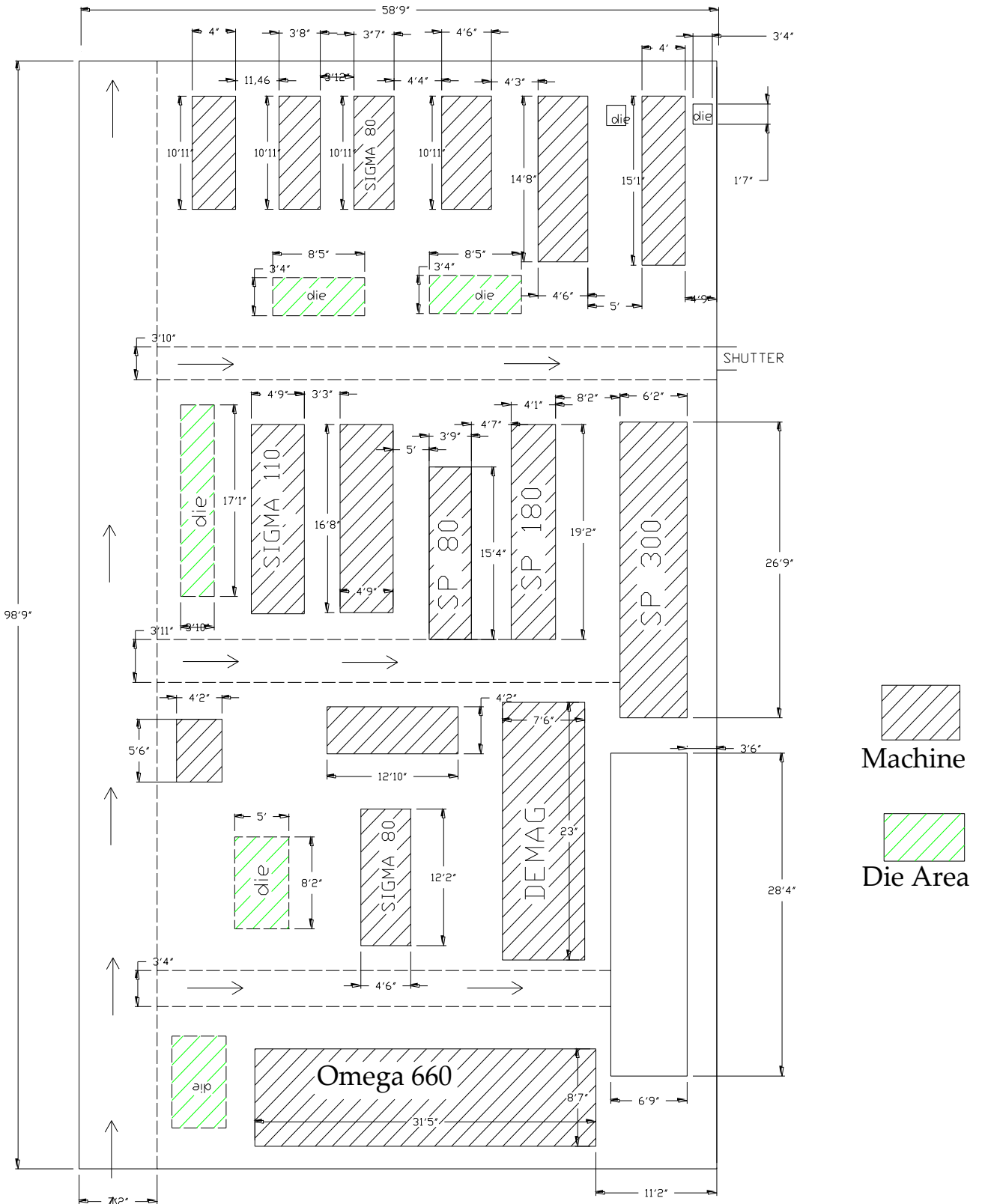


Figure 5.14(a): Existing Layout of the Moulding Shop

MOULDING SHOP

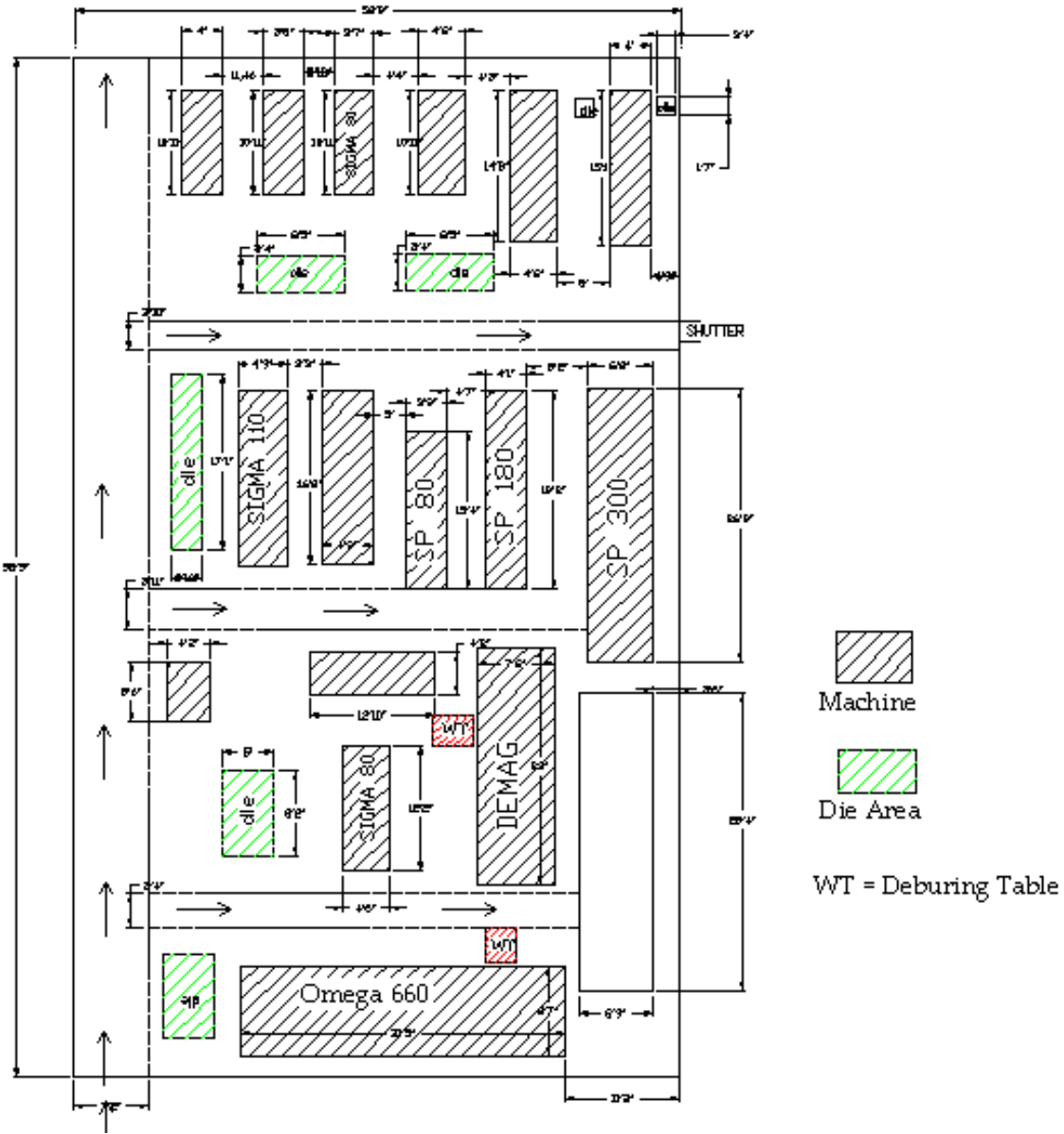


Figure 5.14(b): Proposed Layout of the Moulding Shop

5.1.9 Manpower Deployment at the Moulding Station

Deployment per shift – Permanent Manpower

Sub Area (Machine No.)	Actual Deployment per day	Proposed Deployment after implementation of recommendations at the machine		Remarks
		Machine	Deflashing	
A	1 in each shift = 3	1 in each shift = 3	1 in each shift = 3	Deflashing online
B	1 in each shift = 3	1 in each shift = 3	2 in each shift = 6	Deflashing online
C	1 in each shift = 3	1 in each shift = 3	2 in each shift = 6	Deflashing online
D	1 in each shift = 3	1 in each shift = 3	-	-
E	1 in each shift = 3	1 in each shift = 3	-	-
F	1 in each shift = 3	1 in each shift = 3	-	-
G	1 in each shift = 3	1 in each shift = 3	-	-
H	1 in each shift = 3	1 in each shift = 3	-	-
I	1 in each shift = 3	1 in each shift = 3	-	After reorientation the machine
J	1 in each shift = 3			
K	1 in each shift = 3	1 in each shift = 3	-	After reorientation the machine
L	1 in each shift = 3			
M	1 in each shift = 3	1 in each shift = 3	-	After reorientation the machine
N	1 in each shift = 3			
O	1 in each shift = 3	1 in each shift = 3	-	After reorientation the machine
P	1 in each shift = 3			
Q	1 in each shift = 3	1 in each shift = 3	-	After reorientation the machine
R	1 in each shift = 3			
S	1 in each shift = 3	1 in each shift = 3	-	-
Total	57	42	15	

Total manpower saving = 15

Table 5.4: Manpower deployment (present and proposed) for the moulding shop

6.1 INTRODUCTION

Gauge Repeatability and Reproducibility (GR&R) is used to measure capability of a measurement system by comparing it to the total variability. Repeatability is the variability of the measurements obtained by one person while measuring the same item repeatedly and is also referred to as equipment variation. Reproducibility is the variability of the measurement system caused by differences in operator skills. The commonly used method for calculating GR&R is the Range and Average method [29].

Here OEE matrices are used to assess the capability of a process by using the Range and Average method typically used for GR&R calculations. The current method used for measuring the process capability, like C_p/C_{pk} , lays large emphasis on the quality of the output (variation) when it is compared to the specification limits provided by the customer. This method does not include some vital process conditions such as downtime losses, adjustment times and setup parts, operator skill, part complexity and is focused completely on the output quality. As explained above, OEE data for a machine includes some of this information and if the two matrices are combined, it will result in broader definition of capability rather than just the ability to meet the specifications. The OEE data of the machine for a consecutive period of 8 weeks was used to assess the capability of the process consisting of the man, machine, method, material, measurement system and the environment. Three cases studies were completed at a plastic emblems manufacturing facility using large injection molding machines. The OEE data for consecutive 8 weeks was collected and analyzed for assessing the process capability.

6.2 METHODOLOGY

Although experimenting in a real manufacturing environment on the shop floor is expensive and time consuming, it is still the most effective and desirable way to understand a manufacturing system. In the present study, the OEE data of critical machines has been used to understand the capability of a process. The current methods to assess capability of a process, such as C_p/C_{pk} , do not provide the complete picture of a manufacturing process. The focus in a capability analysis is solely on measuring and reducing variation which works well as a quick assessment tool and does not provide a glimpse of the process performance over the long run. OEE measurements

have wider ramifications as it includes data related to all losses and not just the losses due to quality. The study was carried out in a leading Indian company manufacturing plated plastic molded emblems. The company is supported by in-house design and development facilities like modern tool room for manufacturing of moulds, dies, jigs and fixtures, and design facility is supported with leading modeling software. The study was carried out in the molding section housing 15 large to medium sized plastic injection molding machines. The process on these machines is highly automated and is operated by skilled workers under qualified and controlled process conditions. The precise details of the molding section are proprietary information of the company.

A conceptual OEE measurement methodology was developed using standard MS Excel® sheet using the indices reported in the literature. The data was collected from each machine in the manufacturing facility on a daily basis consecutively for a period of three months.

6.3 PROPOSED METHOD FOR CAPABILITY ASSESSMENT

The OEE data from each machine was calculated for each working, each part and each operator separately. The machines run 24 hours, three operators worked on these machines rotating in three shifts. Since the OEE data was available for three different operators making the same part for a significantly longer duration of time, the assessment of their performance and capability was the next step. One of the potential outcomes of this study was to study the effect of three different operators, who are all skilled and have been running the machines for a long duration of time, on the process capability. The Average and Range method for assessing the GR&R was used to complete the capability assessment of the process. The Average and Range method for GR&R is used to determine the equipment and the appraiser variation and the same has been used in this study to evaluate the process capability using the OEE data. This method allows the process to be decomposed into two separate components, equipment and the operator variation.

6.4 CONDUCTING THE STUDY

The operators in these studies have been referred to as A, B and C who work on an Injection Molding Machine 'M1' to produce Part 1001. Each of the three operators routinely work on this machine to make Part I. The OEE data for each of the three operators was calculated for each working day of the month for this part. The OEE data for one week (same week for each operator) was recorded on the observation sheet shown in Figure 6.1 for the first month for each

operator. Similar one week data for each operator for the next two months was also recorded in Table 6.1. The calculations for equipment and operator variation are shown in Table 6.1.

6.4.1 Equipment and Operator Variation - Calculations

The range of variation for the OEE data for each operator for the OEE data of three weeks was calculated by subtracting the largest OEE from the smallest and recorded at the appropriate column in Figure 2. The average range, R_A , R_B , and R_C for each operator was calculated by dividing the sum of all ranges by the number of range values. The average of the three mean ranges for the three operators was designated as R_{mean} . The R_{mean} value is indicative of the equipment variation which is calculated by equation 6.1.

$$Equipment\ Variation(EV) = \bar{R} \times K_1 \quad \dots\dots\dots eq. (6.1)$$

Where K_1 is a constant that depends upon the number of trials used in this study.

The mean OEE for each operator was calculated by averaging the OEE for each day and then dividing the sum by the number of repetitions in each month. The range of the difference in the means, designated as X_{mean} for the three operators was calculated by subtracting the maximum mean OEE from the minimum OEE. The X_{mean} is a measure of the variations due to differences in the skill level of the operators. The operator variation is then given by equation 6.2.

$$OV = \{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2} \quad \dots\dots\dots eq. (6.2)$$

Where n is no. of pieces, r is no. of repetitions and K_2 is a constant that depends upon the number of appraisers used in this study.

The combined effect of the two variations is given by equation 6.3.

Equipment and Operator Variation (EOV)

$$E \ \& \ O = \{(EV^2 + AV^2)\}^{1/2} \quad \dots\dots\dots eq. (6.3)$$

Then we calculate the OEE Variation (OEEV) which is given by equation 6.4

$$OEEV = R_p \times K_3 \quad \dots\dots\dots eq. (6.4)$$

LSL for OEE is 90%. This is the Acceptable OEE (AOEE).

So now we can calculate the percentage of each of the variation.

$$\% \text{ EV} = 100 (\text{EV/A OEE})$$

$$\% \text{ OV} = 100 (\text{OV/A OEE})$$

$$\% \text{ E \& O Variation} = 100 (\text{E\&O/AOEE})$$

$$\% \text{ OEEV} = 100 (\text{OEEV/AOEE})$$

Similarly OEE data of the different machines recorded and calculate the repeatability of the machine and reproducibility of the different operator. GR&R calculation for some of the machines are given in table 6.1 to table 6.4 and for other machines given in appendix.

M/C: M1				Gage Name			Appraiser A: OP1		
NUMBER									
Part Name:1001				Gage Number			Appraiser B: OP2		
NAME									
Characteristic/Specification				Gage Type			Appraiser C: OP3		
Characteristic Classification				Trials	Parts	Operator	Date Performed		
				3	6	3			

APPRAISER/	PART										AVERAGE
TRIAL #	1	2	3	4	5	6	7	8	9	10	
1. A	1	91.74	91.74	93.27	92.66	91.74	91.74				92.148
2.	2	90.21	93.27	92.42	93.88	95.41	91.74				92.822
3.	3	88.68	88.68	88.68	91.74	85.62	82.56				87.660
4.	AVE	90.21	91.23	91.46	92.76	90.92	88.68				$\bar{X}_a =$ 90.877
5.	R	3.06	4.59	4.59	2.14	9.79	9.18				$\bar{R}_a =$ 5.558
6. B	1	90.79	91.74	91.74	91.74	93.75	92.66				92.070
7.	2	94.8	93.88	94.8	92.35	92.96	91.74				93.422
8.	3	93.57	93.88	93.27	90.21	91.74	86.23				91.483
9.	AVE	93.05	93.17	93.27	91.43	92.82	90.21				$\bar{X}_b =$ 92.325
10.	R	4.01	2.14	3.06	2.14	2.01	6.43				$\bar{R}_b =$ 3.298
11. C	1	92.81	92.66	92.96	92.35	93.27	94.18				93.038
12.	2	92.66	91.74	92.66	92.66	93.46	88.68				91.977
13.	3	93.57	92.66	88.07	92.96	85.62	85.62				89.750
14.	AVE	93.01	92.35	91.23	92.66	90.78	89.49				$\bar{X}_c =$ 91.588
15.	R	0.91	0.92	4.89	0.61	7.84	8.56				$\bar{R}_c =$ 3.955
16. PART											$\bar{X} =$ 91.597
AVE (\bar{X}_p)		92.09	92.25	91.99	92.28	91.51	89.46				$R_p =$ 2.822
17.											$\bar{R} =$ 4.271
18.											$\bar{X}_{DIFF} =$ 1.448
19.											UCL _R = 11.018
20.											LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Equipment Variation(EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	4.271 x 3.05		2	4.56		=	14.47244
	=	13.025		3	3.05			
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(1.448 \times 2.7)^2 - (13.025^2/(6 \times 3))\}^{1/2}$					=	2.691111
	=	2.422		Appraisers	2			
				K₂	3.65			
					3			
Equipment and Operator (E & O) Variation								n = number of parts
								r = number of trials
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(13.025^2 + 2.422^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	13.248		3	2.70		=	14.72051
OEE Variation (OEEV)								
OEEV	=	$R_p \times K_3$		4	2.30		=	
	=	2.822 x 1.93		5	2.08			
	=	5.447		6	1.93	% OEEV	=	100 (OEEV/AOEE)
				7	1.82		=	6.052099
Acceptable OEE(AOEE)=								
	=	90 % Minimum		8	1.74			
				9	1.67			
				10	1.62			

Table 6.1: EOV Calculation for Machine ‘M1’ [30]

M/C: M2	Gage Name	Appraiser A: OP1		
NUMBER	Gage Number	Appraiser B: OP2		
Part Name: 1002	Gage Type	Appraiser C: OP3		
NAME				
Characteristic/Specification				
Characteristic Classification	Trials 3	Parts 6	Operator 3	Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	89.14	88.57	88.57	83.42	86.11	89.14					87.492
2.	2	97.14	95.83	98.57	93.88	91.66	95.27					95.392
3.	3	96.07	94.44	95.55	93.05	93.05	93.05					94.202
4.	AVE	94.12	92.95	94.23	90.12	90.27	92.49					$\bar{X}_a =$ 92.362
5.	R	8.00	7.26	10.00	10.46	6.94	6.13					$\bar{R}_a =$ 8.132
6. B	1	89.14	86.39	86.11	88.85	85.71	82.85					86.508
7.	2	96.85	93.61	95.56	93.88	91.94	92.22					94.010
8.	3	93.89	93.33	92.22	85.55	86.27	88.76					90.003
9.	AVE	93.29	91.11	91.30	89.43	87.97	87.94					$\bar{X}_b =$ 90.174
10.	R	7.71	7.22	9.45	8.33	6.23	9.37					$\bar{R}_b =$ 8.052
11. C	1	91.42	90.57	90.57	91.42	91.42	90.57					90.995
12.	2	95.42	95.42	93.33	94.70	92.77	91.94					93.930
13.	3	94.44	96.91	93.61	94.44	94.44	94.44					94.713
14.	AVE	93.76	94.30	92.50	93.52	92.88	92.32					$\bar{X}_c =$ 93.213
15.	R	4.00	6.34	3.04	3.28	3.02	3.87					$\bar{R}_c =$ 3.925
16. PART												$\bar{X} =$ 91.916
AVE (\bar{X}_p)		93.72	92.79	92.68	91.02	90.37	90.92					$R_p =$ 3.349
17.												$\bar{R} =$ 6.703
18.												$\bar{X}_{DIFF} =$ 3.039
19.												$\bar{R} \times D_4^* =$ 17.293
20.												$\bar{R} \times D_3^* =$ 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Equipment Variation(EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	6.703 x 3.05		2	4.56		=	22.71497
	=	20.443		3	3.05			
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(3.039 \times 2.7)^2 - (20.443^2/(6 \times 3))\}^{1/2}$					=	6.355556
	=	5.720		Appraisers	2			
				K₂	3.65			
					3	n = number of parts		
Equipment and Operator (E & O) Variation							r = number of trials	
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(20.443^2 + 5.720^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	21.229		3	2.70		=	23.58735
OEE Variation (OEEV)					4	2.30		=
OEEV	=	$R_p \times K_3$		5	2.08			
	=	3.349 x 1.93		6	1.93	% OEEV	=	100 (OEEV/AOEE)
	=	6.463		7	1.82		=	7.181506
Acceptable OEE(AOEE)=					8	1.74		
	=	90 % Minimum		9	1.67			
				10	1.62			

Table 6.2: EOV Calculation for Machine ‘M2’

M/C: M3				Gage Name			Appraiser A: OP1		
NUMBER									
Part Name:1003				Gage Number			Appraiser B: OP2		
NAME									
Characteristic/Specification				Gage Type			Appraiser C: OP3		
Characteristic Classification				Trials	Parts	Operator	Date Performed		
				3	6	3			

APPRAISER/ TRIAL #	PART										AVERAGE
	1	2	3	4	5	6	7	8	9	10	
1. A	1	91.42	91.42	91.42	91.42	84.21	84.39				89.047
2.	2	84.21	84.21	84.21	90.16	74.21	70.17				81.195
3.	3	87.72	84.21	84.21	84.21	84.21	84.21				84.795
4.	AVE	87.78	86.61	86.61	88.60	80.88	79.59				$\bar{X}_a =$ 85.012
5.	R	7.21	7.21	7.21	7.21	10.00	14.22				$\bar{R}_a =$ 8.843
6. B	1	91.42	91.42	91.42	91.42	81.57	76.19				87.240
7.	2	84.73	84.21	75	85.52	73.68	72.18				79.220
8.	3	86.05	86.05	85.52	85.52	85.52	85.52				85.697
9.	AVE	87.40	87.23	83.98	87.49	80.26	77.96				$\bar{X}_b =$ 84.052
10.	R	6.69	7.21	16.42	5.90	11.84	13.34				$\bar{R}_b =$ 10.233
11. C	1	91.42	91.42	90.16	85.71	84.21	84.21				87.855
12.	2	88.89	86.84	84.21	89.63	84.21	78.94				85.453
13.	3	84.21	84.21	84.21	84.21	78.94	78.94				82.453
14.	AVE	88.17	87.49	86.19	86.52	82.45	80.70				$\bar{X}_c =$ 85.254
15.	R	7.21	7.21	5.95	5.42	5.27	5.27				$\bar{R}_c =$ 6.055
16. PART											$\bar{X} =$ 84.773
AVE (\bar{X}_p)		87.79	87.11	85.60	87.53	81.20	79.42				$R_p =$ 8.369
17.											$\bar{R} =$ 8.377
18.											$\bar{X}_{DIFF} =$ 1.202
19.											$\bar{R} \times D_4^* =$ 21.571
20.											$\bar{R} \times D_3^* =$ 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Equipment Variation(EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	8.377 x 3.05		2	4.56		=	28.38948
	=	25.551		3	3.05			
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(1.202 \times 2.7)^2 - (25.551^2/(6 \times 3))\}^{1/2}$					=	5.633333
	=	5.070		Appraisers	2			
				K₂	3.65			
					3	n = number of parts		
Equipment and Operator (E & O) Variation							r = number of trials	
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(25.551^2 + 5.070^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	26.049		3	2.70		=	28.94299
OEE Variation (OEEV)								
OEEV	=	$R_p \times K_3$		4	2.30		=	
	=	8.369 x 1.93		5	2.08			
	=	16.152		6	1.93	% OEEV	=	100 (OEEV/AOEE)
				7	1.82		=	17.94662
Acceptable OEE(AOEE)=								
	=	90 % Minimum		8	1.74			
				9	1.67			
				10	1.62			

Table 6.3: EOV Calculation for Machine ‘M3’

M/C: M4		Gage Name		Appraiser A: OP1	
NUMBER					
Part Name:1004		Gage Number		Appraiser B: OP2	
NAME					
Characteristic/Specification		Gage Type		Appraiser C: OP3	
Characteristic Classification		Trials	Parts	Operator	Date Performed
		3	6	3	

APPRAISER/	PART										AVERAGE
TRIAL #	1	2	3	4	5	6	7	8	9	10	
1. A	1	86.87	86.65	86.25	86.25	86.25	86.25				86.420
2.	2	98.82	94.12	94.12	94.12	82.35	97.64				93.528
3.	3	80.00	75.00	74.37	75.00	75.00	75.00				75.728
4.	AVE	88.56	85.26	84.91	85.12	81.20	86.30				$\bar{X}_a =$ 85.226
5.	R	18.82	19.12	19.75	19.12	11.25	22.64				$\bar{R}_a =$ 18.450
6. B	1	86.66	87.5	87.5	87.5	86.25	86.25				86.943
7.	2	95	90	94.11	94.11	84.7	96				92.320
8.	3	80	76.92	76.25	75	75	75				76.362
9.	AVE	87.22	84.81	85.95	85.54	81.98	85.75				$\bar{X}_b =$ 85.208
10.	R	15.00	13.08	17.86	19.11	11.25	21.00				$\bar{R}_b =$ 16.217
11. C	1	86.87	87.5	86.87	86.87	86.56	86.25				86.820
12.	2	98.82	94.11	94.11	90.7	84.7	97.64				93.347
13.	3	78.61	74.37	75	73.75	75	80				76.122
14.	AVE	88.10	85.33	85.33	83.77	82.09	87.96				$\bar{X}_c =$ 85.429
15.	R	20.21	19.74	19.11	16.95	11.56	17.64				$\bar{R}_c =$ 17.535
16. OEE											$\bar{X} =$ 85.288
AVE (\bar{X}_p)		87.96	85.13	85.40	84.81	81.76	86.67				$R_p =$ 6.204
17.		$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$									$\bar{R} =$ 17.401
18.		$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$									$\bar{X}_{DIFF} =$ 0.221
19.		$\bar{R} \times D_4^* =$									UCL _R = 44.893
20.		$\bar{R} \times D_3^* =$									LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)		
Equipment Variation(EV)							
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	= 100 (EV/A OEE)
	=	17.401 x 3.05		2	4.56		= 58.96855
	=	53.072		3	3.05		
Operator Variation (OV)							
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	= 100 (OV/A OEE)
	=	$\{(0.221 \times 2.7)^2 - (53.072^2/(6 \times 3))\}^{1/2}$					= 14.23778
	=	12.814	Appraisers	2	3		
			K₂	3.65	2.70	n = number of parts	
Equipment and Operator (E & O) Variation							r = number of trials
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃		
	=	$\{(53.072^2 + 12.814^2)\}^{1/2}$		2	3.65	% EOV	= 100 (E&O/AOEE)
	=	54.597		3	2.70		= 60.66304
OEE Variation (OEEV)							
OEEV	=	$R_p \times K_3$		4	2.30		
	=	6.204 x 1.93		5	2.08		
	=	11.975		6	1.93	% OEEV	= 100 (OEEV/AOEE)
Acceptable OEE(AOEE)=							
	=	90 % Minimum		7	1.82		= 13.30509
				8	1.74		
				9	1.67		
				10	1.62		

Table 6.4: EOV Calculation for Machine ‘M4’

6.5 COMPARISON OF CAPABILITY INDEX AND EOV VALUE

To find the value of C_p and C_{pk} thirty pieces on each machine are checked. Table 6.5 shows the result of Gauge R&R and C_p and C_{pk} value.

M/C No.	Equipment Variation (%)	Operator Variation (%)	EOV/Combined Variation (%)	C_p Value	C_{pk} Value
M1	14.47	2.69	14.72	1.28	1.22
M2	22.71	6.35	23.58	0.86	0.78
M3	28.38	5.63	28.94	0.97	0.90
M4	58.96	14.23	60.66	0.63	0.58
M5	14.41	0.5	14.4	0.86	0.81
M6	19.3	9.2	21.4	1.13	0.98
M7	20.4	5.0	21.0	0.98	0.91
M8	17.6	2.6	17.7	1.05	0.95
M9	21.7	2.6	21.8	1.13	1.08

Table 6.5: Combined Variation and C_p and C_{pk} Values

6.6 INTERPRETING THE RESULTS

Combined Variation :

- Combined Variation of less than 20% - Measurement/Manufacturing facilities System Acceptable
- Combined Variation 20% to 30% - Measurement/Manufacturing facilities System May Be Acceptable. Make your decision based on the classification of characteristics, operator training issues, hardware application, part-to-part variation, customer input, realistic tolerancing, etc. Do not automatically assume that a new measurement system is needed.

- Combined Variation over 30% - Measurement/Manufacturing facilities System Unacceptable. Find the problem and remove the root cause. Evaluate other measurement systems after attempting to correct the current system [31].

6.7 RESULTS

It was found that in moulding machine M4 the value of combined variation is more than 30% so this machine is unacceptable for long term production. Combined variation in machine M2,M3,M6 and M7 range inbetween 20% to 30% which is more than lower acceptable value. So there is need of improvement to reduce this variation. Combined Variation of machines M1, M5 and M8 are within the specified control limit.

From the above result it was concluded that capability index C_p/C_{pk} affects the value of combined variation. Values of C_p/C_{pk} reduce as the combined variation increase and value of C_p/C_{pk} increase as the combined variation reduce. This behavior in the trends of combined variation and C_p/C_{pk} indicates that there is a relationship between the OEE of a machine and its capability. As quality factor is used to calculate the OEE therefore if there is any improvement in the value of C_p/C_{pk} will reduce the combined variation.

As C_p/C_{pk} only measures the quality parameter of the process so capability assesment by using machine OEE with Gauge R&R is a reliable method.

7.1 RESULTS

OEE measurement is used since a long time to evaluate the performance of a machine and manufacturing line. OEE helps to detect the bottleneck areas of the machine and manufacturing lines. After knowing the bottleneck areas improvement activity can be done to improve the OEE. OEE study done in the moulding shop is to know about the performance of the individual machine. OEE study of different machines shows that there is a lot of variations in the performance of the different machine. Machine wise OEE analysis also shows that the major reason for low OEE is low performance of moulding machines. Availability and Quality rate also affect the OEE but major reason for low OEE is low performance of machines. When machine wise OEE analysis is done for a month some machines it also shows low availability of machines.

When OEE study is done for part against operator, it come in to picture that there is a lot of variation in OEE of different part even they are manufactured on same machine by same operator. OEE study of operator against part shows there is considerably different in between different operator OEE even they are manufacturing similar part on same machine.

To improve the productivity of the moulding shop Time and Motion study and Method study was done on the different machines. Many unnecessary activities was detected. Process study and material flow was also studied to improve the material flow and for the purpose of line balancing. It was observed that moulding machine operator had idle time which can be utilized for other work. So for full utilization of the moulding machine operator deflashing operation (for big machines parts only) was shifted to moulding machine saving one manpower. Similarly for small machines it was proposed to operate two moulding machines (with small improvement) by one operator so one man power can be saved. For all these improvement a new layout was proposed. And after implementation of new layout, new manpower deployment sheet was prepared which showed a saving of 15 personnel from the moulding and deflashing stations. All these activity of moulding machine and deflashing are shown in chapter 5.

Die changing time on moulding machines was very high so in an effort to reduce that setup time study was also done. Many activities were identified which can be simplified to reduce setup time . One jig was designed for mold alignment which will further save 7 mins.

Capability assessment of different moulding machines was done by using machine OEE data with Gauge R&R. Combined variations of machine and operator calculated which shows its relationship with the capability indices C_p/C_{pk} . Values of C_p/C_{pk} reduce as the combined variation increase and value of C_p/C_{pk} increase as the combined variation reduce. Because of some random cause of variations are present in the system there is not any linear relationship developed in-between combined variation and C_p/C_{pk} .

7.2 CONCLUSION

OEE is a very powerful tool which can be utilized as a productivity improvement. For small/medium scale industries (where technology used is not so high) can use OEE as a tool to find the hidden and bottleneck areas for improvement and can increase their profit. A systematic approach is necessary for better results.

Use of OEE data with Gauge R&R is a better option for the purpose of long term capability assessment of machine or manufacturing line. Capability indices consider only quality parameter of the machine. OEE data also includes availability of machines, performance of machines which is affected by man, part design complexity, material flow, environment etc. So to measure the capability of the machine by using OEE data gives us better picture of machine ability to perform for a longer period.

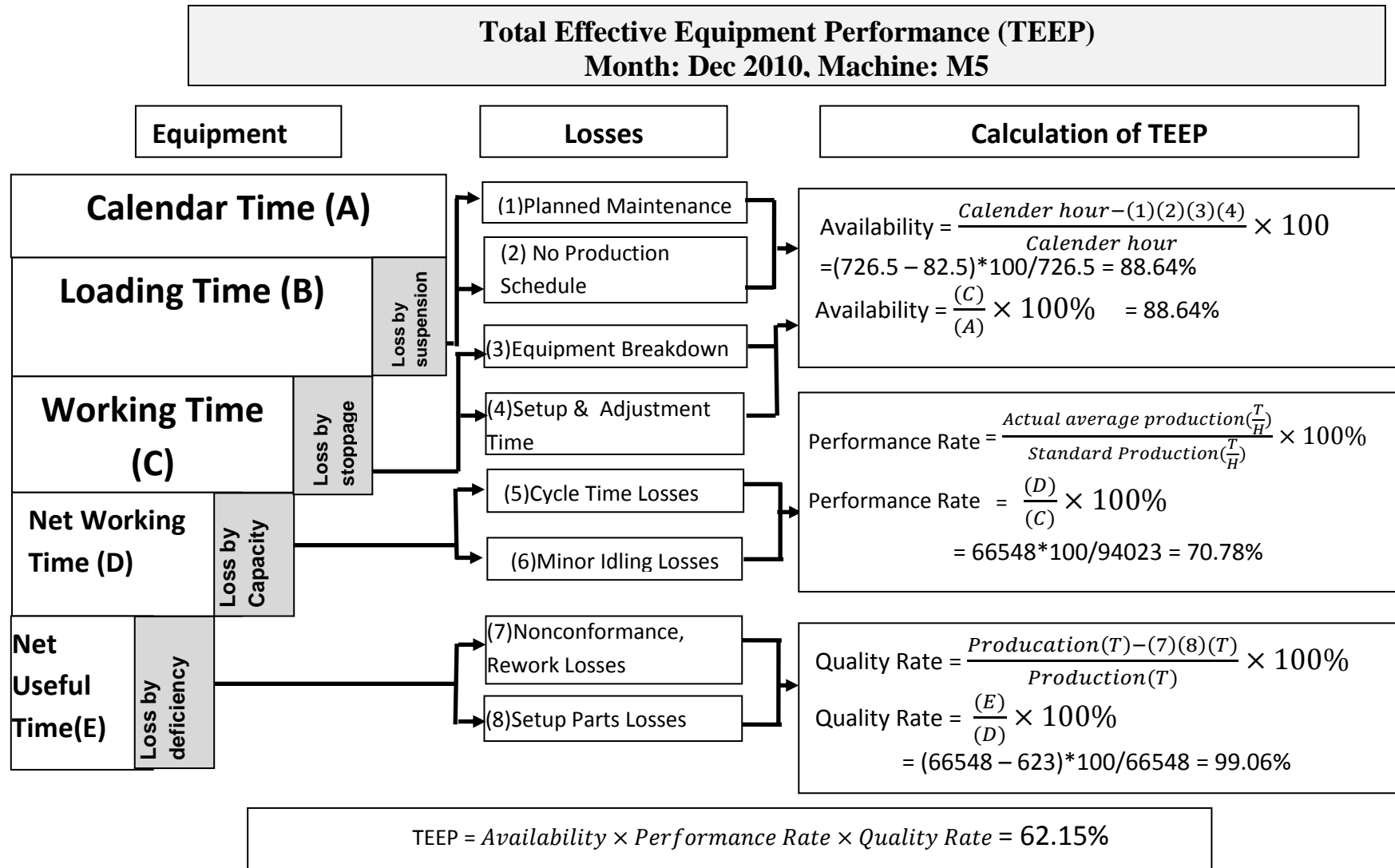
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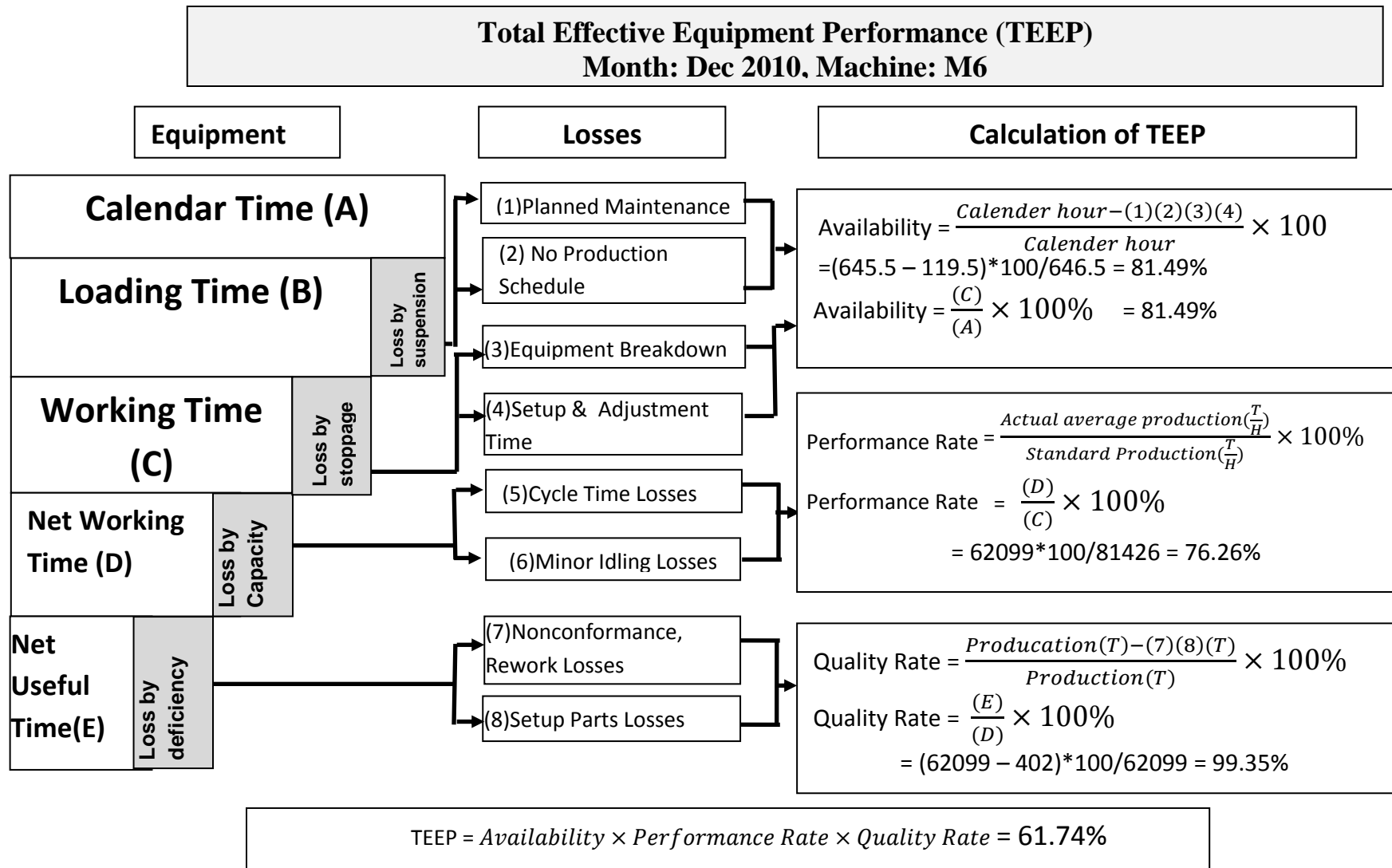
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APPENDIX 1: TEEP of M/C 'M5'

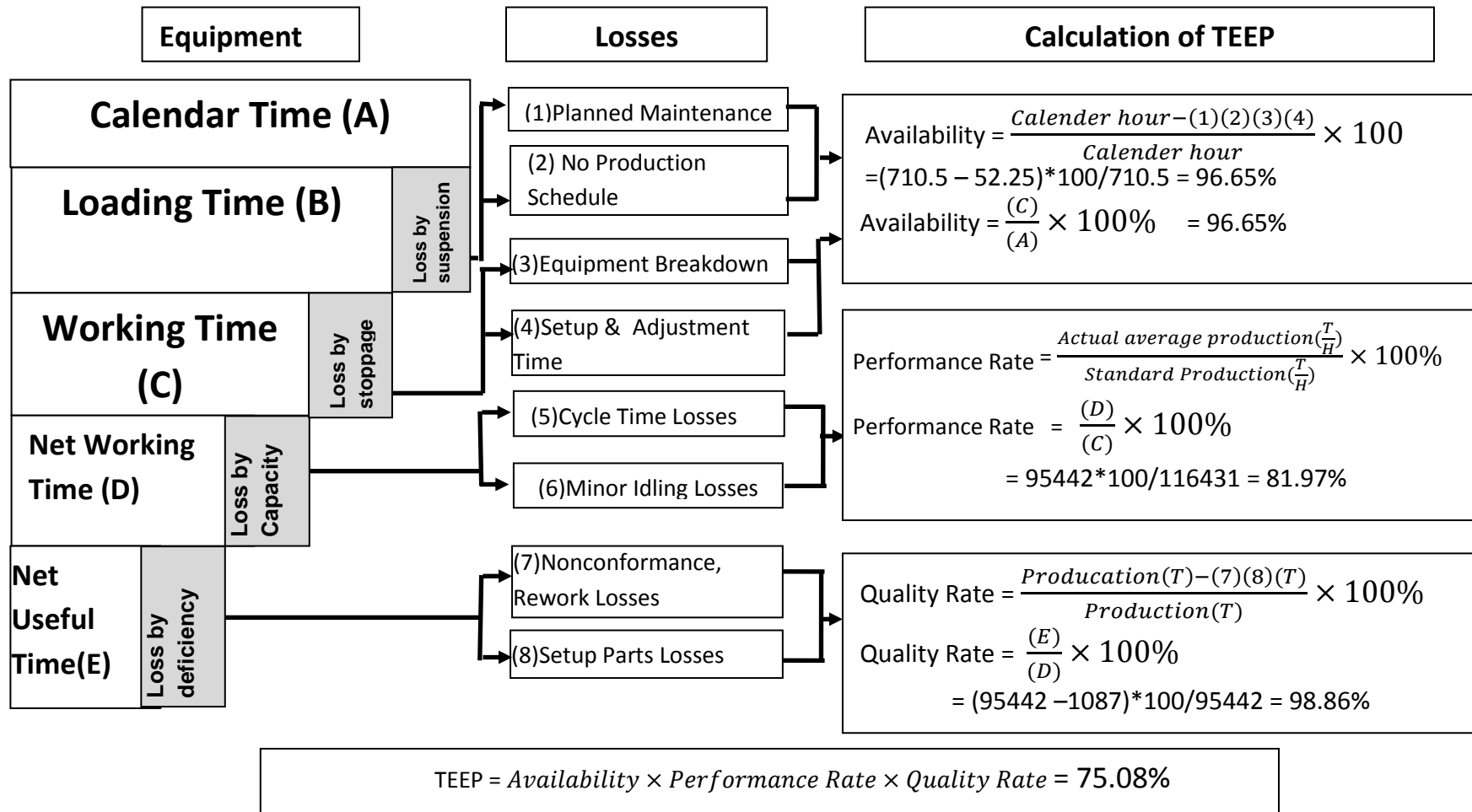


APPENDIX 2: TEEP of M/C 'M6'



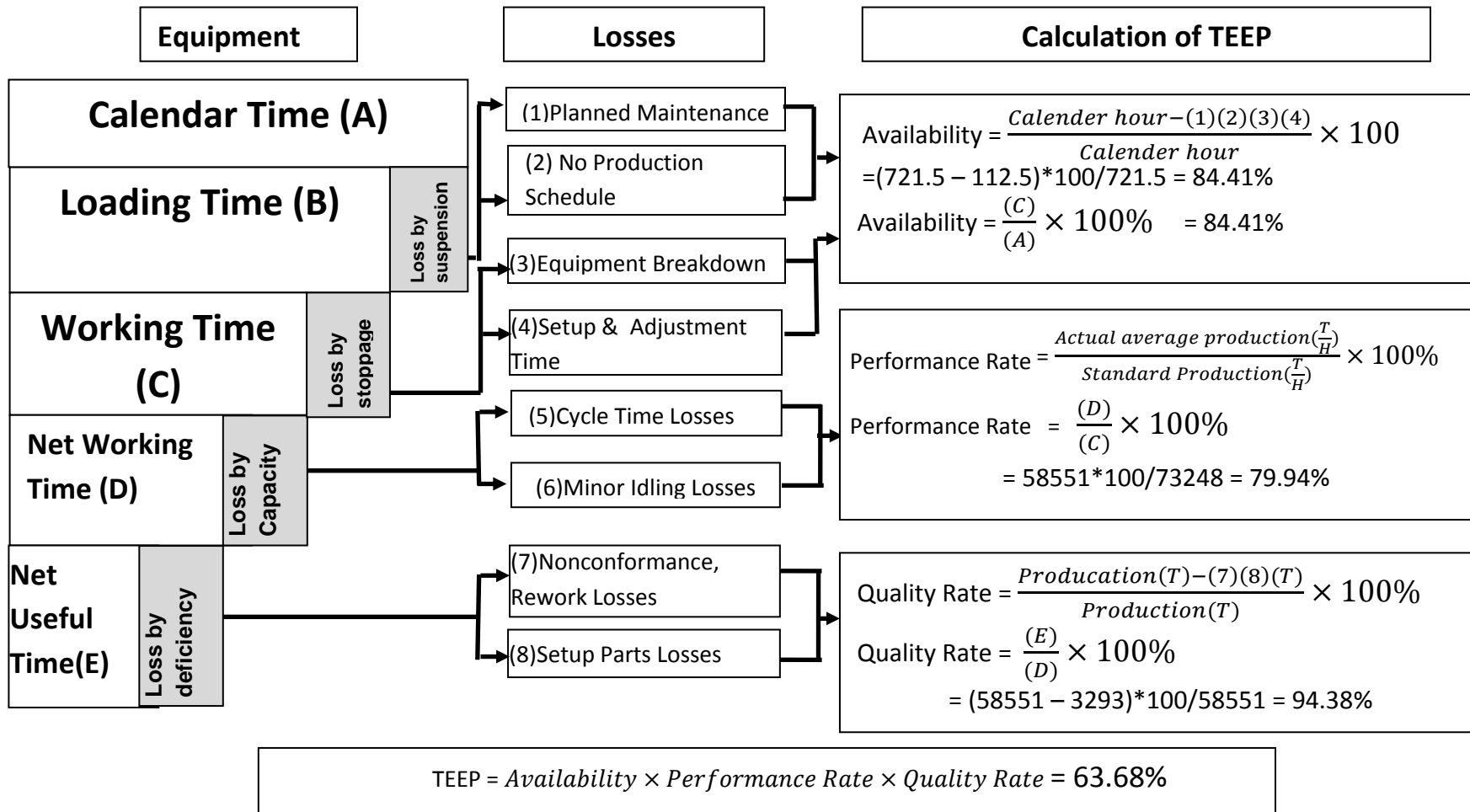
APPENDIX 3: TEEP of M/C 'M7'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M7

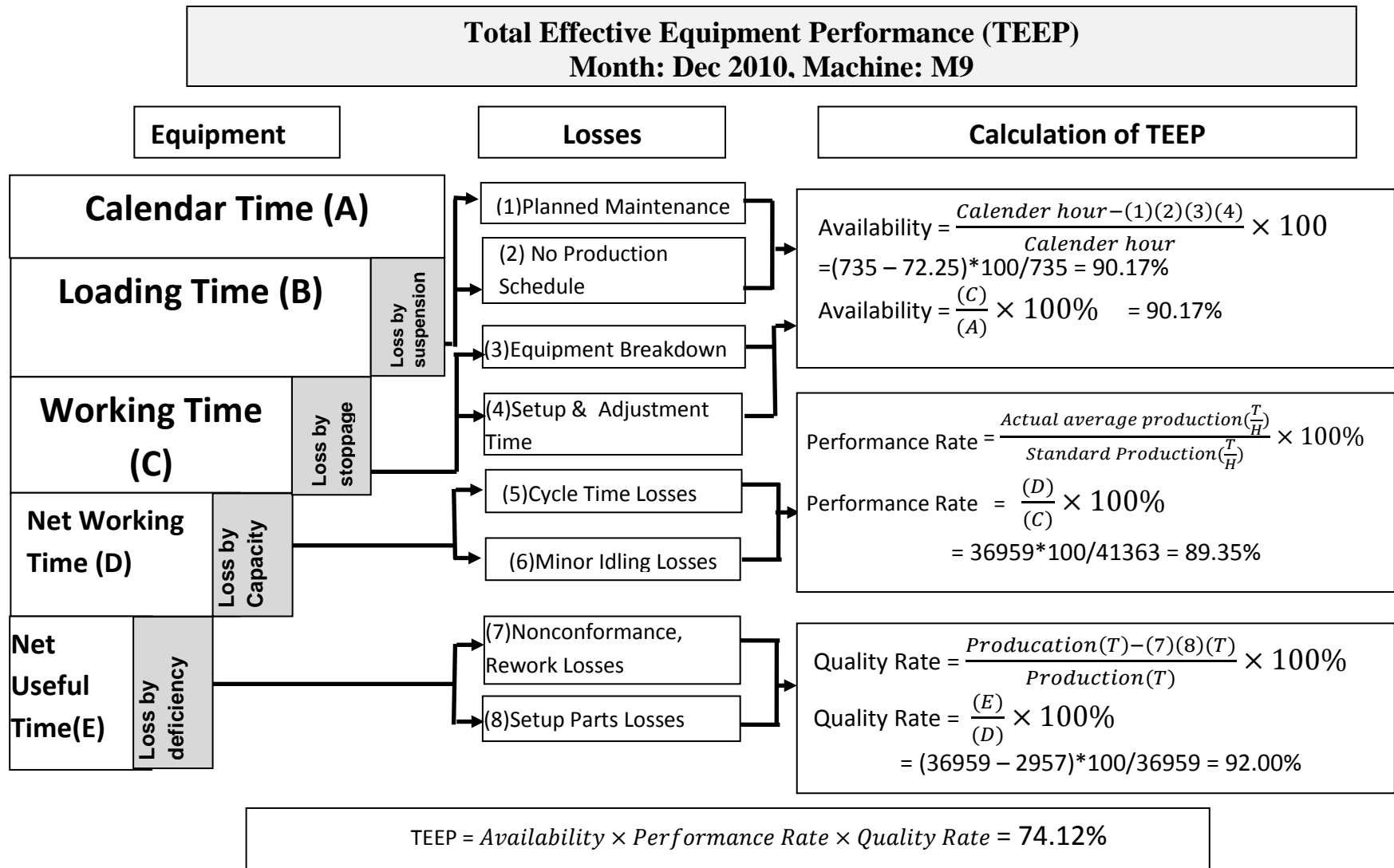


APPENDIX 4: TEEP of M/C 'M8'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M8

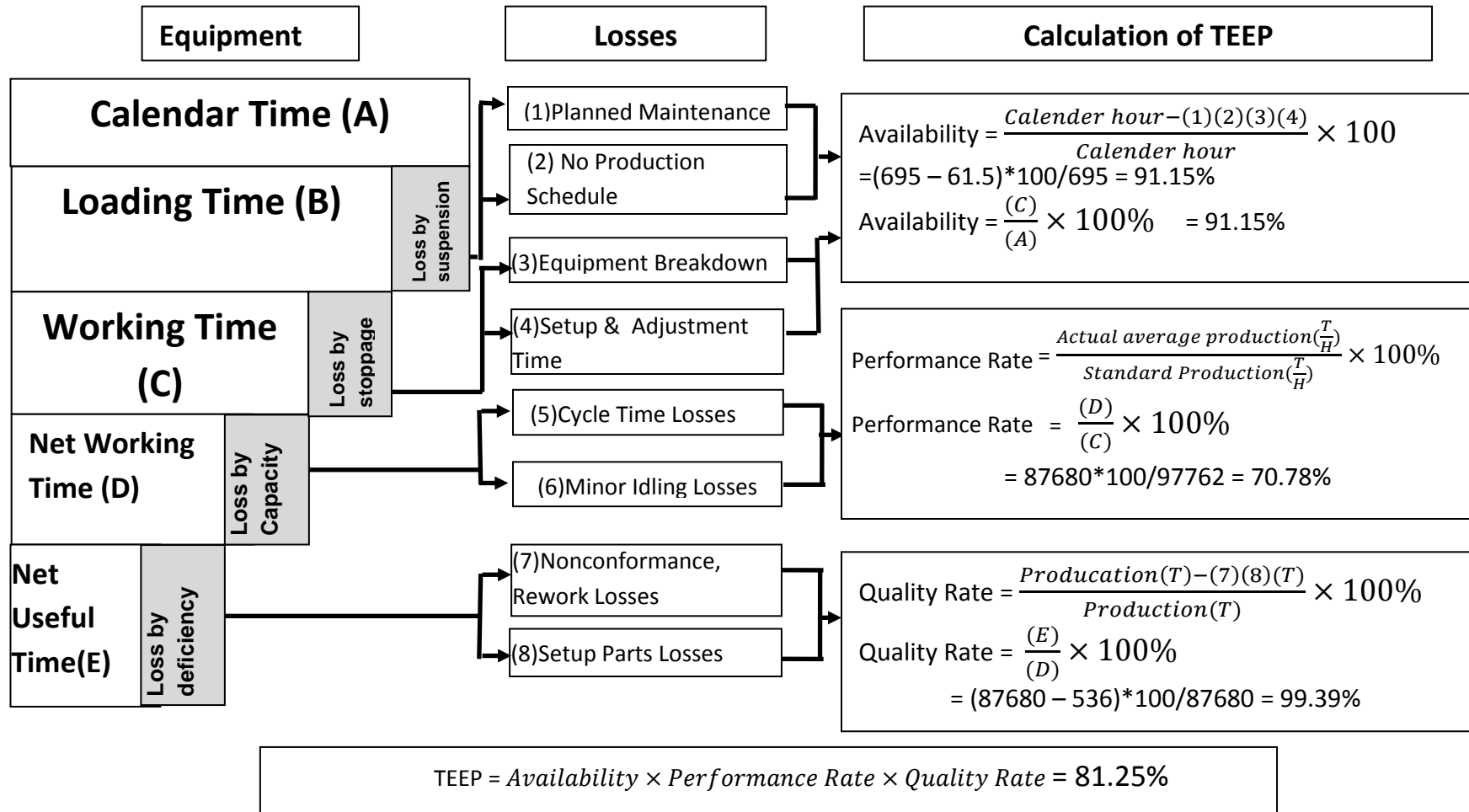


APPENDIX 5: TEEP of M/C 'M9'

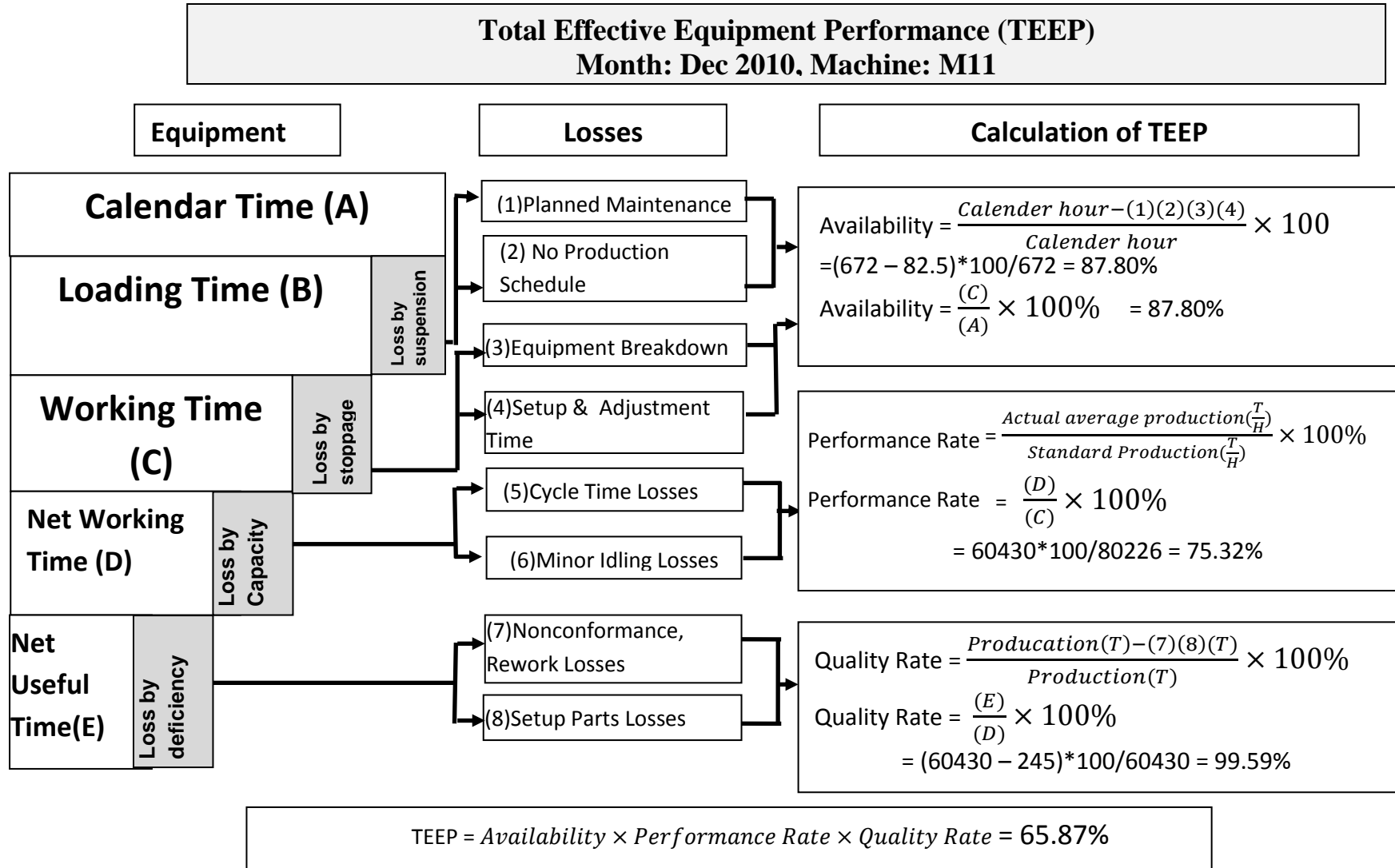


APPENDIX 6: TEEP of M/C 'M10'

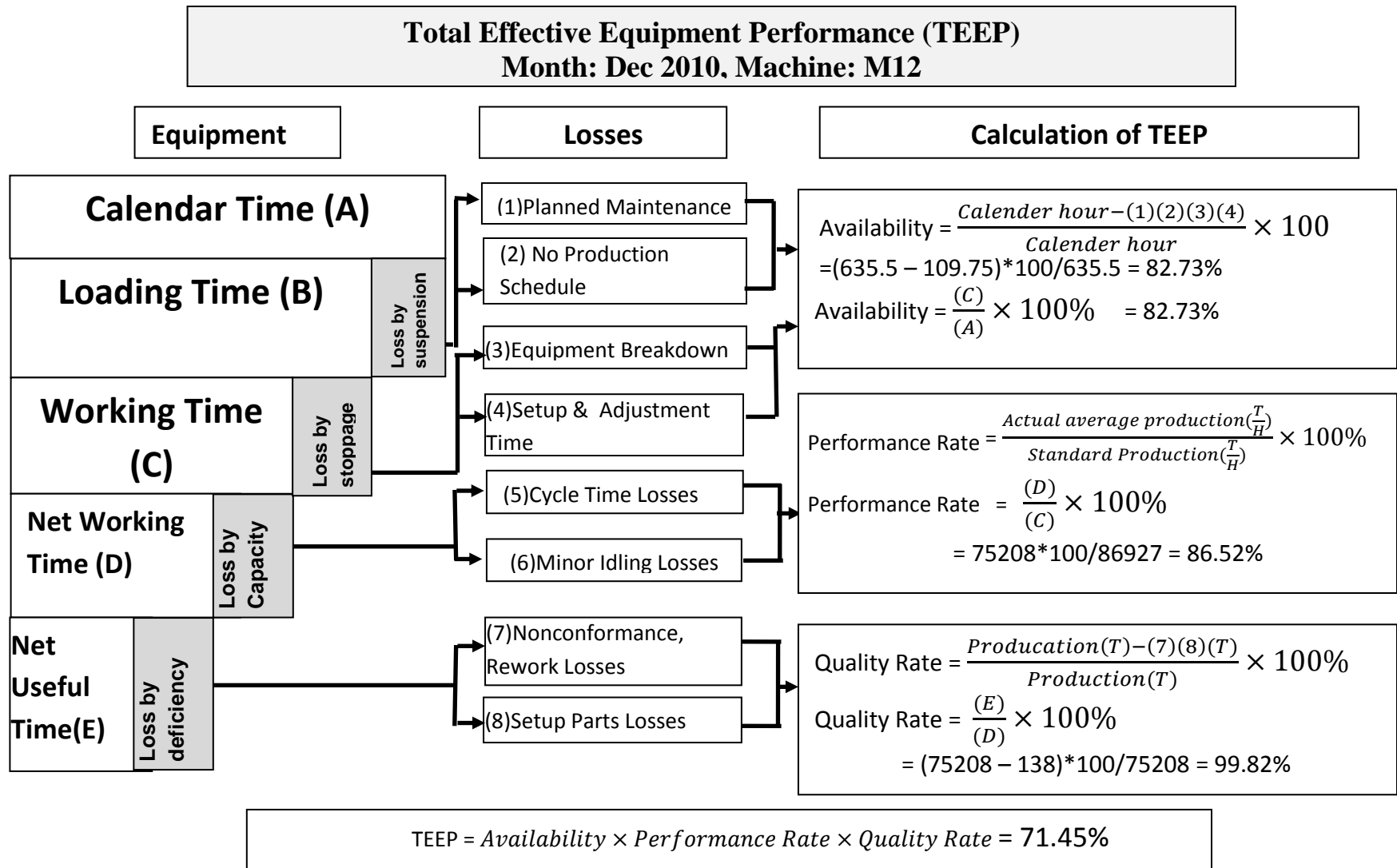
Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M10



APPENDIX 7: TEEP of M/C 'M11'

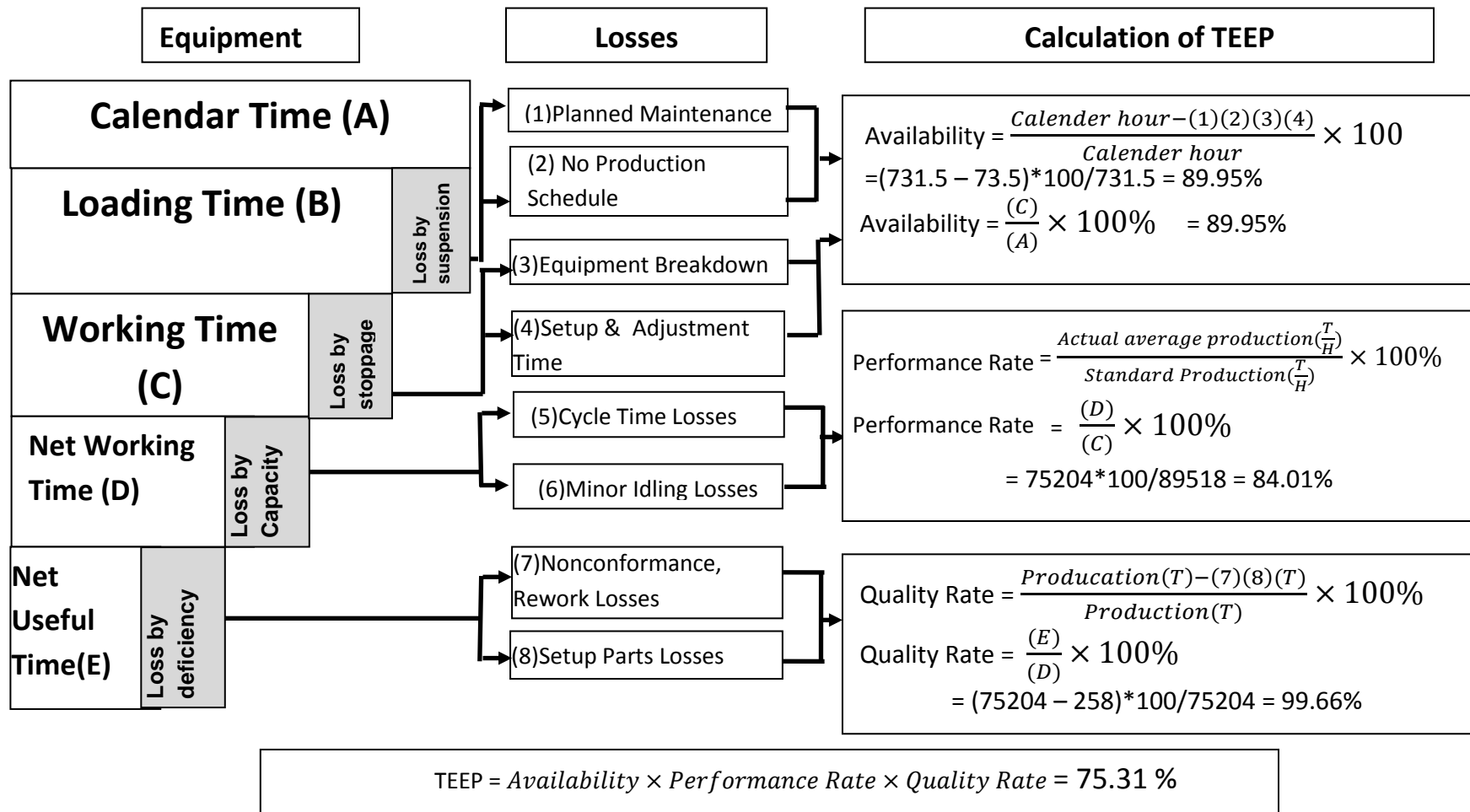


APPENDIX 8: TEEP of M/C 'M12'



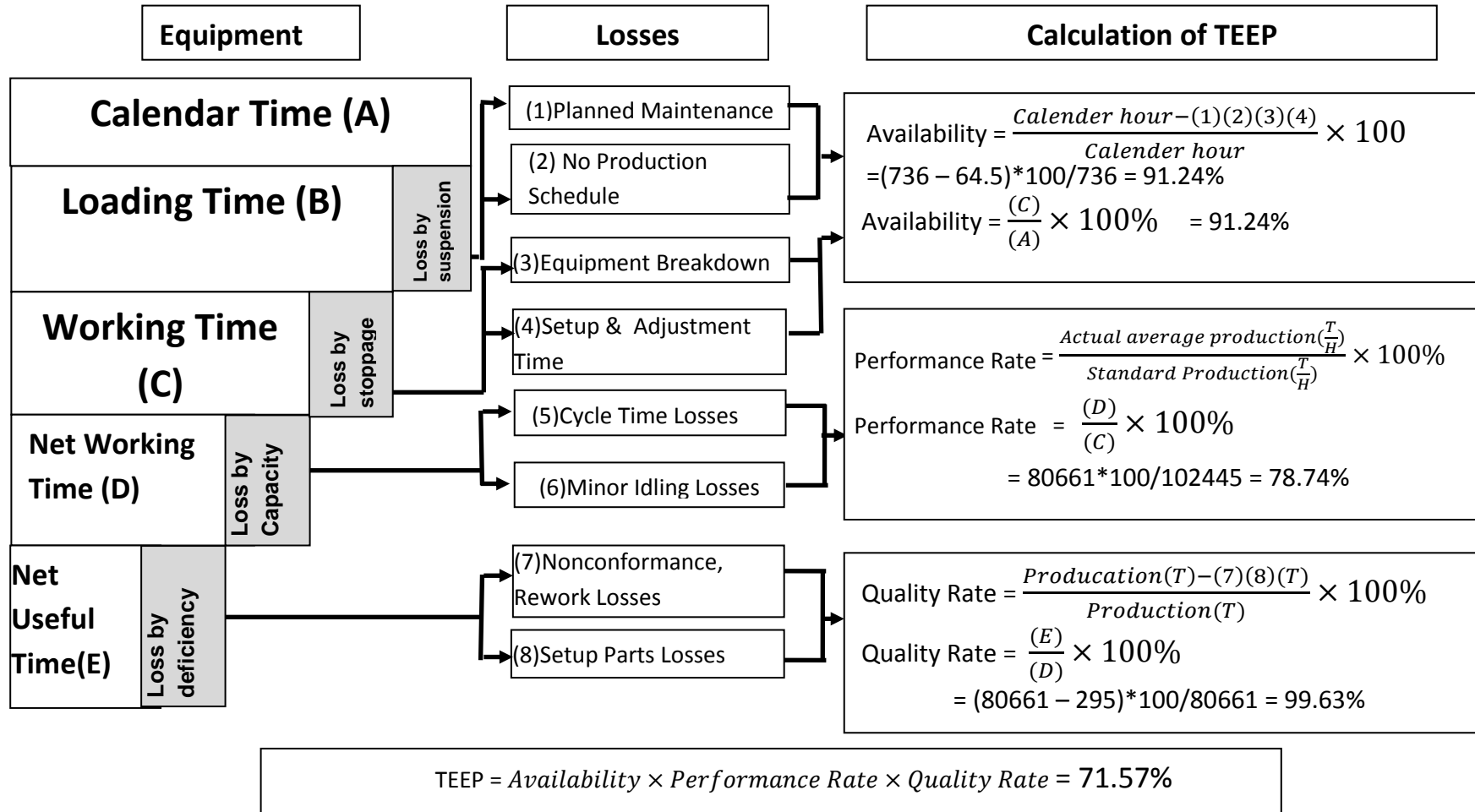
APPENDIX 9: TEEP of M/C 'M13'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M13



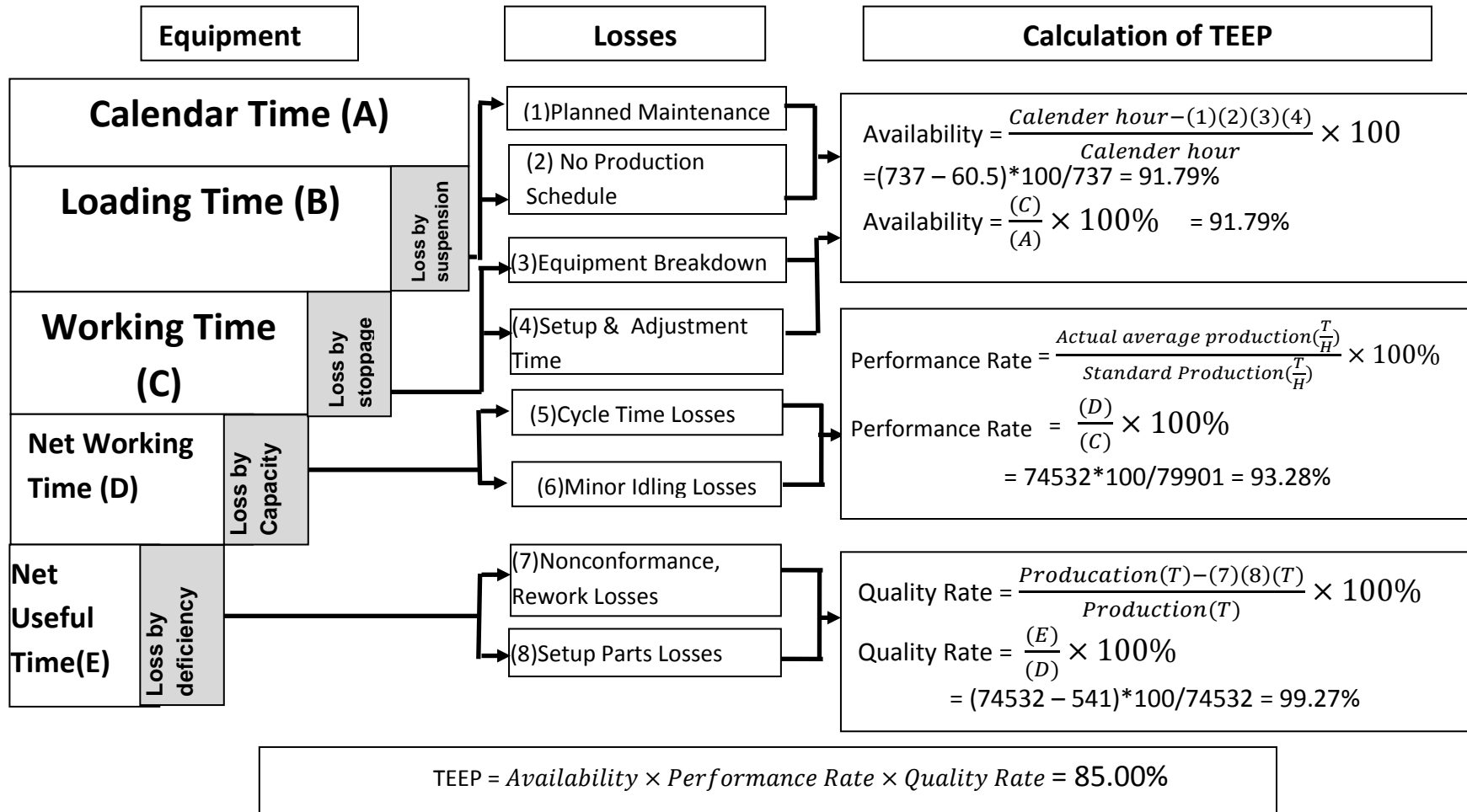
APPENDIX 10: TEEP of M/C 'M14'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M14

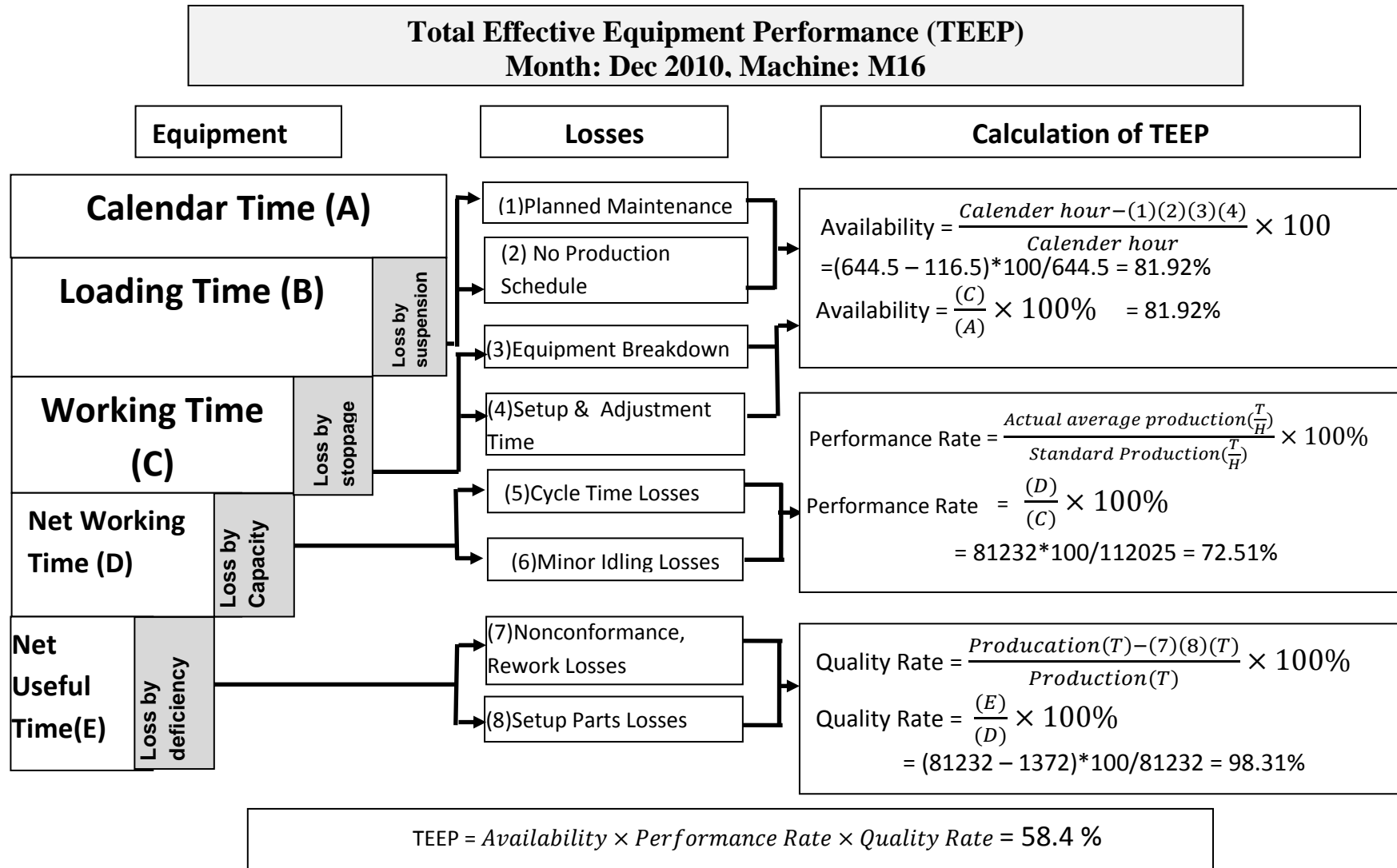


APPENDIX 11: TEEP of M/C 'M15'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M15

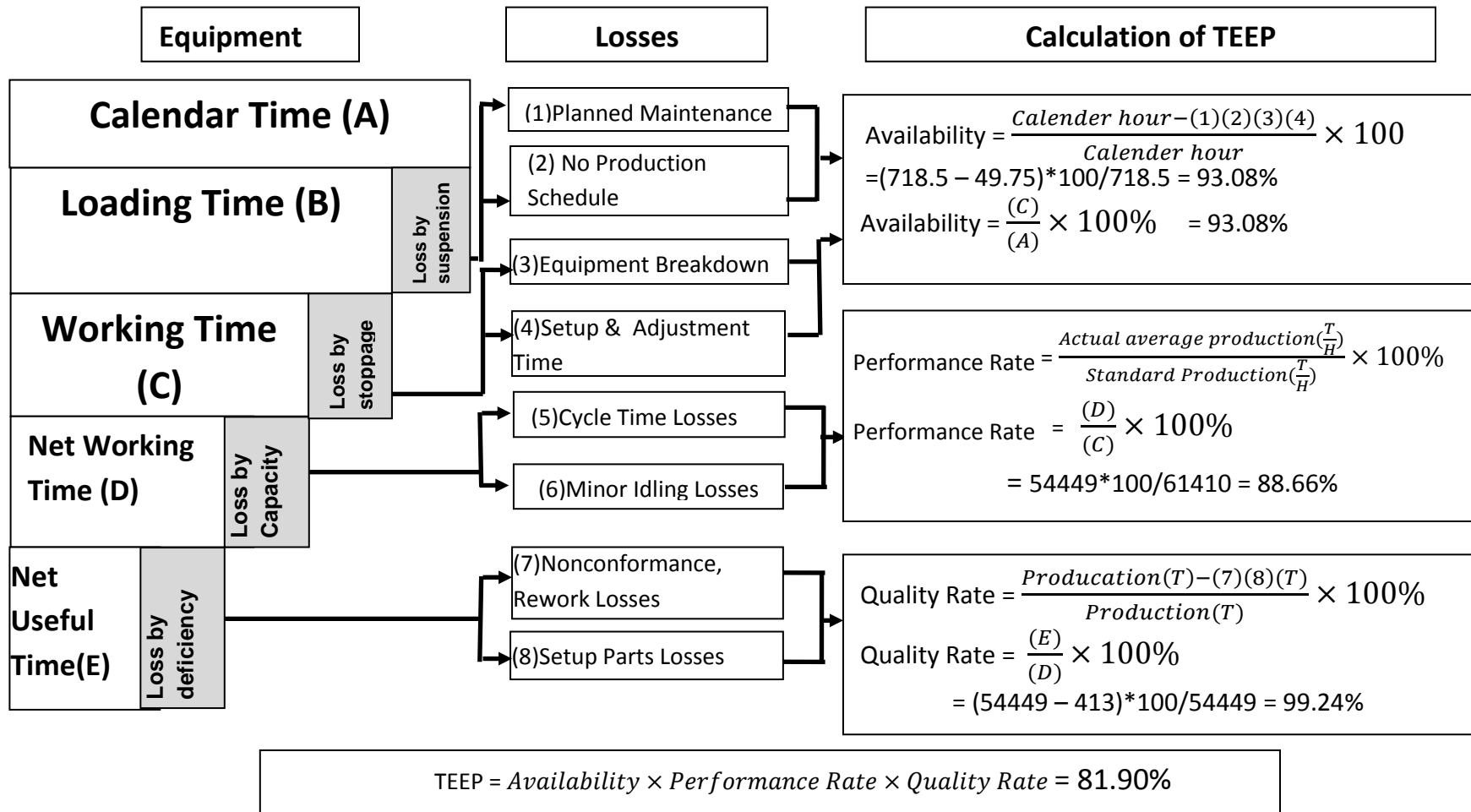


APPENDIX 12: TEEP of M/C 'M16'

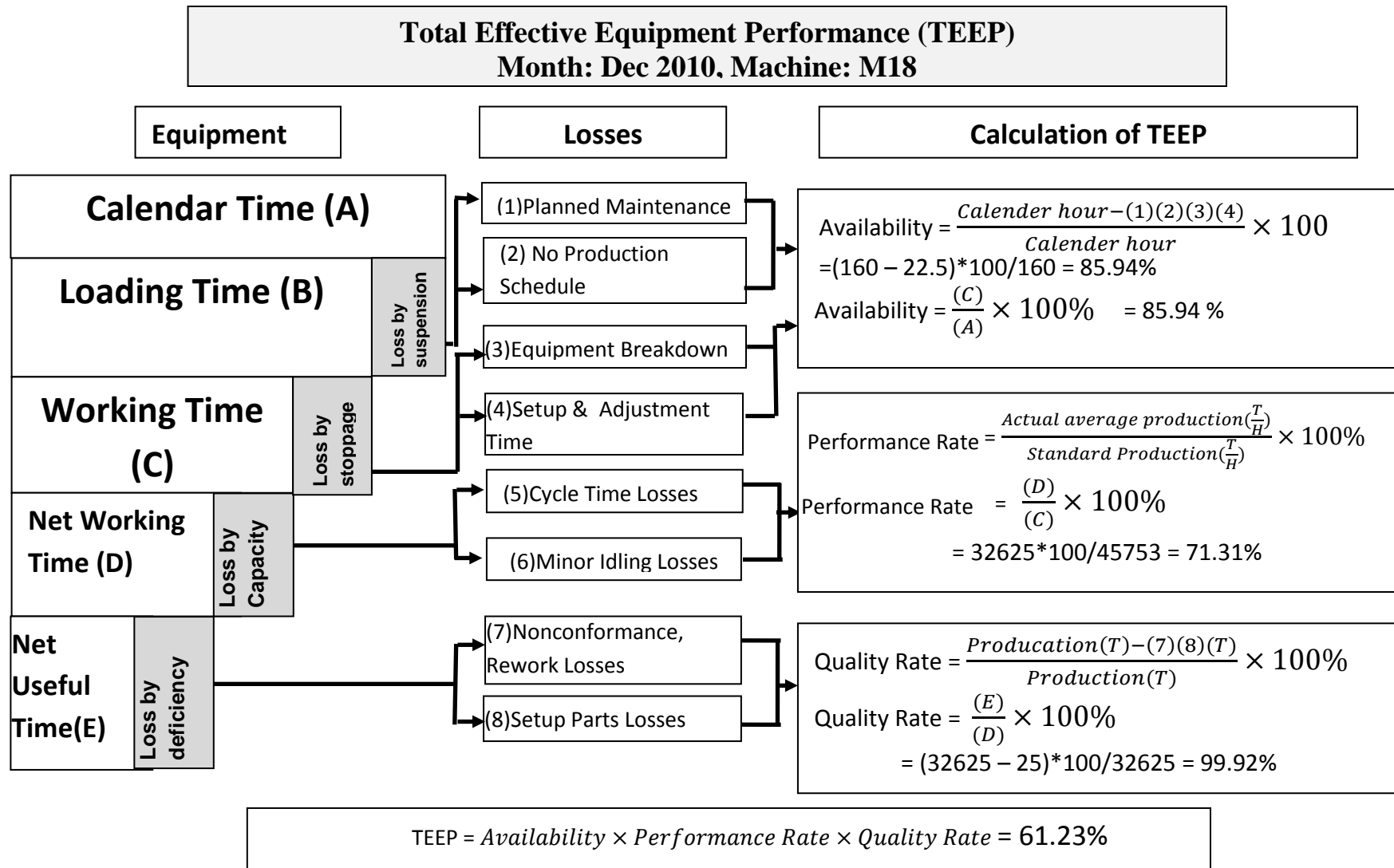


APPENDIX 13: TEEP of M/C 'M17'

Total Effective Equipment Performance (TEEP)
Month: Dec 2010, Machine: M17



APPENDIX 14: TEEP of M/C 'M18'



APPENDIX 15: EOY Calculation for Machine ‘M5’

M/C: M5	Gage Name	Appraiser A: OP1		
NUMBER				
Part Name: 1005	Gage Number	Appraiser B: OP2		
NAME				
Characteristic/Specification	Gage Type	Appraiser C: OP3		
Characteristic Classification	Trials 3	Parts 6	Appraisers 3	Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	93.65	93.75	90	88.88	86.84	86.84					89.993
2.	2	92.5	92.5	83.33	88.88	83.33	88.76					88.217
3.	3	93.65	93.65	91.35	91.35	84.67	82.44					89.518
4.	AVE	93.27	93.30	88.23	89.70	84.95	86.01					$\bar{X}_a =$ 89.243
5.	R	1.15	1.25	8.02	2.47	3.51	6.32					$\bar{R}_a =$ 3.787
6. B	1	94.66	94.66	93.75	88.88	85.47	88.76					91.030
7.	2	92.85	92.85	92.4	84.57	84.37	88.47					89.252
8.	3	98.19	94.66	93.65	91.35	82	84.44					90.715
9.	AVE	95.23	94.06	93.27	88.27	83.95	87.22					$\bar{X}_b =$ 90.332
10.	R	5.34	1.81	1.35	6.78	3.47	4.32					$\bar{R}_b =$ 3.845
11. C	1	96.66	90.27	90.00	85.47	85.47	88.88					89.458
12.	2	94.17	94.17	91.87	86.66	93.12	91.87					91.977
13.	3	96.66	90.27	90.27	91.87	83.75	85.47					89.715
14.	AVE	95.83	91.57	90.71	88.00	87.45	88.74					$\bar{X}_c =$ 90.383
15.	R	2.49	3.90	1.87	6.40	9.37	6.40					$\bar{R}_c =$ 5.072
16. PART												$\bar{\bar{X}} =$ 89.986
AVE (\bar{X}_p)		94.78	92.98	90.74	88.66	85.45	87.33					$R_p =$ 9.330
17.		$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$										$\bar{\bar{R}} =$ 4.234
18.		$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$										$\bar{X}_{DIFF} =$ 1.141
19.		$\bar{\bar{R}} \times D_4^* =$										UCL _R = 10.925
20.		$\bar{\bar{R}} \times D_3^* =$										LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Repeatability - Equipment Variation (EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	4.234 x 3.05		2	4.56		=	100(12.915/90.000)
	=	12.915		3	3.05		=	14.4
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(1.141 \times 2.7)^2 - (12.915^2/(6 \times 3))\}^{1/2}$					=	100(0.466/90.000)
	=	0.466		Appraisers	2		=	0.5
				K₂	3.65			
					2.70	n = number of parts		
Equipment and Operator (E & O) Variation							r = number of trials	
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(12.915^2 + 0.466^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	12.923		3	2.70		=	100(12.923/90.000)
OEE Variation (OEEV)								
OEEV	=	$R_p \times K_3$		4	2.30		=	14.4
	=	9.330 x 1.93		5	2.08			
	=	18.007		6	1.93	% OEEV	=	100 (OEEV/AOEE)
				7	1.82		=	100(18.007/90.000)
Acceptable OEE(AOEE)=								
				8	1.74		=	20.0
AOEE	=			9	1.67			
				10	1.62			
	=	90.000	% Minimum					

APPENDIX 16: EOY Calculation for Machine ‘M6’

M/C: M6	Gage Name	Appraiser A: OP1
NUMBER		
Part Name: 1006	Gage Number	Appraiser B: OP2
NAME		
Characteristic/Specification	Gage Type	Appraiser C: OP3
Characteristic Classification	Trials 3	Parts 6
		Appraisers 3
		Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	95.11	93.33	93.33	93.33	92.44	91.25					93.132
2.	2	97.33	97.33	97.33	97.33	97.33	97.33					97.330
3.	3	97.33	97.33	97.33	97.33	97.33	97.33					97.330
4.	AVE	96.59	96.00	96.00	96.00	95.70	95.30					$\bar{X}_a =$ 95.931
5.	R	2.22	4.00	4.00	4.00	4.89	6.08					$\bar{R}_a =$ 4.198
6. B	1	92.67	93.33	90.67	90.67	90.67	89.33					91.223
7.	2	96	93.75	93.75	94.33	90	90					92.972
8.	3	97.33	97.33	97.33	90.16	90.16	87.54					93.308
9.	AVE	95.33	94.80	93.92	91.72	90.28	88.96					$\bar{X}_b =$ 92.501
10.	R	4.66	4.00	6.66	4.17	0.67	2.46					$\bar{R}_b =$ 3.770
11. C	1	90.66	90.66	88.89	86.67	89.33	85.33					88.590
12.	2	97.33	98.66	96.67	91.25	92.00	90.00					94.318
13.	3	98.66	96.66	96.66	97.33	97.33	97.33					97.328
14.	AVE	95.55	95.33	94.07	91.75	92.89	90.89					$\bar{X}_c =$ 93.412
15.	R	8.00	8.00	7.78	10.66	8.00	12.00					$\bar{R}_c =$ 9.073
16. PART												$\bar{\bar{X}} =$ 93.948
AVE (\bar{X}_p)		95.82	95.38	94.66	93.16	92.95	91.72					$R_p =$ 4.109
17.		$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$										$\bar{\bar{R}} =$ 5.681
18.		$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$										$\bar{X}_{DIFF} =$ 3.429
19.		$\bar{\bar{R}} \times D_4^* =$										UCL _R = 14.656
20.		$\bar{\bar{R}} \times D_3^* =$										LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Repeatability - Equipment Variation (EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	5.681 x 3.05		2	4.56		=	100(17.326/90.000)
	=	17.326		3	3.05		=	19.3
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(3.429 \times 2.7)^2 - (17.326^2/(6 \times 3))\}^{1/2}$					=	100(8.310/90.000)
	=	8.310		Appraisers	2		=	9.2
				K₂	3.65			
					2.70	n = number of parts		
Equipment and Operator (E & O) Variation							r = number of trials	
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(17.326^2 + 8.310^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	19.216		3	2.70		=	100(19.216/90.000)
OEE Variation (OEEV)								
OEEV	=	$R_p \times K_3$		4	2.30		=	21.4
	=	4.109 x 1.93		5	2.08			
	=	7.930		6	1.93	% OEEV	=	100 (OEEV/AOEE)
				7	1.82		=	100(7.930/90.000)
Acceptable OEE(AOEE)=								
				8	1.74		=	8.8
AOEE	=			9	1.67			
				10	1.62			
	=	90.000	% Minimum					

APPENDIX 17: EOY Calculation for Machine ‘M7’

M/C: M7	Gage Name	Appraiser A: OP1
NUMBER		
Part Name: 1007	Gage Number	Appraiser B: OP2
NAME		
Characteristic/Specification	Gage Type	Appraiser C: OP3
Characteristic Classification	Trials 3	Parts 6
		Appraisers 3
		Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	86.66	86.66	83.33	83.33	83.33	83.33					84.440
2.	2	90	91.43	88.48	88.48	82.46	75.55					86.067
3.	3	87.91	86.66	85	82.5	87.5	84.16					85.622
4.	AVE	88.19	88.25	85.60	84.77	84.43	81.01					$\bar{X}_a =$ 85.376
5.	R	3.34	4.77	5.15	5.98	5.04	8.61					$\bar{R}_a =$ 5.482
6. B	1	91.85	83.33	83.33	83.33	81.66	80					83.917
7.	2	98.33	97.77	92.46	86.66	81.66	82.43					89.885
8.	3	92.5	92.46	90	89.16	85.71	80					88.305
9.	AVE	94.23	91.19	88.60	86.38	83.01	80.81					$\bar{X}_b =$ 87.369
10.	R	6.48	14.44	9.13	5.83	4.05	2.43					$\bar{R}_b =$ 7.060
11. C	1	91.85	91.85	83.33	83.33	81.66	81.66					85.613
12.	2	92.50	92.46	89.43	90.16	84.44	82.43					88.570
13.	3	89.16	89.16	89.16	89.16	88.33	88.33					88.883
14.	AVE	91.17	91.16	87.31	87.55	84.81	84.14					$\bar{X}_c =$ 87.689
15.	R	3.34	3.30	6.10	6.83	6.67	6.67					$\bar{R}_c =$ 5.485
16. PART												$\bar{\bar{X}} =$ 86.811
AVE (\bar{X}_p)		91.20	90.20	87.17	86.23	84.08	81.99					$R_p =$ 9.208
17.		$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$										$\bar{\bar{R}} =$ 6.009
18.		$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$										$\bar{X}_{DIFF} =$ 2.313
19.		$\bar{\bar{R}} \times D_4^* =$										UCL _R = 15.503
20.		$\bar{\bar{R}} \times D_3^* =$										LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Repeatability - Equipment Variation (EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	6.009 x 3.05		2	4.56		=	100(18.327/90.000)
	=	18.327		3	3.05		=	20.4
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(2.313 \times 2.7)^2 - (18.327^2/(6 \times 3))\}^{1/2}$					=	100(4.509/90.000)
	=	4.509		Appraisers	2		=	5.0
				K₂	3.65			
					2.70			
Equipment and Operator (E & O) Variation								
								n = number of parts
								r = number of trials
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(18.327^2 + 4.509^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	18.874		3	2.70		=	100(18.874/90.000)
OEE Variation (OEEV)								
				4	2.30		=	21.0
OEEV	=	$R_p \times K_3$		5	2.08			
	=	9.208 x 1.93		6	1.93	% OEEV	=	100 (OEEV/AOEE)
	=	17.771		7	1.82		=	100(17.771/90.000)
Acceptable OEE(AOEE)=								
				8	1.74		=	19.7
AOEE	=			9	1.67			
				10	1.62			
	=	90.000	% Minimum					

APPENDIX 18: EOY Calculation for Machine ‘M8’

M/C: M8	Gage Name	Appraiser A: OP1		
NUMBER				
Part Name: 1008	Gage Number	Appraiser B: OP2		
NAME				
Characteristic/Specification	Gage Type	Appraiser C: OP3		
Characteristic Classification	Trials 3	Parts 6	Appraisers 3	Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	90.27	90.27	88.88	88.88	89.58	84.07					88.658
2.	2	95.14	95.14	95.14	95.14	95.83	94.44					95.138
3.	3	94.44	94.44	94.44	88.88	88.88	86.48					91.260
4.	AVE	93.28	93.28	92.82	90.97	91.43	88.33					$\bar{X}_a =$ 91.686
5.	R	4.87	4.87	6.26	6.26	6.95	10.37					$\bar{R}_a =$ 6.597
6. B	1	90.27	90.27	88.88	88.88	88.88	88.88					89.343
7.	2	95.83	94.58	94.44	94.44	94.44	91.66					94.232
8.	3	94.44	94.44	94.44	93.75	93.05	86.48					92.767
9.	AVE	93.51	93.10	92.59	92.36	92.12	89.01					$\bar{X}_b =$ 92.114
10.	R	5.56	4.31	5.56	5.56	5.56	5.18					$\bar{R}_b =$ 5.288
11. C	1	91.66	90.97	88.88	84.72	86.80	85.71					88.123
12.	2	94.44	94.44	94.44	89.58	88.89	88.89					91.780
13.	3	94.44	94.44	93.75	88.89	88.89	88.89					91.550
14.	AVE	93.51	93.28	92.36	87.73	88.19	87.83					$\bar{X}_c =$ 90.484
15.	R	2.78	3.47	5.56	4.86	2.09	3.18					$\bar{R}_c =$ 3.657
16. PART												$\bar{\bar{X}} =$ 91.428
AVE (\bar{X}_p)		93.44	93.22	92.59	90.35	90.58	88.39					$R_p =$ 5.048
17.		$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$										$\bar{\bar{R}} =$ 5.181
18.		$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$										$\bar{X}_{DIFF} =$ 1.629
19.		$\bar{\bar{R}} \times D_4^* =$										UCL _R = 13.366
20.		$\bar{\bar{R}} \times D_3^* =$										LCL _R = 0.000

Measurement Unit Analysis					% Total Variation (TV)			
Repeatability - Equipment Variation (EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	5.181 x 3.05		2	4.56		=	100(15.801/90.000)
	=	15.801		3	3.05		=	17.6
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(1.629 \times 2.7)^2 - (15.801^2/(6 \times 3))\}^{1/2}$					=	100(2.342/90.000)
	=	2.342		Appraisers	2		=	2.6
				K₂	3.65			
					2.70			
Equipment and Operator (E & O) Variation								
								n = number of parts
								r = number of trials
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(15.801^2 + 2.342^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	15.973		3	2.70		=	100(15.973/90.000)
OEE Variation (OEEV)								
				4	2.30		=	17.7
OEEV	=	$R_p \times K_3$		5	2.08			
	=	5.048 x 1.93		6	1.93	% OEEV	=	100 (OEEV/AOEE)
	=	9.742		7	1.82		=	100(9.742/90.000)
Acceptable OEE(AOEE)=								
				8	1.74		=	10.8
AOEE	=			9	1.67			
	=			10	1.62			
	=	90.000	% Minimum					

APPENDIX 19: EOY Calculation for Machine ‘M9’

M/C: M9	Gage Name	Appraiser A: OP1
NUMBER		
Part Name: 1009	Gage Number	Appraiser B: OP2
NAME		
Characteristic/Specification	Gage Type	Appraiser C: OP3
Characteristic Classification	Trials 3	Parts 6
		Appraisers 3
		Date Performed

APPRAISER/ TRIAL #	PART										AVERAGE	
	1	2	3	4	5	6	7	8	9	10		
1. A	1	96.53	95.14	95.14	95.14	84.1	79.16					90.868
2.	2	83.33	83.33	83.33	83.33	83.33	83.33					83.330
3.	3	83.33	83.33	83.33	83.33	83.33	83.33					83.330
4.	AVE	87.73	87.27	87.27	87.27	83.59	81.94					$\bar{X}_a =$ 85.843
5.	R	13.20	11.81	11.81	11.81	0.77	4.17					$\bar{R}_a =$ 8.928
6. B	1	89.16	88.89	86.8	84.72	83.33	83.33					86.038
7.	2	84.72	84.3	86.11	84.72	83.33	83.33					84.418
8.	3	84.72	84.72	84.72	83.33	83.33	83.33					84.025
9.	AVE	86.20	85.97	85.88	84.26	83.33	83.33					$\bar{X}_b =$ 84.827
10.	R	4.44	4.59	2.08	1.39	0.00	0.00					$\bar{R}_b =$ 2.083
11. C	1	96.52	97.22	90.28	94.44	87.50	84.44					91.733
12.	2	84.72	83.33	83.33	83.33	83.33	83.33					83.562
13.	3	84.72	83.33	83.33	83.33	83.33	83.33					83.562
14.	AVE	88.65	87.96	85.65	87.03	84.72	83.70					$\bar{X}_c =$ 86.286
15.	R	11.80	13.89	6.95	11.11	4.17	1.11					$\bar{R}_c =$ 8.172
16. PART												$\bar{\bar{X}} =$ 85.652
AVE (\bar{X}_p)		87.53	87.07	86.26	86.19	83.88	82.99					$R_p =$ 4.538
17.	$(\bar{R}_a + \bar{R}_b + \bar{R}_c) / (\# \text{ OF APPRAISERS}) =$										$\bar{\bar{R}} =$ 6.394	
18.	$(\text{Max } \bar{X} - \text{Min } \bar{X}) =$										$\bar{X}_{DIFF} =$ 1.458	
19.	$\bar{\bar{R}} \times D_4^* =$										UCL _R = 16.498	
20.	$\bar{\bar{R}} \times D_3^* =$										LCL _R = 0.000	

Measurement Unit Analysis					% Total Variation (TV)			
Repeatability - Equipment Variation (EV)								
EV	=	$\bar{R} \times K_1$		Trials	K1	% EV	=	100 (EV/A OEE)
	=	6.394 x 3.05		2	4.56		=	100(19.503/90.000)
	=	19.503		3	3.05		=	21.7
Operator Variation (OV)								
OV	=	$\{(X_{DIFF} \times K_2)^2 - (EV^2/nr)\}^{1/2}$				% OV	=	100 (OV/A OEE)
	=	$\{(1.458 \times 2.7)^2 - (19.503^2/(6 \times 3))\}^{1/2}$					=	100(2.372/90.000)
	=	2.372		Appraisers	2		=	2.6
				K₂	3.65			
					2.70	n = number of parts		
Equipment and Operator (E & O) Variation							r = number of trials	
EOV	=	$\{(EV^2 + AV^2)\}^{1/2}$		Parts	K₃			
	=	$\{(19.503^2 + 2.372^2)\}^{1/2}$		2	3.65	% EOV	=	100 (E&O/AOEE)
	=	19.647		3	2.70		=	100(19.647/90.000)
OEE Variation (OEEV)								
OEEV	=	$R_p \times K_3$		4	2.30		=	21.8
	=	4.538 x 1.93		5	2.08			
	=	8.758		6	1.93	% OEEV	=	100 (OEEV/AOEE)
				7	1.82		=	100(8.758/90.000)
Acceptable OEE(AOEE)=								
				8	1.74		=	9.7
AOEE	=			9	1.67			
				10	1.62			
	=	90.000	% Minimum					