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e-book: World-Class TPM - How to calculate Overall Equipment Effectiveness (OEE)
January 2009

"How to calculate Overall Equipment Effectiveness (OEE)"
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Dear e-Participant,

Welcome to this e-Course! I am confident you will find it of interest, beneficial and, at times, also a bit entertaining.

To begin with, a quick presentation: I am Carlo Scodanibbio, Italian, Engineer, graduated in 1970, and with some 38 years of post-graduate experience in Project Engineering, Plant Engineering, Project Management, Industrial Engineering and Operations Management Consulting.
I have been a free-lance Industrial Consultant for the past 28 years, and a HR Trainer for the past 18.
My field of activity is: World Class Performance in the Small and Medium Enterprises.
I have operated in several Countries, including Italy, Romania, Malta, Turkey, Cyprus, Lebanon, Cape Verde, Kenya, Mauritius, Malaysia, India, Saudi Arabia, South Africa and neighbouring Countries.

My "real-world" training style is very interactive. I am afraid this won't be possible in the case of an e-Course, such as this one.

And yet, as a participant in this e-Course, you are entitled to contact me for clarifications or further explanations with regard to the topics of this Course.
You may do so by e-mail: mail@scodanibbio.com

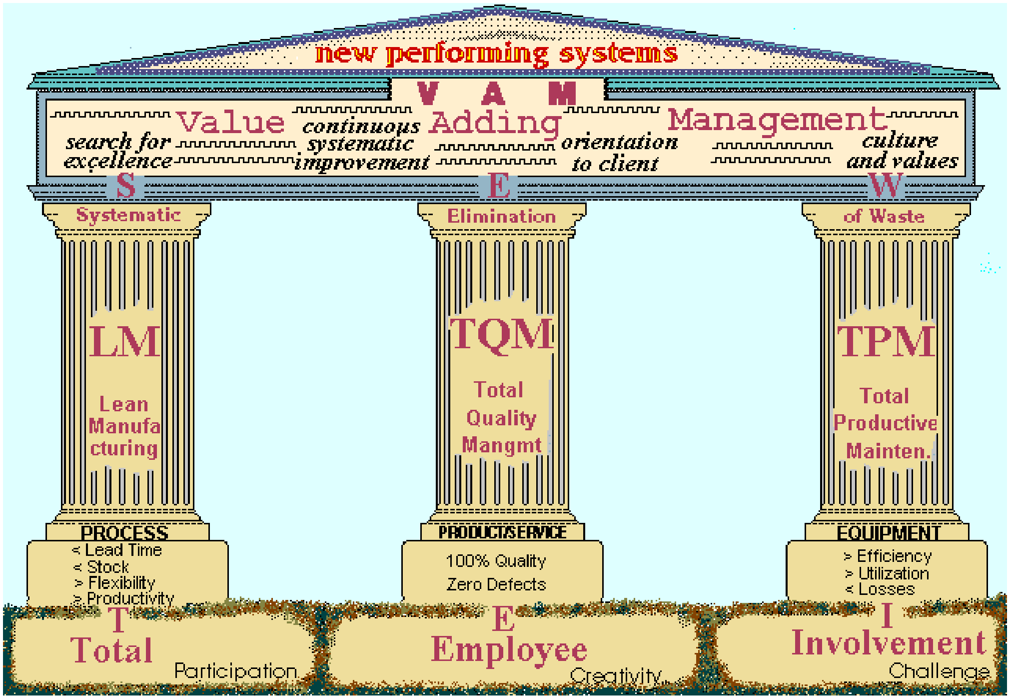
And now let's start.
The title of this Course is:

"How to calculate Overall Equipment Effectiveness (OEE)"

This is a primary-importance topic in the **Total Productive Maintenance** (**TPM**) discipline.

Before discussing about OEE, let me remind you of some basic principles of TPM. TPM was created originally by Nakajima over 20 years ago, and still considered today the leading Plant Management philosophy.

Actually, TPM is one of the pillars supporting any type of *world-class Operations*, be they Manufacturing, Construction or Service operations (the architectural representation below refers to World Class Manufacturing Operations):



In the ideal productive process, equipment should be operating at 100% capacity 100% of the time.

TPM is a powerful discipline leading, in a process of continuous, systematic improvement, towards the ideal, with 0 downtime, 0 defects and 0 safety problems.

"Traditional" TPM (as created by Nakajima) is a set of participative programs designed to increase equipment effectiveness (productivity - quality - safety) and aiming at various goals:

- elimination of the 6 big losses, in order to maximise equipment effectiveness
- restoration of equipment to optimal operating conditions
- elimination of accelerated deterioration
- autonomous maintenance activities to maintain basic equipment conditions
- increase in efficiency and cost-effectiveness of maintenance function
- maintainability improvement and development of a maintenance system for the equipment life
- maintenance prevention
- total involvement of people from all depts. that plan, design, use or maintain equipment - involvement of top management
- increase of operation and maintenance skills
- max. safety and environment conservation/pollution control
- and others

In this course we shall deal only in part with the first goal (elimination of the 6 big losses, in order to maximise equipment effectiveness).
Before going into that, let's point out that TPM has developed over the years, and today's TPM is somewhat different from the original concept.

Modern TPM is primarily concerned with the **value** generated by equipment, or by equipment and people together (as applicable).

Today's TPM focuses on the entire productive process to assure that the right equipment is part of a **value-adding/waste-free** series of operations, to assure (by deploying "traditional" TPM approaches) that equipment contributes "effectively" to the primary objective of **value-generation**.

As such, a valid TPM program starts with a thorough, critical examination of each productive process, querying the **value-adding status** of each piece of equipment (or equipment and people) in relation to the process.

The above illustrates the "lean" (waste-free) nature of modern TPM. Today's TPM overlaps with and is integral part of a newly-born discipline called Lean Maintenance.

Back to Overall Equipment Effectiveness.
Firstly, let's introduce the concept of Equipment Efficiency (as distinguished from Effectiveness):

$$\text{EQUIPMENT EFFICIENCY} = \frac{\text{OPTIMAL CONDITIONS THROUGHOUT EQUIPMENT LIFE}}{\text{LCC (LIFE CYCLE COST)}}$$

From this definition, one can see that Equipment Efficiency is higher/highest when that piece of equipment operates under optimal conditions with the minimum possible Life-Cycle Cost (or, overall Cost of a piece of equipment throughout its entire life-cycle, including: procurement cost, installation cost, maintenance cost, special tooling cost.... and, eventually, disposal cost).
What does "Optimal Conditions" mean? Under the TPM angle of view, we define optimal conditions those required for the concerned equipment to operate at its set performance parameters: mainly, design speed or design capacity.
In conclusion, the Equipment Efficiency refers to its ability to perform well at the lowest overall cost.

Efficiency is never alone, in a "lean" environment. Some machinery may work very efficiently but produce "junk" product. Not acceptable.
Hence we must define also the concept of Equipment Effectiveness:

$$\text{EQUIPMENT EFFECTIVENESS} = \text{MEASURE OF THE VALUE ADDED TO PRODUCTION THROUGH EQUIPMENT}$$

Equipment Effectiveness relates to the ability of a piece of Equipment to produce repeatedly what is intended to produce, i.e. **value**.
In which circumstances value is not produced? In all those occasions in which a piece of equipment "malfunctions": either it breaks down – or idles – or stops from time to time – or does not output the wanted quantity and/or quality – or shows yield losses on start-up/warming-up – or there is wasted manpower around it – or at its inlet – or at its outlet – or there is excessive Work-in-Progress between that piece of Equipment and a downstream operation – or there is excessive handling of materials within or around that piece of equipment - or….. the list could be very long, but that's enough.

Let's simply summarise by saying that Effectiveness lessens or goes lost whenever **waste** or **losses** reduce it.

There is in fact: **Equipment-related Waste** and **Equipment-related Losses**.
Traditional TPM targets at:

- Minimising Equipment Life-Cycle Cost
- Minimise Equipment-related Losses
- Maximise Efficiency
- Maximise Effectiveness (or part of it)

To point out again the main difference between "traditional" TPM and today's TPM, Nakajima only took into consideration Equipment-related Losses, covering the subject in an excellent way, but ignored the fact that there is also Equipment-related Waste (which may be predominant!).
I shall deal with Equipment-related Waste at the end of this course. Now let's focus on

Equipment-related Losses

Nakajima identified 6 types of Equipment-related Losses, the so-called 6 Big Losses. They are:

A] INACTIVITY LOSSES
There are two of them, and fall under this heading because when they occur the concerned piece of equipment is not "active".

1) BREAKDOWN LOSSES
This is a conspicuous type of Loss. When a break-down occurs in a factory (but not only in a factory) it is definitely noted, to the extent that everybody may jump up and down in despair, until it gets fixed. Generally a break-down:

- Is evident
- Is noted
- Has a considerable time duration
- Is hard/difficult/expensive/time consuming to repair
- Causes quantity losses (no output production)
- May cause as well quality losses (defective production just before the breakdown occurs or after it gets fixed)
- May be "sporadic" (occurs once in a while)
- May be "chronic" (it keeps re-occurring in spite of past repairs carried out)

As such, machinery breakdowns are considered evil N. 1 in every productive environment.
TPM target is to reduce breakdowns to 0 (zero), by deploying a number of approaches and techniques suited to the purpose (not falling within the scope of this course).

2) SET-UP LOSSES
Another conspicuous type of loss. When a machine or a production line gets "set-up" or "changed-over" there is, again, a halt to production. Set-up or Change-Over operations include for instance: replacing moulds (such as in an injection moulding machine), dies (for instance in a sheet-metal working press), tools (for instance in a milling machine), blades (for instance in a guillotine), plates (for instance in a silk-screen printer), etc. Generally, all set-up operations include some form of "adjustment" to be made (positioning – calibrating – centring – fine-tuning – etc.), also time consuming.

In many productive concerns set-ups are not even considered a loss, but simply a “necessary evil”. This mentality today is totally inadequate. Set-ups originate a “no-production situation” - as such they are a real and proper Loss, “chronic” in its nature (it keeps repeating regularly).
TPM considers set-ups a Big Loss, and addresses the issue through its allied discipline “**Achieving Quick Change-Over**”, based on the famous **SMED** (*Single-Minute-Exchange-of-Dies*) of Shigeo Shingo. The target is: drastic reduction of the set-up time to minimal levels - wherever possible to 0 (zero). This topic does not fall within the scope of this course.

B] SPEED LOSSES
There are two of them, and fall under this heading because when they occur what is affected is the speed or productive capacity of the concerned piece of equipment.

3) IDLING – MINOR STOPPAGES
Definitions:
IDLING: Equipment running without producing (“...processing fresh air.....”).
Production machines may idle for a number of reasons. The classic example is idling caused by absence of input material (for instance in an automated machine): the machine works but no material gets processed because it gets “clogged” somewhere upstream in the machine. The machine produces “fresh air”.
MINOR STOPPAGE: Equipment stops temporarily as a consequence of a (generally) small problem (could be material jamming, or a vibrator not vibrating properly, or a limit switch gone out of setting, etc.).

Both losses, usually, are timely noticed by operators and quickly/simply rectified (generally, in a “stop-gap” fashion). In many factories one may notice operators running up and down around a machine to remedy this kind of problems.
Each occurrence is generally of small entity but, cumulatively, the overall loss may be conspicuous by the end of the day or the shift (1 minute + half a minute + 1 minute + 1,5 minutes ++++ may become half an hour or more…..).
Moreover, both losses contribute to an ineffective utilisation of operators: in many instances, rather than using machines, <u>operators are abused by them</u>.

BOTH LOSSES ARE DIFFICULT TO ELIMINATE FOR VARIOUS REASONS:
- (Each) individual problem is fast and difficult to observe and analyse
- The entity of (each) problem is generally small, difficult to measure
- In factories with a large numbers of automated machines, these occurrences may develop with a tremendous variety of features, locations, timing, frequency, etc.
- Production people (operators first) get easily used to them
- Maintenance people, often, are not even aware of them, and anyhow loaded with more pressing problems
- Even at Production Management level, “due allowance” in production schedules is made to cater for unforeseen/s of this nature

Conclusion: both losses may develop, exist and persist, to the extent that they become “normal” and even “institutionalised”.
TPM target is to reduce both these “chronic” losses to 0 (zero), by deploying a number of approaches and techniques suited to the purpose (not falling within the scope of this course).

4) REDUCED SPEED (PRODUCTION CAPACITY) LOSSES
These losses, generally “chronic”, take into account the difference between ***design*** or ***ideal speed*** of a machine and ***actual operating speed***.

Causes may be many: mechanical problems, defective quality, history of past problems, fear of abusing the equipment...... Often, the ideal or optimal or design speed is not even known.
In many factories, foremen and production supervisors prefer “quiet sleeps”: why trying to run a machine at maximum capacity? “…quality may suffer….” – “…you don’t run your car at maximum speed all the times, do you?.....” – “…why risking a break-down… reduce the speed a bit….”.
So, every machine fitted with speed control gets that knob turned down a little: maybe to 90%, maybe to 80%, maybe to 70% (or less) of the rated speed.
The net conclusion? Output quantity is reduced proportionally: it is like if the machine would produce at full steam but for a shorter time. Loss.

TPM target is to reduce speed losses to 0 (zero) and even to surpass design speed if possible and convenient by deploying a number of approaches and techniques suited to the purpose (not falling within the scope of this course).

C] DEFECTS LOSSES

There are two of them, and fall under this heading because when they occur what is affected is the output quality of the product produced by the concerned piece of equipment.

5) QUALITY DEFECTS & RE-WORK

Machines may produce defects or non-conforming product due to: equipment malfunctioning – defective input material – inadequate maintenance – non-appropriate operation – etc.
When defects are produced, generally the machine must be stopped to eliminate the cause of defectiveness. Unfortunately, the faster a machine the larger the amount of defective output product if the machine is not stopped timely (faster machines may become fast junk producers….).
If defects are produced, some additional loss (or, in fact, waste) may occur: the matter must be investigated and analysed – the matter must be rectified – a decision must be made with regard to the defective product produced: scrap it? (pure loss) – re-work it? (pure loss) – degrade it? (partial loss) – and so on.
Machine-related defectiveness is often extremely difficult to fight: in many instance there is not a *simple cause-effect relationship* (single cause) but rather a number of concurring factors influencing the problem (*multi-cause situation*). So the problem may become very difficult to solve.

TPM target is to reduce quality losses to 0 (zero) by deploying a number of approaches and techniques suited to the purpose (not falling within the scope of this course).

6) START-UP YIELD LOSSES

Many machines suffer from what I call the “Alfa Romeo syndrome”. Do you remember the old Alfa Romeo that needed the engine to idle for 2-3 minutes at 1200 rpm before you could get it into gear? (But after that it would perform almost like a Porsche!.....).
Some machinery need to go through a “warm-up” process, during which defective product is produced until the correct operational parameters are all achieved, generating as such a “yield” type of Loss. Many printers, plastic welders, winders, and so on suffer from this syndrome.
The net result is (again) a quality-related loss, not during normal operation of the machine but only on its start-up. So Yield Losses occur during early stages of production, from machine start-up to stabilisation. They include "*Trial Runs*" losses.
Yield Losses are normally “chronic” and “latent” losses, often difficult to eliminate because of uncritical acceptance of their inevitability.

TPM target is to reduce these losses to minimal, acceptable levels by deploying a number of approaches and techniques suited to the purpose (not falling within the scope of this course).

In order to calculate the OEE – Overall Equipment Effectiveness index we need to correlate the 6 Big Losses as described above to time: the productive time.

In every productive concern (a factory, a plant, a construction site and even an office in which any equipment is used) we can define a number of different times for the concerned machinery for which OEE should be calculated (please note the terminology I have adopted is slightly different from the original Nakajima's one and also from that used by other authors):

AVAILABLE TIME

During a given period, a day, a week or a month, we can identify an Available Time.
This is the time "available" for production. So, if a factory operates on a single shift basis (8 hours per day, for instance) for 5 days a week, the Available Time is 8 hours/day for 5 days a week (or +- 22 days in a month).
If it operates round-the-clock on a 3 shifts basis for 5 days a week, the Available Time is 24 hours/day for 5 days a week.
If a Plant (for instance, a refinery – or a chemical complex) operates round the clock throughout the year, the Available Time is 24 hours/day for 365 days per year.
And if a Construction Site operates (as it happens) on a single 12-hour shift for 6 days a week, the Available Time is 12 hours/day for 6 days a week (or +- 26 days per month).
The above seems rather straight-forward, however I keep receiving lots of questions on this subject in my real-world courses, hence all those examples.

PLANNED DOWNTIME

During the Available Time, equipment may be not operating for a number of reasons: planned breaks in production schedule – planned maintenance – precautionary resting time – lack of work – and others. So, if there is any Planned Downtime, this should be subtracted from the Available Time and what is left is the

ACTIVE TIME

Or, that time during which equipment is actually scheduled to operate and available for production. So,

ACTIVE TIME = AVAILABLE TIME – PLANNED DOWNTIME

During the Active Time, however:

- Equipment may be subject to ***break-downs*** (Big Loss N. 1) – and/or
- Equipment may need to be ***set-up*** (Big Loss N. 2)

with the net result that the concerned piece of equipment may not operate all along the entire Operating Time.
If Losses 1 and/or 2 occur, their corresponding duration in time must be subtracted from the Operating Time, and what is left is the

OPERATING TIME

that is that time during which equipment actually operates.
So,

OPERATING TIME = ACTIVE TIME – LOSSES 1-2 DOWNTIME

For instance, if a packaging machine has an Available Time of 8 hours per day – there is a Planned Downtime of 45 minutes per day (production breaks) – with a resulting Active Time of 7 hours and 15 minutes – during which there is a set-up to be made lasting 1 hour and 15 minutes – besides that machine has a minor break-down fixed in a total of 30 minutes – the Operating Time would be 5 hours and 30 minutes (7H15' – 1H15' – 30' = 5H30').

The Operating Time may be reduced further by a number of ***Minor Stoppages*** and some ***Idling*** (Big Loss N. 3). The cumulated time of these minor losses must be subtracted from the Operating Time, and what is left is the

NET OPERATING TIME

that is the time during which equipment operates under stable conditions. Idling and Minor Stoppages cause a "hiccup" type of production, in extreme cases becoming a "stop-and-go" production, very unstable, not continuous.

NET OPERATING TIME = OPERATING TIME – LOSS3 DOWNTIME

The cumulated duration of Minor Stoppages and Idling times may be conspicuous at the end of the period under consideration.
For instance, in the same example of the packaging machine above, if the cumulated duration of idling and minor stoppages in that day is 45 minutes, the Net Operating Time would be 4 Hours and 45 minutes (5H30' – 45').

Not finished, yet.
A machine may (for the reasons highlighted above) not operate at full speed or at full capacity.
If a machine has a rated speed of 100% but we "turn its knob down" and let it run at 80%, 20% of its Net Operating Time goes down the drain, isn't it? There is a ***Speed Loss***.
It is like if that machine would operate for 20% less time but at full, rated or design speed.
When this type of Loss (Big Loss N. 4) comes onto the scene we must chop the Net Operating Time even further, by an amount corresponding at that reduced speed rate.
What is left is what I call the

PERFORMING TIME

or the time during which equipment operates under stable conditions AND at an optimal (or rated – or designed) speed or capacity.

PERFORMING TIME = NET OPERATING TIME – LOSS4 DOWNTIME

The downtime corresponding to this type of Loss may sometimes be tricky to calculate.
We shall see below some practical ways to take it into account.
In the example of the packaging machine, if it operates at 80% of its rated speed, the corresponding downtime would be 20% of the Net Operating Time (4 Hours and 45 minutes = 245 minutes), or 49 minutes. Thus its Performing Time would be 3 Hours and 56 minutes (4H45' – 49' = 3H56').

Not finished, yet,
During the Performing Time:

- A piece of equipment may produce some ***Yield Losses***, for instance at morning start-up (Big Loss N. 6) – and
- While it operates, it may produce defective product (***Quality Defects*** – Big Loss N. 5)

The time spent to produce Yield Losses (which is actually a Downtime) must be subtracted from the Performing Time. The time spent to Produce Quality Defects (and to re-work them, if at all possible) must also be subtracted from the Performing Time.
What is left is what I call

VALUABLE OPERATING TIME
or the time during which equipment actually operates, under stable conditions, at optimal speed, AND producing acceptable output product.

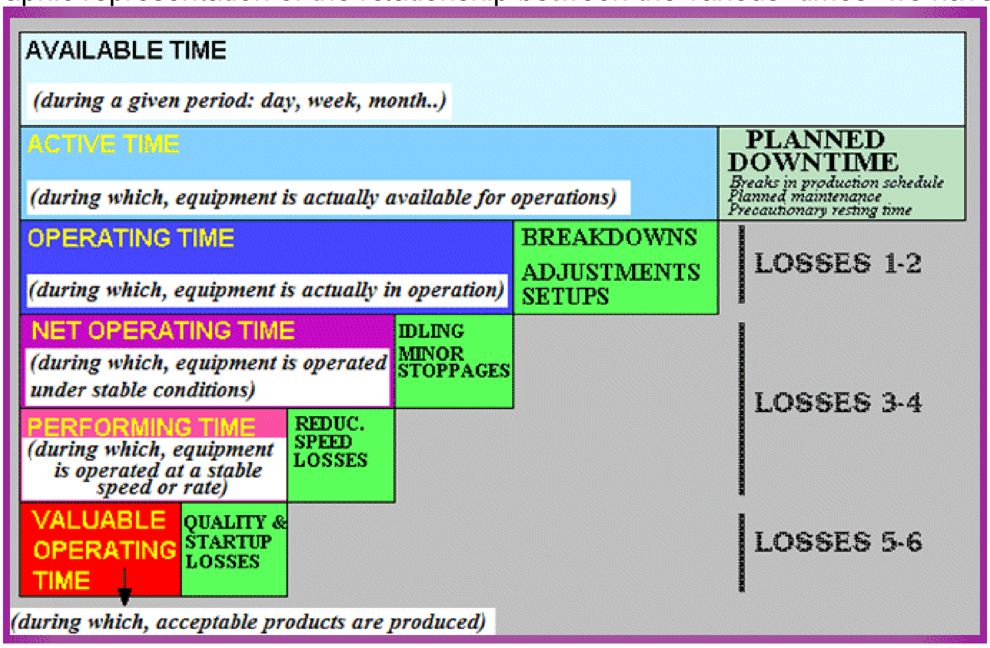
VALUABLE OPERATING TIME = PERFORMING TIME – LOSSES5-6 DOWNTIME

To take into account Big Loss N. 6 Downtime is rather straight-forward: it's all that "warm-up" time during which un-acceptable product is still produced until the machine "stabilises".
To calculate Big Loss N. 5 Downtime (Quality Defects) may at times be somewhat tricky, especially if non-conforming product produced can be re-worked to bring it back to conforming status. Practical tips are given below.

In the example of the packaging machine, if it took 10 minutes of morning start-up time to bring it to stabilisation, and during actual production produced defective products for 5 minutes before a busy operator would notice it and stop it, the corresponding overall downtime for Losses 5 and 6 would amount to 15 minutes, and the Valuable Operating Time would be 3 Hours 41 minutes (3H56' – 15'). Not brilliant for a production day, is it?

Now a remark.
Why "*Valuable*" Operating Time?
Because this is the "net" time during which equipment actually contributes to add "value" to production, now that all losses and lost downtime have been taken out.
BUT!! We are referring to Equipment-related Losses ONLY. We have not considered "waste" around that concerned piece of equipment or within the process in which that piece of equipment operates!
This aspect will be taken into consideration below, when I shall discuss about to the "leanness" of a manufacturing process.

Here is a graphic representation of the relationship between the various "times" we have identified:



It's easy to understand that the ***OEE – Overall Equipment Effectiveness Index*** of a piece of equipment in a given time is nothing else than the ratio between the Valuable Operating Time and the Active Time.
By definition, **the OEE is a measure of the value added to production by a certain machine in a certain period of time**.
If that machine was operating 100% of the Active Time without being subject to any Loss, the Valuable Operating Time would coincide with the Active Time: the entire Active Time would be devoted to add value to production.
Unfortunately there are Losses….

So,

$$\textbf{OEE = OVERALL EQUIPMENT EFFECTIVENESS} = \frac{\textbf{VALUABLE OPERATING TIME}}{\textbf{ACTIVE TIME}}$$

Generally, the OEE Index is expressed as a percentage, therefore,

$$\textbf{OEE = OVERALL EQUIPMENT EFFECTIVENESS} = \frac{\textbf{VALUABLE OPERATING TIME}}{\textbf{ACTIVE TIME}} \times 100$$

So, this course is over, you will say…….

NO! Not at all!
An Index like that would be somewhat meaningful but, in practice, useless.
To know that our packaging machine in the example above has an OEE = 50,8% (100 x 3H41'/7H15' = 100 x 221'/435') doesn't say much: it says that the machine did not perform very well at all in that day, but does not say WHY it performed badly and WHAT went wrong.
We need to know that "why" (details of how the various Losses contributed to a poor OEE) in order to launch corrective, improvement actions, isn't it?

So, let's go step-by-step in the calculation of the OEE.

GENERAL STEP-BY-STEP METHOD FOR CALCULATING THE OEE INDEX

This is a general method for OEE calculation.
However, we have to distinguish between types of machinery, since the way to calculate Speed and Idling/Minor Stoppages Losses varies:

- We have a first class of machines processing work-pieces one by one (like in an automated labeller that sticks labels onto bottles or cans one at a time, one piece by one piece). And we have machines that process work-pieces in small lots (6 – 12 – 24….) like in an automated beer can packaging machine that outputs 6 packaged cans of beer at a time. In all these cases we can identify a ***Cycle Time***, or the amount of time required to carry out repetitively one single processing operation (sticking one label or packaging 6 cans of beer). We can actually refer to the Cycle Time to identify and classify the processing *Speed* or *Productive Capacity* of a machine: so we say that a labeller has a rated speed of 60 labels per minute, meaning that the unit Cycle Time (the time required to stick one label) is one second – therefore 60 labels are stuck in a minute. Most machines used in the Manufacturing Industry fall under this class.

- Then we have a second class of machines that do not process work-pieces, but “lots” of material measured in litres, kilograms, tons, cubic metres and so on. In this class belong many machines used in the Manufacturing Industry for some form of Continuous Processing: for instance, dairy products processing equipment such as pasteuriser – mixers – and the like. They process so many litres, or kilolitres or kilograms or whatever per hour, and not pieces per second or per minute. In the Continuous Process Industry , like in chemical complexes, cement factories, steel factories, etc, there are as well many pieces of equipment falling in this class. The same applies to some Construction Industry equipment like batching and concrete mixing plants, concrete pumps, earthmoving equipment like excavators, etc. In this cases we define a “***productive rate***” (and not a *cycle time*) expressed in tons/hour, cubic metres/hour, and so on.

This distinction comes useful when calculating the impact caused by Speed and Idling/Minor Stoppages Losses.

And now we can start our step-by-step approach.

MACHINERY CLASS A (most Manufacturing Equipment)

Let’s identify all components of the OEE Index - we call these components ***rates***.

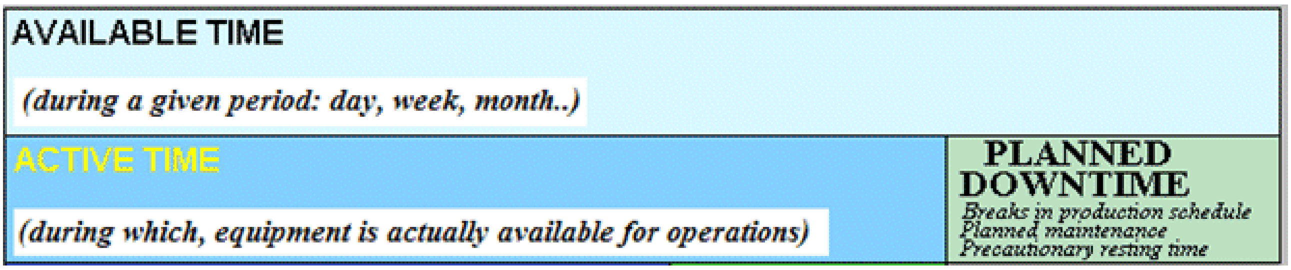
ACTIVITY RATE

This is not a component of OEE, but comes handy for a couple of reasons.

By definition

$$\textbf{ACTIVITY RATE} = \frac{\textbf{AVAILABLE TIME} - \textbf{PLANNED DOWNTIME}}{\textbf{AVAILABLE TIME}} \times 100$$

The Activity Rate reflects the actual utilisation of equipment and is a measure of the ACTIVE TIME.



Why does it come handy? Because – generally speaking – equipment is there to be utilised, ideally 100% of the Available Time. If the Activity Rate is less or much less than 100%, Production/Operation Management may wish to query the reasons “*why*”. Which may lead to some good thinking about ways to reduce Planned Downtime and maximise this rate.

➢ OPERATIVITY RATE

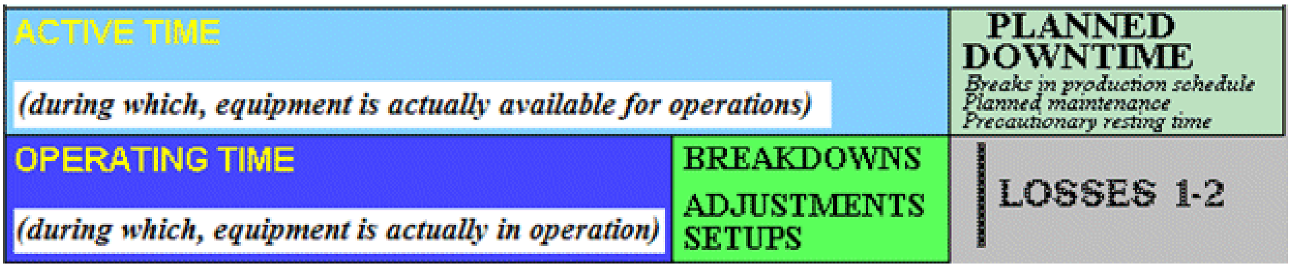
This is a primary component of OEE.

By definition

$$\text{OPERATIVITY RATE} = \frac{\text{ACTIVE TIME} - \text{MAJOR STOPPAGE LOSSES}}{\text{ACTIVE TIME}} \times 100$$

This rate reflects the impact of ***major losses*** (***break-down*** and ***set-up*** losses are considered *major losses*) on the overall effectiveness of a piece of equipment in a given time, and as such refers to the OPERATING TIME.

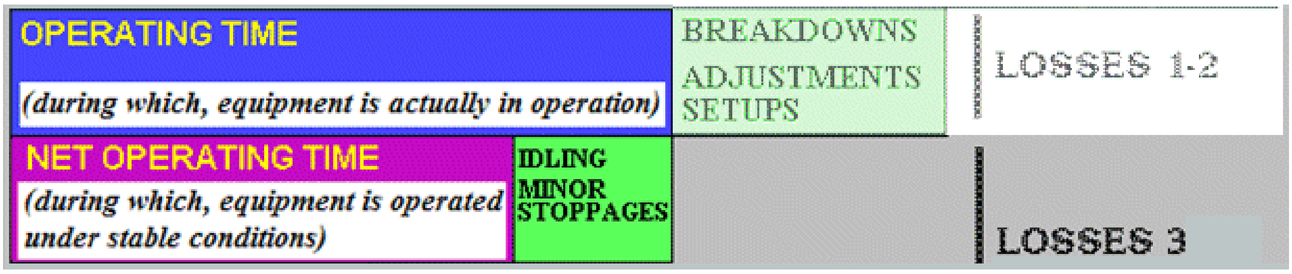
If you remember the definition of Operating Time



you will see immediately the relationship between Operating Time and Active Time and the impact of major stoppage losses.

NET OPERATING RATE
This is not a direct component of OEE but contributes to define one of its main composing rates.

By definition, this rate reflects losses resulting from ***idling*** and ***minor stoppages***, and as such refers to the NET OPERATING TIME.



How do we take into account Idling and Minor Stoppages Losses?
Difficult or awkward because of their duration (short) and their frequency (generally high). In most automated machines it's practically impossible to measure this type of losses unless we fit a counting/timing device to the machine that measures the duration of each and every occurrence.
There is a shortcut, however, and that's where the distinction into 2 classes of machinery introduced above comes handy.
In this Class A machinery there is always a real ***cycle time*** (***actual cycle time***) or the time it takes to process one unit of product (one work-piece or one small lot of work-pieces) at the actual speed the machine is working.

Now think aloud with me:

If the machine under consideration was not subject to any idling or minor stoppage during the concerned period, it would output product according to the formula

OUTPUT = OPERATING TIME/ACTUAL CYCLE TIME

For instance if a machine has an actual cycle time to process one work-piece of 2 seconds and its Operating Time in a shift is 6 Hours, the output product at the end of the shift would be 10800 units of product (6 hours = 360 minutes = 21600 seconds/2second = 10800 pieces).

BUT, if the machine was subject to some Idling here and there and some Minor Stoppages from time to time, the overall output would be less, wouldn't it?
So, to assess the impact of Losses 3, all we have to do is to count the output product at the end of a shift or a day or whatever, which we normally do anyway for good production administration practices.

Therefore the Net Operating Rate can be easily calculated as follows:

$$\text{NET OPERATING RATE} = \frac{\text{OUTPUT x ACTUAL CYCLE TIME}}{\text{OPERATING TIME}} \times 100$$

If the same machine above would produce at the end of the shift only 9720 items of product instead of 10800, its Net Operating Rate would be 100 x (9720 x 2 seconds)/21600 seconds = 19440 seconds/21600 seconds = 90%. As a double check: 100 x 9720/10800 = 90% - clear?

NB1: Obviously the ***actual cycle time*** must be known. If not it must be measured with a stop watch.
NB2: As we shall see below, the ***actual cycle time*** is the real one at which the machine actually operates, not the ideal one, or the design one, or the one written in the specification manual! Very important to re-measure it regularly!
NB3: The ***OUTPUT*** is actually all the ***INPUT PRODUCT***, the ***GROSS INPUT***. Why? Because if some input work-piece came out of the machine with some defect, this will be accounted below when we consider Quality Losses! What we are assessing now is only the impact of Idling and Minor Stoppages!

OUTPUT = INPUT PRODUCT = GROSS INPUT

OPERATING SPEED COEFFICIENT

This is not a direct component of OEE but contributes to define one of its main composing rates.

The definition of the Operating Speed Coefficient (which caters for ***speed losses***) for this Class A of machinery, is:

$$\text{OPERATING SPEED COEFFICIENT} = \frac{\text{IDEAL CYCLE TIME}}{\text{ACTUAL CYCLE TIME}}$$

As pointed out above, the ***actual cycle time*** may well differ from the ***ideal cycle time*** (or ***design cycle time***), for all reasons highlighted when illustrating Speed Losses.

For Class A of machinery, this coefficient is the perfect way of reflecting the impact of speed losses: if a machine goes slower than its ideal or design speed, the time it takes to process one unit of product is longer so its *actual cycle time* is longer.

For instance, if the same machine above has an *ideal cycle time* of 0,8 seconds whereas its *actual cycle time* is 1 second, its *operating speed coefficient* would be 0,8 (0,8/1).

NB: This coefficient is normally not expressed as a % (but it would be the same).

An now we can introduce another component of OEE, the

➢ PERFORMANCE RATE

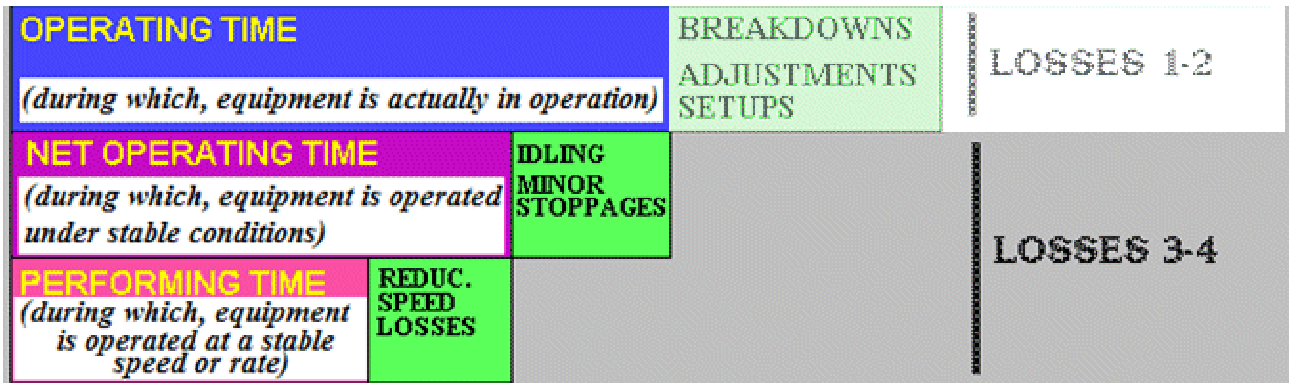
This is another primary component of OEE.

By definition:

PERFORMANCE RATE = NET OPERATING RATE x OPERATING SPEED COEFFICIENT x 100

This rate reflects the impact of ***losses3 and 4*** (***idling/minor stoppages*** and ***speed losses***) on the overall effectiveness of a piece of equipment in a given time, and as such refers to the PERFORMING TIME.

If you remember the definition of Performing Time



you will see immediately the relationship between *Performing Time* and *Operating Time*: the impact of ***idling and minor stoppages losses*** is taken into consideration by the *Net Operating Rate* – the impact of ***speed losses*** is reflected by the *Operating Speed Coefficient*. The overall impact gives origin to the *Performing Rate.*

Now, if you remember

$$\textbf{NET OPERATING RATE} = \frac{\textbf{OUTPUT x ACTUAL CYCLE TIME}}{\textbf{OPERATING TIME}} \times 100$$

and

$$\textbf{OPERATING SPEED COEFFICIENT} = \frac{\textbf{IDEAL CYCLE TIME}}{\textbf{ACTUAL CYCLE TIME}}$$

With simple maths, we have a practical formula for calculating the Performance Rate:

$$\text{PERFORMANCE RATE} = \frac{\text{OUTPUT} \times \cancel{\text{ACTUAL CYCLE TIME}}}{\text{OPERATING TIME}} \times \frac{\text{IDEAL CYCLE TIME}}{\cancel{\text{ACTUAL CYCLE TIME}}} \times 100$$

So,

$$\text{PERFORMANCE RATE} = \frac{\text{OUTPUT} \times \text{IDEAL CYCLE TIME}}{\text{OPERATING TIME}} \times 100$$

Well, simple maths, but sometimes confusing.... No worry!

NB1: Obviously the ***ideal cycle time*** must also be known. Possibly, it can be found in the machine's Operation Manual or in its Specifications. Otherwise, it must be estimated realistically! There is no other way.

NB2: once again, the ***OUTPUT*** is actually all the ***INPUT PRODUCT***, the ***GROSS INPUT***, as pointed out above.

OUTPUT = INPUT PRODUCT = GROSS INPUT

And, finally,

- **QUALITY RATE**

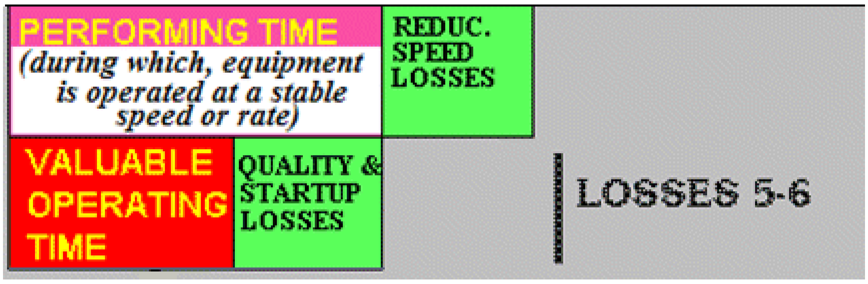
The third core component of OEE.

By definition:

$$\text{QUALITY RATE} = \frac{\text{GOOD OUTPUT PRODUCT}}{\text{INPUT}} \times 100$$

This rate reflects the impact of ***losses5 and 6*** (***quality defects losses*** and ***start-up yield losses***) on the overall effectiveness of a piece of equipment in a given time, and as such refers to the VALUABLE OPERATING TIME.

Let's recall the definition of Valuable Operating Time:



The rather easy way to calculate this rate is by measuring the ***good output product*** (**GOP**) and to relate it to the ***input***. In number of pieces:

GOP = INPUT – (STARTUP DEFECTS + TRIAL DEFECTS + PROCESS DEFECTS)

In fact, a **Class A Machine** (most Manufacturing Equipment) may produce:

- defective product on *start-up/warm-up* (***yield loss***)
- defective product during *trial runs* (both at the end of a start-up operation AND after fixing a quality problem during normal operation) – (***yield loss*** and/or ***quality defect loss***)
- defective product during *normal operation* (***quality defect loss***)

All we have to do is to sum up ALL defective/non-conforming product produced during the *Active Time* under consideration.

So, if we fed a machine a total number of 8600 input pieces during its Active Time, and

- there were 120 defects during start-up
- another 20 defects during quality trial runs at the end of the start-up period
- 280 defective output pieces during normal operation
- and another 10 non-conforming pieces during a trial run performed by a maintenance technician after fixing the previous quality defect problem

the total defective pieces would be 120 + 20 + 280 + 10 = 430 pieces and the GOP would be (8600 – 430) = 8170 good pieces.
The Quality Rate of that machine in that period of time then would be 100 x 8170/8600 = 95%

NB1: about ***Trial Runs***. It is good practice to distinguish between *after-start-up-trial-run-defects* and *start-up-defects* – and *after-fixing-quality-problems-trial-run-defects* and *normal-operation-quality-defect*. WHY?
Because if we account for defects produced during trial runs, we can take actions to reduce them!
In a good TPM program we are generally very concerned about junk product produced by machines, but we tend to skip the impact of defects produced for quality assurance purposes during trial-runs. We tend to consider it a necessary evil….
I disagree with this mentality. Maintenance Technicians and/or Operators and/or Quality Controllers generally want to sleep quietly and, by making sure a machine is now “in tune”, do not consider this camouflaged trial-run loss: “…just let the machine run until we are sure that it’s OK…”.
Obviously trial-run output gets all discarded (just in case! – including product that may be good) and becomes a dead loss.
In a good TPM program such mentality must be removed: each piece of product counts! It’s just a matter of making the concerned people “think” a bit more and improve Operators/Technicians “fine-tuning” abilities: those trial-run losses can be reduced to half and then close to zero!

NB2: while on the subject of Trial Runs, what about trial-run defects produced after a set-up or change-over (***big loss N. 2***)?
The ***Internal Change-Over Time*** (that time during which a machine does not produce good product because it’s being set up) includes ***trial-run time*** (time spent for final calibration/fine-tuning of a machine until it outputs good product). That’s all is needed to calculate the impact of ***big loss N. 2*** and then the Operativity Rate. Fair enough.
BUT, in a good TPM program, we should also count all trial-run defects produced at final stages of a set-up operation for the same reasons as in **NB1** above! OK?

Very well, now we finally have the 3 main OEE rates for Class A Machinery:

- the **OPERATIVITY RATE (OR)**
- the **PERFORMANCE RATE (PR)**
- the **QUALITY RATE (QR)**

You may easily imagine that the **Overall Equipment Effectiveness Index** (**OEE**) of a machine in a given period of time is the product of the 3 Rates:

OEE = OVERALL EQUIPMENT EFFECTIVENESS = OR x PR x QR

Do you want a proof? No problem, just get ready for some heavy maths (huh, huh).
Remember!

$$\text{OR} = \frac{\text{ACTIVE TIME} - \text{MAJOR STOPPAGE LOSSES}}{\text{ACTIVE TIME}} \times 100$$

and

$$\text{PR} = \frac{\text{OUTPUT} \times \text{IDEAL CYCLE TIME}}{\text{OPERATING TIME}} \times 100$$

and

$$\text{QR} = \frac{\text{GOOD OUTPUT PRODUCT}}{\text{INPUT}} \times 100$$

and remember also that
the ***OUTPUT*** is actually all the ***INPUT PRODUCT***: the ***GROSS INPUT***

OUTPUT = INPUT PRODUCT = GROSS INPUT

So:

$$\text{OEE} = \text{OR} \times \text{PR} \times \text{QR} = \frac{\text{ACTIVE TIME} - \text{MAJOR STOPPAGE LOSSES}}{\text{ACTIVE TIME}} \times$$

$$\times \frac{\text{OUTPUT} \times \text{IDEAL CYCLE TIME}}{\text{OPERATING TIME}} \times \frac{\text{GOOD OUTPUT PRODUCT}}{\text{INPUT}} =$$

$$= \frac{\cancel{\text{OPERATING TIME}}}{\text{ACTIVE TIME}} \times \frac{\cancel{\text{INPUT}} \times \text{IDEAL CYCLE TIME}}{\cancel{\text{OPERATING TIME}}} \times \frac{\text{GOOD OUTPUT PRODUCT}}{\cancel{\text{INPUT}}} =$$

$$= \frac{\text{GOOD OUTPUT PRODUCT} \times \text{IDEAL CYCLE TIME}}{\text{ACTIVE TIME}} = \frac{\text{VALUABLE OPERATING TIME}}{\text{ACTIVE TIME}}$$

WOWWWWWWWWW! Are you still alive!

You may ask:
but why GOOD OUTPUT PRODUCT x IDEAL CYCLE TIME = VALUABLE OPERATING TIME?

By definition! The *Valuable Operating Time* is that time during which a piece of equipment produces good product, under stable conditions, at maximum speed, without any loss in between. That's exactly the same as saying: ***it's the time that takes to produce all good output products at maximum speed*** (ideal cycle time).

In conclusion

$$\text{OEE} = \text{OR} \times \text{PR} \times \text{QR} = \frac{\text{VALUABLE OPERATING TIME}}{\text{ACTIVE TIME}} \times 100$$

REMARKS

- The conclusion is perfectly valid both for ***Class A Machinery*** and for ***Class B Machinery***. It's the calculation method that varies (see below)
- Since *OEE* is the product of 3 Rates, it's value can only be equal or lower than the poorest of the 3 Rates. So, if OR = 90% and PR = 95% and QR = 97%   OEE = 90% x 95% x 97% = 83% (less than OR).
- As said above, what is important is to determine the 3 Rates individually and then calculate OEE as product of the 3 Rates. The second part of the formula (OEE = VALUABLE OPERATING TIME/ACTIVE TIME) can be used for a shortcut verification of the calculation performed.

Is there a template, or a drill, or a calculation sheet that can help to determine the OEE of a machine in a given period of time?
Yes, there are plenty of them. Just do a search on the Net and you will find many, all the same.

In a sudden impulse of generosity, here is my Calculation Sheet ready for you to use:

MY PHILOSOPHY, MY VISION, MY MISSION

I believe in Value and Lean.

I believe that in many decades of industrialisation we have somehow lost a key word and a key concept: value - value that Enterprises offer to Clients - value generated by productive processes - value produced by managers and employees in their daily confrontation with reality - value produced by plant, equipment, machines, and technology - value brought in by suppliers - value inherent in people know-how - value generated by continuous improvement.........

Today, World Class Performers are re-discovering the vital importance of this key concept, and build enterprises engineered to produce pure, abundant value. World Class Performers are Enterprises that build their competitiveness on the value parameter: their processes are waste-less, and under continuous improvement - their people understand value, and are extremely critical about the way they produce it - their plant and their technology are managed to generate extremely high levels of output value - customers' satisfaction is their primary target, and they achieve it by offering customers an ever increasing level of value - suppliers and sub-suppliers, clients and clients of clients become integral part of a "value-chain" ending only at end-user level - their vision, their mission, their strategies, their targets, their industrial culture, their corporate communication, their organisational structure..... are all focusing on this very, primary concept: value.

I believe that, in a rapidly changing world, featuring globalisation and vanishing borders, all Enterprises, of any size, must and can, today, perform as the "top of the class" by adopting the Value Adding Management discipline as their guiding light.

My philosophy rotates around the key concept of value, and my training and consulting services are structured to enable Small and Medium size Enterprises to achieve higher levels of performance by re-discovering "value" as key parameter for competitiveness and success.

I believe in Integration.

I believe that as specialisation has been the key feature of this century's industry, integration is going to be the key feature of years 2000's industry.

Industry has been built around the concept of "specialisation" from well over a century: processes, products, services, jobs, machine functions, etc. show, even today, a high degree of specialisation. Associated to specialisation, however, there is another feature, which is "fragmentation": fragmentation of processes, of work, of operations, of activities, of tasks........

I believe that specialisation and fragmentation are enemies number one when aiming at high levels of performance. I believe that only integration sets the path to excellence and real industrial performance. Integration is associated with flexibility, adaptability, government and control of change: all important features in our industrial world of today and tomorrow. Integration is associated with overall view, overall control, and overall, holistic approach to performance: for too long many Enterprises, especially of small and medium size, have tried to achieve competitiveness and performance by embracing the "fashion" management discipline of the time, be it Quality Assurance, Total Quality Management, Zero Defects, Productivity Improvement, Process Improvement and Management.... or effective Management techniques, or Leadership techniques, or a Continuous Improvement approach, or Management by Objectives..... and even One-Minute Management..... trusting they had come across the truth and the recipe to success, to discover eventually, in many cases, that the improvement in performance was not real, or consistent, or stable......

I believe that real improvement in performance can only be obtained with an integrated approach, focusing on the key concept of "value" as guiding light, and powered by the use of a number of appropriate disciplines "in consociation" and simultaneous deployment: like to say that targeting at quality improvement without considering simultaneously the productivity aspect is not getting to real improvement, and it has never generated real improvement, because quality and productivity are always the two sides of the same medal - and vice-versa - like to say that focusing on process improvement or process re-engineering without considering simultaneously the primary importance of getting employees highly involved and without the simultaneous deployment of adequate technology-performance techniques can only bring very marginal results - like to say that going for a Kaizen style of continuous improvement without knowing priorities and targets that in certain instances only adequate Benchmarking can provide may fail, as it has failed - and so on: there are many more examples of possible failures due to lack of integration or to excessive focus on an individual, specialised technique.....

Only an integrated view (".....see the tree, not the leaves....." or, referring to my New Performing Systems architectural structure, ".....see the temple, not only the pillars....") can produce valid, high level results.

Because when, and only when, people, machines, methods, techniques and disciplines become an harmonic, integrated combination, in symbiosis one another, can an Enterprise aim at superior performance. This "integration" key feature, besides, should not only be the task of top management of an Enterprise, but should, to my opinion, be a feature of the Enterprise as a whole, as it may be noticed in World Class Performers: I believe that all minds in an high performing Enterprise must be made aware of the strategic importance of "integration" and addressed to that very direction. I believe that processes must be integrated, work must be integrated (and not fragmented), and approaches must be integrated. Because only this way people may achieve real job satisfaction.

I believe in Simplicity.

I believe that being in business, performing well as an Enterprise, manufacturing products or providing services, is and should be simple, and, most of all, be kept simple, especially in a world in which a predominant feature is complexity. It is my view that if any process, situation, or problem is too complex to be understood, solved or managed, there is something very wrong behind it, and, rather than tackling complexity, complexity should be eliminated to begin with.

As I notice that, in many decades of industrialisation, things have gone more and more complex (I refer to: complex, fragmented processes - pyramidal, bureaucratic, complex, split-function organisational structures - processes built on waste rather than around value - complex management practices - complexity of communication - complex and even distorted thinking, at all levels - etc.), I believe that time has come to bring things back to basics, back to elementary shapes, back to reality, back to simplicity, back to value.

I believe that World Class Performers have well understood this basic concept, and I believe that Enterprises aiming at excellence or superior status must, first af all, re-simplify and make very practical their dynamics, their processes, and their approaches.

I often follow the trend and offer, to participants to my courses, the latest techniques in: communication - leadership - team building - self-improvement - etc.

However I believe that practicality and simplicity are even more essential than techniques. I believe that what counts is the ability to simplify processes and to make them more linear, more human, more understandable. I believe that what is important is to assure value generation at every step of any process. I believe that is extremely important to give people well defined responsibilities, rather than trying to inject, with superior leadership and excellent communication abilities, doses of motivation that cannot get anywhere, just because the very task or the very activity is de-motivating and frustrating in itself.

I believe that accountability for the output of a well defined process gives more job satisfaction and more motivation than a salary increase or a performance bonus. I believe that people must return down to earth to simple, basic concepts of daily value generation through hard effort and acceptance of challenges. I believe that brain laziness is a public enemy to be fought very fiercely. And I believe that people must be responsible for providing their own motivation, their own security, their own quality of life.

I believe in Creativity.

I believe that Creativity (and not Products, Services, Finance, Technology, Management abilities.......) is and is going to be the only and real factor of competitiveness in this millennium. As Creativity is the common denominator of all other factors of competitiveness.

I believe that Creativity is essential for the Enterprise aiming at high levels of performance: Creativity is very important in problem solving, in decision-making, in planning, in team-work, in searching and generating opportunities, in continuous improvement practices....... Creativity is the ultimate secret for achieving high levels of Quality, Productivity and Customers' Satisfaction. Creativity is the spark that makes the difference between Enterprise's excellence or mediocrity.

I believe in the very high power of Creativity, channelled to the generation of value by integration-capable minds, and I stress its vital importance in all my consulting and training activities.

I believe in People.

And I believe that people is the most important resource of any Enterprise, as people may make the difference between its failure or its success.

I believe that people can improve considerably themselves, their performance and the performance of their Enterprise, and that a chance to generate such improvements must be given to people. I believe that it is Top Management primary responsibility to create an environment in which people are given the possibility of performing at high levels.

And I believe that this can be obtained by critically (re)designing processes in which people work, and in which people are empowered to generate high levels of value through their efforts, their creativity, their commitment, and their thorough understanding of the process/es to which they are assigned and for which they have high levels of responsibility and accountability. I also believe that responsibility and accountability for a process are a major pre-requisite for people to obtain high levels of job satisfaction.
I believe that people work must be integrated and not fragmented, and that specialisation must gradually make space to multi-skill and multi-function situations.
And I believe that only this way people may re-gain that professional dignity somehow lost in many decades of specialisation and fragmentation.
I believe that work must be a very pleasant experience for all employees, a gymnasium in which people can practise, test and prove themselves, set challenges, improve, excel and be highly satisfied. And I believe that this is easily achievable.
It is my commitment to stress these vital issues in my consulting and training activities, and to convey these priority messages to people in Industry, at all levels.

The above is my vision and my operational philosophy.
It is my mission, and my thorough commitment, to convey its basic principles to Enterprises and people in Enterprises, with the aim of achieving higher and higher levels of performance.
It is my commitment to do my very best, with honesty and professionalism, to enable Enterprises of small and medium sizes (and as such within my reach and within my own personal capacity and abilities) to understand and make operational the best, up-to-date practices that lead to World Class performance.
Finally, it is my pleasure to commit myself to continuous learning, continuous self-improvement, and, wherever necessary, to continuous change, with humility, and with consciousness of my limited knowledge, always insufficient and always perfectible. Along these lines, it is also my commitment and personal pleasure to get in deep contact with industrial realities of many Countries, and with diversified cultures, to continuous personal and professional enrichment, and to the benefit of my Clients, of the Participants to my training courses, and of all the individuals I will have the opportunity and the joy to get in touch with in the course of my life.

Carlo Scodanibbio

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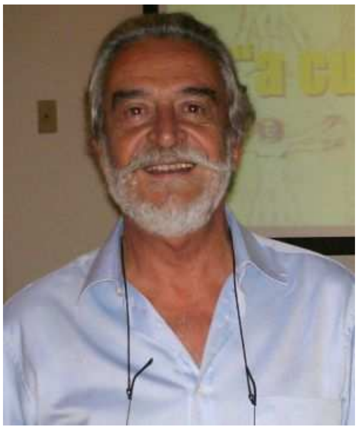

Carlo Scodanibbio, born in Macerata (Italy) in 1944, holds an Italian doctor degree in Electrical Engineering (Politecnico di Milano - 1970).
He has over 38 years of experience in Plant Engineering, Project Engineering and Project Management, as well as Industrial Engineering and Operations Management.
Free-lance Consultant since 1979, he has worked in a wide spectrum of companies and industries in many countries (Southern Africa - Italy - Cape Verde - Romania - Malta - Cyprus - Lebanon - Mauritius - Malaysia - Kenya - India - Saudi Arabia), and operates as an Independent Professional Consultant and Human Resources Trainer to industry.
His area of intervention is: World Class Performance for Small and Medium Enterprises in the Project, Manufacturing, and Service sectors.
His favourite area of action is: the "lean" area.
He has co-operated, inter-alia, with the Cyprus Chamber of Commerce, the Cyprus Productivity Centre, the Malta Federation of Industry, the Mauritius Employers' Federation, the Romanian Paper Industry Association, the United Nations Industrial Development Organisation and the University of Cape Town.
His courses and seminars, conducted in English, Italian and French, have been attended by well over 13.000 Entrepreneurs, Managers, Supervisors and Workers. They feature a very high level of interaction, and are rich in simulations, exercising and real case studies. The approach is invariably "hands-on" and addressed to immediate, practical application.

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