TreeFrogPerformance Management KPI Reference

The Performance Management Solution

CONTENTS

1 Introduction 3
2 Productivity 5
3 Efficiency 6
3.1 Overall Equipment Efficiency (OEE) 6
3.2 Overall Process Efficiency (OPE) 6
3.3 Production Efficiency (PE) 6
3.4 Operational Efficiency (OE) 7
3.5 Running Efficiency (RE) 7
3.6 Others 7
3.6.1 Mean Time Between Failures (MTBF) 8
3.6.2 Mean Time To Repair (MTTR) 8
3.6.3 Failure Frequency Rate (FFR) 8
3.6.4 Failure Duration Rate (FDR) 8
3.6.5 No. Of Failures (NOF) 9
3.6.6 Productivity (PD) 9
3.6.7 Yield (Yd) 9
4 Utilisation 10
4.1 Available Utilisation (Ua) 10
4.2 Asset Availability (Aa) 10
4.3 Asset Utilisation (Au) 10
4.4 Operational Utilisation (Uo) 11
4.5 Production Utilisation (Up) 11
4.6 Effective Utilisation (Ue) 11
5 Capacity 12
5.1 Annual Capacity 12
5.1.1 Available Capacity (Ca) 12
5.1.2 Maximum Capacity (Cm) 13
5.2 Detailed Capacity 13
5.2.1 Production Capacity (Cp) 13
5.2.2 Operational Capacity (Co) 13
5.2.3 Installed Capacity (Ci) 13
5.2.4 Design Capability (Cd) 14

6 Total Productive Maintenance (TPM) 15
6.1 TPM Overview 15
6.2 TPM Loss and Waste 16
7 Inter-Site Comparisons 18
7.1 Discussion 18
7.2 Inter-Site KPI comparison guidelines 19
Appendix A: Definition of Manufacturing Time 20
A.1 Overall Breakdown of Manufacturing Time 20
A.2 Definitions of Manufacturing Time 20
Appendix B: OEE & OPE Formal Definitions 26
B.1 Overall Equipment Efficiency - OEE 26
B.2 Overall Process Efficiency - OPE 28

1 Introduction

TreeFrog Software provides tools that actively support a performance management program, providing reports that detail the key performance indicators (KPI's). This document aims to outline the merits of the various KPI's, acting as a reference for the accepted KPI definitions as well as a reference for the different approaches adopted to achieve sustainable improvements. Not all of the KPI's defined in this document are currently available in TreeFrog Software's products, however, most of the performance management ones are.

The effectiveness of a plant's production depends on the effectiveness with which it uses equipment, materials, people and methods. Raising production effectiveness in process industries, therefore, starts with the vital issues of maximizing overall plant effectiveness (equipment), raw material and fuel efficiency (materials), work efficiency (people), and management efficiency (methods). This is achieved by examining the inputs to the production process (equipment, materials, people and methods) and identifying and eliminating the losses associated with each to maximize the outputs (productivity, quality, cost, delivery, safety, environment and morale).

A more structured view of these effectiveness issues is that taken by industries striving for World Class Manufacturing (WCM) status, which has six key drivers:

P **Productivity** - Capacity, utilization and efficiency of a plant and its people
Q **Quality** - Quality of the product/systems and services
C **Cost** - Cost of production at a plant
D **Delivery/Service** - Reliability, efficiency and customer satisfaction
S **Safety/Health/Environment (SHE)** - Accidents, sickness and pollution/waste
M **Morale** - Motivation and effectiveness of manufacturing staff

KPI Focus

All of these drivers have an impact on the core structure of the manufacturing business. The table below shows where the overlaps occur between this structure as would normally be measured by key performance indicators against elements of the business.

PRODUCT	ASSET	RESOURCE	SITE
Q	P	Q	Q
C	Q	C	D
	C	S	S
		M	M

In the continual quest for World Class Manufacture, several manufacturing excellence programs have been developed. One of the most successful in the last decade is called Total Productive Maintenance. This is a major culture-changing program that engages the whole organization through a focused, systematic approach. This approach is delivered through a structure of 8 pillars:

1. Focused Improvement
2. Autonomous Maintenance
3. Effective Maintenance
4. Training and Education
5. Early Management
6. Quality Management
7. TPM in Administration
8. Safety, Health and Environment

These enable the program to facilitate the development of a world class site. TPM, like all successful manufacturing excellence programs, uses performance management techniques to drive and steer its program. TPM calls this its Loss and Waste Program. This approach is discussed further in section 6.

2 Productivity

Productivity is at the heart of all manufacturing companies, and is often used as a key measure to evaluate the effectiveness of the manufacturing unit. There are three key categories within the productivity measure:

- **Efficiency -** At the asset design ratings (Section 3)
- **Utilization -** Using all appropriate assets (Section 4)
- **Capacity -** Run at optimum output (Section 5)

The following sections discuss how each of these are effectively managed using several Key Performance Indicators (For a definition of the terminology used when referring to manufacturing time, please refer to Appendix A).

All of the definitions and equations in the following sections use set definitions of time, a fuller definition is provided in Appendix A, however, here is a summary:

Calendar time "Calendar Time is the total available time in one calendar year"	
Loading Time "Loading Time is the weekly shift pattern - totaled for year"	**Unused Time**
Working time "The Amount of time the equipment must operate in one day totaled for one years"	**Shutdown Losses**
Operating time "The amount of time the equipment actually runs"	**Major Stoppage Losses**
Net operating time "The amount of time the equipment operates at its standard speed"	**Performance Losses**
Effective operating time "The amount of time the equipment operated producing good quality products"	**Defect Losses**

3 Efficiency

There are three measures for machine efficiency that are normally reported: Operational Efficiency (OE), Production Efficiency (PE) and Running Efficiency (RE).

3.1 Overall Equipment Efficiency (OEE)

This measures the efficiency of the packaging equipment in a factory.

OEE % = Availability **x** Performance **x** Quality

Please refer to Appendix B.1 for a complete definition and to section 6 for an explanation of TPM, the methodology that employs it.

3.2 Overall Process Efficiency (OPE)

This measures the efficiency of the manufacturing equipment in a factory.

OPE % = Availability **x** Performance **x** Quality

Please refer to Appendix B.2 for a complete definition and to section 6 for an explanation of TPM, the methodology that employs it.

3.3 Production Efficiency (PE)

Within the time that a machine was controlled by the production department, this measures how effectively it was operated.

$$\text{PE \%} = \frac{\text{Net Operating Time}}{\text{Operating Time}} \times 100$$

3.4 *Operational Efficiency (OE)*

This is the most commonly used index of efficiency used by the factory. It provides a basis for inter-site comparison, because it measures all of the activities within the control of a factory. It is calculated in two ways, either from recorded times or from output as good product delivered to the stores. For comparison purposes, an OE will state the specified speed at which efficiency was measured (Eg. 70% @ 45 kg/min).

$$\text{OE \%} = \frac{\text{Net Operating Time}}{\text{Working Time}} \times 100$$

OR

$$\text{OE \%} = \frac{\text{Actual Good Output}}{\text{Specified Speed} \times \text{Operating Time}} \times 100$$

3.5 *Running Efficiency (RE)*

This is a much more detailed analysis of manufacturing efficiency and requires a recording process to be in place on the equipment (i.e. Detailed time sheet, Video Camera or automated line monitoring). It measures the efficiency of the machine when it was actually running.

$$\text{RE \%} = \frac{\text{Operating Time}}{\text{Operating Time} + \text{Time Adjustment}} \times 100$$

3.6 *Others*

There are numerous other efficiency measures that are not standardized or have varying units or time frames. The following sub-sections detail a few of the better-known KPI’s.

3.6.1 Mean Time Between Failures (MTBF)

Average operation time between failures.

$$MTBF = \frac{\text{Loading Time}}{\text{No of Failures}}$$

3.6.2 Mean Time To Repair (MTTR)

Average repair time.

$$MTTR = \frac{\text{Repair Time}}{\text{No of Repairs}}$$

3.6.3 Failure Frequency Rate (FFR)

This is the rate of failure occurrence per loading time.

$$FFR\ \% = \frac{\text{No of Downtimes}}{\text{Loading Time}} \text{ x} \quad \mathbf{x}\ 100$$

3.6.4 Failure Duration Rate (FDR)

This is the ratio of time when equipment is stopped due to failures.

$$FDR\ \% = \frac{\text{Failure Downtime}}{\text{Loading Time}} \quad \mathbf{x}\ 100$$

3.6.5 No. Of Failures (NOF)

This is simply the number of failures.

3.6.6 Productivity (PD)

The output volume per unit of labour.

$$PD = \frac{\text{Production Volume}}{\text{Total man-hours}}$$

3.6.7 Yield (Yd)

The ratio of raw materials converted into final product.

$$Yd\ \% = \frac{\text{Volume of Finished Product}}{\text{Volume of Raw Materials}} \times 100$$

4 Utilisation

This is a growing area of importance, especially at the international and regional level, reflecting the globalisation of companies and the importance of utilising capital resources effectively – “Sweating the assets”. There are currently six KPIs that have been used nationally and internationally for annual company comparisons. These KPIs primarily measure the use of an assets time, and to a lesser extent also indicate how they perform.

4.1 Available Utilisation (Ua)

This is used to measure an assets planned use in the time that it is normally operated, when running at its current efficiency.

$$Ua\ \% = \frac{\text{Working Time}}{\text{Loading Time}} \times 100$$

4.2 Asset Availability (Aa)

This is used to measure an assets available time, taking into account statutory and local constraints on manufacturing.

$$Aa\ \% = \frac{\text{Loading Time}}{\text{Calendar Time}} \times 100$$

4.3 Asset Utilisation (Au)

This measures how well as asset is being utilised by production and engineering staff.

$$Au\ \% = \frac{\text{Working Time}}{\text{Calendar Time}} \times 100$$

4.4 Operational Utilisation (Uo)

This is used to measure how an asset is planned to be used in the maximum time available during a period.

$$Uo\ \% = \frac{\text{Planned Working Time}}{\text{Calendar Time}} \times 100$$

4.5 Production Utilisation (Up)

This is a measure of an assets production usage.

$$Up\ \% = \frac{\text{Operating Time}}{\text{Calendar Time}} \times 100$$

4.6 Effective Utilisation (Ue)

This measures how much output can be obtained from an asset running at its current efficiency, in the maximum time available. This is a very severe measure, and is primarily of use for international comparisons of plant long-term use.

$$Ue\ \% = \frac{\text{Net Operating Time}}{\text{Calendar Time}} \times 100$$

5 Capacity

This is defined as the output that can be expected from a site, department or machine over a period of time, when operating under specified conditions with a stated product mix.

There are many uses for capacity, at one end of the scale to obtain realistic figures showing what output factories can be expected to deliver nationally or regionally, under current conditions. Planners and schedulers need figures that are attainable, but allow them to make effective use of installed capacity. At the other end of the scale, engineers need instantaneous output rates when designing plant and machinery.

We will consider two levels of capacity measurement, one for an annual measurement, the other for scheduling and planning tasks or more focused studies.

5.1 Annual Capacity

Both of the KPIs specified here will normally apply to a specific product mix and in effect be calculated using their weighted average Specified Speed. A machine capacity will normally state the Operational Efficiency at which it was calculated (Eg. Maximum Capacity @ 72% OE).

5.1.1 Available Capacity (Ca)

This measures the output that can be expected from a machine when operated at an estimated efficiency in a full year, taking into account holidays, shutdowns and other times when it will not be available.

$$Ca = \text{Specified Speed} \times \frac{\text{estimated OE}}{100} \times \text{Loading Time}$$

5.1.2 Maximum Capacity (Cm)

This is the potential or maximum output that could be obtained from a machine when operated at a stated efficiency over a year.

$$Cm = \text{Specified Speed} \times \frac{\text{given OE}}{100} \times \text{Calendar Time}$$

5.2 Detailed Capacity

5.2.1 Production Capacity (Cp)

This is used for scheduling shifts and general short term (shift, day, week) planning, usually product specific when the time period is shift.

$$Cp = \text{Specified Speed} \times \frac{\text{estimated PE}}{100} \times \underset{\text{(shift, day, week)}}{\text{Working Time}}$$

5.2.2 Operational Capacity (Co)

This is an over-the-horizon medium term planning measure, typically over three or four months. Usually a specific product mix is used for Operational Efficiency, and some assumptions are usually made about its likely increase or decrease, based on historical data.

$$Co = \text{Specified Speed} \times \frac{\text{estimated OE}}{100} \times \underset{\text{(week, month)}}{\text{Working Time}}$$

5.2.3 Installed Capacity (Ci)

This is often used to determine whether the forecast sales for a year can be met. Some allowance for peaking must also be made when estimating this capacity.

$$Ci = \text{Specified Speed} \times \frac{\text{estimated OE}}{100} \times \text{Working Time (Year)} \times \text{Peaking Factor}$$

5.2.4 Design Capability (Cd)

This is the maximum capacity of a machine operated at 100% efficiency for a year.

$$Cd = \text{Specified Speed} \times \text{Calendar Time (8760 hours)}$$

6 Total Productive Maintenance (TPM)

6.1 TPM Overview

So far the techniques discussed have only outlined the key themes for effective performance management and provided KPIs to assist in the management task. TPM identifies, and then seeks to eliminate all the major equipment and process wastes by involving and utilising hidden skills and abilities of the company's workforce. It aims to achieve this by focused continuous improvements, whilst changing and invigorating the corporate culture and making the working environment more pleasant, safer and enjoyable. TPM sets out to improve:

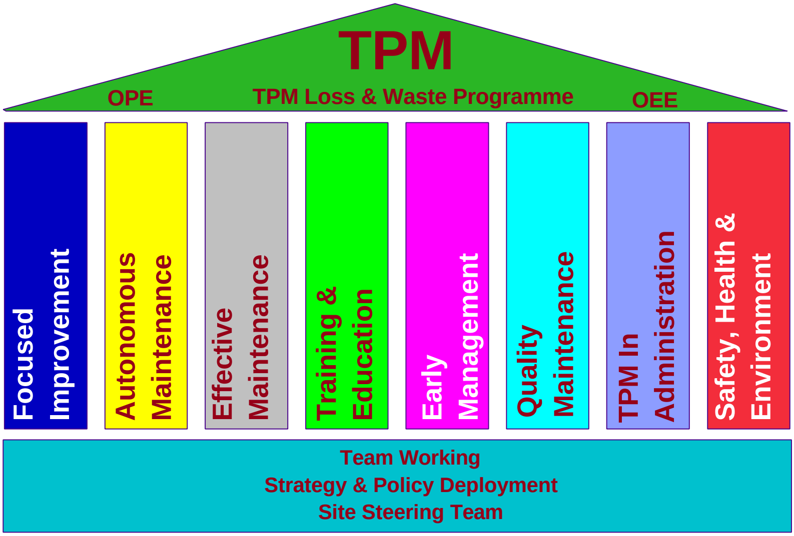
- Human resources
- Plant equipment
- Corporate culture

TPM supports the philosophy of World Class manufacturing, changing the traditional view that labor is the problem and equipment is the solution, to the new focus that equipment is the problem and labor is the solution.

There are eight pillars to the TPM approach (see below), supported by a loss and waste program, team working, strategy and policy deployment and site steering teams.

Finally, TPM has goals which every site wants to achieve and most importantly, the strategies and techniques to meet them:

- Zero Accidents
- Zero Waste
- Zero Losses
- Zero Defects



6.2 TPM Loss and Waste

Within the Loss and Waste Program of TPM, there are KPIs for measuring both the Manufacturing and Packing operations. Overall Process Efficiency (OPE) is used to monitor the Manufacturing process and Overall Equipment Efficiency (OEE) is used to measure the packing operations (Appendix B).

The OEE KPI embodies the OE efficiency measure, however, it sets the target speeds to be design theoretical, and also adds the extra dimension of quality performance. The OPE KPI is a measure that none of the existing KPIs have addressed so far, as it has been deemed to difficult. This uses a comparison of standard batch cycle times with actual cycle times to derive a performance value, as well as also including a quality measure.

The driver for this is the strength of Japans manufacturing industry, which has been leading the way in manufacturing excellence and performance management. It has been demonstrating the achievability that Efficiency, Reliability, Quality and Safety, can all be raised and maintained, and not to the detriment of manufacturing costs. They have achieved zero losses, zero defects, zero waste and zero accidents (4 Zeros).

Therefore the west has now started to embrace these new measures and use them to drive its management improvement programs. OPE and OEE are different from the OE and PE measures in that they use theoretical design speeds (OEE) and times (OPE), ensures that these KPI’s have a target focus, providing base lines for improvement monitoring.

7 Inter-Site Comparisons

7.1 Discussion

If every factory used the same machines, worked the same shifts and produced the same products to the same specifications and order requirements, then direct comparisons of many of the KPIs identified in this document would be realistic. However, every factory has different equipment, different working practices and work patterns, and delivers different products to different customer requirements.

If we take working time as a starting point, regional and national variations in holidays and workers expectations with respect to the working week lead to significant variations in achievable output and performance. It is far easier to produce efficiently over a shorter working week, as non-productive time can be utilised for more intensive maintenance programs, as well as having a less fatigued work force. However, this is usually to the detriment of total output.

When considering the time lost due to startup/shutdown, changeovers and cleaning, an inter-site standard must be enforced, otherwise lost time can be hidden by some sites as planned stoppages, and removed from the working time total. For changeovers in particular, it may be necessary to introduce a measure of the number of changeovers performed during the same KPI reporting period, thus revealing a major cause of poor performance during the comparison process. Sites who employ more production staff, can also boost their production performance by working through breaks and achieving faster changeovers etc. However, production costs, training and safety can become issues.

When considering asset utilization, care needs to be exercised in ensuring that site KPIs report on all assets and not just those they have planned to operate, as under utilised assets can quickly be moved to sites struggling to meet capacity demands. An allowance may also be necessary during utilization comparisons for increased flexibility to meet a variety of output demand. Sites with older assets have other issues, particularly with regard to failure frequencies, repair times and spares availability, leading to a disparity when comparing asset utilisation.

There are no hard and fast rules for inter-site comparisons, however, the following set of guidelines will assist in developing company standards for KPI reporting.

7.2 Inter-Site KPI comparison guidelines

1. Clearly specify the KPIs and the format in which they are to be reported.
2. Pick KPIs that eliminate regional and national work patterns and holidays.
3. Dictate the lost time allocation, eg. Cleaning, Startups/Shutdowns etc.
4. Specify the assets to be included in utilization KPIs, and ensure that central records are maintained with regard to asset age, failure frequencies and manning levels.
5. Assess efficiency indices with respect to number of changeovers and product mix.
6. Before performing comparisons, identify a similar asset or an asset that is used to package similar products on each comparable site. Have all comparison KPIs reported for this individual asset, as well as for the site, to identify a reference index for possible normalisation of the reported KPIs.

Appendix A: Definition of Manufacturing Time

A.1 Overall Breakdown of Manufacturing Time

Time	Losses
Calendar time "Calendar Time is the total available time in one calendar year"	
Loading Time "Loading Time is the weekly shift pattern - totaled for year"	**Unused Time**
Working time "The Amount of time the equipment must operate in one day totaled for one years"	**Shutdown Losses**
Operating time "The amount of time the equipment actually runs"	**Major Stoppage Losses**
Net operating time "The amount of time the equipment operates at its standard speed"	**Performance Losses**
Effective operating time "The amount of time the equipment operated producing good quality products"	**Defect Losses**

A.2 Definitions of Manufacturing Time

Calendar time "Calendar Time is the total available time in one calendar year"	

CALENDAR TIME

52 Weeks in a year
8760 Hours in a year

Loading Time "Loading Time is the weekly shift pattern - totaled for year"	**Unused Time**

UNUSED TIME

This is the time when the machine is not *NORMALLY* operated for the following reasons:

Statutory or Regulatory Reasons:

Religious holidays
Public holidays
Restrictions on weekend working
Enforced factory shutdowns
Working time regulations (WTR)

Local or industry conventions:

Shifts not worked (last shift Friday)
Weekend not worked.

Note:

It is normal that there are no crews available within the factory to man up this UNUSED TIME so if it is reduced it is normally done using overtime.

Working time "The Amount of time the equipment must operate in one day totaled for one years"	**Shutdown Losses**

SHUTDOWN LOSSES

This is the time during which the line could be used but it has been planned out for some or any of the following reasons:

Loss	Definition	Units	Examples of Loss
Shutdown Losses	Losses that occur due to the plant being stopped for a pre-planned activity	Hours	*Planned Maintenance* Overhauls Training Cleaning Safety Drills Meetings R&D Trials No demand Stock Check

WORKING TIME

This is the actual time that the factory PLANNED to produce the yearly production volume.

Operating time "The amount of time the equipment actually runs"	**Major Stoppage Losses**

MAJOR STOPPAGE LOSSES

There are three primary losses that can stop a production line:

Equipment Failure
Changeovers Losses
Start-up Losses

These losses are defined below:

Loss	Definition	Units	Examples of Loss
Equipment Failure	Losses that occur due to key equipment breaking down or deterioration, which causes the production to be stopped	Hours	Breakdown - pumps, motor, cooling system, instrumentation, robots, Palletiser, filling

	(for 5 minutes or more).		machine, services valves etc.
Changeover Losses	Losses that occur from the time lost from the end of production of the previous product through "product-changeover and adjustments required" to the point where the production of the new product is completely satisfactory	Hours	Changing one from one packaging size to another, or one product to another
Start Up Losses	Losses that occur from start up after: periodic maintenance, repairs, weekends, holidays (etc.) to the time when it is possible to make products at the desired quality and production rate.	Hours	Start-up on Sundays/Mondays, start-up after equipment breakdown, start-up after maintenance/overhaul.

Net operating time "The amount of time the equipment operates at its standard speed"	**Performance Losses**

PERFORMANCE LOSSES

There are two primary losses with can effective the overall performance of a production line:

Minor Stoppage & Idling Losses
Speed Losses

These losses are defined below:

Loss	Definition	Units	Examples of Loss
Minor Stoppages & Idling Losses	Losses that occur due to any production stoppages less than 5 minutes	Hours	Product and packaging jams Damaged packaging No services Minor equipment problems Buffer empty No staff No product/packaging Unplanned activities
Speed Losses	Losses caused by the difference between the equipment design speed (theoretical speed) and the actual speed that the equipment is running at (based on the type of product and packaging).	Hours	Running at reduced speeds to stop: quality defects, filling problems or labeling problems etc

Effective operating time "The amount of time the equipment operated producing good quality products"	**Defect Losses**

DEFFECT LOSSES

There are two primary losses with can effective the overall performance of a production line:

Quality Defects
Quality Rework

These losses are defined below:

Loss	Definition	Units	Examples of Loss
Quality Defects	Losses that occur to the packaging and labeling quality of the finished product being unacceptable and this product has to be destroyed or sold at a reduced price	Ton, Amount	Material and time that is permanently lost due to product quality being below standard required and product has to be destroyed or sold a lower prices
Quality Rework	Losses that occur to the packaging and labeling quality of the finished product being unacceptable and this product has to be reworked. (Recycling losses that occur due to passing materials back through the manufacturing process).	Ton, Amount	Damaged packaging, Air or water in products, Under weight, Boxes with wrong label or damaged.

Appendix B: OEE & OPE Formal Definitions

B.1 Overall Equipment Efficiency - OEE

This measure applies to packing lines.

OEE = (Availability rate) **x** (Performance rate) **x** (Quality rate)

AVAILABLITY
Availability Rate = $\frac{\text{Working time - Downtime}}{\text{Working time}}$ x 100
= $\frac{\text{Working time-[equip failures + prod changeover + start-up losses]}}{\text{Working time}}$ **x** 100

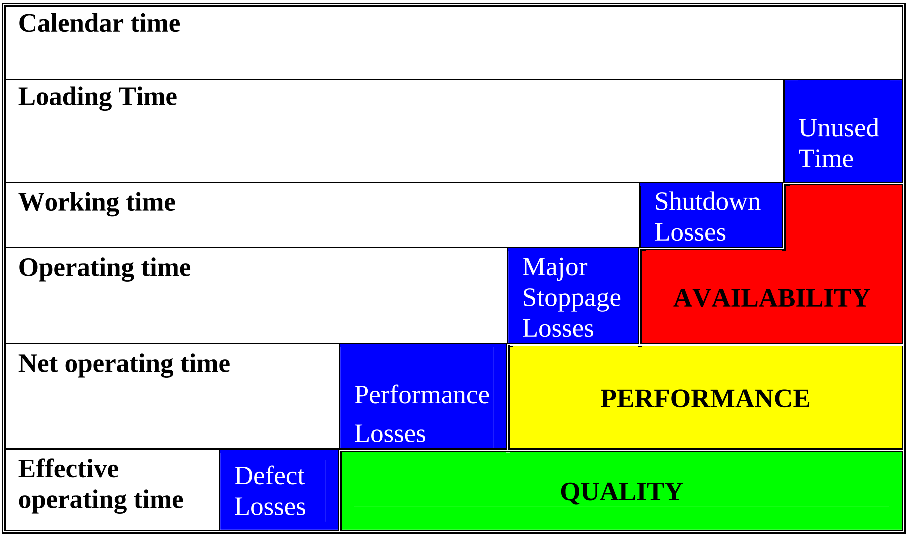
PERFORMANCE		
Performance Rate	=	Net Operating Rate x Speed Operating Rate
Notes		
Net Operating Rate	=	Output x Actual Cycle Time Working time - Downtime
Speed Operating Rate	=	$\frac{\text{Standard cycle time}}{\text{Actual cycle time}}$
Actual Cycle time	=	number of products produced per min (this number is usually taken from the filling

		machine) per product filled that shift and filled in on the log sheet on a shift-by-shift basis.
Standard Cycle time	=	theoretical number of products that could be filled per min (based both on machine capability and product formulation).
Output	=	number of products produced per shift

QUALITY
Quality Rate =   Total tons produced in week - (quality defects + quality rework) x 100   Total tons produced in week
Notes
Total tons produced = Total weekly amount of product from all log sheets

The data we need to do the OEE calculation is taken from the OEE Log sheets & the factory standard cycle speeds for the filling machines and is calculated on a weekly basis.

In order to better understand how OEE Availability, Performance and Quality relate to the other KPI's defined in this document please refer to this simple table:



B.2 Overall Process Efficiency - OPE

This measure applies to the process plant.
OPE = (Availability rate) x (Performance rate) x (Quality rate)

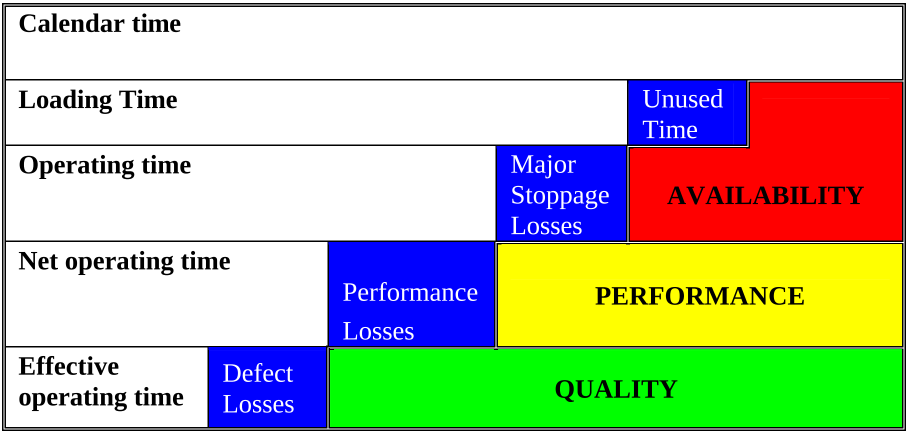
AVAILABLITY
Availability Rate = $\dfrac{\text{Loading time - Downtime}}{\text{Loading time}} \times 100$
= $\dfrac{\text{Loading time-[Planned + Equipment + Process + Logistic Losses]}}{\text{Loading time}} \times 100$

PERFORMANCE			
Performance Rate	=	Actual Output / Theoretical Output	x 100
Notes			
Theoretical Output	=	Using Operating Time, sum of actual output that could be achieved for each batch, based on standard batch cycle time.	

QUALITY		
Quality Rate	=	
$\frac{\text{Total tons produced in week - (quality defects + quality rework)}}{\text{Total tons produced in week}}$ x 100		
Notes		
Total tons produced	=	Total weekly amount of product from all log sheets

The data we need to do the OPE calculation is taken from the OPE Logsheets & the factory standard batch cycle times for the process equipment and is calculated on a weekly basis.

In order to better understand how OPE Availability, Performance and Quality relate to the other KPI's defined in this document please refer to this simple table:


Calendar time
Loading Time
Unused Time
Operating time
Major Stoppage Losses
AVAILABILITY
Net operating time
Performance Losses
PERFORMANCE
Effective operating time
Defect Losses
QUALITY