OEE

Overall Equipment Effectiveness

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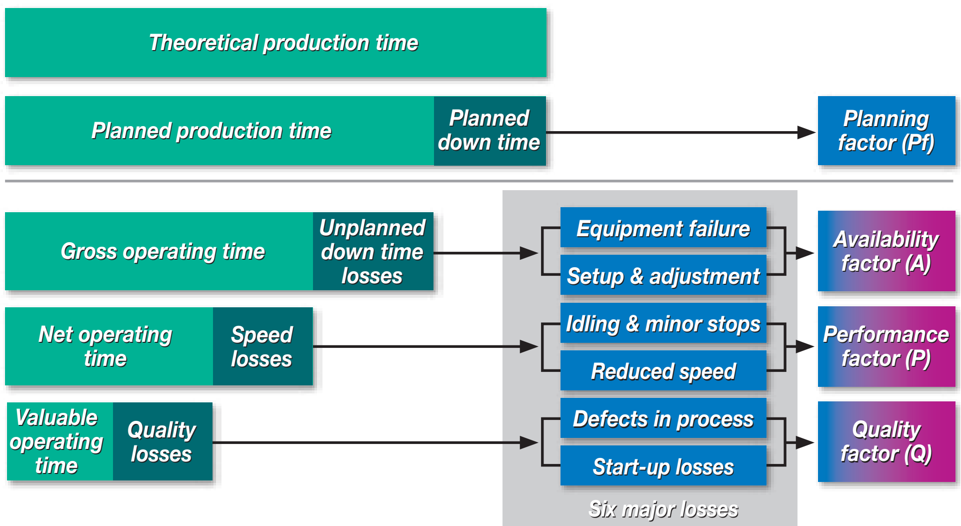


Overall Equipment Effectiveness: OEE = A × P × Q
Total Productivity = OEE × Pf

If you cannot measure it, you cannot manage it. Overall Equipment Effectiveness, or "OEE," is a well known concept in maintenance and is a way of measuring the effectiveness of a machine. It is the backbone of many techniques employed in asset management programs.

This white paper begins with an explanation of the difference between efficiency, effectiveness and productivity. OEE is also defined, as are ways of calculating OEE. An example of OEE is presented, as well as an alternate definition.

Contents

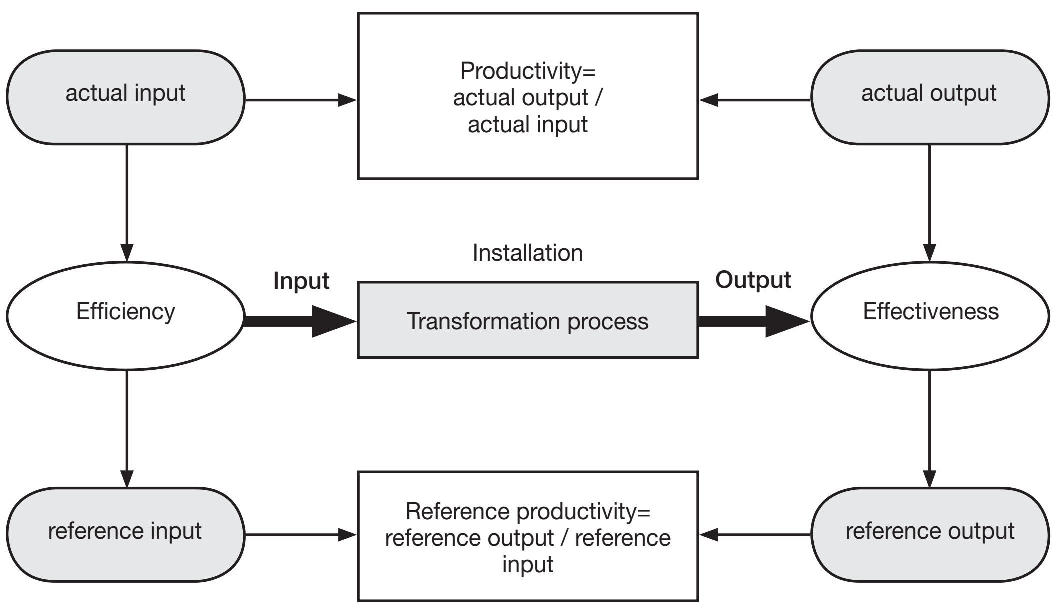
OEE (Overall Equipment Effectiveness)

1. Efficiency, effectiveness and productivity

There are certain terms that are often used in different ways. Three of them are efficiency, effectiveness and productivity. Therefore it is necessary to start with giving their definition.

An installation produces outputs by transforming inputs. An installation is a certain well-chosen level of corporate assets where a transformation process takes place. For instance, in the welding line of a car factory, steel (input) is transformed into car doors (output). However steel is not the only input. Labor and energy are other examples of an input.

Productivity is defined as the actual output over the actual input (e.g. number of cars per employee). The effectiveness of the installation is the actual output over the reference output. Productivity can be influenced not only by changing the effectiveness but also by altering the efficiency, this is the actual input over the reference input.



It is obvious that installation effectiveness is one of the important factors that influence the production cost-prize. Other contributing factors are raw materials, utilities, people and work methods. Raw materials as input can be actual raw materials as well as semi-manufactures (altering the raw material to create a portion of, but not the final product), from a previous installation but they have to be exterior to the own installation. It should be clear that the maximization of installation effectiveness can't be the one and only goal. The costs of maximizing effectiveness should not outweigh the benefits.

OEE stands for Overall Equipment Effectiveness. It is a measure of how effective your installations are. There are different ways of defining OEE. In this chapter one definition will be given. In the appendix another definition will be given that is widely spread in literature but is not always applicable in practice. The latter definition is only added for reasons of completeness.

2 Definition of OEE

2.1 Downtime, speed and quality losses

Analyzing the output of an installation, a number of situations can occur.

- If the output is (for a longer period, for instance 3 minutes) zero, the installation produces nothing. The unused segments of time, during the examined period, are downtime losses.
- The output is smaller than the output at reference speed: these are called speed losses. When considering speed losses, one does not check if the output conforms to quality specifications.
- The produced output either does or does not conform to quality specifications. If it does not comply, this is considered a quality loss.
- An output for a certain period that corresponds to a volume at reference throughput and that complies with quality specifications, corresponds to a utilization of 100 percent. There are no losses.

Theoretical production time			
Valuable operating time	Quality losses	Speed losses	Downtime losses

If the output is zero for a small time, for instance 3 minutes, this is considered a speed loss and not a downtime loss. How long that time should be, has to be decided by the company itself.

Irreparably defective products are obvious losses. Less obvious are the losses generated by partially defective products requiring additional man-hours in rework or repair. Because they can be repaired, partial defects are often not counted as defects. In a successful program to reduce quality losses all defective outcomes should be treated with equal concern, and one should measure the total volume produced (including rejects, reworked items and start up losses) compared to the number of acceptable products.

2.2 Causes of the losses

Instead of dividing by the different types (downtime, speed, quality), the losses can be divided by their causes. For all losses, three different causes can be found: machine malfunctioning, process and external.

Theoretical production time			
Valuable operating time	Machine malfunctioning	Process	External

The definitions of these losses are as follows:

- Machine malfunctioning: a machine as a part of an installation does not fulfill the demands resulting in losses of the installation.
- Process: the way the installation is used and treated during production resulting in losses of the installation.
- External: cause of losses that cannot be altered by the production or maintenance team resulting in losses of the installation.

The phrase ‘resulting in losses of the installation’ is added each time, because it is possible that a part of an installation does not function; yet losses are not incurred.

When dividing the losses by their causes, the direct cause is used, not the underlying one. An example will make this clear: If a bearing breaks, the cause of the resulting loss is a machine malfunctioning. The underlying reason for the breaking of the bearing is that the machine is constantly operated at an excessive speed. So the underlying reason is the process. Nevertheless, this loss will be qualified as caused by machine malfunctioning.

There is a reason why this model is used. If the equipment effectiveness has to be improved, only the losses caused by machine malfunctioning and the process can be changed by the daily organization. The external causes are external for the production and maintenance organization. This division makes it possible to find the causes of the development of the losses and the organization that is responsible for them. Thus the daily (production and maintenance) organization can take its responsibility without having problems with the rest of the organization that is not so willing to make changes.

The following diagram shows the available production time. This is the time for which production and maintenance are responsible. It consists of the losses caused by process or machine malfunctioning. They are taken together in what is called technical losses.

<table>
<tr><td colspan="4">Theoretical production time</td></tr>
<tr><td colspan="3">Available production time</td><td></td></tr>
<tr><td rowspan="3">Valuable operating time</td><td colspan="3">Losses</td></tr>
<tr><td colspan="2">Technical losses</td><td rowspan="2">External</td></tr>
<tr><td>Process</td><td>Machine malfunctioning</td></tr>
</table>

The OEE of the installation can then be calculated as

$$\frac{\text{Valuable operating time}}{\text{Available production time}}$$

2.3 External losses

There are two types of external losses: planned and unplanned, as shown below.

External losses					
Unplanned losses			Planned losses		
Shortage of personnel	Shortage materials (quality / quantity)	Environment deals	Revision / modifications	Limited need	Social

Possible examples of unplanned external losses are:

-Environment deals

For instance, the company has made deals with the other companies in the industrial area about the exceeding of certain values of environmental parameters that imply reducing the throughput or even stopping production (note: if the exceeding is caused by the machine malfunctioning or the process, the losses should be registered under that cause and not as an external loss).

-Shortage of raw and help materials (quality or quantity)

These losses are about the malfunctioning of the organizations that support production and maintenance or the suppliers (internal or external). These losses are the consequence of no/shortage of raw or help materials or materials that are not in accordance with specifications.

-Lack of personnel

A (temporary) lack of personnel can cause installations to be stopped or to produce at a lower speed. A lack of personnel can be caused by an epidemic, strike, …

Planned external losses can be:

-Social

Whether or not to produce continuously or to produce during week-ends / holidays / etc., is a policy choice with a social implication. To produce continuously can be a necessity because of the type of production process but it can also be the consequence of the policy to make full use of the installation.

-Limited demand

If planned sales (market demand) are smaller than the capacity of the installation, it will be stopped for a certain amount of time or work at reduced speed.

-Revision / great maintenance / modifications

Among these are the losses caused by the maintenance activities on a yearly or larger basis. Those activities require the complete stop of the installation and are meant to keep the losses during the available production time within limits in the period between two revisions.

Note that revisions would normally belong to the losses caused by 'machine malfunctioning'. But a choice has to be made. Putting revisions/great maintenance under external prevents the daily organization from getting the feeling that losses occur for which they are responsible. Usually top management will make decisions about these revisions in consultation with the other corporate functions (including marketing, sales, logistics) concerning the most favorable time and duration. This kind of decision will never be taken by the daily organization itself because of the impact on the other corporate functions and the company itself. There is only a matter of planned losses concerning modifications if they are not executed during revision or if they exceed the time of the revision.

It should be clear that the external losses are of great importance for top management. They should be examined with great care; the reduction of the losses can directly influence positively the revenues and profit if the needs of the market are not met. The time periods concerning revisions and modifications have to do with the future and less with current production. This is clearly linked to the policy of top management.

Note that not all external losses are downtime losses. The example was given of the limited need leading to producing at reduced speed instead of stopping the installation. Also quality losses can appear because of an external cause, namely a loss of quality induced by the choice of a bad supplier.

2.4 Further division of the losses

The losses have been divided according to their type on one hand (downtime, speed, quality), or according to their causes (machine malfunctioning, process, external) on the other.

<table>
<tr><td colspan="4">Theoretical production time</td><td></td></tr>
<tr><td rowspan="2">Valuable operating time</td><td colspan="3">Losses</td><td>Type of loss</td></tr>
<tr><td>Quality losses</td><td>Speed losses</td><td>Downtime losses</td><td>Cause of loss</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Machine malfunctioning</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Process</td></tr>
<tr><td></td><td></td><td></td><td></td><td>External</td></tr>
</table>

When the losses because of external causes are taken out, the other losses can still be divided in downtime, speed and quality losses. The complete division of the losses is indicated in the diagram below.

<table>
<tr><td colspan="5">Theoretical production time</td></tr>
<tr><td colspan="4">Available time for production</td><td rowspan="2">External losses</td></tr>
<tr><td>Valuable operating time</td><td>Quality losses</td><td>Speed losses</td><td>Downtime losses</td></tr>
</table>

In the rest of this chapter will be shown how each one of the three types (quality, speed, downtime) can be further divided dependent on whether the cause is the machine malfunctioning or the process.

2.4.1 Downtime

Only the downtime losses for the available time for production are analyzed. This means that the external reasons are not considered. Examples will be given of downtime caused either by machine malfunctioning or the process.

Most common reasons for downtime caused by machine malfunctioning:

- Arising malfunction
- (Un)planned preventive maintenance work that must be done outside of the big revisions

Most common reasons for downtime caused by process:

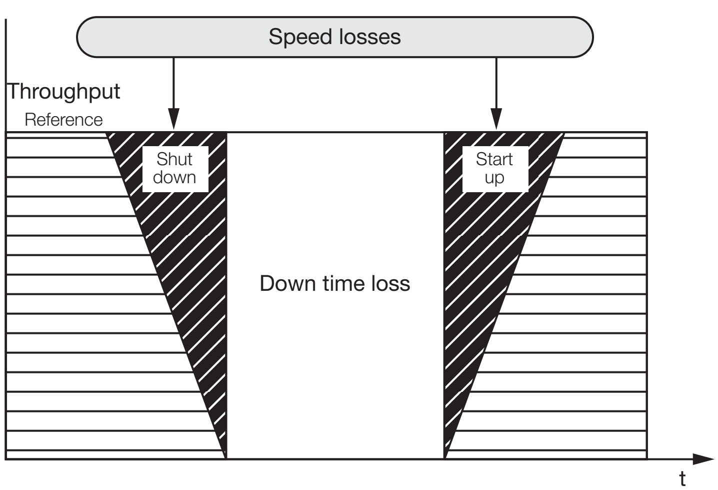
- Setup time caused by (un)planned product change (process-, metal-, food- and tobacco industry)
- Exchange of catalyst, sand filter, … (petrochemical and process industry)
- Changing or correction of print cylinder (printing industry)
- Begin/end of the week (preparatory or terminal) activity like cleaning (food and printing industry)

2.4.2 Speed

Most common reasons for speed losses caused by machine malfunctioning:

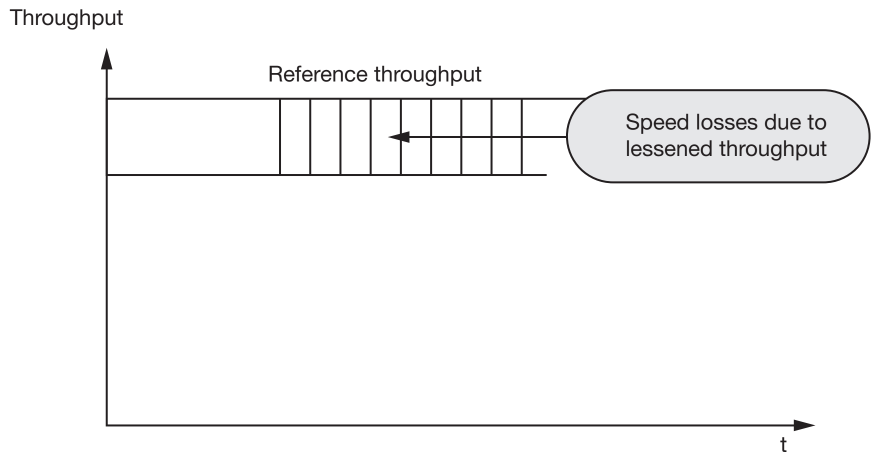
- Decreased machine malfunctioning resulting in decreased but non zero speed
- Small technical imperfections that can be corrected by the operator, like stuck packaging material (food and tobacco industry)

- Lack of grippers on the conveyer belt of packaging machines (all industries)
- Mold of which some positions do not yield a product because of lack of forms (metal, food, …)
- Reduced throughput because of the startup or shutdown of the installation related

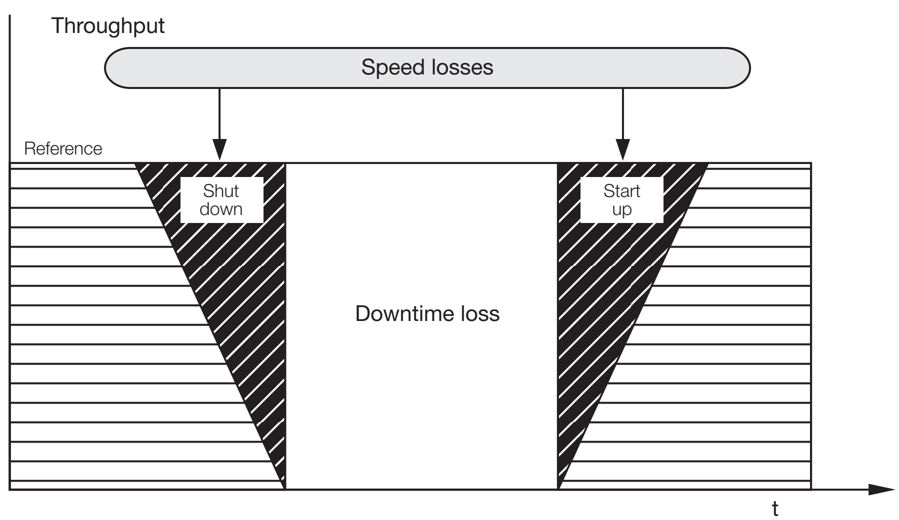


Most common reasons for speed losses caused by process:

- Unconsciously tuned to a lower throughput than reference throughput
- Process parameters not tuned to standard
- Reduced throughput because of the startup or shutdown of the installation for production purposes, like the transition to a different product, start up of the installation because of a holiday, week-end…



The installation cannot be brought from zero to reference throughput because, for instance, of the risk of possible damages during startup. The gradual increase/decrease of throughput causes a loss in the form of less produced units that will be indicated as a speed loss. The speed loss caused by startup and shutdown can be schematically shown as below:



It is possible to indicate this loss on the previous graph.

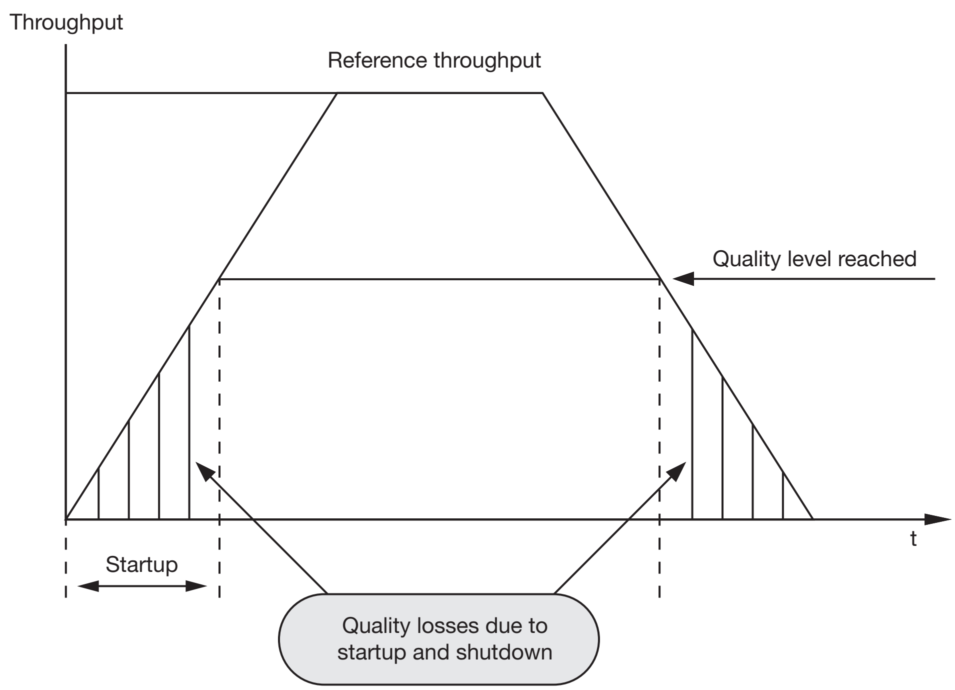
Theoretical production time				
Valuable operating time	Losses			
	Quality losses	Speed losses	Downtime losses	
				Machine malfunctioning
		X		Process
				External

The size of the loss is a function of the slope of the throughput line during startup, relative to the time axis. A standard procedure, in which the optimal startup is described with the reference, forms the basis for defining the minimum losses.

2.4.3 Quality

Most common reasons for quality losses caused by machine malfunctioning:

- Startup or shutdown of the production process caused by an intervention of maintenance to restore the machine malfunctioning. Quality losses occur because an installation, in the time between startup and completely stable throughput, yields products that do not (completely) conform to quality demand. This is depicted in the diagram below.



- Incorrect functioning of the machine, like the incapacity to cool enough or keep the right pressure, can result in a quality loss, possibly combined with speed losses.

Most common reasons for quality losses caused by process:

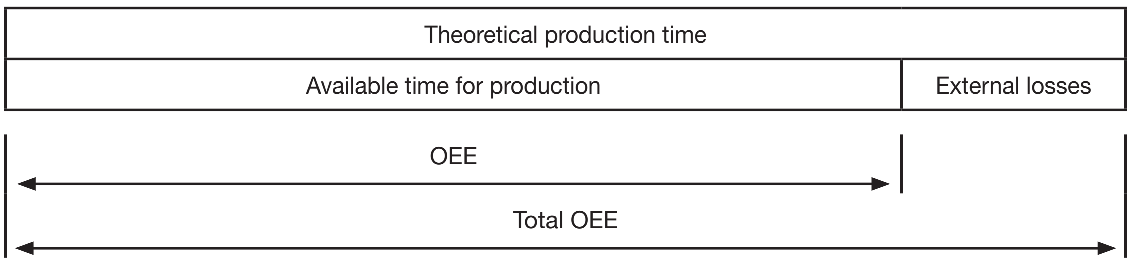
- Unconsciously tuned to a lower throughput than reference throughput
- Process parameters not tuned to standard (for example: the temperature should be 35 degrees F for a process, but the heat/cool device was set for 22 degrees F.)
- Quality losses due to start up or shut down for production purposes as change over, …

3 OEE calculations

Two types of OEE can be recognized:

- Total OEE
- OEE

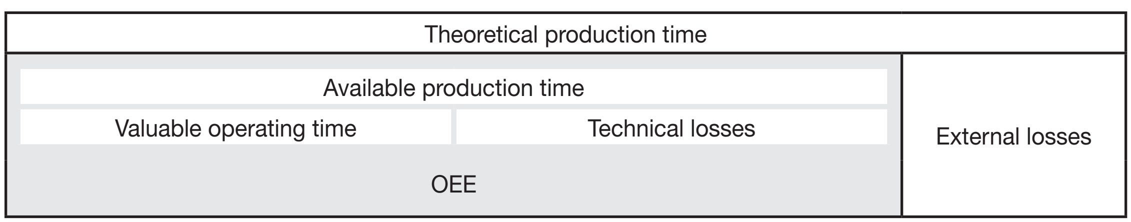
Total OEE has to do with the theoretical production time. OEE has to do with available production time.



The value of the OEE is an indication for the technical losses as a whole. It does not differentiate however every type of loss (downtime, speed, quality). The effectiveness factors are used for this purpose. They will also be discussed in this paragraph.

3.1 OEE

The value of the OEE is a measure for the effectiveness of the installation in the available time for production.



The OEE is quantified as

$$OEE = \frac{\text{Valuable operating time}}{\text{Available production time}}$$

The value of the OEE is an indication for the size of the technical losses as a whole. The difference between the value of the OEE 0 or 100 % indicates the share of technical losses in relation to the available production time.

3.2 Planning factor

Planning factor is a measure for the utilization of the installation in the theoretical production time and can be quantified as follows:

$$\text{Planning factor} = \frac{\text{Available production time}}{\text{Theoretical production time}}$$

The planning factor indicates the percentage of the total theoretical production time planned for - or realized, without expressing anything about the way the installation has been used in terms of effectiveness. It is a measure for the extent of not utilizing the installation.

The available production time is the time in which normally production is planned/realized. The span of the available production time can vary for the planned as well as the realized value. It depends on the amount of (planned and unplanned) external losses that in turn depend on the market needs. Seasonal fluctuations cannot always be overcome or prevented.

The theoretical production time is the (maximum) amount of time units (hours/days) available in the observed period and is a constant in time. A day always consists of 24 hours of 60 minutes. A week always consists of 7 days of 24 hours. A year always consists of 52 weeks.

With an increase of the (planned/unplanned) external losses the value of the planning factor will inevitably decrease, the theoretical production time is a constant value for a fixed observed period (365 days).

Note that the planning factor as designation is not completely correct as it can be changed by an unplanned event, for instance a lack of raw material.

3.3 Total OEE

$$\text{Total OEE} = \frac{\text{Valuable production time}}{\text{Theoretical production time}}$$

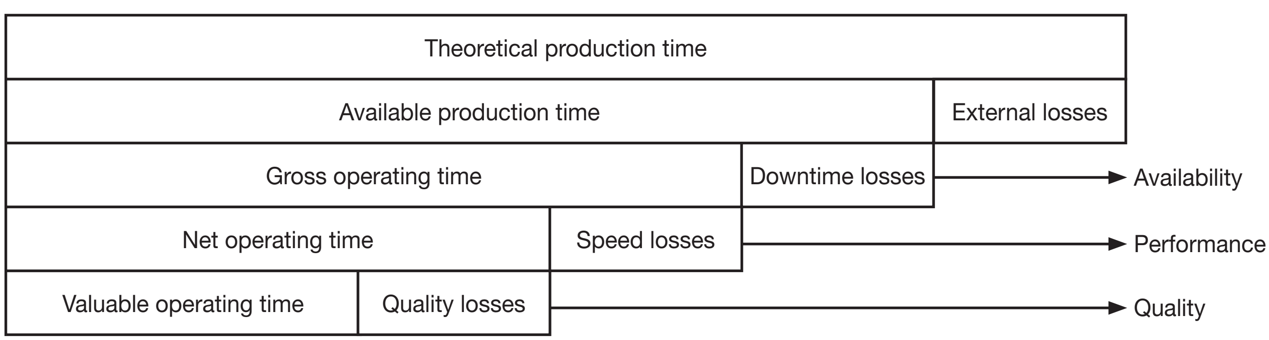
The total OEE is an indication of how effectively your machine has been used compared to how its use could theoretically be maximized. The consequences of not working during weekends or having two 8-hour shifts a day instead of three are reflected in this factor.

Note that the total OEE can also be calculated as follows:

$$\text{Total OEE} = \text{OEE} \times \text{Planning factor}$$

3.4 Effectiveness factors

With the effectiveness factor, the OEE is examined in more detail. Note that the available production time is examined, not the theoretical production time.



3.4.1 Availability

The previous diagram indicates that the availability is a measure for the downtime losses. The definition is as follows:

$$\text{Availability} = \frac{\text{Gross operating time}}{\text{Available production time}}$$

When downtime losses are zero, the availability is 1 or 100%, the gross operating time equals the available time for production. In other words, the installation throughput equals zero in no point of time, during the available time for production. At the end of the installation, there is continuously an output and this without interruption.

3.4.2 Performance

The performance only concerns the gross operating time. A property of the gross operating time is that the speed exceeds zero at any time. There are no downtime losses in the gross operational time.

The speed is not zero but this does not mean that the reference throughput is continuously achieved. The performance factor is a measure for the speed losses and is quantified as follows:

$$\text{Performance} = \frac{\text{Net operating time}}{\text{Gross operating time}}$$

Speed losses can be calculated as:

$$P = \frac{\text{Number of parts produced}}{\text{Gross operating time / Theoretical cycle time}}$$

In order to quantify speed losses, the theoretical cycle time has to be known. This is not necessarily the design cycle time.

The theoretical cycle time depends on installation and product. It is useful to pay attention to its value. If it is falsely calculated, parts of the losses are not visible and a better effectiveness is shown than is the case. These false calculations come about by taking into account unavoidable losses. These are for instance losses caused by cleaning activities:

- Imposed from a legal/hygienic point of view (food industry)
- Necessary to prevent contamination of products

It can‘t be stressed enough that it is worthwhile to find out the manner in which the value of theoretical cycle time comes about. Usually the client becomes aware of the importance to correctly quantify the theoretical cycle time and the consequences if this is not done properly. The theoretical cycle time can in principle be determined by a neutral instance. It is necessary that production and maintenance be consulted.

3.4.3 Quality factor

During the net operational time, no downtime or speed losses occur. In other words, the output related to the net operational time is the product of the reference throughput (units per time unit) x the number of time units of the net operational time. However it is not certain that the total produced output is conform quality specifications. To gain insight into this, the quality factor is defined:

$$\text{Quality factor} = \frac{\text{Valuable operating time}}{\text{Net operating time}}$$

Product specification and product planning (at what time what product should be produced) are the starting points for quantifying quality losses. When reasoning in this way, there are only approved and rejected products. Producing products that are not included in production planning means that the entire production is rejected, resulting in a zero quality factor and OEE. This is also the case if products are made according to the production plan, but do not conform to product specification. This resembles a black and white situation and this is not always necessary or wanted.

A conscious decision for differentiation of quality losses should be made. If opting for quality differentiation, a decision has to be made concerning producing, not conform product planning (other products than required/agreed). In principle production should be considered “not conform” in this case. But then there is still the question of what to do with product that is in the “not conform,” category. For example: A product is produced that does not fit the original specification, yet it is acceptable for a different (lower cost) product specification. So, this lower-spec, lower cost product may be sold. In this case, the product is not a complete loss, and some money can still be recuperated. But there is still some loss, since the machine and tools used to make this product are designed to deliver a different product. The investment is probably higher in this case, so you have to calculate some losses. This should be addressed in the product specification portion of the planning.

A decision has to be made when a product is completely rejected and subsequently the different quality levels must be determined with the accompanying product specification. When determining the number of quality levels, one should reckon with what still can be traded in the (internal or external) market. Per class hard criteria and norms will have to be defined, possibly with the help of quality aspects.

Finally, per class the total size of the loss should be quantified. For example, when producing a product of a certain quality class, 14% of the produced volume/numbers are losses because they do not live up to the quality specifications of that class.

An overview table will have to be made per product indicating:
- The different quality levels
- The quality specification per level
- The factor per level to quantify the losses

3.4.4 OEE

Previously in this document, the OEE was defined as the valuable operating time over the available production time. The three effectiveness factors offer a second way to quantify the OEE:

$$OEE = Availability \times Performance \times Quality\ factor$$

The individual value of the three effectiveness factors lies between 0 and 1. Studying each one of the effectiveness factors independently, a satisfactory value would be 0.9 or 90%. The value of the OEE is in this specific case = 0.9 x 0.9 x 0.9 = ca. 0.73. The size of the technical losses is in this case approximately 27% of the available time for production, which is a serious amount. This results mainly from the multiplication effect of the three factors.

Note that in many cases, downtime losses also cause speed and quality losses. The reference throughput is not immediately achieved after a downtime of the installation and the first products do not necessarily comply with quality specifications.

The use of effectiveness factors helps with prioritizing the size, but does not indicate the financial consequences that can differ per factor.

3.5 OEE and maintenance

Based on the previous division of the losses, it is possible to define factors that are indicators of the losses that are to be imputed on maintenance.

The scheme below shows the different losses that will be used to define those factors and will be explained in the text.

Theoretical production time A Available production time losses technical losses

<table>
<tr><td colspan="5">Theoretical production time</td></tr>
<tr><td colspan="3">A Available production time</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Valuable operating time</td><td colspan="4">Losses</td></tr>
<tr><td colspan="2">Technical losses</td><td colspan="2">External</td></tr>
<tr><td>Process</td><td>B Machine malfunctioning</td><td>D Revisions/TA</td><td></td></tr>
</table>

Maintenance is responsible for two types of losses:
- Technical losses due to machine malfunctioning during available production time (B)
- The external losses necessary to make turnaround/revisions (D)

3.5.1 Upkeep effectiveness

The ratio "B/A x 100%" is an indication of the technical losses due to machine malfunctioning. It is called the upkeep effectiveness. It only concerns the available production time and hence does not allow the evaluation of maintenance on all of its merits.

3.5.2 Turnaround effectiveness

It is useful to define a parameter indicating the losses due to revisions/turnarounds. These take place in periods in which no production is planned. Thus, they are indicated as "external losses." This could cause the maintenance team to neglect the fact that they can sometimes affect revision/turnaround time. The turnaround effectiveness is calculated as D/C x 100% and allows monitoring the evolution over the years, as C is a constant value.

3.5.3 Maintenance effectiveness

The value of D is a necessary insurance prime that has to be paid in order to keep B within limits. In order to evaluate maintenance on its full merits, the maintenance effectiveness is calculated as (B+D)/C x 100%.

3.6 Effectiveness factors calculated in other units

To define the three effectiveness factors, time was used as a measuring unit. Other possibilities are:
- Speed
- Volume

A choice has to be made but it is clear that not all effectiveness factors can be calculated with all types of units. The unit speed is not fit for the availability factor. For instance, the speed is zero (by definition.) The same is true for the unit volume and availability.

The following table shows how the effectiveness factors can be calculated using different units.

	Time	Speed	Volume
Availability factor	Gross operating time Available production time		
Performance factor	Net operating time Gross operating time	Actual speed Reference speed	Total number produced Theor. possibly produced in gross operating time
Quality factor	Valuable operating time Net operating time		Approved Total number produced
OEE	Valuable operating time Available production time		Approved Theor. possibly produced in avail. prod. time

From this table, it is again clear that

$$\text{OEE} = \text{availability factor} \times \text{performance factor} \times \text{quality factor}$$

Note that the performance factor expressed in units speed is a theoretical value. The 'actual speed' is, despite the name, an average over a certain period of time.

4 Example

"Company XYZ" produces chocolates. They have two production lines: Line One is a multi product line, Line Two is a mono-line. In other words, on Line One a mix of four products is produced. Because the optimization of this line will yield more results, only this one is analyzed. It was decided to examine the period from January to September.

The OEE, the planning factor and the total OEE are calculated first. Availability, performance and quality factor are calculated next.

4.1 Theoretical, available and valuable operating time

4.1.1 Theoretical production time

The examined period is January to September. This means that the theoretical production time is 273 days. This corresponds to 273 X 24 = 6552 hours.

4.1.2 Available production time

Out of the 273 days, work was not planned on some days, for the following reasons:

Week-ends	78
Holidays	7
Leave/Vacation	11
Total	96 days

There are two shifts of 8 hours per day. In total there were (273-97) X 2 X 8 = 2816 hours of work during shifts. There are also work stoppages/pauses: 1 hour every day, totaling 273-97 = 176 hours. This leaves 2816-176 = 2640 hours.

The lack of personnel or raw materials caused the rest of the time losses. Because there was no direct data available, an estimate had to be made. The production leader decided upon 5%, leaving the available production time 2640 X 0.95 = 2508 hours.

4.1.3 Valuable operating time

To calculate the valuable operating time, it was necessary for the company to make some calculations. The valuable operating time was calculated per product (reference throughput X number approved). This lead to the following table:

Product	Reference throughput	Number approved	Valuable operating time
Product type 1	1500 kg/hr	720 tons	480 hours
Product type 2	750 kg/hr	334 tons	445 hours
Product type 3	900 kg/hr	160 tons	178 hours
Product type 4	680 kg/hr	36 tons	53 hours
Total valuable operating time			1156 hours

4.2 OEE, planning factor and total OEE

The previous results are summarized as follows:

Theoretical production time = 6552 hours

Available production time = 2508 hours

Valuable operating time = 1156 hours

4.2.1 OEE

$$\text{OEE} = \frac{\text{Valuable operating time}}{\text{Available production time}} = \frac{1156}{2508} = 46\%$$

4.2.2 Planning factor

$$\text{Planning factor} = \frac{\text{Available operating time}}{\text{Theoretical production time}} = \frac{2508}{6552} = 38\%$$

4.2.3 Total OEE

$$\text{Total OEE} = \frac{\text{Valuable operating time}}{\text{Theoretical production time}} = \frac{1156}{6552} = 18\%$$

Note that the result can be obtained by multiplying the OEE by the planning factor.

4.3 Availability, performance and quality factor

The previous calculations do not give insight as to the different types of losses. Calculating the different effectiveness factors below can do this.

4.3.1 Availability

Company XYZ kept record of its downtime - 551 hours during the examined period. Therefore the gross operating time is 2508-551 = 1957 hours.

$$\text{Availability} = \frac{\text{Gross operating time}}{\text{Available production time}} = \frac{1957}{2508} = 78\%$$

4.3.2 Quality

From all produced tablets, 95% is transferred to the warehouse (Company XYZ works on stock), in other words 5% is rejected. The quality factor is thus 95%. Due to the available data, the quality factor had to be calculated before the performance factor.

4.3.3 Performance

The net operating time is the valuable operating time divided by the quality factor: 1156/0.95 = 1217 hours.

The gross operating time is 1957 hours.

$$\text{Performance} = \frac{\text{Net operating time}}{\text{Gross operating time}} = \frac{1217}{1957} = 62\%$$

4.3.4 OEE

Note that the OEE can also be calculated as

$$OEE = Availability \times Performance \times Quality\ factor = 78\% \times 62\% \times 95\% = 46\%$$

This corresponds with the previous calculation.

Available production time = 2508 hours

Gross operating time = 1957 hours

Net operating time = 1217 hours

Valuable production time = 1156 hours

5 OEE measurements

When measuring OEE it is important to know who will be the recipients of the measured results and what is the objective (is it to identify the total cost of the production, to make some specific installations more effective, or to reward the personnel, etc.)?

Examples of the benefits of measuring OEE:

OEE as an internal indicator

- Awareness of the losses
- Verification that established objectives have been achieved
- Comparison of results in time (trends analysis)
- Comparison of results against the results of other installations

OEE as an external indicator

- Be careful when comparing your OEE figures with figures from other plants. To make a fully accurate comparison one must be sure that the OEE is calculated in the same way at both places. It is however always interesting to know the approximate OEE values for similar production installations.

What to expect:

Based on results by Total Productive Maintenance (TPM) Prize winning companies (see www.jipm.com for more information on the TPM awards).

Availability > 90%

Performance > 95%

Quality > 99%

OEE = A × P × Q = 90% × 95% × 99% = 85%

An OEE of 85% is considered to be World Class Manufacturing (WCM) for the TPM prize winners.

The table below shows top-level OEE and Total OEE values from different types of industries

Industry	OEE top-level	Total OEE
Manufacturing	85%	60%
Process	> 90%	> 68%
Metallurgy	75%	55%
Paper	95%	> 70%
Cement	> 80%	60%

5.1 Economical Measurements based on OEE

Different analyses can be made using OEE. We will introduce two of them.

'Production Economy' is a way of looking at the economic aspects of maintenance. The aim is to have an idea of all costs involved in maintenance at a given moment in time. This can be used to make companies aware of these costs or to get a picture of the costs when offering a full service contract, for instance.

With a 'Dupont' analysis it is possible to find out how the OEE affects the ROA (Return On Assets). It is however, also a tool for prioritizing lines (this will be explained in the rest of the text) or evaluating possible OEE improvement proposals.

Both models make use of the idea of 'contribution.' The next paragraph will explain what this is.

6 Appendix: Definition of OEE with the six big losses

6.1 Division of the losses (Planning factor and the six big losses)

In principle, an installation could work continuously: every hour of the day, every day of the year (365 days per year). If it worked continuously at reference throughput and all products had the reference quality, there would be no losses. In reality, there are always losses. There are different ways to divide those losses. So far, one method has been given. In this appendix, a different model will be explained. The second one is very well known in literature but not always applicable in practice. Since it is considered basic knowledge when discussing OEE, it is presented here.

The two models are relatively similar but differ in two ways. Neither divides all losses by breakdown, speed and quality: they first take out a group: 'external losses' (first model: 'Production Economy') or 'unplanned downtime losses,' (second model: 'Dupont Analysis'.) The difference between these groups will be explained in this appendix. Secondly, the three types of losses (breakdown, speed and quality losses) can be divided even further. The two models differ in the how this subdivision is made.

6.2 External losses versus 'planned downtime losses'

'External losses' are losses that cannot be altered by the production or maintenance team, resulting in losses of the installation.

'Planned downtime losses' are downtime losses that were planned.

Note that the latter are downtime losses, whereas 'external losses,' can be speed/quality losses. For instance, speed losses because of environmental deals (see chapter 1) are external losses but are not planned downtime losses. Quality losses that are caused by the raw materials of the supplier are external losses but are not downtime.

Also note that external losses are not always planned. For instance, an external power cut or lack of raw materials is an external loss, but is not a planned downtime loss.

This is why the 'available production time' is different in the two models. When working with planned downtime losses, it is sometimes called the 'planned production time'.

<table>
<tr><td colspan="3">Theoretical production time</td></tr>
<tr><td colspan="2">Available time for production / Planned production time</td><td>Planned downtime losses</td></tr>
<tr><td>Available time for production</td><td colspan="2">External losses</td></tr>
</table>

The OEE is calculated on the basis of the available time for production. When working with planned downtime losses, some external losses, like lack of raw materials, are still comprehended in the available time for production. That is why in some manuals 'planned downtime losses' are defined as 'all external (losses which are beyond the control of the plant or production line) downtime losses'. This means that external speed / quality losses are still in the available time for production. Note that with this definition the 'planned downtime losses' are not always planned.

Under 'planned downtime,' the following are categorized:

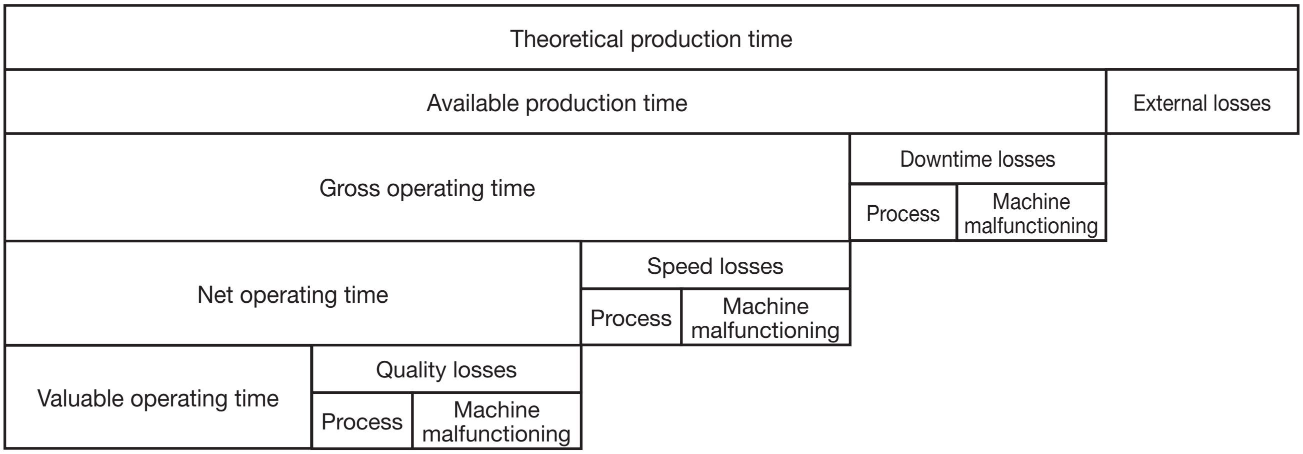
- Authorized breaks (pauses) during the working day
- Not working during weekends
- Scheduled stoppages for product changes
- Modifications and improvements to equipment (work financed under investments)
- Decreased production time due to lack of demand for the product
- Planned maintenance work (inspections, preventive maintenance, improvements)
- Problems in production planning
- Saturation of machines (upstream and downstream)
- Authorized shop floor meetings
- Classroom or 'on the job' training sessions for operators
- External power cuts
- Lack of raw material

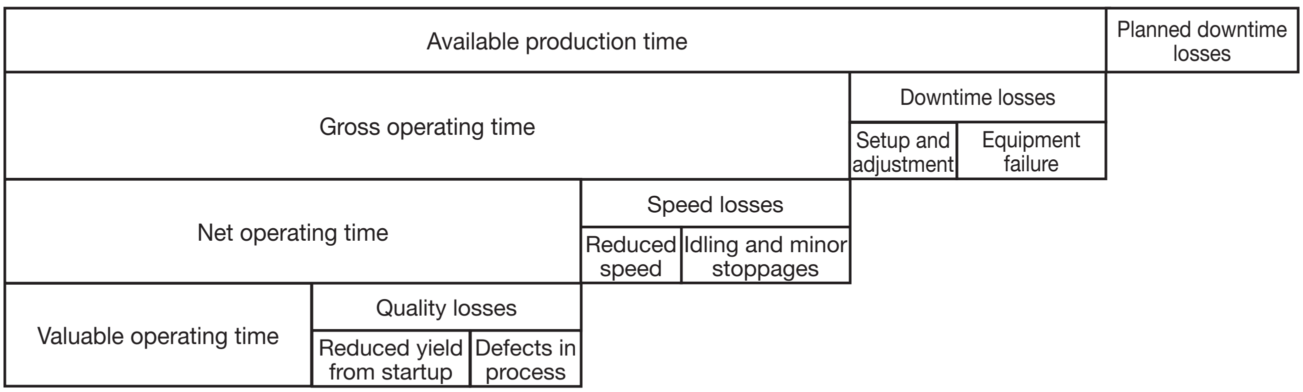
6.3 Subdivision of the losses

The losses that occur in the available production time can be divided in three groups: downtime, speed and quality losses. These can be divided in two subgroups. In the text they were all subdivided into the two causes: 'Process' and 'Machine malfunctioning'.

In the model with the 'planned downtime losses', they are subdivided in six subgroups in total. The whole of these subgroups is called 'The Six Big Losses'. The groups and subgroups are:

- Unplanned downtime losses (Availability Factor)
  - Equipment failures (breakdown losses)
  - Set-up and adjustment losses
- Speed losses (Performance Factor)
  - Idling and minor stoppages
  - Reduced speed
- Quality losses (Quality Factor)
  - Defects in process and reworking
  - Start up losses





Downtime

Equipment failure (breakdown losses)

Equipment failures (breakdown losses) are by far the biggest of the “six big losses”. There are two types of equipment failures: sporadic and chronic. The breakdown is often referred to as sudden, dramatic failure in which the equipment stops completely. Such unexpected breakdowns are clearly losses, because production is stopped. Even if the cause lies in a single specific function, the breakdown results in cessation of all equipment functions. Problems and losses related to deterioration (chronic failures) are also considered as breakdown losses. Generally people tend to overlook these breakdown losses. However, they often account for the largest proportion of Overall Equipment Effectiveness losses.

Set-up and adjustment losses

Set-up and adjustment losses can occur after breakdowns. They can also be the consequence of defects in products that occur when production of one product ends and the equipment is adjusted to meet the requirements of another product.

Speed losses

Reduced speed

Reduced speed refers to the difference between planned speed and actual operating speed. Equipment may be run at less than planned speed for various reasons: non-standard or difficult raw materials, mechanical problems, history of past problems, or fear of overloading the equipment.

Idling and Minor stoppages

Idling losses occur when equipment idles i.e., that it continues to run without producing. Minor stoppage losses occur when equipment stops for a short time as a result of a temporary problem (micro stop). For example, a minor stoppage occurs when a work-piece is jammed in a chute or when a sensor activates and shuts down the machinery. As soon as someone removes the jammed work piece or resets the sensor, it operates normally again. Since idling and minor stoppages interrupt functions, they can also be categorized as breakdowns. Even so, the two are essentially different in that a minor stoppage can be dealt with quickly, i.e., as soon as it is noticed (the operator can correct a minor stoppage and the duration is usually less than 10 minutes).

Quality losses

Startup losses

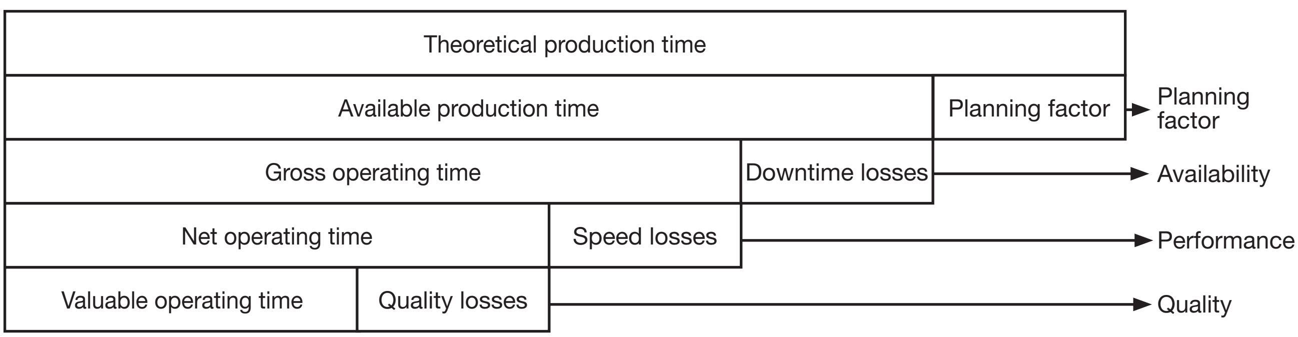
Startup losses are yield losses that occur in the early stages of production, from machine set up to stabilization of product quality. The volume of losses varies with the degree of stability of processing conditions, maintenance level on equipment, operators' technical skills, etc.

Quality defects

Quality defects are quality losses that are not attributed to start up.

6.4 Effectiveness factors

Effectiveness factors are calculated in a way similar to the model in the text. The values however, are usually different as the losses are divided differently.



6.4.1 Total productivity and total OEE

In the model with the 'planning factor,' the total productivity is defined as:

$$\text{Total productivity} = \frac{\text{Valuable operating time}}{\text{Theoretical production time}}$$

Note that the term 'Productivity' is misused, as it is a measure for effectiveness. From the definition, it is clear that total productivity and total OEE have the same value.

In some manuals a 'planning factor' (model with the 'planned downtime losses') is defined similar to the one in the first model:

$$\text{Planning factor (Pf)} = \frac{\text{Planned production time}}{\text{Theoretical production time}}$$

Note that that the total productivity can then also be calculated as

Total productivity = OEE × Pf

With the value of the OEE and the "planning factor" as calculated in the model with the 'Planned downtime losses'.

6.4.2 Availability

$$\text{Availability} = \frac{\text{Gross operating time}}{\text{Available production time}}$$

6.4.3 Performance

$$\text{Performance} = \frac{\text{Net operating time}}{\text{Gross operating time}}$$

6.4.4 Quality factor

$$\text{Quality factor} = \frac{\text{Valuable operating time}}{\text{Net operational time}}$$

6.5 Why this appendix?

As explained in the beginning of the appendix, the main reason that this second model is presented is because it is well known in literature. It is however, not always applicable in reality.

The model in the text deserves our preference because it can always be applied. It is easier to divide the losses by their causes than it is to try to determine which of the six big losses to attribute a specific loss to, or to try to determine whether or not they should be put together with the 'planned downtime losses.' It also makes it possible to find out the effects of maintenance more easily (look at the losses due to machine malfunctioning). Attributing the losses to external circumstances, process or machine malfunctioning also enables you to determine the responsible person/organization .

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