White paper

How to control manufacturing efficiency: An OEE approach

Executive summary

In the manufacturing environment, efficiency and predictability of the process is key to guaranteeing the production plan and optimizing the manufacturing cost of the final product. There are several methods and metrics that have been developed over the years to track different factors that influence the process, such as cycle time and critical performance parameters. These parameters are used to detect any deviation of the process performance as soon as possible to guarantee a reliable performance. The Overall Equipment Efficiency (OEE) is a metric that integrates the tracking and control of the entire end-to-end manufacturing process, enabling the quick detection of any deviation that appears in any point of the process.

HP Jet Fusion 3D 4200/4210 Printing Solutions are 3D printing systems designed to work in manufacturing environments. Therefore, the same metrics that are being used to measure the efficiency in traditional manufacturing technologies such as CNC machining or injection molding can be adapted to measure and control the process efficiency in these 3D manufacturing systems. This paper will explain how to measure the OEE of HP Multi Jet Fusion (MJF) technology.

The OEE is calculated by multiplying the manufacturing process availability, quality, and performance.

OEE (%) = Aviability (%) × Performance (%) × Quality (%)

The main objective of the OEE measure is to find the areas of inefficiencies that could be improved or optimized, increasing the overall efficiency of the process.

This document includes a detailed procedure explaining how to calculate the OEE in a production process where an HP Jet Fusion 3D 4200/4210 Printing Solution is used.

There are several recommendations that could help to optimize the OEE for the HP MJF process:

- **Availability improvements:** Unexpected waiting times are reduced through the prioritization of operator tasks; proper training provided to the operator to reduce inefficiencies during their ramp up; structured maintenance performed on the printer at the required frequency; additional Build Units as backup, etc.

- **Performance improvements:** Use of full jobs and parts redesign to increase the job height.

- **Quality improvements:** Use design guidelines and tips and tricks to improve part quality and automation of the post-process.

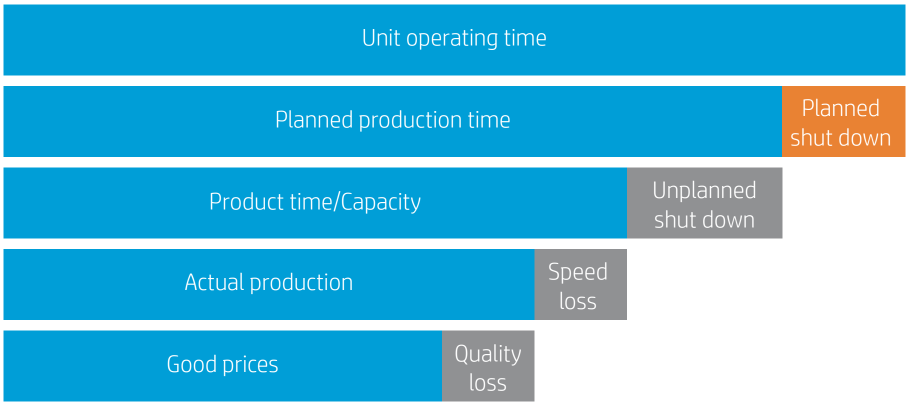
OEE overview

The OEE is a metric that is widely used in manufacturing industries to measure the efficiency and effectiveness of the end-to-end manufacturing process. The metric tracks the performance of the process by measuring the equipment availability, performance, and quality, so as to quickly detect any variation to these factors.

The analysis of the OEE obtained in a production environment helps in the identification of the contributing factors influencing process performance. By identifying the impacting factors, optimization efforts can be focused on defining a suitable measure for improvement and mitigation.

The OEE is frequently used as a key metric in Total Productive Maintenance (TPM) and lean manufacturing programs offering a consistent method of measuring the effectiveness of TPM and other initiatives by providing an overall framework for measuring production efficiency.[1]

The OEE provides a ratio of actual production time compared to the planned production time. However, in order to better identify the areas requiring improvement within the process, three main factors (unplanned shut downs, speed loss, and quality loss) are taken into account to detect which are causing a negative impact on the final production time.



OEE breakdown

OEE factors

There are three main factors used to calculate the OEE. These are the **availability, performance,** and **quality** of the process. The OEE is calculated by multiplying the percentage result of these three manufacturing variables:

$$\text{OEE (\%)} = \text{Aviability (\%)} \times \text{Performance (\%)} \times \text{Quality (\%)}$$

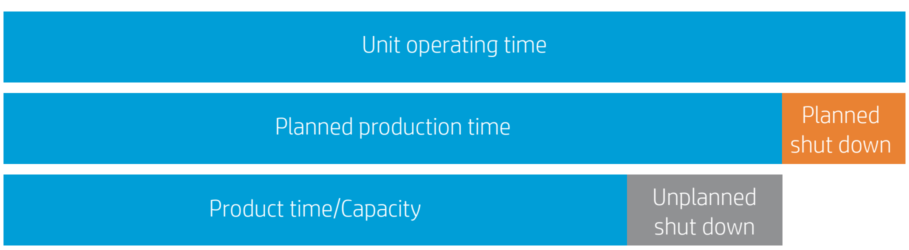
Availability

The *availability* factor measures the time the manufacturing process is running versus planned running time and is expressed as a percentage. Any unscheduled shut downs will affect this metric. Examples of typical shut down scenarios can be an equipment failure or material shortage. Analysis of the types of shutdowns and their frequency and impact in a production environment will help to mitigate or correct them.

The planned production time is already considering the number of shifts per days, and the working days the process is running per month (e.g., 24x5, 24x7, etc.). It also needs to discount the planned shut down time of the process. This includes maintenance or any preventive operation done in the system. A 100% availability result means the process has been running without any unscheduled stops.

$$\text{Aviability (\%)} = \frac{\text{Product time (h)}}{\text{Planned production time (h)}}$$

$$\text{Product time (h)} = \text{Planned production time (h)} - \text{Unplanned shut down (h)}$$



Aviability breakdown

Performance

The *performance* of the manufacturing process is measuring the factors that cause the unit to operate at less than maximum speed. For example, one factor that could impact performance operator inefficiency, the remaining available time, is called *Net Operating Time.*

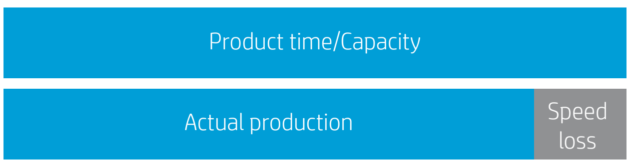
A 100% performance result means the process has been consistently running at its theoretical maximum speed.

$$\text{Performance (\%)} = \frac{\text{Actual production}}{\text{Production capacity}}$$

$$\text{Actual production (h)} = \text{Production time (h)} - \text{Speed loss (h)}$$

In real environments, the performance is calculated by the following formula:

$$\text{Performance (\%)} = \frac{\text{Ideal cycle} \times \text{Total pieces}}{\text{Production time}}$$



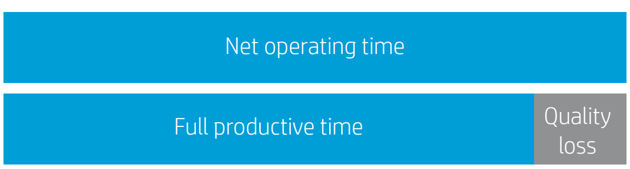
Performance breakdown

Quality

The *quality* factor measures the percentage of parts that do not meet the quality requirements of the final product. It quantifies the yield of the manufacturing process.

$$\text{Quality (\%)} = \frac{\text{\# Number of good parts}}{\text{\# Total number os parts produced}}$$

A quality factor of 100% indicates that there is no rejected or reworked part in the process.



Quality breakdown

OEE references in other industries

Companies with manufacturing processes that are considered to be "best in class" have an OEE of 85% or above.[2]

Although the value of 85% of OEE may seem a low value to be a reference for the industry standard, it must be remembered that this is an average of all three categories. It can be achieved by having a 90% availability, 95% performance, and 99.9% quality in the process, which are very challenging numbers in a continuous manufacturing process. [2]

Studies indicate that the average OEE score for discrete manufacturing plants is approximately 60%. [2]

OEE measurement procedure with HP Jet Fusion 3D 4200/4210 Printing Solutions

A method for effectively measuring the OEE with HP Jet Fusion 3D 4200/4210 Printing Solutions is explained below for each of the three main factors being tracked.

Printer operation method consideration

Before starting to calculate the OEE using the HP Jet Fusion 3D 4200/4210 Printing Solutions it needs to be taken into account that the OEE calculation is defined and modeled for an environment with continuous operation—a manufacturing environment.

Production on demand is not a good printing process to be measured using this metric. In such a case, there is no planned time for printers or production targets because jobs depend on the number of requests coming in. For production on demand with low printer usage (<0.5-0.75 full buckets/day), availability can be simplified to 100%.

Availability

The availability is calculated as:

$$\text{Aviability (\%)} = \frac{\text{Run time (h)}}{\text{Planned production time (h)}}$$

The OEE is recommended to be measured on a weekly basis. Therefore, the time reference calculated in the following examples is a working week.

Planned production time

The planned production time can be calculated as:

$$\text{Planned production (h)} = \left(\text{Unit operating time per day} \times \text{Days per week}\right) - \text{Planned shutdown time}$$

The possible planned shutdown events are:

- **End-of-job maintenance time:** This maintenance is done after every job is printed. It is mandatory and it takes 20 min.
- **Weekly maintenance time:** This maintenance is mandatory and it takes 60 min.
- **Other maintenance routines:** There are two additional maintenance routines. One is done every 6 months and the other is done annually. They take 120 and 15 min respectively.

- **Preventive maintenance:** This depends on the usage of the printer. For optimal performance of the system, HP recommends performing a preventive maintenance routine every 750 jobs. In a 24/7 operation, this service would be recommended yearly.
  This service is performed by HP operators and includes, both part replacement and labor costs. This task will take approximately 2 business days.

Example
A manufacturing plant is running 24 hours a day, 5 days a week, and will have a planned production time that cannot be higher than 24 x 5 – 1 h (weekly maintenance) – number of jobs printed x 20 min.

Run time

The most practical way to calculate the run time is to quantify the number of hours that the printer has been actually printing. This can be tracked by the operators writing down the predicted printed time that appears in the Smartstream Build Manager or in the printer's front panel.

Example
Let's take a printer in the manufacturing factory of the previous example, which has a planned printing production of 108 h in total. During that week, the operators have written down a total printing time of 101 h:

$$\text{Aviability (\%)} = \frac{101\text{ h}}{108\text{ h}} = 93.5\%$$

Performance

The performance factor is measuring the actual production obtained versus the maximum capacity that could be achieved with the planned production time.

$$\text{Performance (\%)} = \frac{\text{Actual production}}{\text{Production capacity}}$$

To calculate the maximum capacity of parts printed in a planned time, the printmode needs to be selected because there are printmodes with different printing times. However, the use of buckets with the maximum height produces the maximum number of parts printed with a defined printmode. This happens because before and after printing there are some operations like warm up cooling performed inside the printer. These operations take a fixed time, independent of the number of layers that are going to be printed and, for this reason, the printing process can be optimized by using full buckets.

To calculate the production capacity, it is first necessary to determine the maximum number of layers that can be printed per hour, with the defined printmode used in production. Thereafter, the actual production is calculated from the real number of layers per hour that are printed during the same period of time.

$$\text{Production capacity (layers/h)} = \frac{\text{\# Layer of a full job}}{\text{Total printing time of a full job (h)}}$$

Example
A production factory has selected a production printmode that has a production capacity of 475 layers/hour. However, the builds height used to print provides an actual production of 400 layers/hour. The performance in this situation is 85.1%

Quality

The quality factor measures the number of parts that are accepted in the final quality check of the process, before sending them to the final customer, compared to the total number of parts printed.

$$\text{Quality (\%)} = \frac{\text{Number of good parts}}{\text{Total number of parts produced}}$$

The number of good parts must be quantified after all the production steps are done, including any additional post-process that could be done to the printed part. For example, if a part needs to be painted after being printed, the number of goods parts should be quantified in a quality inspection after painting is done.

It is recommended to have a quality metric before and after applying the post-process. This could be used to identify what percentage of bad parts come from the printing process and from the post-process.

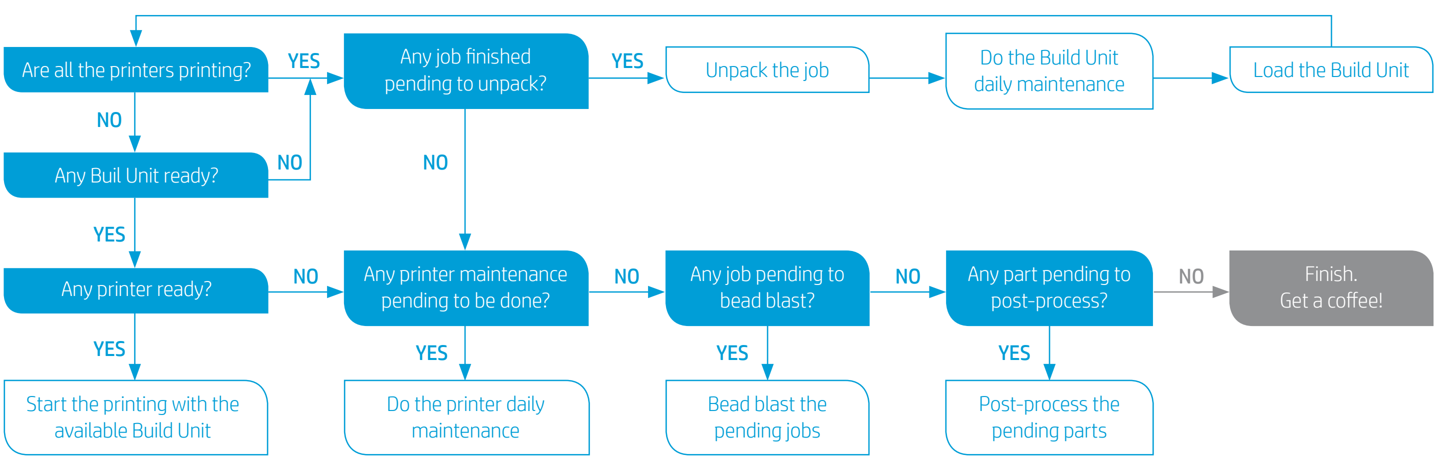
OEE optimization considerations

The main objective to measure OEE is to find areas where there are inefficiencies that could be improved or optimized to increase the efficiency of the process.
There are some considerations that can be used to improve and optimize the manufacturing process for HP Jet Fusion 3D 4200/4210 Printing Solutions.

Actions to improve the availability of the manufacturing process

The risk of an unplanned shutdown is plausible and can impact process availability. Detailed below are some actions to minimize the risk:

- **Unexpected waiting times:** This happens with the printer has stopped and it could start printing again but does not because the operator has missed a previous operational step, for example, cleaning the Build Unit to have it ready to print, perform the printer maintenance, etc. In order to avoid this, the operator tasks must be prioritized. The first priority of the operator is to do the printer maintenance after printing, and then make sure that there is always a Build Unit unpacked, cleaned, and ready to print before printing ends (or before the next print is planned). A workflow shown below has been created to help the operator prioritize duties.



Optimized workflow of operator tasks

- **Lack of availability of Build Units:** The production plan should consider the availability of Build Units. The capacity of the printing process varies depending on the number of Build Units the customer has per printer, and the cooling method used. As an example, a 3D printing factory working 24 h x 7 days with 2 Build Units per printer and an operator per three printers will have a printing capacity of 98% of the total time. However, a 100% printing capacity using natural cooling is achieved by using three Build Units.
  Having Build Units as backup for any operator inefficiency or Build Unit failure helps to minimize unplanned stops.
- **Operator inefficiencies:** An operator inefficiency could occur when the end-of-job maintenance, or any other job, takes longer than expected. This could be due to the operator being new or having improper training. The investment of time to train the new operators in all the maintenance operations will help to carry out their job more efficiently and within the expected timeframe.
- **Replacement of printer supplies:** The printer consumables include agents, printheads, cleaning roll, fusing lamps, heating lamps, and filters. The life of each supply depends on printer usage. The replacement of some of the printer consumables could become a planned shutdown to improve process efficiency. For example, the amount of cleaning roll consumed for a job can be determined. If the printer is printing the same job daily, the amount of cleaning roller consumed can be easily predicted and a pre-planned shutdown scheduled accordingly.
- **Hardware failure:** Printer, Processing Station, or Build Unit failure requires anything from a printer reboot, to a repair done by service technicians. Proper maintenance and environmental conditions help to minimize failures. A Processing Station or Build Unit failure impacts the final lack of availability of Build Units when the printer is already ready to print. This event could be minimized by having Build Units as backup.

Actions to improve the performance of the manufacturing process

- **Print full jobs:** Before and after the printing process, the printer undertakes a series of necessary operations, such as the warm up, system checks, and cooling. The time taken to complete these operations is fixed, irrespective of the number of layers to be printed. For this reason, printing a full bucket improves efficiency by increasing capacity.

- **Part redesign:** By redesigning a part for the HP 3D Jet Fusion additive process, it is possible to improve the packing density, enabling a greater yield. This increased yield can improve the capacity of the printing process.

Actions to improve the quality of the manufacturing process

- **Follow the HP MJF design guidelines and printing tips and tricks:** Part quality is mainly impacted by its design, printing orientation, packing density of the job, part position in the job, and the printmode used. All these variables can be modified to obtain the best possible print quality whilst meeting the part requirements. To do that, HP User Guide and additional documents outlines design guidelines and tips and tricks to optimize the print quality.

- **Post-process automation:** Typically, after a build is completed, manual post-processing steps are required. Due to the repeatability of the process, a small number of bad parts are inevitable. For example, a manual dyeing process could promote staining in some parts which could result in them being rejected. The automation of these additional post-processes will help to maintain a better homogeneity between parts, resulting in an overall higher production yield.

References

[1] Vorne Industries Inc. (2002-2006). OEE pocket guide. Retrieved from www.oee.com.
[2] Vorne Industries Inc. (2002-2006). The Fast Guide to OEE. Retrieved from www.oee.com.

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