Using Production Performance to Measure Maintenance Effectiveness

Thereby regulating maintenance activity and investment

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1. Abstract

This paper demonstrates a direct relationship between maintenance activity and Production Performance of large and complex industrial facilities. It shows how to use your daily production records to configure genuinely useful measures of equipment performance and maintenance effectiveness. These measures provide production-based evidence for prioritizing maintenance effort and operational investment, thereby supporting superior production performance.

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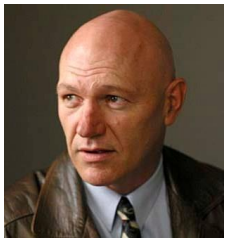
2. Contents

[1] About the Author:

Ian has over 35 years of international manufacturing and industrial engineering experience and is a recognised leader in asset management and reliability engineering. Ian has worked with major international companies including ExxonMobil, Kodak, Siemens and GE-Digital on asset capability, operational improvement, workforce engagement, and digital transformation. Ian now consults independently with Flagstaff Consulting Group.



3. Executive Summary

Managers of large and complex industrial facilities know that maintenance can make or break their production performance. Yet in decades of "asset management" evolution and countless metrics, there has rarely been an example of where the effectiveness of maintenance activity is directly and consistently measured by its impact upon production output.

This paper demonstrates a direct relationship between maintenance activity and "Production Performance". With existing digital technology, this scheme can be readily deployed, ***if users are prepared for a mind-set shift: to use production units as the measurement medium.***

In this paper two measures of maintenance activity are defined using the same yardstick that production staff and production planners use. The maintenance measures are:

- Preventive Maintenance Effectiveness ("PM Effectiveness") %
- Plant Availability %

These measures are derived within the boundary of two well-established operational performance metrics:

- Overall Equipment Effectiveness (OEE) %
- Utilization %

Furthermore, another insightful indicator is proposed within this framework of measurement:

- Operational Availability %

The rationale for the *mind-set shift* is first explained within the framework of "*Production Loss Accounting*".

4. Accounting for Production Loss

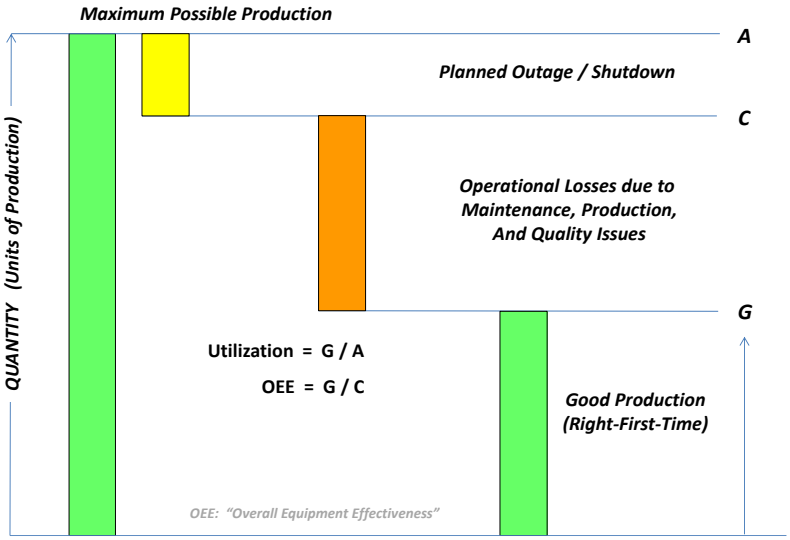
4.1 Production Performance is "Absence of Loss"

Most sophisticated production facilities will have a form of *Production Loss Accounting*, where daily production losses are identified and accumulated over time (in a database). The database should record the reasons for the losses, and thus provide tangible operational evidence for improvements. The basic principle is to identify the losses in the gap between the ***Actual*** production quantity, and the ***Maximum Possible Production*** on a shift-basis or daily-basis, as illustrated below[2].

All quantities are expressed in the facility's **units-of-production** (e.g. tonnes, barrels, pallets, widgets, etc.)

In this measurement paradigm, production performance is measured by the ***absence of loss***, where "loss" is a quantity expressed in the *units-of-production*.

This scheme can be readily applied to any production scenario, with key metrics determined by easily recognizable ratios of production units (which are equivalent to the time-based metrics OEE and Uptime).



Specifically, the well-known metric OEE (Overall Equipment Effectiveness) is arithmetically identical to the ratio of G / C.

Note that Planned Outages (production shutdowns) are promulgated by management and are beyond the daily accountability of operations staff. This quantity of forgone production is recorded as the *production loss* (A – C).

4.2 Measuring Maintenance Impact

There are three steps in defining production-based measures for the effectiveness of the maintenance investment.

- Steps 1 and 2 (below) establish the conceptual framework and terminology required to identify the maintenance activity. These two steps are a "one-time" design effort.

[2] See Appendix 1 for determination of "*Maximum Possible Production*"

- Step 3 requires ongoing daily effort to categorize maintenance activity within the ***Production Loss Accounting*** paradigm described above. These records can be readily captured through appropriate configuration of digital systems, and initiated by an operating discipline featuring close collaboration between operations, maintenance and engineering staff.

Step 1: Align activity with Maintenance Policies

The entire spectrum of maintenance work must assigned to major categories of activity. All activity must be accounted for, under the well-defined categories such as those described below.

The categories of activity are commonly known as "Maintenance Policies", namely:

1. **Breakdown** (BD) For assets that are allowed to breakdown (or "run-to-failure").
2. **Preventive Maintenance** (PM) For assets that should receive attention to prevent failure.
3. **Planned Shutdown** (SD) For assets requiring a production shutdown.

The second category (the Preventive Maintenance policy), may be further delineated into the sub-categories of:

- Time- or Cycle-Based actions… for evident failures,
- Condition-Based Monitoring actions… for evident failures,
- Failure Finding (or testing) actions… for hidden failures,
- Inspection actions… for contingency after an event (e.g. a storm).

Site experts usually determine the Maintenance Policy for the various assets within the facility, through various means: judgment, experience, maintenance history, vendors' recommendations, and/or various types of risk assessment such as RCM (Reliability Centred Maintenance).

Step 2: Ensure every Asset is assigned a default Maintenance Policy

Make sure that every asset (aka maintainable item) in the facility is assigned a Maintenance Policy (1, 2 or 3 above). This assignment of maintenance policy should be registered against each asset within the company's maintenance management system. The policy directs what ***default*** *(or intended)* type of maintenance should be done for each asset.

Key concepts to understand are that:

- Assigning a "**Breakdown**" policy to assets means that these items are "expected" to fail at some future time, and indeed *are allowed to fail* (presumably with appropriate mitigation such as repair & recovery procedures, with spare parts identified and on-hand or available).

- Assigning a **"Preventive Maintenance"** policy means that the item is **NOT expected to fail**. Such failures indicate a failure of the associated preventive maintenance strategy and/or its execution.

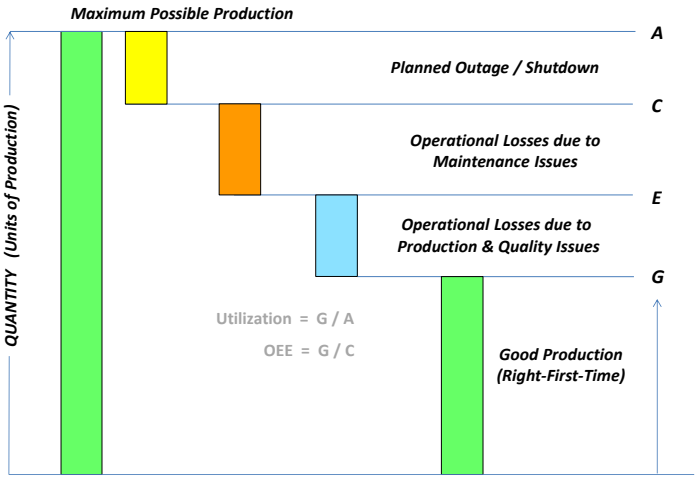
- Assigning the "**Planned Shutdown**" policy to assets means that these items can only be serviced during pre-planned plant outages.

At this point, staff may gain valuable insights by comparing the relative costs of the maintenance within the categories of Shutdown, Breakdown, and Preventive Maintenance.

However, staff are still unable to gauge the effectiveness of this maintenance effort in relation to the productive capacity of the facility, or to compare the relative effectiveness between major facilities.

Step 3: Identify Production Losses due to Maintenance Activity

On a daily, or shift-based cadence, operations and maintenance staff together collaborate to determine the amount of production loss attributable to Operational Issues (such as slowdowns, fouling, environment, off-spec quality, etc), and how much is attributable to Maintenance Issues (such as equipment failure for any reason).



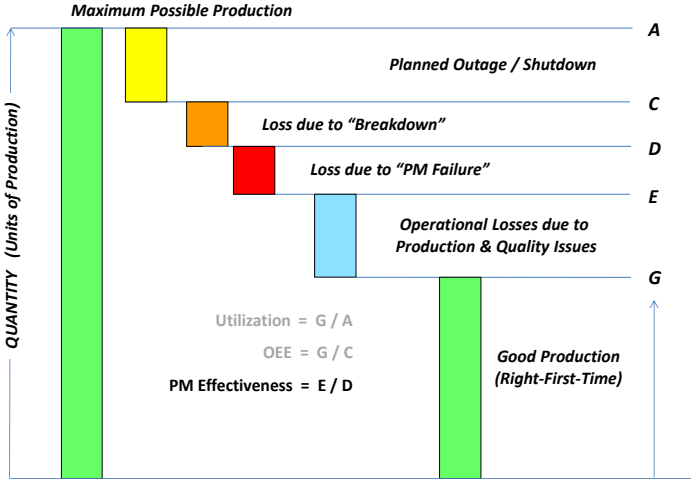
The maintenance objective here is to allocate the appropriate production loss to the correct asset (aka maintainable item in the asset register). This procedure is rule-based, according to apparent root cause, as determined by company experts.

As per Step 2 above, every asset will already have been assigned a default Maintenance Policy. Therefore, for each loss incident, the database can associate that quantity of loss to a Maintenance Policy (via the offending asset).

This then enables the "***Operational Losses due to Maintenance Issues***" (quantity C – E) to be bifurcated according to the Maintenance Policy (BD or PM) assigned to the offending assets, as follows:

- "***Losses due to Breakdown***": losses that have been *allowed to happen* (those assets that have been assigned a "Breakdown" maintenance policy), and

- "***Losses due to PM Failure***": losses that have occurred due to a failure of the Preventive Maintenance strategy – that is, assets that have failed despite the preventive maintenance activity (or lack thereof).



4.3 Define Preventive Maintenance Effectiveness

At this point, **PM Effectiveness** can be calculated in terms of the impact upon production. The **ratio E/D** exquisitely expresses just how effective the company's pre-determined Preventive Maintenance Strategies actually are. Given the massive investment in Reliability and Maintenance staff, tools and processes, the ratio E/D should ideally be close to 100%.

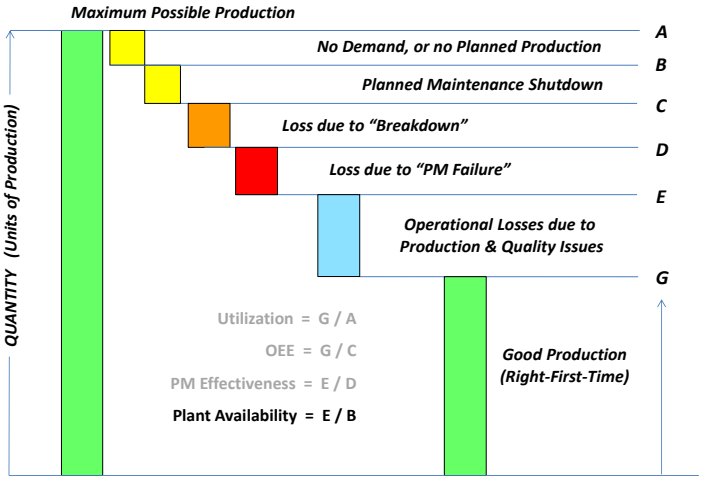
> Issues Arising: What if this ratio E/D is not near 100% ? Are the PM activities being done correctly ? Are the procedures effective ? Is the Preventive Maintenance based on good science and/or good data, and targeting the correct failure modes ? How are failures followed up, and are the same failures recurring on the same assets, and/or on identical or similar assets ?

Given the investment in Preventive Maintenance, owners can legitimately ask why production is being impacted by assets which are expected to perform under normal operational conditions *without* failure. **PM Effectiveness (E/D)** is the ultimate indicator for the integrity of maintenance strategy and execution.

4.4 Define Plant Availability

In order to define Plant Availability, the production loss due to "***Planned Maintenance Shutdown***" should be identified separately from other shutdown losses that are the result of "*No Demand*" or no production for other business reasons: i.e. the loss quantity (A – B). Planned Maintenance Shutdown losses are usually periodic/intermittent, and some businesses amortize the effect of these losses into the measurement period of interest, which is represented by the loss quantity **(B – C).**

After subtracting the production loss due to "*No Demand or No Planned Production*" The maximum possible quantity that the facility can produce is represented by the quantity **B**.



Therefore, ***Availability*** can be defined as a percentage of **B**.

Considering all losses due to maintenance activity (the sum of SD, BD and PM losses), then we can define:

Plant Availability = the ratio E / B

If there were no production losses due to SD, BD and PM, then Plant Availability would be 100%.

4.5 Define Operational Availability

There are numerous other circumstances, other than inadequate maintenance and/or equipment reliability, that may generate production losses (such as slowdowns and quality issues)[3]. Considering all these losses due to operational reasons only (where equipment has not failed), then:

Operational Availability = the ratio G / E

4.6 Advantages of measuring in Units-of-Production

Measurement of Utilization and OEE in units of production is arithmetically identical to the traditional time-based calculation methods. **Human-oriented** advantages are:

1. Quantities and their ratios are immediately recognizable by all organizational parties and personnel within a production facility.
2. The framework provides a common focus for Operations & Maintenance functions.
3. Quantities easily articulate into Production Planning and Supply Chain planning systems.
4. Quantities can be translated easily into Currency Values by multiplying by the Variable Margin of the product(s).

Furthermore, *lucidity is enhanced* by virtue of the order in which losses are arranged in the stack, as the indicators are visible as simple ratios.

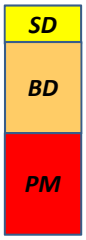
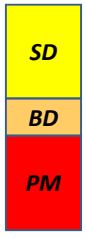
5. Insights from Maintenance Losses

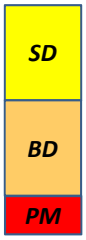
All parties may gain insight into maintenance effectiveness by examining the absolute values of production losses, and the relative impact of Maintenance Policies as they apply and influence production.

- These magnitudes can be used as *drivers* of improvement at a single plant, and indicators of improvement over time.
- Also, they provide a useful comparison between multiple facilities with similar asset sets (e.g. Refineries).

The following six brown-field scenarios provide tangible evidence of performance, and fertile basis for improvements when (a) the sub-categories of losses are analysed and targeted for elimination, and (b) the losses are trended over time.

[3] See Appendix 2 for a typical example of maintenance and operational loss categorization.

Losses	Insights derived from Maintenance Activity
1 	**SD (*Shutdown*) Losses Dominate** Good (low) levels of BD and PM losses. Questions: ¬ is too much planned shutdown work being done (which is relatively more expensive) ? ¬ Are there ways to do more (less expensive) maintenance work on the run, without interrupting production ?
2 	**BD (*Breakdown*) Losses Dominate** Assets are *allowed to breakdown*, and interrupt production. ¬ How many of these BD assets are safety or production critical ? ¬ Should RCM / FMEA be applied to these BD assets ? ¬ Should some assets be re-allocated to a PM or SD Policy ?
3 	**PM (*Preventive Maintenance*) Losses Dominate** Too many UNEXPECTED losses due to failing assets with preventive strategies. ¬ This shows that the Preventive Maintenance Strategies are either poorly conceived, poorly targeted and/or poorly executed. The PM program is **<u>not effective</u>**.
4 	**SD Losses Minimal** PM & BD Losses out-weigh SDs Sometimes indicative of high production delivery pressures – running the plant too hard without time-out for shutdowns. ¬ Can more work be done in planned shutdowns to reduce unplanned outages ?
5 	**BD Losses Minimal** Relatively minor incidence of *expected breakdowns*, overshadowed by PM failures. ¬ Are we over-maintaining items that can be allocated to BD ? ¬ Does the PM program need better strategies ? ¬ Is it well-designed new plant, prior to onset of wear-out ?

6	**PM Losses Minimal**
	The PM program is very effective. ¬ Can more SD and BD assets be placed in the PM program – thereby reducing the overall magnitude of the losses ?

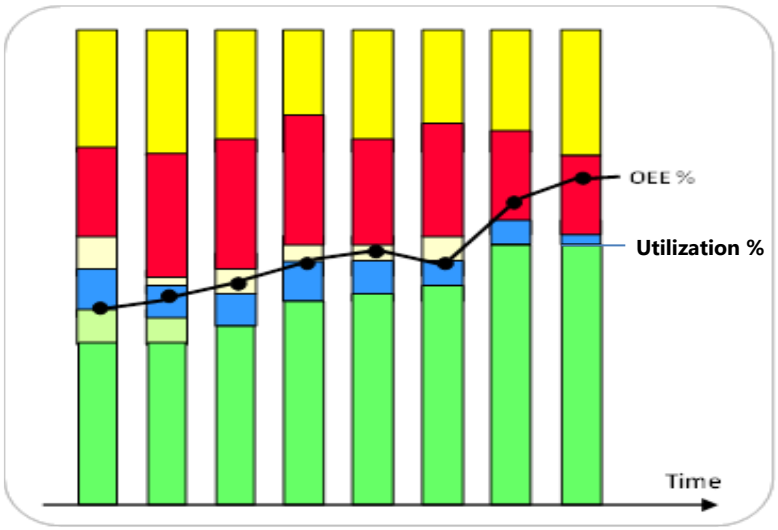
6. Broader Operational Insights

The representation of maintenance effectiveness through the medium of "production loss" is an important sub-set of the broader appreciation of Production Performance which uses two widely known measures:

- ¬ Overall Equipment Effectiveness (OEE) %
- ¬ Utilization %

The magnitude of losses within each loss category can be sub-categorized and "budgeted". Actuals can be trended against loss-reduction targets, as improvement initiatives are applied to relevant sub-categories[4]. The real value is created when the losses within sub-categories are incisively examined and eliminated. *(See Appendix 2 for an example of sub-categorization).*

A macro trend of loss elimination will appear in the format below, where each bar represents a time-period of measure (e.g. a shift, a day, a week, a month). Obviously, smaller time periods may be consolidated into larger periods for reporting purposes.



[4] See Appendix 2 for a typical example of maintenance and operational loss categorization.

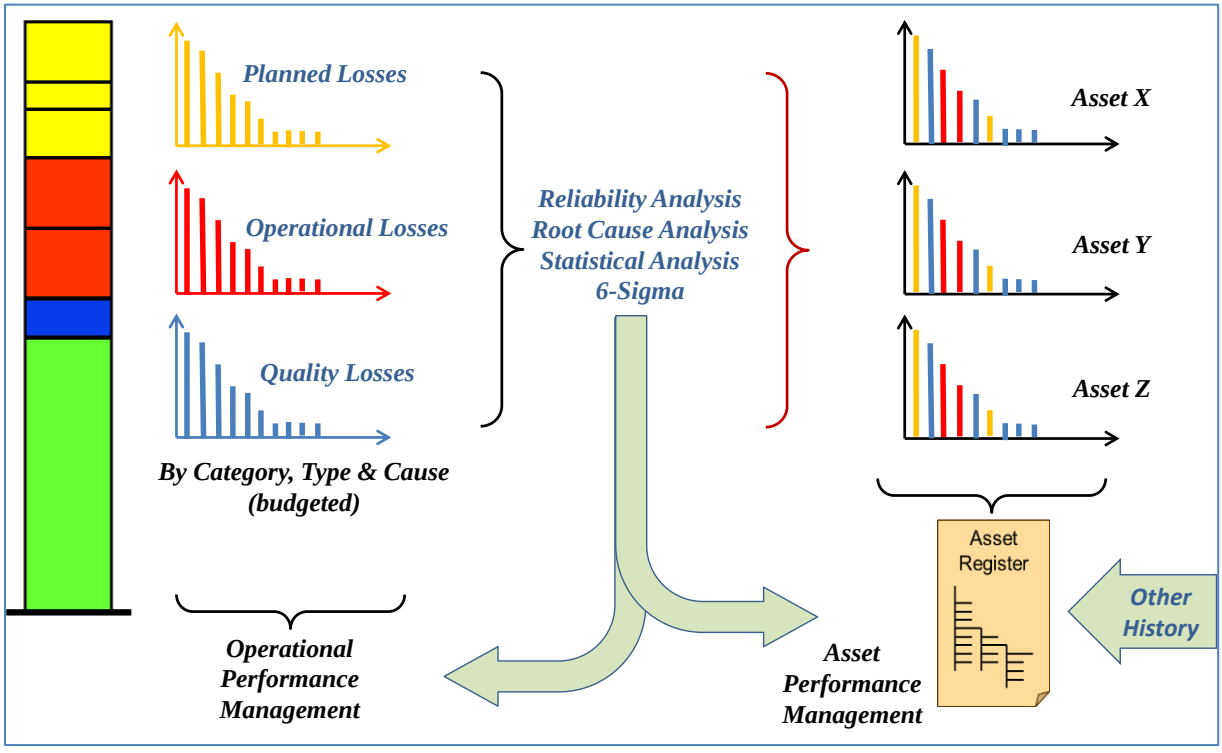
6.1 Extending capability with enterprise-scale software:

Substantial additional value may be released if the Production Loss Accounting principle is applied to both:

- Operational Performance Management, and
- Asset Performance Management.

With the assistance of digital technology, databases may be configured to link many of the Operational and Quality Losses to equipment in the Asset Register (in addition to the Maintenance Losses illustrated in the previous section). Thus, greater insight regarding the influence of asset performance may be derived, and used in loss elimination.

The diagram below illustrates how losses may be identified, categorized, analysed, and simultaneously assigned to both Operational, and Asset databases.



7. Conclusion

By approaching production optimization via the ***absence of loss***, the performance of large and complex facilities may be comprehensively measured in *units-of-production* which are widely understood. This establishes a common focus (across multiple departments) for collaboration, prioritization, and improvement initiatives.

The five measures of performance are derived using simple ratios of the production and loss quantities. The five measures are:

- Utilization %
- Overall Equipment Effectiveness (OEE) %
- Preventive Maintenance Effectiveness %
- Plant Availability %
- Operational Availability %

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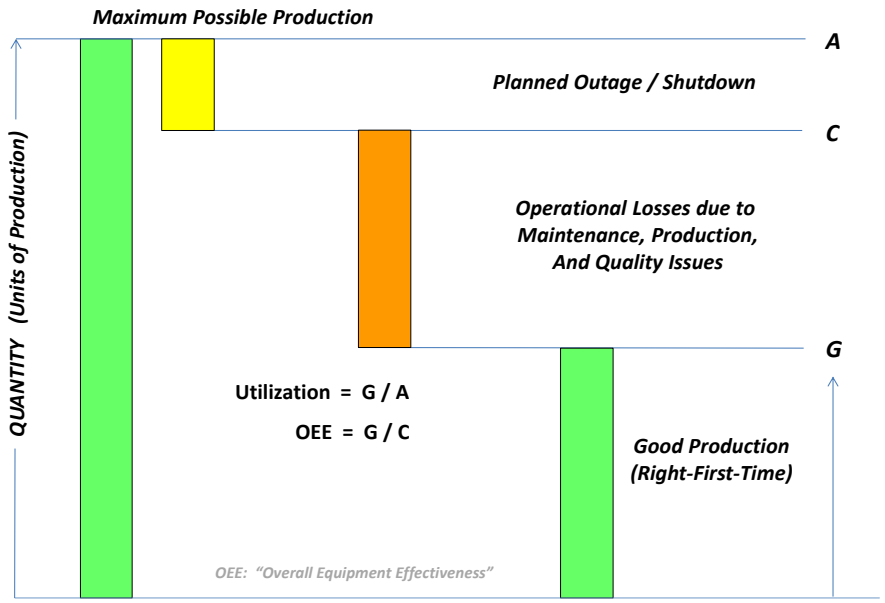
Appendix 1 - Maximum Possible Production

The integrity of the bar-chart view of production quantities relies upon a **credible** determination of "Maximum Possible Production" (MPP).

This is achieved by first defining MDR: Maximum Demonstrated Rate. Then:

MPP = MDR x T

Where T is the time-period of interest.



Maximum Demonstrated Rate

MDR is defined as the maximum amount of ***Good Production*** that a unit has ever sustained for a short time-period. For example, XXX Tonnes/Day, or YYY Kg/Hour.

A "short time period" depends on the type of process, for example:

- in a batch process - the time taken to produce a single batch.
- in a continuous process – duration of a full production run, or a production shift.
- in a complex multi-unit process – a 24-hour period.

The maximum rate of production is achieved with the fastest grade of product running perfectly, with no losses or rate limits.

Examples of MDR may therefore be defined as:

- The best achieved (i.e. demonstrated) during the short time-period.
- An average of the best 5 (or 7) 24-hr production days ever achieved.
- MDR will usually be determined by the process bottleneck.
- MDR is not a long-term average, but rather, a credible and achievable target.

Good Production is defined as the quantity of **First Pass / First Quality Yield:** "The on-aim product that was produced for the intended customer, expressed as a percentage of the product which could have been produced from the on-spec raw material, without reclassification, sorting, rework, blending, or adjustment"

Maximum Possible Production

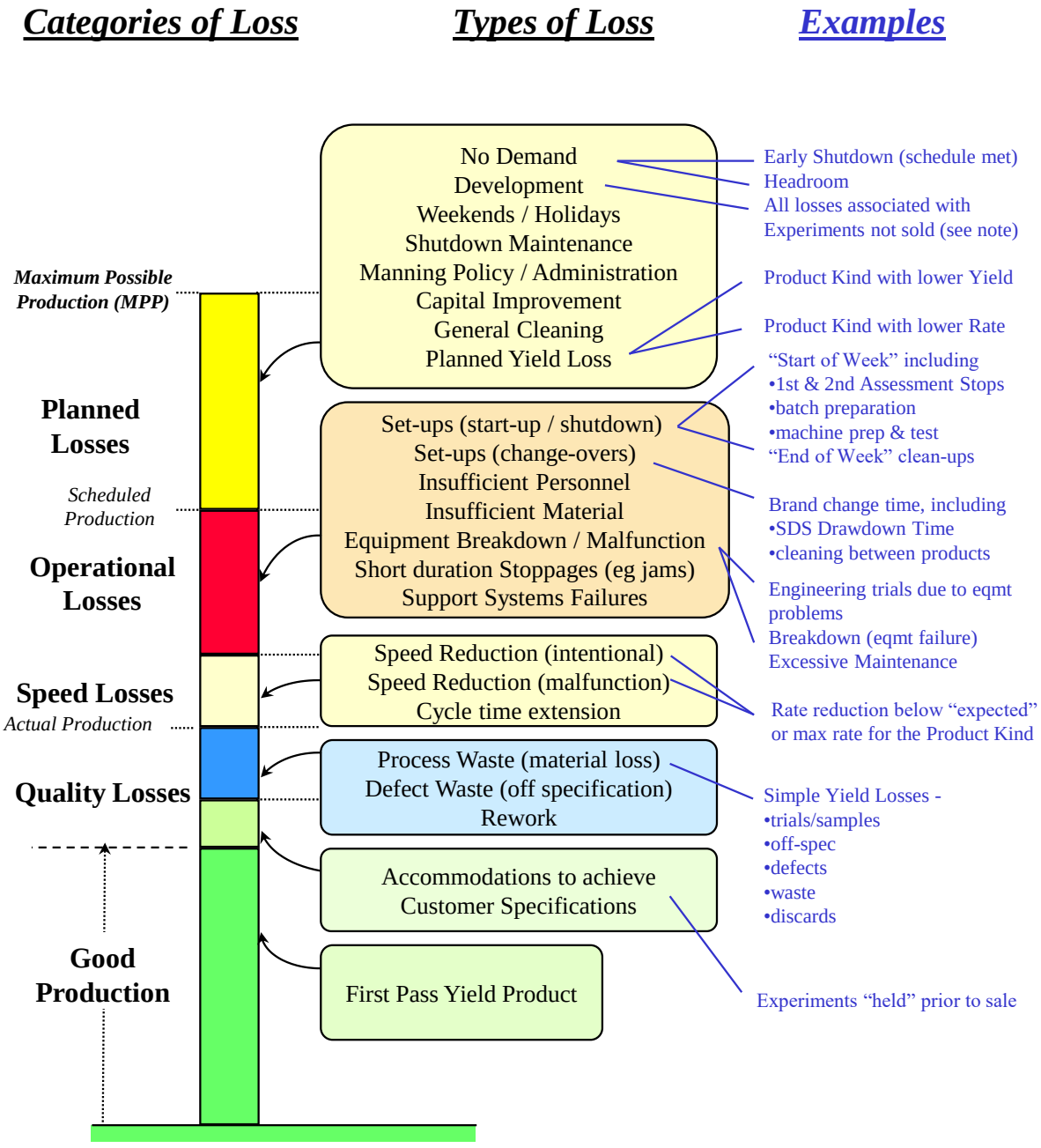
MPP is then used as the maximum value (100%) on the bar chart.

- ***Good Production, and Quality Losses*** (which are real quantities) are measured *upwards* from zero.
- All other ***Losses*** are recorded *downwards* from MPP, as these are all estimated quantities and represent lost opportunity.

Inevitably, there will be a reconciliation gap representing "unknown" amounts of loss. These amounts should be recorded as unknown operational losses to encourage (a) transparent reporting, and (b) an incentive the discover the unknown causes.

Finally, as losses are identified and eliminated, production performance will improve over time with new MDR's being achieved. Also, improvements due to operational and capital investment will lead to expectations of increased production. These two factors mean that MPP should be reset upwards periodically, implying that **MPP itself may be used as a long-term KPI of production capability**.

Appendix 2 - Generic example of loss categorization



Note on Experiments:
If the product of an experiment is not intended for sale, all losses are deemed "Planned".
If the product of an experiment is intended for sale, then the production time is considered as normal operation, and losses are categorized under Operational, Speed or Quality. Product held for inspection / test / evaluation is classed as an Accommodation, but categorized as Good Product if passed for sale.