Knowledge-based services for and optimization of machines

Deliverable D1.5c_2

Description of demonstrator implemented in 3D printing domain

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Revision History

Version	**Date**	**Description**
v 1.0	30/01/2023	Initial draft

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1. Abstract

This document describes the Dutch use case demonstration activities for the Machinaide project. The Dutch ecosystem contains two use-cases:

- Farm logistics for food production
- Additive manufacturing processes in a Smart Factory

This deliverable focuses on the Additive manufacturing processes in a Smart Factory demonstrator.

2. Introduction

2.1. Summary of Use Case

Additive Industries use case is about developing a toolset to automate, improve and visualize the Overall Equipment Effectiveness improving services to the customer.

2.2. As-Is Status

The MetalFAB1 is a 3D printing system for metal based on Laser Powder Bed Fusion technology

Additive Industries works with the SEMI E10-0304E (Specification for definition and measurement of equipment reliability, availability, and maintainability) and SEMI E79-1106 (Specification for definition and measurement of equipment productivity) to define the Overall Equipment Effectiveness (OEE). This OEE has proven to be an effective way of working with customers to optimize machine performance. OEE consists of 4 parts as depicted in the following figure:

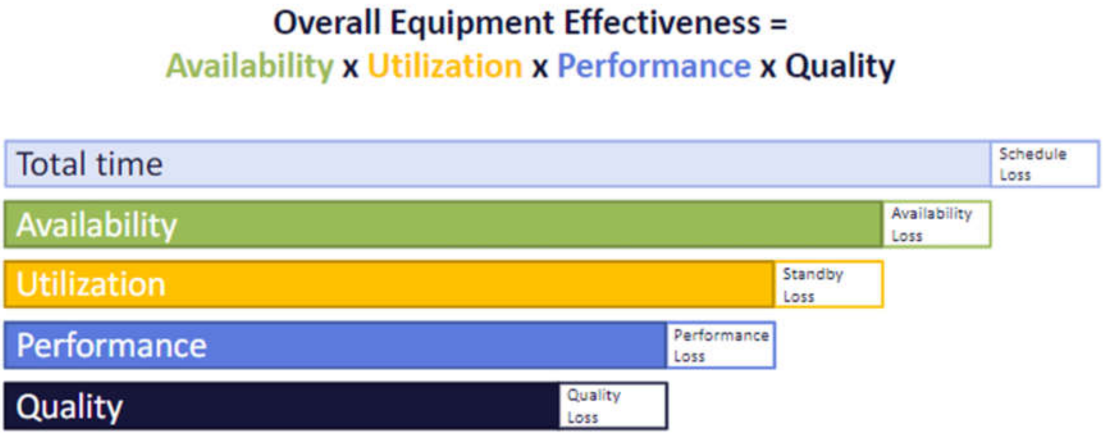


Figure 28 Additive Industries OEE breakdown

To be able to report performance on these budgets, for availability, utilization and performance software status is monitored.

The last budget, part quality, cannot be measured directly inline during production. During the printing process, a lot of optical, chemical, aerodynamics and mechanical processes are active in parallel. To monitor these processes, sensors are included to measure key parameters. Part quality can be guaranteed by ensuring these key parameters keep within their process window. To that purpose, the sensor and software status is logged into a database on the system.

Current state is that the company has not yet developed any tooling to mine the available sensor and software data to come to standardized OEE reporting. Nor has AI any tooling available to apply machine learning algorithms on this data for continuous improvement.

2.3. Use case definitions

The following use cases are identified:

Use case	Goal
System data export	Export system sensor and software status data to a central database. Enables the ability to identify most common issues over all systems as well as machine learning algorithms to find unknown relationships.
System data handling, storage, and visualization	Give customer reporting and visualization services on OEE status
System data visualization	Generate visualizations, using a digital twin, of system productivity
System concept improvements visualization	Ability to generate visualizations, using a digital twin, of improved generated system sequences/productivity.

3. Demonstration

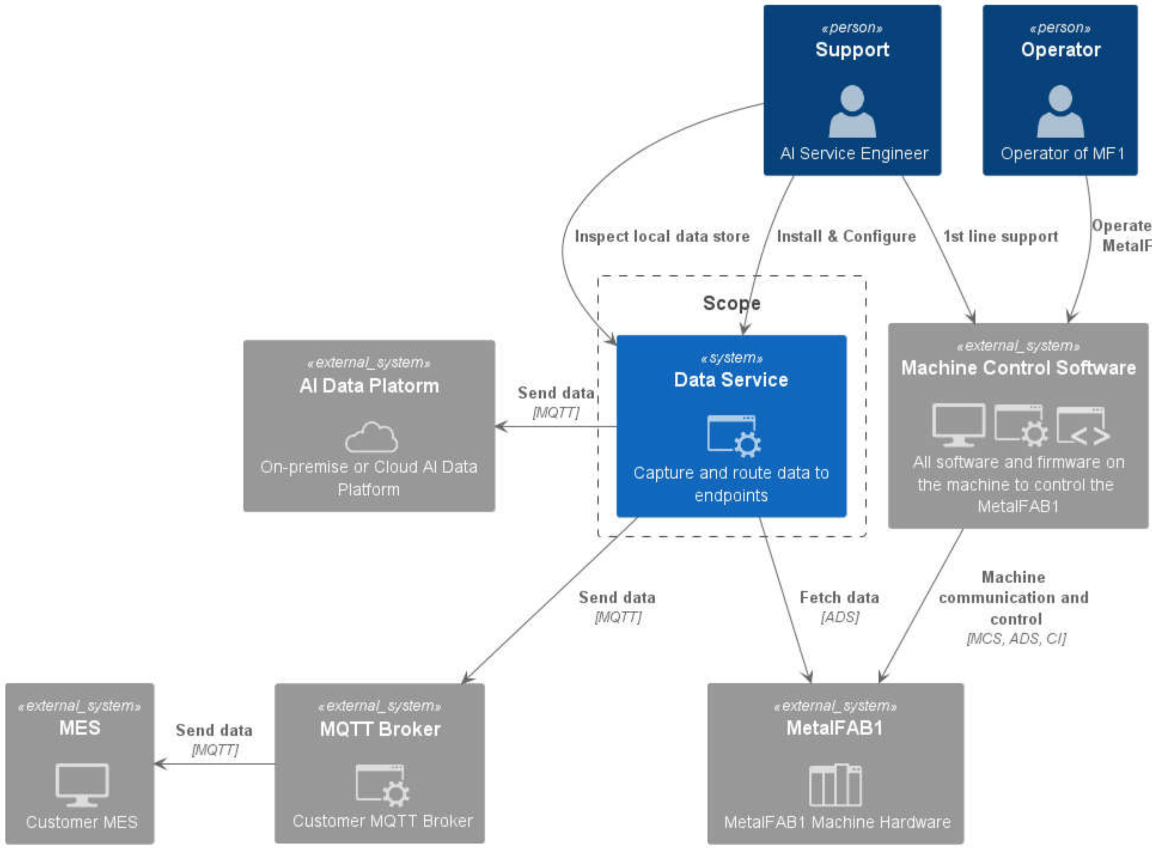
3.1. Data export from MetalFAB1 machine

On the MetalFAB1 machine a DataService is created to offload data to external systems.

3.1.1. Design

The Data Service captures data from the MetalFAB1 and routes the data to the endpoints. The data to capture is configurable and there are multiple possible endpoints e.g., MQTT, OPC-UA, Azure IotHub.

The context of the Data Service is shown in the next diagram.



Context Diagram - Data Service

The Data Service captures data from the MetalFAB1 and routes the data to the configured endpoints. In the diagram above 2 MQTT endpoints are shown.

1. One endpoint forwards the machine data to a customer MQTT Broker. A single MQTT Broker in the customer network can be used to collect data from multiple machines. The MQTT broker then forwards the machine data to other systems e.g., MES.
2. The other endpoint is the Additive Industries Data Platform. The data platform can be used to collect and visualize machine data using dashboards. The AI Data platform can run on-premises in the customer network or in the cloud.

The data to capture is configurable and there are multiple possible endpoints of the same type or of different types.

The endpoints are protocol adapters. The endpoints are responsible for delivering the configured data items to a destination. This involves implementing the data protocol, converting the data items to the message format, and sending the data over the physical layer.

Endpoints are also responsible for:

- Buffering data items when the destination is (temporarily) offline or unavailable
- Aggregating data items to upload less frequently when the protocol requires it e.g. upload to cloud every 5 min to avoid too frequent uploads

3.1.1.1. MQTT endpoint

https://mqtt.org/

MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications, oil and gas, etc.

This endpoint allows the MetalFAB1 to connect to the MQTT message brokers running on the infrastructure of the customer.

3.1.1.2. Azure IotHub endpoint

https://docs.microsoft.com/en-us/azure/iot-hub/iot-concepts-and-iot-hub

The Internet of Things (IoT) is typically defined as a network of physical devices that connect to and exchange data with other devices and services over the Internet or other communication network. There are currently over ten billion connected devices in the world and more are added every year. Anything that can be embedded with the necessary sensors and software can be connected over the internet.

This endpoint allows the MetalFAB1 to connect to the Additive Industries Data Platform via Azure IoTHub services.

3.1.1.3. OPC-UA endpoint

https://opcfoundation.org/about/opc-technologies/opc-ua/

The OPC Unified Architecture (UA), released in 2008, is a platform independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specifications into one extensible framework.

This endpoint allows the MetalFAB1 to act as an OPC-UA server that is implemented according to https://reference.opcfoundation.org/Core/docs/Part8/4/ specification, meaning that the telemetry data is in a vendor-specific format.

3.1.2. Result

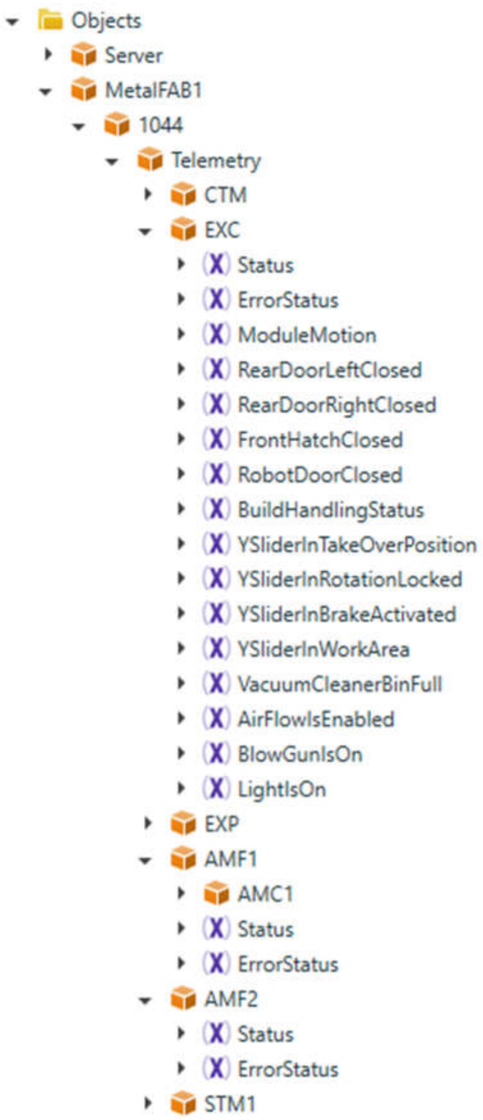
The data service is an integral part of the software deployment on a MetalFAB1 machine. Configuration determines which endpoint is active for that customer.

3.1.3. Demonstration

The data service runs as a background service, therefore there is not much to demonstrate.

Below is a view from an OPC-UA browser tool, which shows telemetry data from a MetalFAB machine. The EXC (exchange) module telemetry is shown. There is much more data (approx. 300 data points per machine).

Note: The MetalFAB1 is a configurable system. A small machine or a larger machine with more modules is possible. More modules result in more data points.



3.2. AI Data Platform

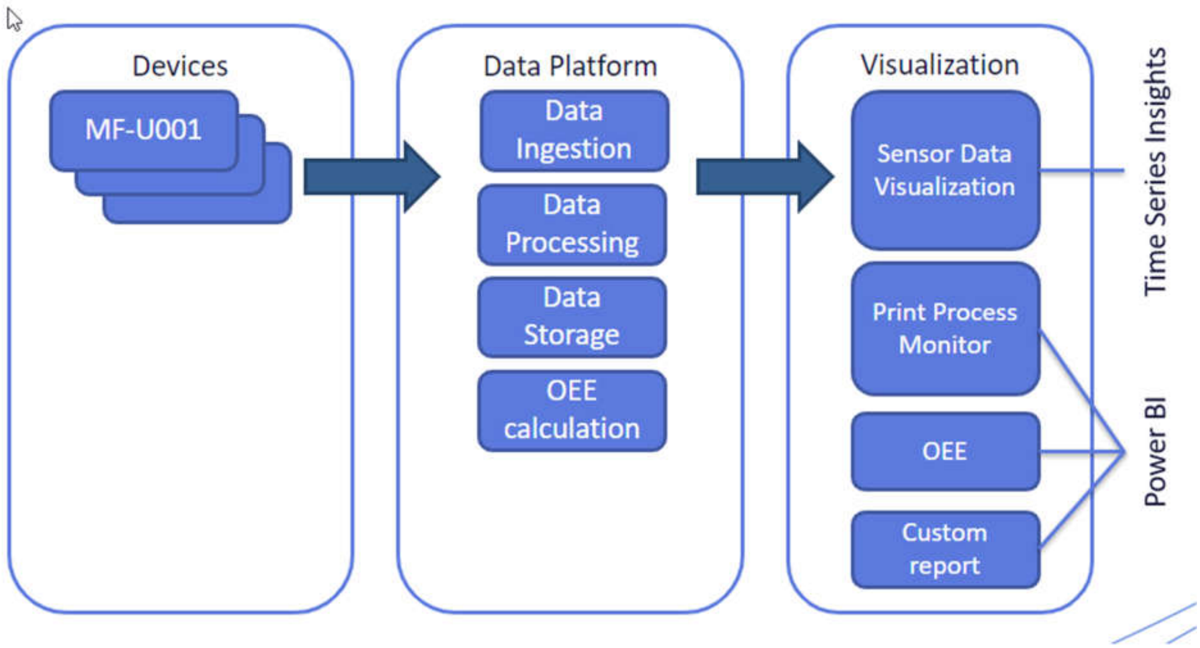
The AI Data Platform is developed to address data handling, storage, and visualization. With a new platform we aim:

1. to allow you to access machine data easily and quickly
2. to build the foundation for services that can be sold to customers, e.g.,OEE calculation, Print process monitoring
3. to accelerate innovation based on insights

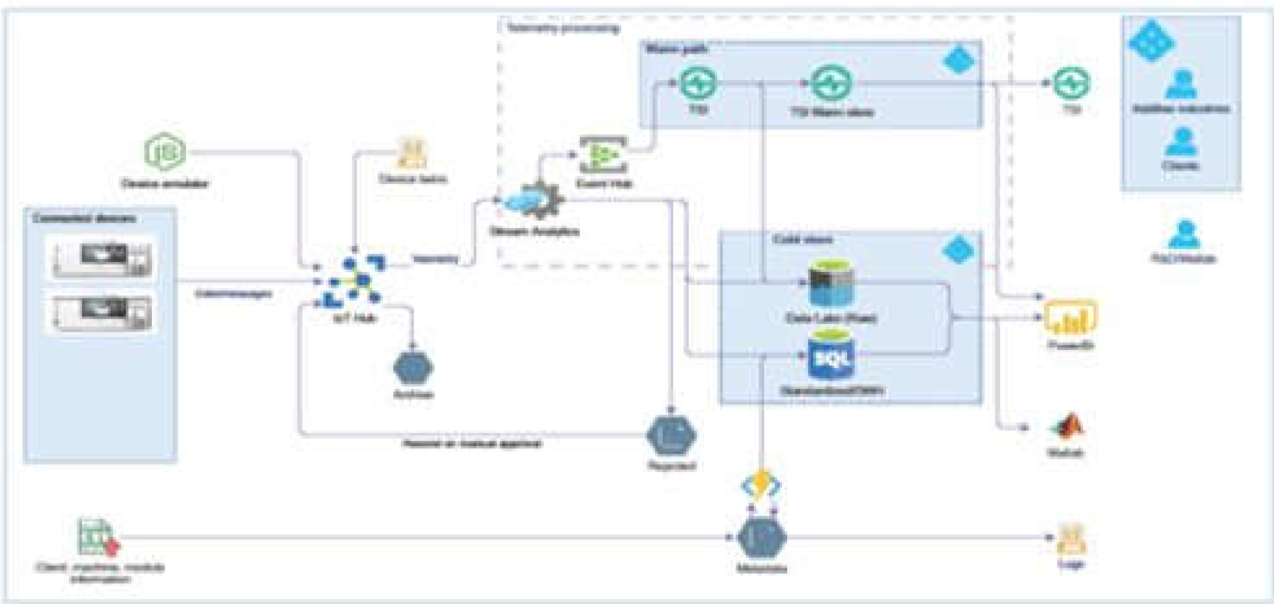
3.2.1. Design

The AI Data Platform is developed in Azure.

The following diagram shows the overall structure:



A more technical overview of the architecture is:



The platform components will be discussed grouped by function:

- Data acquisition
- Data processing
- Data storage
- Visualization

3.2.1.1. Data acquisition

On the machine the Data Service is used to collect the data and send it to an IotHub instance running in the AI Data Platform. IoTHub is a high-available receive of data from multiple machines connected to the Data Platform.

Some characteristics:

- DataService transmits data over a secure internet connection
- DataService supports over 300 data points
- Data is formatted in a json string and compressed to minimize cost
- Data is transmitted at 1Hz

A Device simulator in Node.js is also available for testing purposes.

3.2.1.2. Data processing

Data processing is done by Azure Stream Analytics. Stream Analytics picks up the data from IoTHub, processes it by checking validity and allocating the data to the right machine modules identities, based on serial id.

Some characteristics:

- Received machine data is checked, only known machine configurations are processed
- Telemetry is stored in a data lake
- Telemetry is transmitted to Time Series Insights
- Subset of telemetry is stored in a SQL database

Nightly OEE calculations are performed:

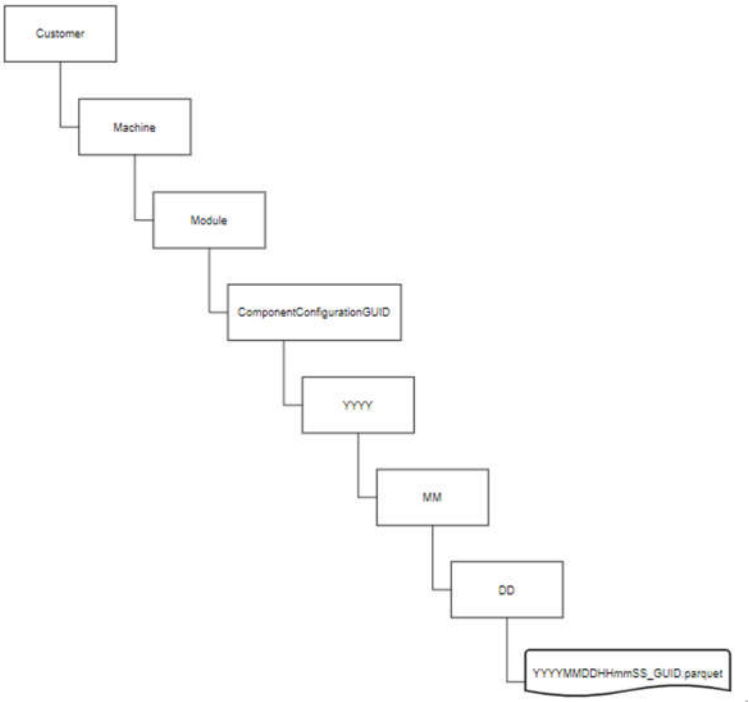
- Each night, Machine Status and Status according to the SEMI standard is calculated for each machine that transmitted data to the platform
- The results of this calculation are available for reporting on the next day
- Maintenance time is respected – a user can specify periods as scheduled or unscheduled down

3.2.1.3. Data storage

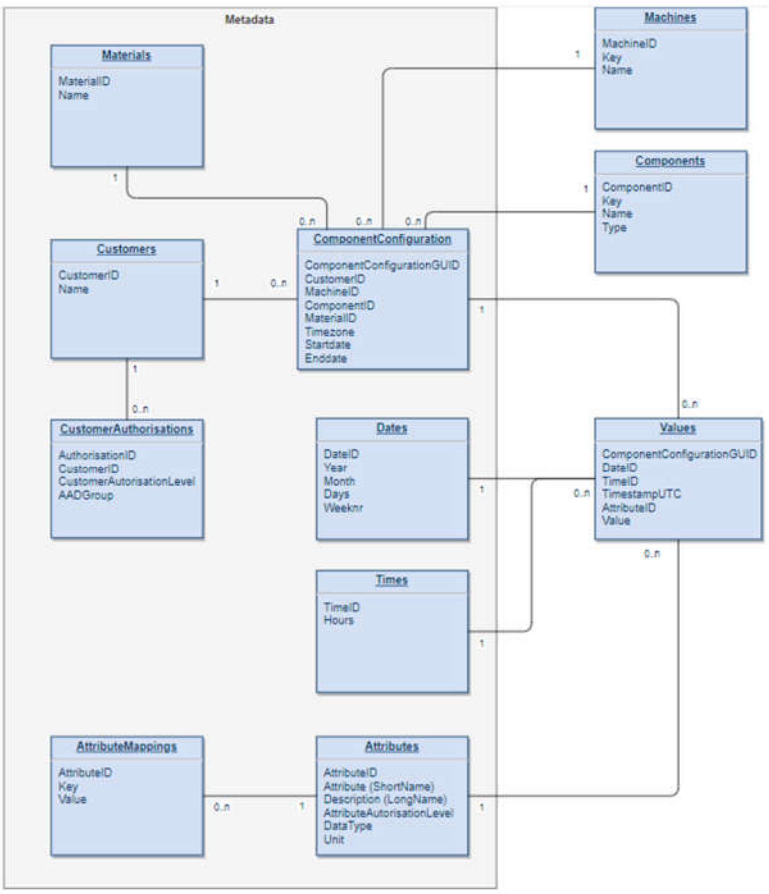
Data storage is concerned with structured storage of all received data. The data is stored on multiple locations depending on the use case of the data.

1. Time Series Insight: fast access to time series data. Supports hot storage and a warm storage. The most recent data is stored in memory (hot storage), while older data is stored on disk, which results in somewhat slower access.
2. Data Lake: the data is stored in a raw format in a data lake. The data lake is the storage of all data received in a structured format.
3. Data Warehouse: the data warehouse contains a selection of data structured in a SQL data warehouse. The data is easy to query by general purpose visualization tools such as PowerBI. The data is categorized per customer, per module, per machine

Data lake structure



Data warehouse data model



3.2.1.4. Visualization

The following visualization tools are used:

1. Time Series Insight
2. General purpose visualization with PowerBI

3.3. MetalFAB1 is Modular

The MetalFAB1 is a modular system. A minimum and a maximum system makes a big difference.

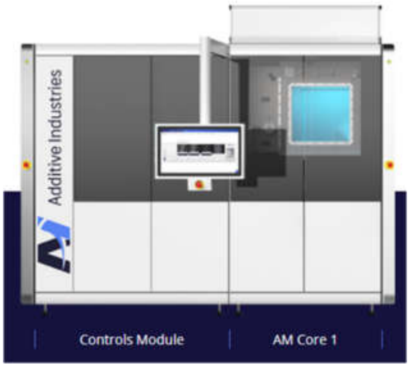


Figure 1: Minimum system

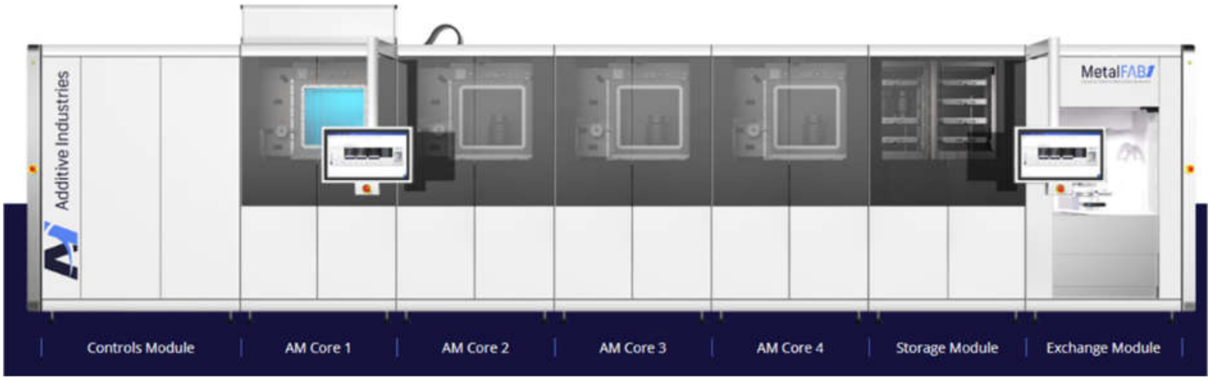


Figure 2: Maximum system

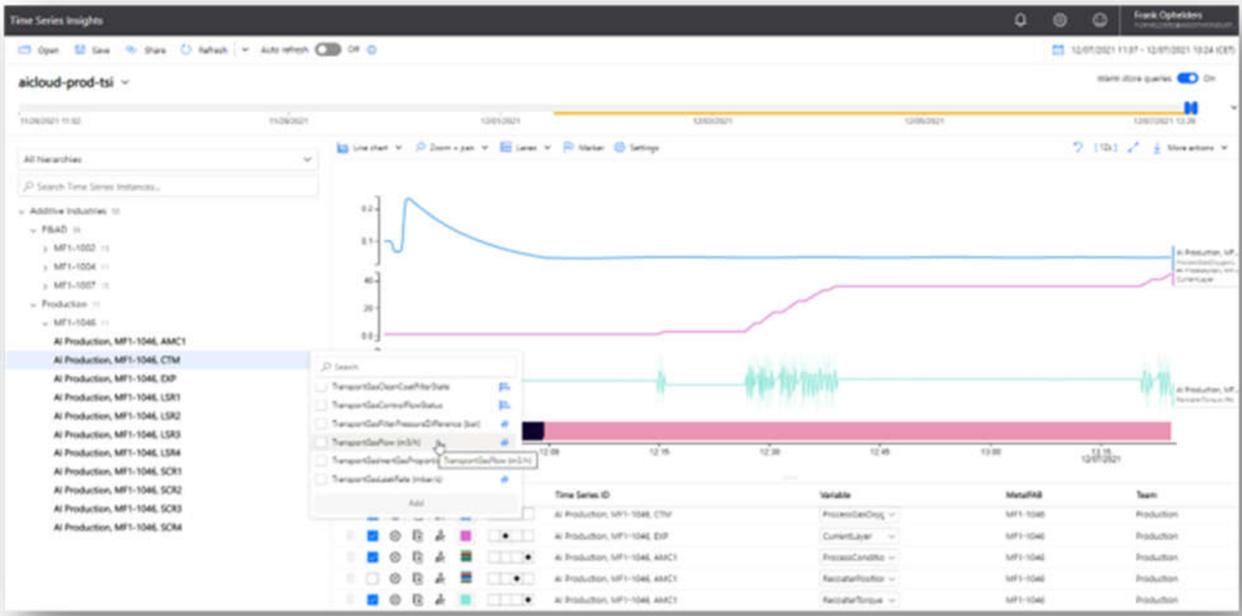
The Data Platform must be able to handle the minimum and maximum system with everything in between.

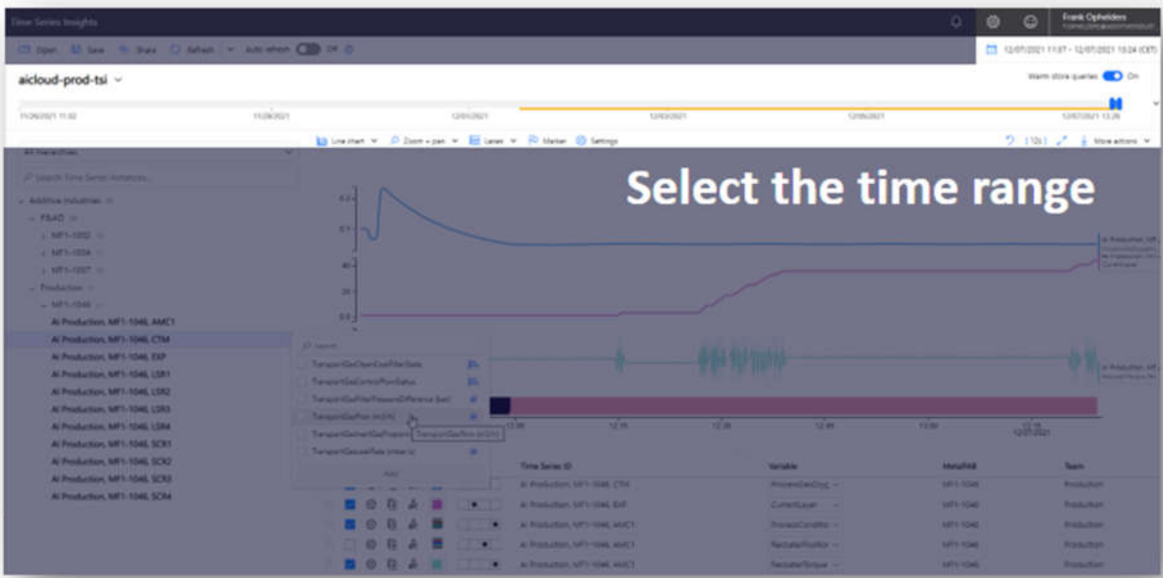
In addition to the modules that are visible on the images above there are components inside that are modular as well. For instance, the system can be equipped with 1 to 4 lasers and scanners.

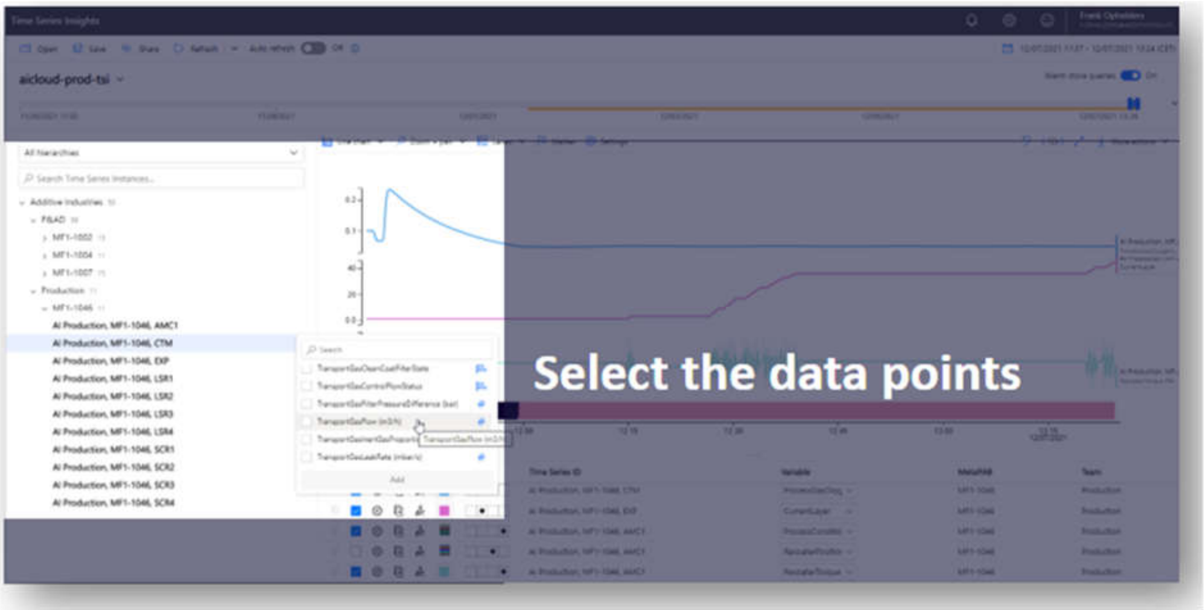
3.4. Use Case: self-service sensor data visualization

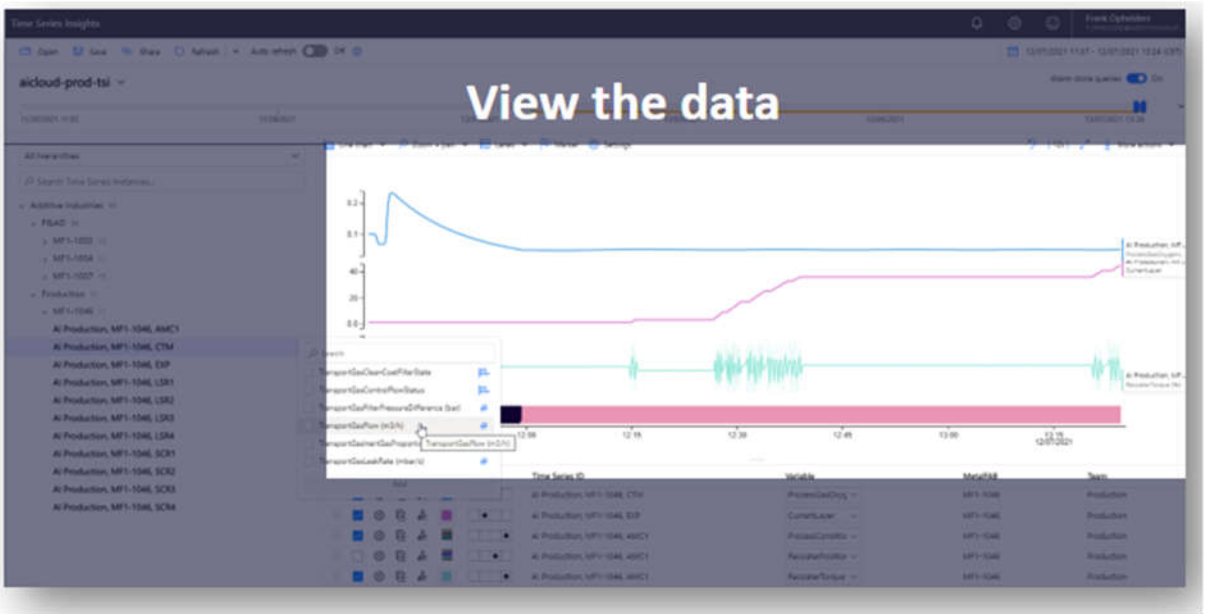
Self-service sensor data visualization use case is realized by using Time Series Insight.

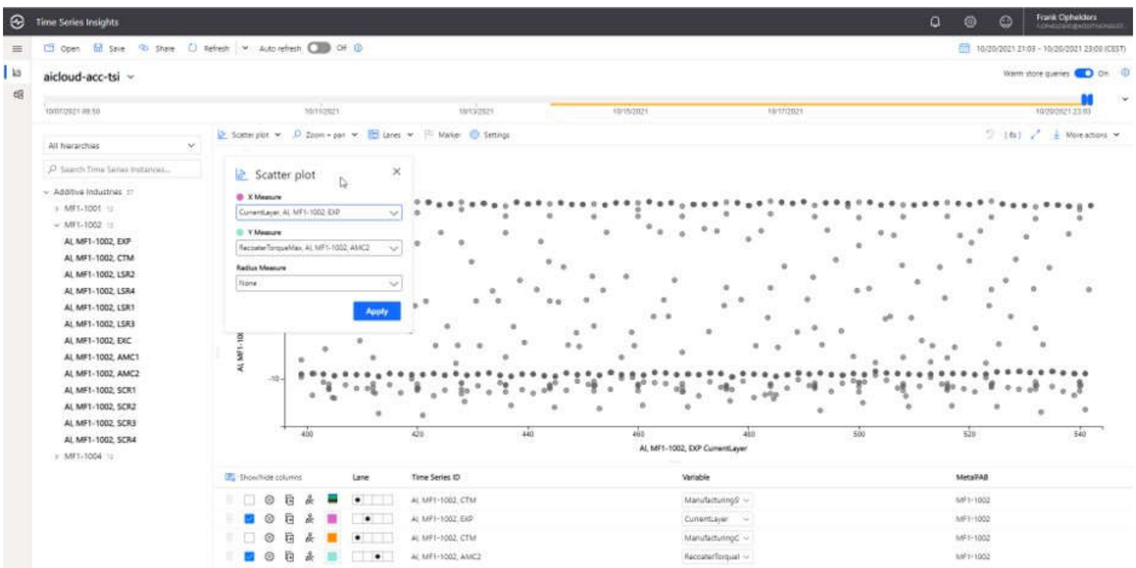
The engineers of Additive Industries have access and can select data to plot. The data is grouped by customer, by machine and by module. The timeframe can be selected. The type of plot can be selected. The data is always shows as a time series. Multiple data elements can be viewed along-side or as overlay.


Time Series Insights
aicloud-prod-tsi


aicloud-prod-tsi
Select the time range

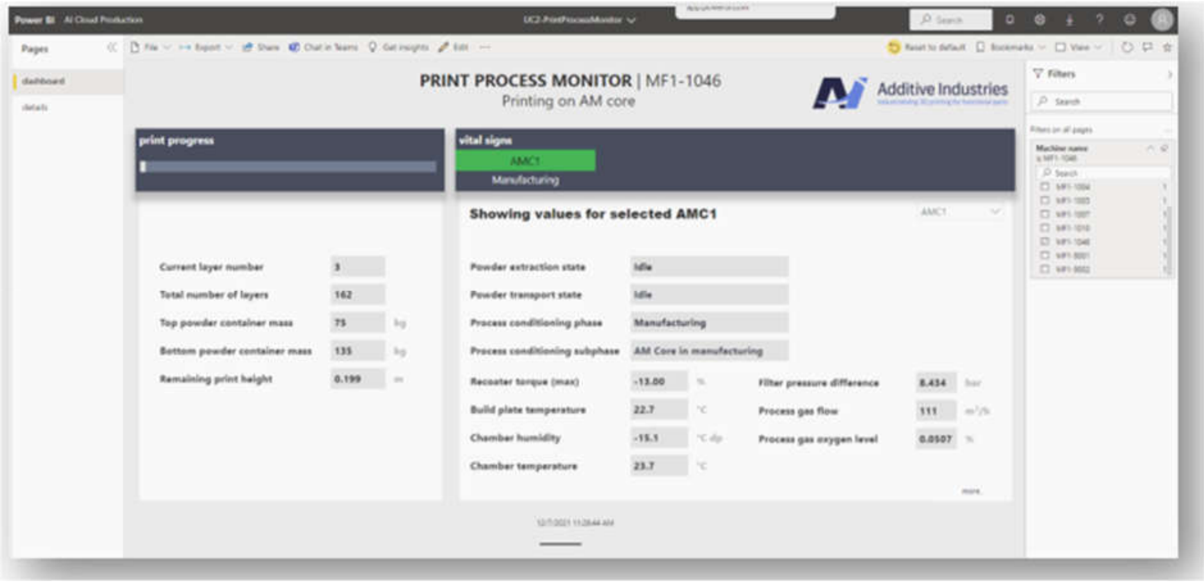

Time Series Insights
aicloud-prod-tsi
Select the data points

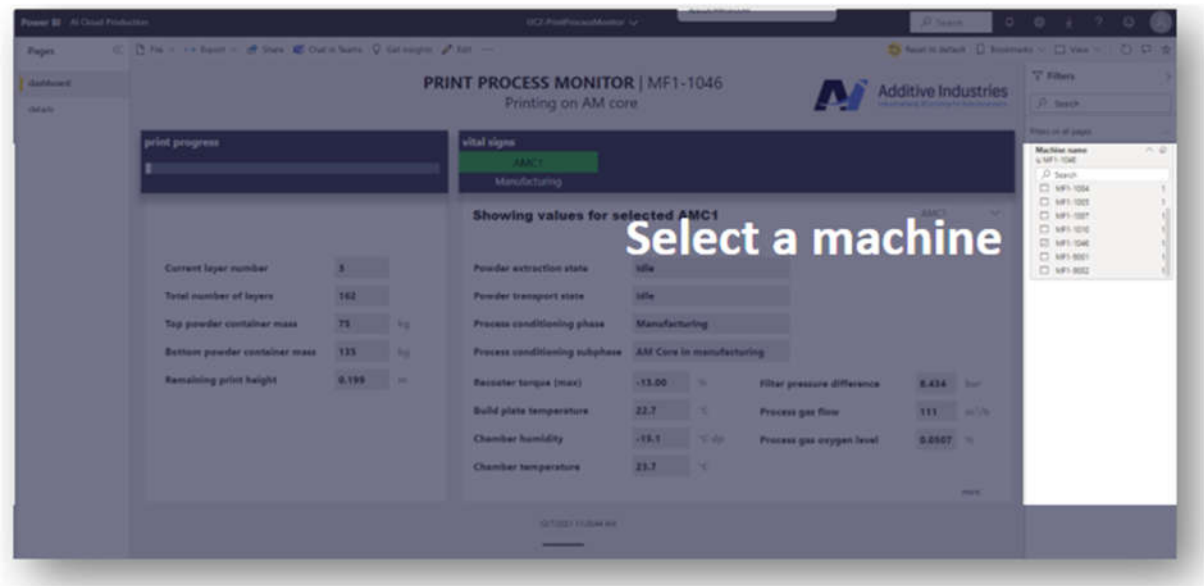

Time Series Insights
aicloud-prod-tsi
View the data


Time Series Insights
aicloud-acc-tsi
Scatter plot
Apply

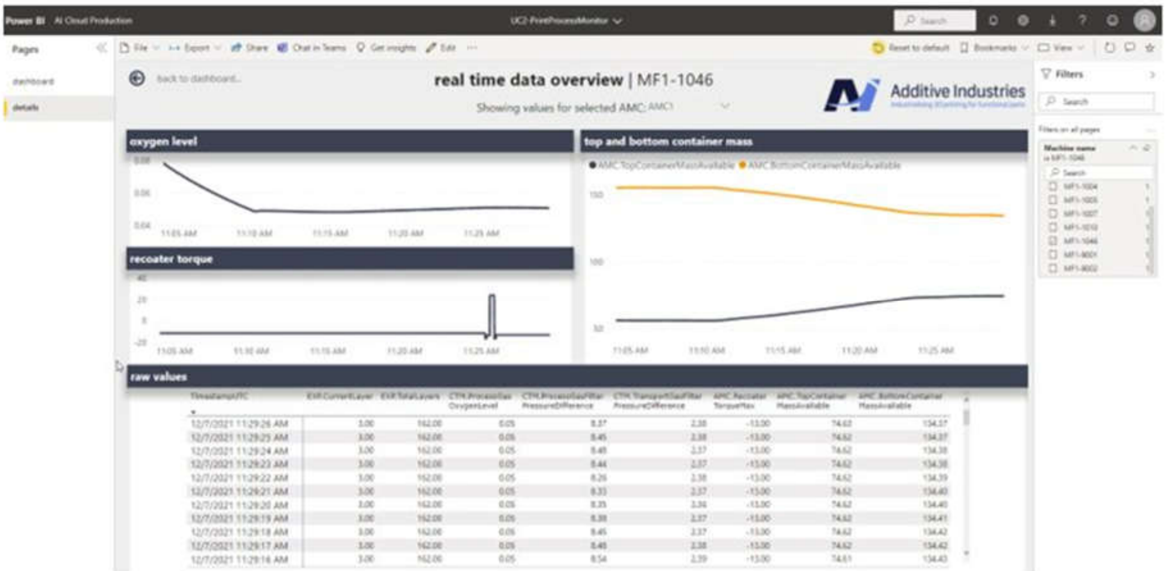
3.5. Use Case: Print Process Monitor

The print process monitor is a remote view of the print running on the machine. The most important vital signs and the progress can be viewed / monitored remotely.





A deeper level view is also available:



3.6. Use Case: OEE

Overall Equipment Effectiveness is implemented in the data platform.

Key driver for total cost of parts is the productivity of the MetalFAB1, defined by its nominal capacity and overall effectiveness:

*Productivity = Process nominal capacity [dm3/hr] * Overall equipment effectiveness [hrs/year]*

Here, the Process nominal capacity represents the specified capacity of the system: how many dm3 metal per hour can the system print. The overall equipment effectiveness specifies a measure for the probability the machine is actual printing products with the specified quality.

Where possible, terms and definitions from the SEMI E10-0304E and SEMI E79-1106 standard are used.

3.6.1. SEMI E10 States

The SEMI E10 standard specifies the following breakdown for machine time:

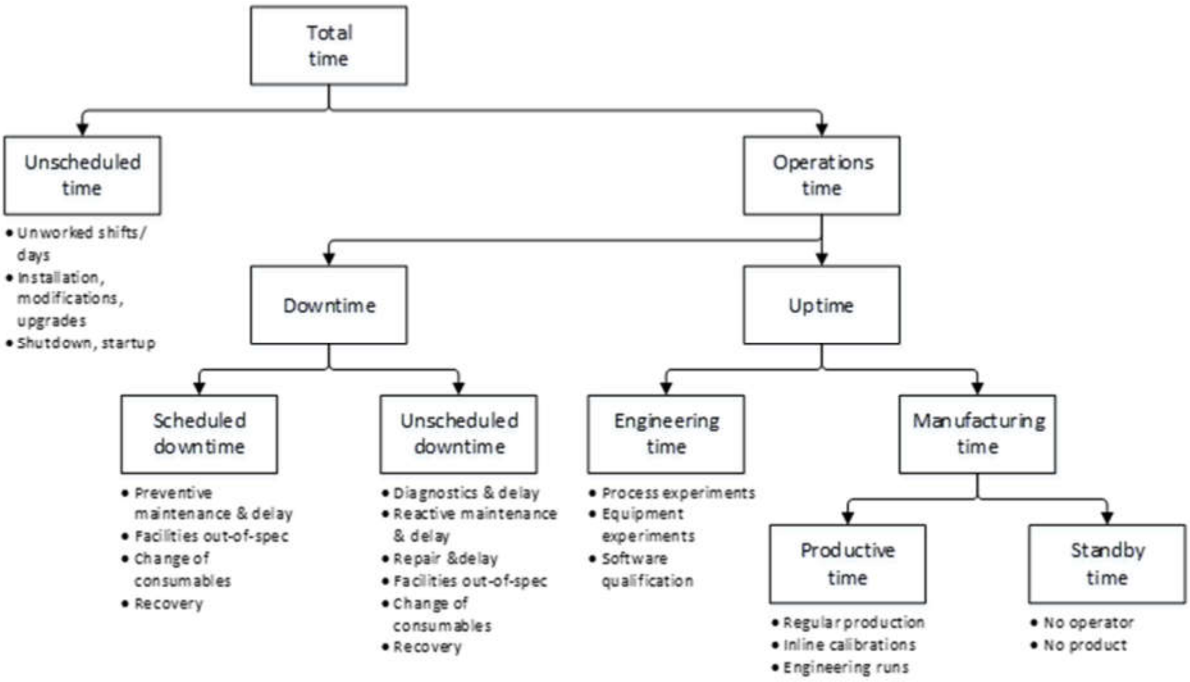


Figure 1 Timing budget definitions semiconductor E10 standard

With the following definitions:

Table 1 Timing definitions

Item	Description
Total time	365x24 hours a year
Unscheduled time	Module is shutdown, starting up or shutting down (excluding downtime). Including module install, upgrades and unworked shifts
Operations time	Module is not in unscheduled time: scheduled for production
Down time	Module is not available to process/perform its intended function due to a failure, any repair activity or maintenance activity
Scheduled downtime	Downtime due to planned maintenance/service events
Unscheduled downtime	Downtime due to unplanned interrupt/repair/service events
Uptime	Module is available to process/perform its intended function
Engineering time	Module is processing for experimentation/testing purposes by customer
Manufacturing time	Module is available for production purposes
Productive time	Module is processing for production purposes
Standby time	Module is available but not processing e.g. no operator, no powder

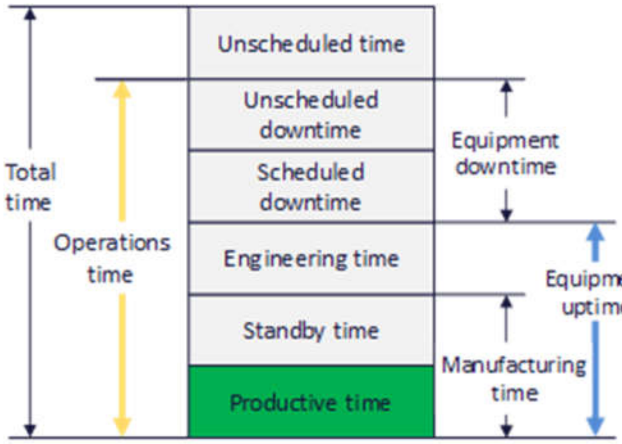


Figure 2 Overview timing budgets

3.6.2. Mapping SEMI E10 to MetalFAB1

3.6.2.1. Unscheduled time

The MetalFab1 is defined as a fully automated printing machine capable of running 24x7 hours a week. Therefore, unscheduled time is only due to the customer 'missing a shift'. Furthermore, the system cannot monitor unscheduled time. It is chosen to define Unscheduled time as zero. Any time for modifications or upgrades will be part of (scheduled or unscheduled) downtime and as such, after install, the total time is equal to the production time.

3.6.2.2. Engineering time

In the same way, the machine cannot identify if a job is scheduled for engineering purposes or for actual manufacturing. Therefore, the engineering time is set to zero and Uptime is equal to Manufacturing time.

This gives the following timing definitions for the MetalFab1:

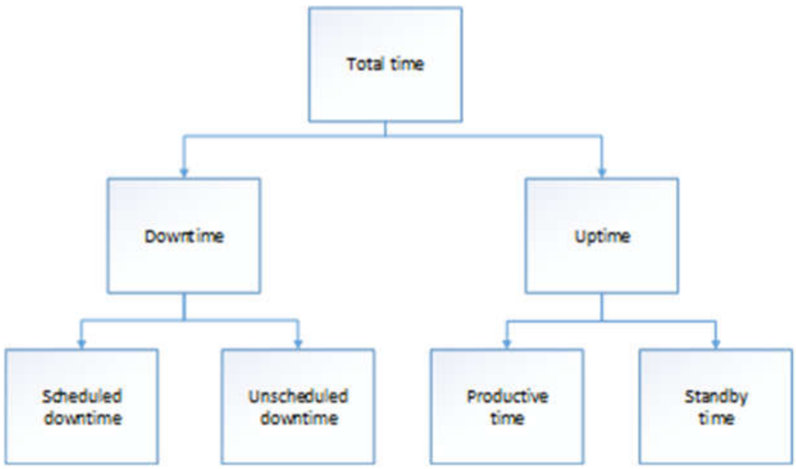


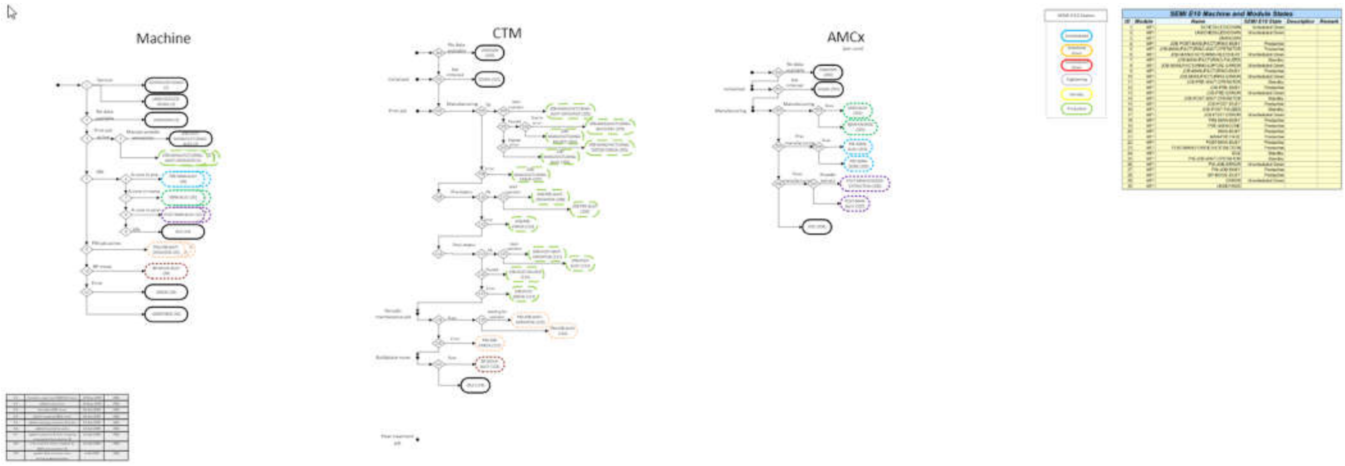
Figure 3 Timing budget definitions MetalFab1

The MetalFAB1 does not support a single machine state but rather exports states of all applications running on the various processors. Therefore, these states are used to:

- Determine the status of the CTM module and all AMC modules
- Determine the system state based on the derived module states

Below, a decision tree is specified which specifies:

- Which combination of application states combine to which module state.
- Which combination of module states combine to which system state.



3.6.3. Overall equipment effectiveness (OEE)

This section discusses the functional requirements for measurement of MetalFAB1' system Overall Equipment Effectiveness (OEE). OEE is a standard for measurement of production equipment performance in the manufacturing industry. It can be used to evaluate how effective manufacturing equipment is utilized. According to the SEMI E79 standard, OEE is defined as:

'the fraction of total time that equipment is producing effective units at theoretical efficient rates'

and is defined as the product of four efficiencies:

*OEE = Availability Efficiency * Operational Efficiency* Rate Efficiency * Quality Efficiency*

3.6.3.1. Assumptions

In order to determine the MetalFab1 machine status, the following assumptions are made:

Machine offline
If the machine is not reporting (connected to the internet and data uploaded to AWP) and as a consequence no data is available, the machine status is reported as Unknown

Service
If machine or any module service is reported as Scheduled down or Unscheduled down, the machine gets the applicable status. Consequently, when one core is reported as in service, the machine could still be printing and be Productive. This situation does not happen a lot in the field and would make the logic very complicated. Therefor it is chosen that if one or more modules are reported for service at AWP, the whole machine is set to the status as specified on AWP.

No jobs/idle
MetalFAB1 is Unscheduled down if no jobs are active, and MetalFAB1 is not available to process a job.

MetalFAB1 is standby if MetalFAB1 could process a job, but no job is active.

Periodic maintenance jobs
MetalFAB1 is scheduled down if a Periodic Maintenance job is active.

MetalFAB1 is unscheduled down if a Periodic Maintenance job has an error.

Production

MetalFAB1 is productive if a Manufacturing (print) job is active in phase Manufacturing without errors.

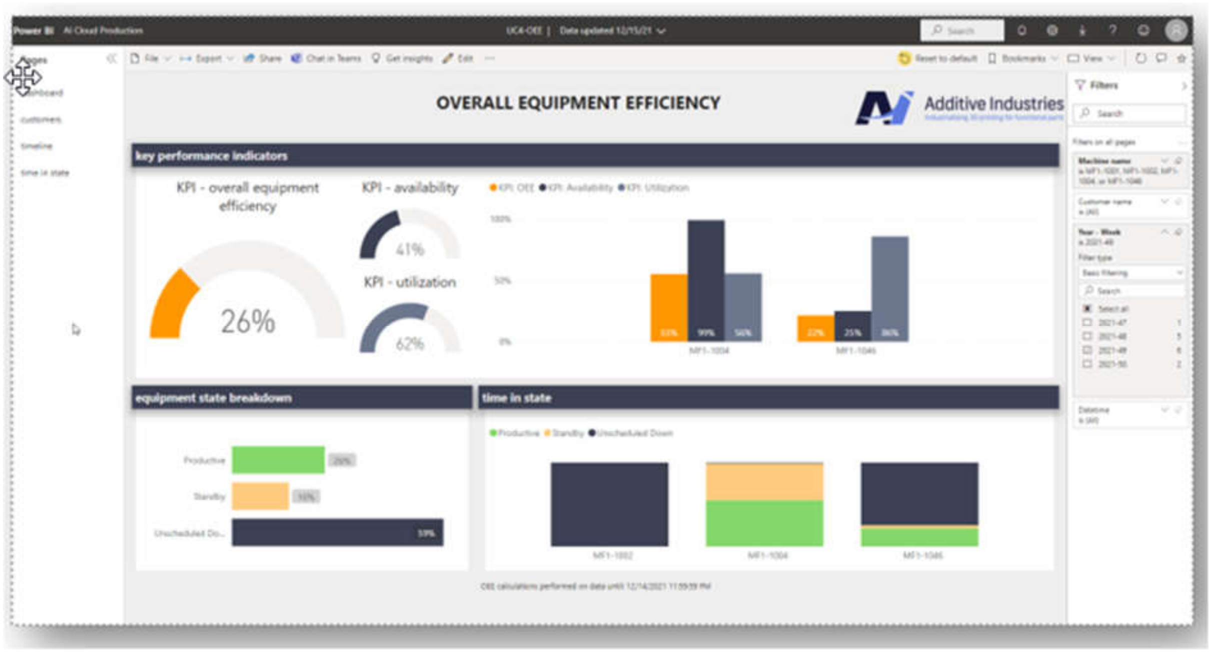
MetalFAB1 is unscheduled down if all active jobs are not in phase Manufacturing and with errors

MetalFAB1 is productive if all active jobs are not in phase Manufacturing, and at least one job is without errors and can continue.

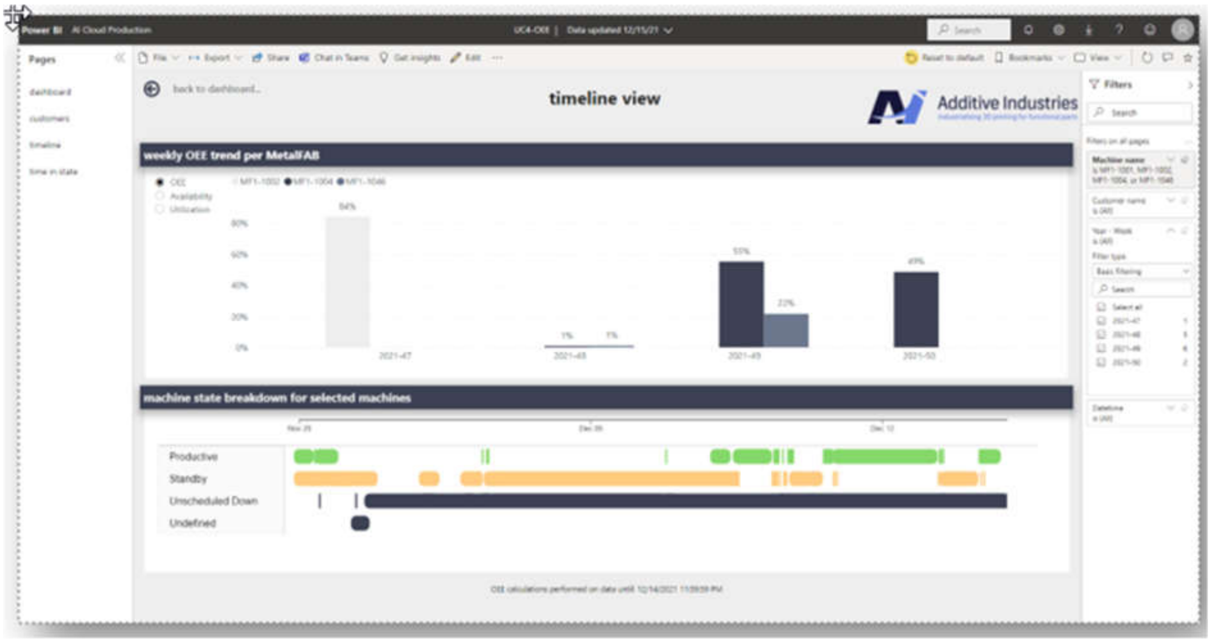
The following job phase is included as standby time: Build Plate Move

3.6.4. Demonstration OEE

One or more machines can be selected on the right. The OEE is aggregated over multiple machines if more than one machine is selected.



Timeline view: shows when a machine over time was in a certain state. This allows to identify in which period a machine was productive or not.



4. Conclusions and future directives

The data service is an integral part of the machine control software of a MetalFAB. It allows when internet is available, and the customer agrees to connect MetalFAB1 machines to the AI Data Platform.

A connected machine allows AI engineers to provide better support and to provide OEE insights to the customer.

Next steps

1. More sensor data
2. Additional types of data e.g., logs, errors, and events
3. Make the Data Platform available to customers
4. Start data analytics on the data in the data lake