POLITECNICO DI TORINO

Department of Engineering

Master's degree course in Management Engineering

Master's Degree Dissertation

The Manufacturing Management System: a case study in the Aerospace Industry

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Filippo Mazzanti

Abstract

Digitization and interconnection are two key features of the world we live in. Companies need to embrace these concepts in order to survive in red oceans, so-called business segments with a very high level of competition.
Lots of software products are available and can be used to drive digitization in several fields. However, many companies do not presently implement an interconnected infrastructure to manage information. Integration of Product Lifecycle Management, Manufacturing Execution Systems and Enterprise Resource Planning allow for the generation of a knowledge management system for the whole company, increasing procedural standardization and data consistency across different offices.
By analysing the solution planned for an aerospace company, the impact of such a system in an industry based on discrete production for international projects lasting several months can be evaluated.
To work through the problems and difficulties encountered in the system implementation a trial and error methodology has been used.
The dissertation begins with a brief explanation of the state of the art of Manufacturing Execution System before moving to the current situation section and then, through a step by step description of the required operations, ends with the integration of the Manufacturing Execution System within the corporate landscape.
Lastly, in order to grasp the innovative potential of this system, a cost analysis based on rework time simulations for different mechanical operations has been carried out. While this analysis contains many assumptions, the estimated final cost nevertheless outlines the importance of having a system to record operations times.

Glossary

AIT Assembly Integration and Test.

ASI Agenzia Spaziale Italiana.

BOM Bill of Materials.

CAD Computer Aided Design.

CCB Configuration Control Board.

CCPI-I Competence Center Platform Integration Italy.

CDF Cumulative Distribution Function.

CIM Computer-Integrated Manufacturing.

CRM Customer Relationship Management.

DESI Dominio Esplorazione e Scienza.

EBOM Engineering Bill of Materials.

ECO Engineering Change Order.

ERP Enterprise Resource Planning.

ESA European Space Agency.

ETL Extract, Transform and Load.

FPY First Pass Yield.

HSE Health Safety Environment.

IDoc Intermediate Document.

IT Information Technology.

MBOM Manufacturing Bill of Materials.

MES Manufacturing Execution System.

MESA Manufacturing Enterprise Solutions Association.

MOS Manufacturing Operations Sheet.

MPCV-ESM Multi-Purpose Crew Vehicle European Service Module.

MPLM Multi-Purpose Logistics Module.

MRP Material Requirements Planning.

NASA National Aeronautics and Space Administration.

OSR Optical Solar Reflectors.

PDF Probability Density Function.

PDM Product Data Management.

PLM Product Lifecycle Management.

PMM Permanent Multi-purpose logistics Module.

SAR Synthetic Aperture Radar.

TIG Tungsten Inert Gas.

W/O work order.

XML eXtensible Markup Language.

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Chapter 1

Introduction

Manufacturing Execution Systems play a pivotal role within the digital transformation that is occurring at company level, enabling improved control and organization of each stage of production. The goal of this thesis work is to delve into the argument and evaluate its applicability to the Aerospace industry.

Before outlining the framework of the thesis, it is important to define what a MES is, when it was first conceived and some key concepts related to its implementation.

The idea of developing integrated production systems (i.e. Computer-Integrated Manufacturing (CIM)) came into being in the mid-1980s.

At the end of the 1990s, the need for better and faster product information systems became apparent. Initially it was believed that an independent production management system would be unnecessary because of the possibility to integrate the automation level in Enterprise Resource Planning system. But results were rather modest, mainly for lack of real-time information which were required by a large number of production companies. This problem have been overcome with the conception of Manufacturing Execution Systems.

Interest in these systems arose in the mid-1990s in the USA, when a non-profit organization called Manufacturing Enterprise Solutions Association (MESA) started standardizing MES solutions and prepared a list of activities that would be included in a full MES implementation.

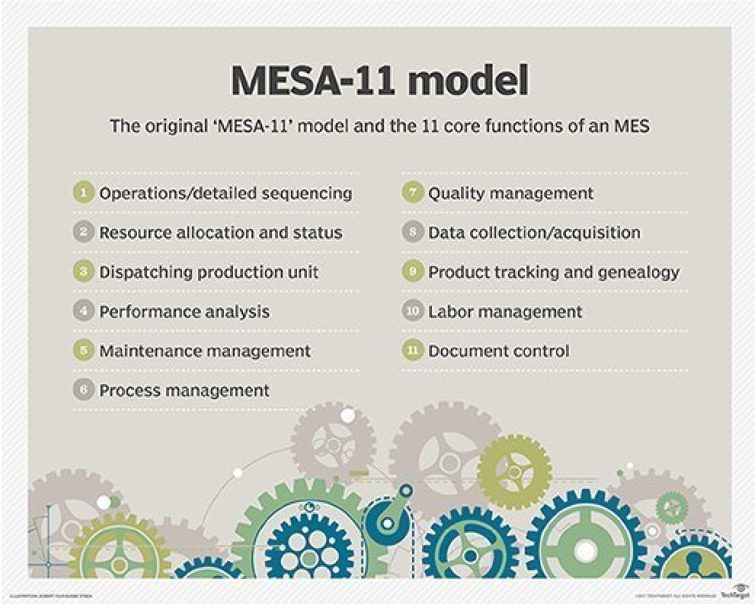


Figure 1.1. MES core activities for MESA organization

MESA [**1**] is an industrial association that focuses on improving business processes in the production area via the introduction of information technology to provide real-time visibility.

Figure 1.2. MESA logo

Industrial literature provides many MES definitions but the most inclusive and specific one, as stated in Michael McClellan's "Applying Manufacturing Execution Systems" book, might be the following: "A Manufacturing Execution System is an on-line integrated computerized system that is the accumulation of the methods and tools used to accomplish production" [**2**].

The MES, then, is primarily a formalization of production methods and procedures into an integrated computer system that tracks the transformation of raw materials into finished products.
Nowadays, Manufacturing Execution Systems have become more widespread, being introduced into almost all industries that require manufacturing operations. What's more, such systems continue to gain in popularity. A look at Gartner's hype cycle methodology [**3**] (which is a graphical representation to evaluate the maturity and adoption of a given technology) shows that the MES solution is in the plateau of productivity phase, meaning that it has already been adopted by a great part of the potential audience and its applicability is paying dividends.

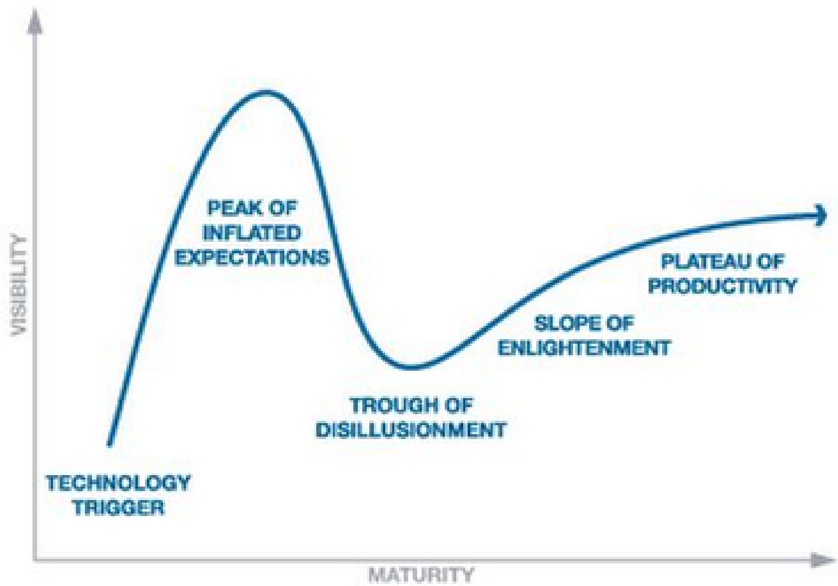


Figure 1.3. Gartner's hype cycle representation

This completes the introduction on MES solutions. The broad outline of the thesis can now be discussed:

- The first section deals with the state of the art of such systems, in which a general description of activities and improvements linked to their implementation is provided. A brief definition of the Product Lifecycle Management system and Enterprise Resource Planning is also given;
- The subsequent section concerns Thales Alenia Space and its business activities, especially focusing on the ones carried out in the Torino site;

- Once the above arguments have been discussed, it will be possible to move on to the core section of the entire text. This section starts with an explanation of the as-is information system architecture, analyzing the current data flow among different actors. Then, it examines the implementation of a Manufacturing Execution System and all the complementary operations that need to be executed in order to end with an integrated information system. These operations refer also to the Product Lifecycle Management and the Enterprise Resource Planning environments. At the end of this section there is also a sub-section on the improvements that the MES system can bring to the company. Here, a cost analysis for different rework operations is carried out, the aim being to understand how a MES system can help executives and workshop supervisors make better decisions regarding such operations;

- The last chapter investigates the HE-R1000 pilot project. Firstly, its mechanical structure and main components, produced in Torino, are illustrated. Then, the data structure to be obtained in the PLM system and the information flow representing data exchanges with other systems is visually exhibited.

Finally, a conclusions section sums up the work done and problems faced during the time spent in the Company.

Chapter 2

The state of the art in Manufacturing Execution System implementation

2.1 Industry 4.0 automation pyramid

It is important to contextualise MES application against the backdrop of "Industry 4.0". This term defines a trend toward digitization of manufacturing, seen by many as a new industrial revolution.

The first industrial revolution (the mechanization of processes) led to the second (mass production and assembly lines) and then evolved into the third (the adoption of computers and automation). But now, by deploying the power of digitization and interconnected systems, a new paradigm is emerging and its key strength lies in the extensive usage of collected data.

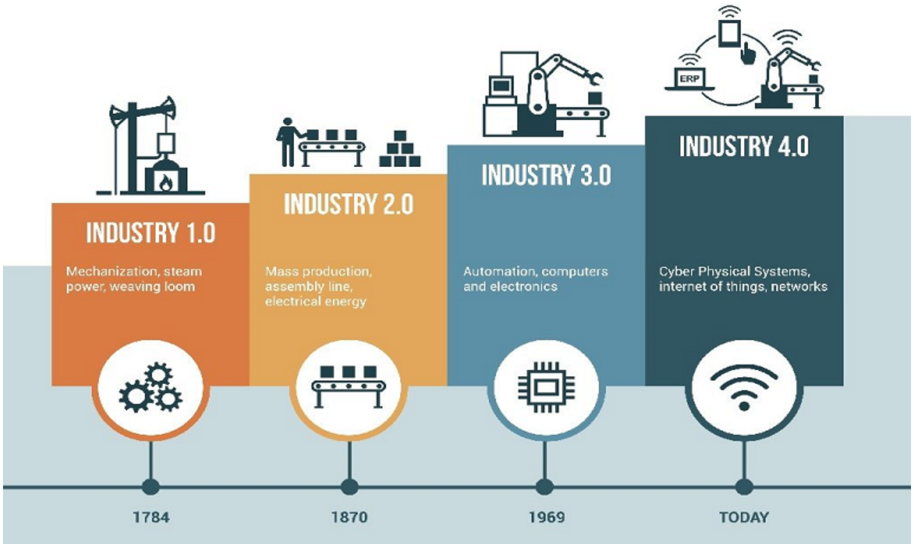


Figure 2.1. Industrial revolutions timeline

Many contributions on this topic can be found on the Web, but a simple and easy-to-understand description on the key advantages that stem from Industry 4.0 was outlined in Forbes [**4**]. Interconnection and communication among systems lets computers take autonomous decisions or lend enormous support to decision-making. As a result of this "collaboration" between humans and smart machines, factories will become more and more efficient and productive as additional data becomes available. Ultimately, it is the network of these digitally interconnected data-sharing machines that gives Industry 4.0 its true power.
At this point we can introduce the automation pyramid [**5**], a concept essential to the implementation of Industry 4.0. It represents the five communication layers that must be interconnected in order to achieve full automation.

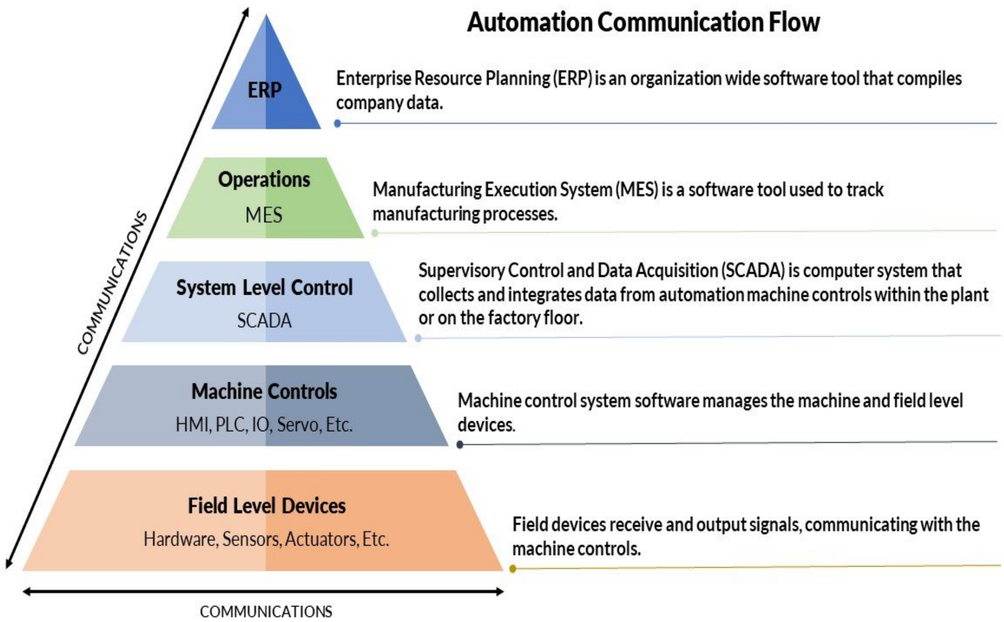


Figure 2.2. Industrial automation pyramid

The base of the pyramid represents field-level devices, which measure variables of interest and provide inputs to the machine control system (the second level), where such inputs are analysed. If their values fail to match with set points, the machine control system returns outputs to actuators to adjust process values.

Moving one step up the pyramid takes us to system control level, where workers monitor process data coming from the machine control system via user interfaces and store them on databases.
Until now data has been collected, but no information has been generated yet. This activity is done through the Operations layer, which is also used to track manufacturing processes and manage Work Orders. This, then, is the task of a Manufacturing Execution System.
The top layer is Managerial, where an Enterprise Resource Planning system is employed to track business resources and long term planning.

2.2 Overview of MES role and activities

2.2.1 The role of MES in the industrial automation process

Before analysing MES solutions in depth, this subsection refers to the automation pyramid outlined above and delves into the linking role the Manufacturing Execution System plays within this structure. Implementing the MES allows vertical integration throughout all layers, connecting corporate management and shop floor operations. With such a model there is no longer any need for protracted and time-shifted manual recording and data acquisition routines that have so far prevented real-time information exchange.

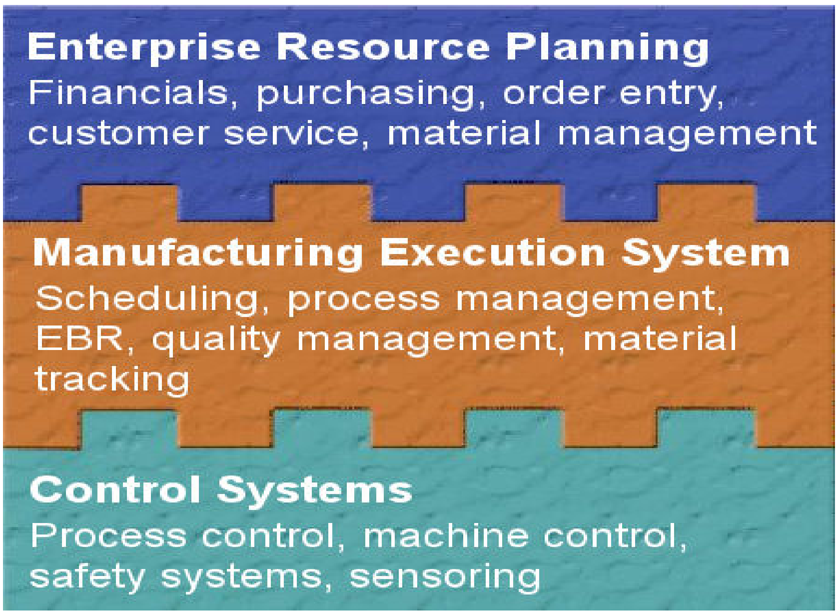


Figure 2.3. MES vertical integration role

Thanks to the development of MES solutions it is now possible to assign specific activities to each of the three levels:

- Corporate management tends to work on a long term basis (i.e. years or months). Rough production planning deals with the medium term (i.e. weeks or months), while detailed planning acts in the short term (days or weeks);
- Decisions taken within production management must be made within a shorter time frame (i.e. usually shifts or days, but sometimes even minutes);
- Machine and plant control systems need to react within minutes or even seconds, as they are directly involved in the manufacturing production process.

In any case, there are no precise boundaries between the tasks and functions of the three levels. Depending on the type of production, advanced planning and scheduling tend to be closer to ERP or to MES, while the line between the MES and data gathering control systems can be a faint one.

2.2.2 MES key concepts

This sub-section aims to summarise key contributions from literature on MES activities and scope, providing us with a comprehensive view on the analysed solution.
Three textbooks constitute the building blocks of this summary: "Applying Manufacturing Execution Systems" by Michael McClellan [**2**], "Manufacturing Execution Systems" by Heiko Meyer [**6**] and "Manufacturing Execution System - MES" by Jürgen Kletti [**7**]. Although published at different times and with additional features that have been rolled out in recent years, some recurring concepts are found throughout each of them.
The first property of MES solutions is their evolutionary nature. Full MES implementation needs to embrace many areas of a company and it is unlikely that the initial solution will include all required functionalities. Opportunities for later integration of plug-ins should be considered and this feature is an important driver for the continuous improvement process within companies. In fact, the MES must be adaptable to whatever change might occur in the manufacturing area.

Moreover, thinking ahead during MES implementation ensures smooth integration of future technologies, without the need to replace the current solution.
Following MESA description [**8**], the core functions of a full MES solution would be:

- **Resource Allocation and Status**: manages resources including machines, tools, labour skills, materials and other aspects such as documents that must be available in order to start working on an operation;
- **Operations/Detail Scheduling**: provides sequencing based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation;
- **Dispatching Production Units**: manages the flow of production units in the form of jobs, orders, batches, lots, and work orders. Dispatch information is presented in the sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter the prescribed schedule on the factory floor;
- **Document Control**: controls records/forms that must be kept in the production department, including work instructions, recipes, drawings, standard operating procedures, part programs, batch records, engineering change notices, and shift-to-shift communications;
- **Data Collection/Acquisition**: this function provides an interface to obtain the intra-operational production and parametric data which populates the forms and records that were attached to the production unit;
- **Labor Management**: provides status of personnel in an up-to-the-minute time frame;
- **Quality Management**: provides real-time analysis of measurements collected from manufacturing to ensure proper product quality control and identify problems requiring attention;
- **Process Management**: monitors production and either automatically adjusts or provides decision support to operators to correct and improve in-process tasks;

- **Maintenance Management**: tracks and directs the activities needed to maintain the equipment and tools to ensure their availability for manufacturing and ensure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems;
- **Product Tracking and Genealogy**: makes the current stage of work and its status visible at all times. Status information may include personnel working on it, component material by supplier, lot and serial number, current production conditions, and any alarms, re-processing or other product-related exceptions;
- **Performance Analysis**: provides up-to-the-minute reporting of actual manufacturing operations results plus a comparison with history and expected business results.

The integration process of these functionalities will depend on the specific company requirements. Some systems will require all the core functions from the beginning, others will need only some throughout their usage, while in some instances it may be necessary to begin with a very simple solution and add other functions as and when needed. Moreover, the relative importance of some core functions over others depends on the specific company and its manufacturing process.

Another key requirement for MES solutions to be effective is a user-friendly interface and the possibility of customising software operations for different production areas.

Generally, manual and automatic workstations can be found. For the latter, suitable mechanisms for data exchange among automatic machining centers and the MES must be provided.

On the other hand, on manual workstations user-friendly operating interfaces must be available. Although this task takes a long time during MES development and many issues need to be overcome, investing in this features is fundamental to system acceptance because complex interfaces discourage workers and require additional time to understand how to use the system.

Lastly, a fundamental characteristics that has guaranteed the worldwide diffusion of the MES is its limitless applicability to all manufacturing environments, from continuous processes to discrete-part production. Of course, each industry has its own system variation: in the former case, machines and plant control systems have a very important role in the MES. With regard to the latter case, MES is commonly used as an online information system to foster paperless communication and obtain feedbacks from production.

Furthermore, a company's MES can also be used by its suppliers. They receive credentials with limited system access rights from their in-house devices and, once logged in, they can display operations associated with the client company work orders.

2.2.3 Routing definition and construction

The main purpose of the MES is the tracking and real time management of production work orders to ensure better control of the transformation of raw materials into finished goods.
To work properly, it requires routings and construction documents (i.e. 3D and 2D drawings). The latter item is not discussed in this section.
Routings are process instructions containing a detailed sequence of operations to manufacture a part. The operations outline the activities that must be performed, while the technological content regarding how these operations must be carried out resides in work instructions connected to them.
Each item on the bill of material that is to be constructed in-house must have an associated routing. Once the work order for a part is launched, it will be found in the MES with a certain code. A sequence of operations linked to this work order also appears on the MES interface, representing the routing structure for that part. Some operations will be available, others not. This is because of operation precedence constraints in part manufacturing.
To build a comprehensive production document, each operation listed in the routing needs to include additional information, such as:

- The work center where the operation must be performed;
- The tools and materials that must be used within the operation;
- Some compulsory characteristics (e.g. a measurement must be within a certain interval, otherwise it is unacceptable);
- The skills required to perform the operation (e.g. forklift truck drivers require a license);
- The estimated completion time.

2.2.4 MES Pros and Cons

MES implementation is a complex project, requiring strong project management capabilities. Since it affects all production areas, representatives from every production office must be involved in the core team, which is mainly responsible for project management throughout the entire implementation period, for the appointment of departmental project managers and for the allocation of financial resources.
The core team and the project managers should arrange weekly or monthly meetings according to the stage of the project. Such meetings should consider questions, open points and the list of tasks to be completed before the next meeting. Should an issue not be settled immediately, it should be added to the list of open points alongside the name of its responsible and the relative deadline.
The above-described process is lengthy, involves many people and delays are highly likely. Alongside very high overall cost, these are the main cons of MES implementation.
Although its impact on time consumption and costs is considerable, once the system has been implemented effectively the upsides more than offset the downsides.
Surveys carried out in companies that have implemented a MES show the main benefits of its adoption to be:

- **Integrated data transparency**: supervisors have real-time access to shop-floor data indicating exactly how the production process is running;

- **Increased data consistency**: paper procedures, which can be lost or damaged, are replaced by digitally recorded documents. Signatures for completed tasks are recorded electronically as well;

- **Shorter lead times**: integration with other systems reduces the need for manual data entry and the downtimes associated with documents transportation;

- **Improved planning processes**: short term scheduling (via the dispatching production unit function) balances the available resources among various tasks in keeping with constraints;

- **Traceability**: by managing the entire manufacturing process, it can link raw material lot numbers to finished goods;

- **Early warnings**: measurements that are outside the control interval can be easily be identified through frequent status updates.

These are the direct pros of MES integration within the corporate landscape. However, the indirect advantages may be even greater.
As outlined in an article by iBASEt [**9**], a leading software manufacturing digitization provider, regarding a Gartner [**10**] study, "the largest benefits of MES stem from capitalising on the insights it provides into manufacturing performance and capabilities across the organisation and the supplier network."
Lots of companies highlight the role of MES in driving continuous improvement in their workplaces. This confirms the fact that long term advantages can be substantially greater than those derives from the direct implementation of the new system.

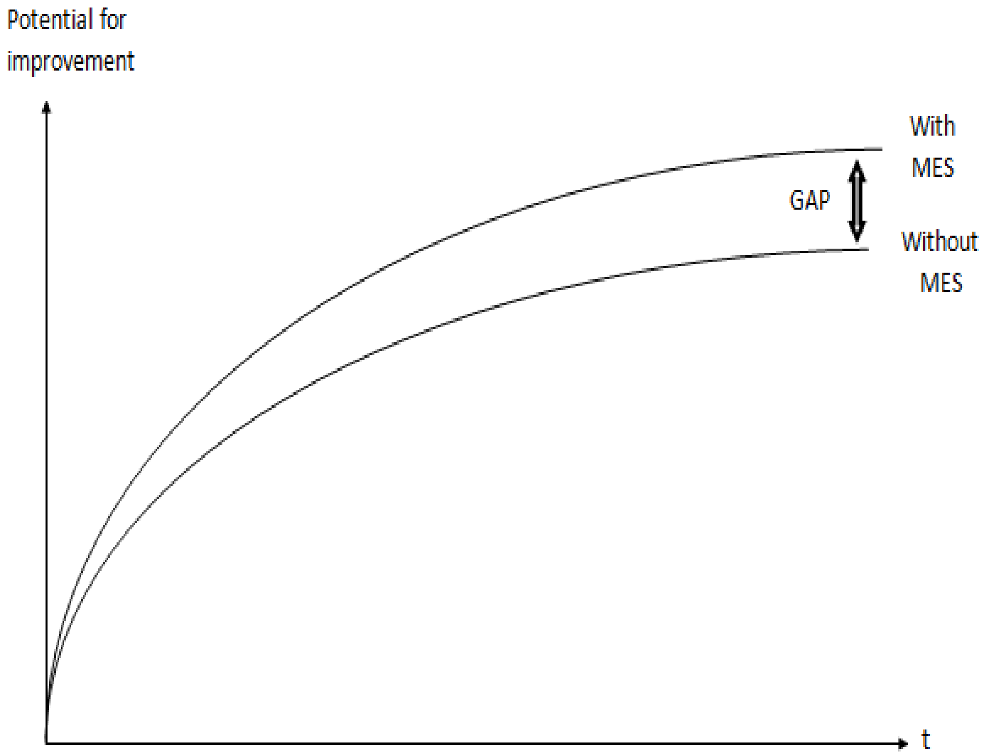


Figure 2.4. Potential for improvement comparison

2.3 Integration of PLM, MES and ERP systems

2.3.1 PLM and ERP: what do they do?

The real power of adopting a MES depends on its level of integration with other company applications, such as the Product Lifecycle Management system and the Enterprise Resource Planning.
The main functionality of a PLM system is to accompany the entire lifecycle of a product, from development to the production process and, lastly, the service process. PLM systems provide a structure in which all types of information (used to define, manufacture, and support products, such as electronic documents, digital files and master data) is collected. This may include:

- Product configurations and variants;
- Part definitions and other design data;
- Part materials;
- CAD drawings;
- Manufacturing routings;
- Numerically controlled part programs;
- Electronically stored documents and additional notes.

In a nutshell, any information concerning the life of a product can be managed by a PLM system, making data accessible to all authorised persons.
Typical PLM system functions include:

- **Data Vault** to provide secure data storage and retrieval of product definition information;
- **Process Management** to manage any changes to product configuration, definition, relationships and data versions. This functionality defines and controls the process of reviewing and approving changes to product data; it is done via a sequence of actions that must occur before modified data referred to a new product version can be released;
- **Product Structure Management** to facilitate the creation of customised bills of materials. As configurations change over time, the system tracks product versions

and design history. Standard bills of materials can be generated automatically from the product design, while others may require variations to align the structure with the process. Usually, product structures contain attributes for each sub-component, such as number of items required and location information.

- **Classification** by materials, parts and processes with common attributes, allowing their re-use for different products. This leads to greater product standardisation and reduced work when designing brand new models;
- **Notification** to inform everybody regarding the current state of a part or document. Moreover, an employee is notified in case he/she has been required to perform certain actions on the software;
- **Data Transport** to ensure availability of information to all users. The system keeps track of data locations and allows access to any information via a data set form;
- **Data Translation** to automatically convert data among different applications through triggers procedures. This is done at selected times and ensures data consistency across various systems;
- **System Administration** to allocate rights to users and perform data backup at selected times.

Connection and integration of PLM systems with MES can have a dramatically positive impact on production plan execution and delivery date compliance, providing a wide variety of information throughout company departments and aligning different tasks.
As far as the ERP is concerned, its diffusion has been pivotal to overcoming the troubles that previously stemmed from management of a bundle of applications to satisfy different task requirements. This because it is an integrated system containing different suites, each one fulfilling a specified functionality.
The main business processes integrated in an ERP system are:

- **Accounting**: recording of accounts receivable, accounts payable and general ledger instances. But the main pros of using an ERP for this purpose reside in the centralised database, which supplies data from the processes directly to the accounting module. This reduces the time needed to collect financial information from different documents; it also lessens the likelihood of entering redundant data or making errors;
- **Human Resources**: integrated management of employee payroll data, training plans, vacations and performance-based benefits;

- **Planning**: automated strategic and product-related planning and production scheduling. This last function (included in the MRP module) makes it possible to schedule the entire sequence of actions needed to carry out product manufacture effectively (e.g. the material management) and comply with delivery dates;

- **Customer Relationship Management**: integrated customer data in one place, allowing for quick user access when information is needed for shipping, billing or marketing purposes. Without its integration in an ERP system, customer data is located in different applications, creating issues stemming from lack of information availability in one place (i.e. different sources need to be accessed to get a complete overview);

- **Inventory Management**: automated traceability of inventory items during the entire lifecycle. As outlined in accounting process integration, the main pro of inventory management in the ERP is data exchange with other modules, which ensures greater visibility of the supply chain situation and helps employees identify future issues associated with low inventory levels. Demand can be forecast using analytic tools;

- **Distribution**: purchasing, order fulfillment, order tracking and customer support management. Integration with other suites give access to critical information, such as product positioning within the inventory management function and CRM functionality to establish priorities for different orders, allowing customers' importance to be kept into consideration in the distribution management.

Advantages for companies that decides to adopt an ERP include: increased productivity, better coordination among different offices and procurement optimisation.
Moreover, ERP hinges on two main factors:

1. Its centralised data repository, which is used for different operations. This way, duplication and misalignment of data is avoided;

2. Its modular structure, allowing suite selection and integration into the system depending on company requirements. This ensures the best possible customisation and alignment with company activities.

2.3.2 Insights regarding systems integration

Following the description of the role of PLM and ERP systems within corporate processes, it is worthwhile investigating how integration among different applications can be executed.

An important factor in this regard is seen in the ISA95 - IEC62264 standard, which outlines a data exchange framework to facilitate information systems integration within an enterprise. Nevertheless, it mainly focuses on ERP-MES-Control systems integration [**12**]. For this reason, references are used to identify advantages stemming from systems integration and to evaluate possible solutions to accomplish this task.

Regarding the first topic, the main points of interest to accomplish systems interoperability are product quality improvement, obtained via a feedback mechanism that acts as a conformity checker, and faster reactivity to solve the problems faced in production that might require redesign work. These insights are provided alongside additional results, as shown by an automotive manufacturing case study illustrating a collaborative situation and a survey to evaluate Italian companies' propensity to implement information systems integration [**12**] [**13**].

Delving into the technical description on how to build an automated collaborative framework, several papers have been published [**15**] [**14**] [**19**] [**16**] [**20**] [**17**] [**18**]. Although each one proposes a different integration framework, a recurrent tool (which is taken into account in all contributions) is ontology.

An ontology is a formal description of a domain knowledge as a set of concepts defined by classes, properties and the relationships between them. Because ontologies are used to specify common modelling representations of data from distributed and heterogeneous systems, they enable database interoperability and smooth knowledge management [**21**]. The usual ontology structure to solve information systems incompatibility require a two-stage course of action.

Firstly, a specific ontology is created for each system to convert data into a structured model. Then, independent systems ontologies are mapped together and their concepts are interlinked in super-concepts in a 'n to 1' relationship, where n is the number of information systems to be integrated.

When the conceptual model has been developed, no data has so far been exchanged. In fact, ontologies are used to model data structures, but not to effectively accomplish data exchange procedures.

Because eXtensible Markup Language (XML) is emerging as the standard language for data exchange among information systems, it is also desirable to apply ontologies through an XML arrangement.

XML is a data format featuring a number of tools and functions that let users exchange information among several computer programs.

The main XML elements needed to enable consistent data transfer are:

- **XML document**: an XML file containing the code;
- **XML schema**: an XML file that defines custom markup tags. They define objects, their relationships, their attributes, and the structure of the data model;
- **XML stylesheet**: an XML file containing instructions to format XML code for a Web page.

```
  <?xml version="1.0"?>
- <job>
  - <production>
      <ApprovalType>WebCenter</ApprovalType>
      <Substrate>carton 150 gr</Substrate>
      <SheetSize>220-140</SheetSize>
      <press>SuperFlat2</press>
      <finishing>standard</finishing>
      <urgency>normal</urgency>
    </production>
  - <customer>
      <name>FruitCo</name>
      <number>2712</number>
      <currency>USD</currency>
    </customer>
  </job>
```

Figure 2.5. An XML document file

Finally, data transfer procedures are carried out via web services, such as middlewares and/or software agents.

Chapter 3

Thales Alenia Space background information

3.1 Timeline

The long Company history begins in 1968, when the Thomson-Brandt's electronic businesses merge with Compagnie Générale de Télégraphie Sans Fil (CSF) to form the Thomson-CSF, thus establishing a space department.

In 1984 the CGE (formerly Alcatel Alsthom) and Thomson-CSF merge to form Alcatel Thomson-Espace.

In April 1998, Aerospatiale, Alcatel, Dassault Industries and Thomson-CSF reach a co-operation agreement endorsed by the French government whereby the professional and defence electronics businesses of Alcatel and Dassault Électronique are merged with Thomson-CSF, and the satellite businesses of Alcatel, Aerospatiale and Thomson-CSF are merged to form Alcatel Space, owned jointly by Alcatel and Thomson-CSF. Located in 8 European countries, Alcatel Space is one of the world first manufacturer of space systems.

These mergers, as well as internal growth, radically alter the Group's portfolio of businesses. A strategic review stresses the increasing importance of civil applications, particularly mobile telecommunications. In line with this strategic focus, a new organisation with three business areas (i.e. defence, aerospace and information technology and services) is introduced in July 2000. As a consequence, the Group embarks on a divestment program of non-strategic assets.

In December 2000 Thomson-CSF, recently renamed Thales, forms the first transatlantic joint venture in the defence sector with the American company Raytheon, becoming the world leader in air defence. In May 2001, Alcatel purchases Thales shares in Alcatel Space (48,8%), giving it 100% ownership.
Looking at the Italian landscape, the alliance between space activities of Aeritalia and Selenia Spazio give rise to Alenia Spazio in 1989.
In June 2004, Alcatel and Finmeccanica sign an agreement to unite their space businesses. One year later, two new companies are created, Alcatel Alenia Space and Telespazio, each partner contributing its specific industrial skills and services.

Figure 3.1. Thales Alenia Space logo

In April 2006, the Thales Board approves the project to take over Alcatel leading satellite activities (67% of Alcatel Alenia Space and 33% of Telespazio). In December, just a few months later, the newly constituted Alcatel-Lucent and Thales sign a final agreement concerning the transfer of the space activities and in April 2007 the European Commission gives its final approval to the operation. Alcatel Alenia Space thus becomes Thales Alenia Space.
Lastly, in January 2017 the Finmeccanica group S.p.A becomes Leonardo S.p.A.

3.2 Company businesses

Combining 40 years of experience and a unique array of expertise, talents and cultures, Thales Alenia Space designs and delivers high-tech solutions for telecommunications, navigation, Earth observation, environmental management, exploration, science and orbital infrastructures.

Figure 3.2. International Space Station

As mentioned in the preceding paragraph, Thales Alenia Space teams up with Telespazio to form the parent company Space Alliance. Their complementary capabilities in satellite systems and services provides the Joint Venture with all the assets needed to respond positively and effectively to market needs, which are, today, increasingly focused on applications related to space technologies. Thales Alenia Space is Europe's largest satellite manufacturer, employs around 8,000 people in nine countries and posted consolidated revenues of about 2.5 billion € in 2018, with sales of 19 billion € during the same period. Through its business segments, Thales Alenia Space is involved in projects for the ASI, the ESA and the NASA. This because Space agencies around the world rely on its expertise to explore the solar system and our galaxy. For example, the Company has contributed to the realization of several pressurized modules for the ISS over the years: Columbus, the Nodes (Harmony and Tranquility), the MPLMs (Raffaello and Donatello) and PMM (Leonardo), Cupola and, for the near future, Bishop Airlock (for Nanoracks LCC). Besides MPLMs, which was also used to transport cargo inside Space Shuttle orbiters to and from the ISS, Thales Alenia Space realized also the pressurized vessels for the Automated Transfer Vehicle and Cygnus spacecrafts.

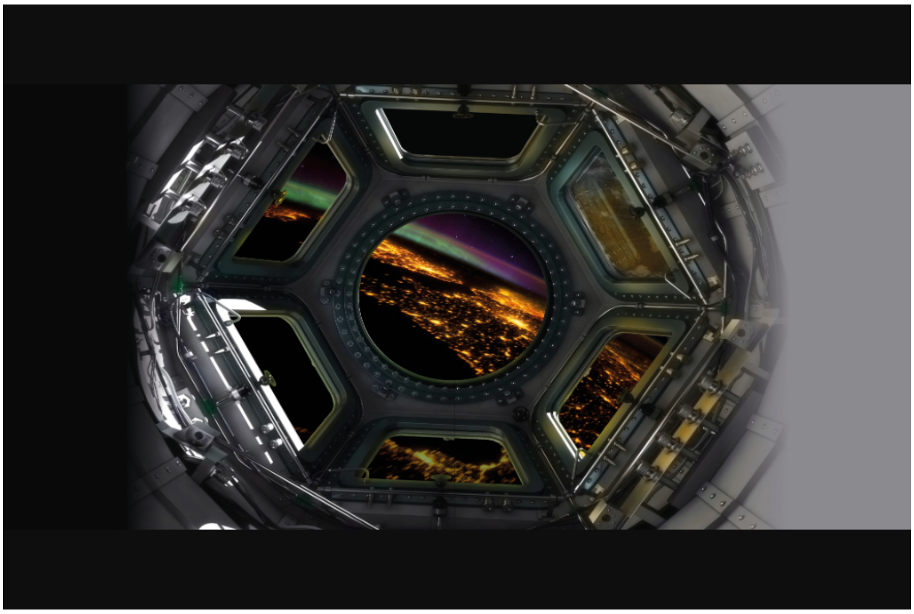


Figure 3.3. View of Earth from the ISS Cupola module

In addition, it provides telecommunications solutions and services for National Governments armed forces, security forces and essential operators.
It is, even from this brief overview of Thales Alenia Space, easy to ascertain its importance worldwide.

3.2.1 Core business of the Torino site

As a follow-up to the previous section, this sub-section focuses on the core business of the Torino site and its most important ongoing projects.
Starting from the first point, the activities carried out in Torino are focused on two main topics: the robotic exploration of outer space and the manned spaceflight (e.g. space stations). The two main in-house organizations responsible for this activities are CCPI-I and DESI.
For what concerns DESI, the main task is to design and to manage spacecraft projects. Actual running projects are:

- Multi-Purpose Crew Vehicle European Service Module (MPCV-ESM) for Airbus Defence and Space and Lockheed Martin, that is the service module of NASA Orion spacecraft that will take back to moon the next generation of astronauts with project Artemis;

- Cygnus for Northrop Grumman, which is a single-use automated cargo spacecraft, designed to transport supplies to the ISS. Once it has delivered its payload, it is filled with no-longer-needed items from ISS crew and burns up returning to Earth in order to dispose of itself and of the useless objects inside it;

- Euclid, an ESA disruptive project to understand the nature of dark energy and dark matter by accurately measuring the acceleration of the Universe and gravitational strength on a cosmological scales. Euclid is a space telescope designed to shed light on the large-scale structure of the Universe across 10 billion light years. Euclid is part of the ESA "Cosmic Vision" (2015–2025) program and its planned launch date is June 2022;

- Exomars, a joint programme of the European Space Agency (ESA) and the Russian space agency Roscosmos aiming at investigate the evolution and habitability of Mars through a orbiter and the landing of an automated rover.

For what concerns CCPI-I, the main task is the manufacturing, assembly and test of previously mentioned spacecraft projects. Besides that, the organization has its own engineering office, that is responsible for the design and management of HE-R1000 platform. The first application of HE-R1000 platform is a SAR satellite, for which the mechanical main structure is fully developed and built in Torino CCPI-I.
Being a brand-new project, with no previous data on any system, with the design and manufacturing in the same organization, it has been chosen as the pilot project to evaluate the new Information System architecture derived from the implementation and integration of the MES system.

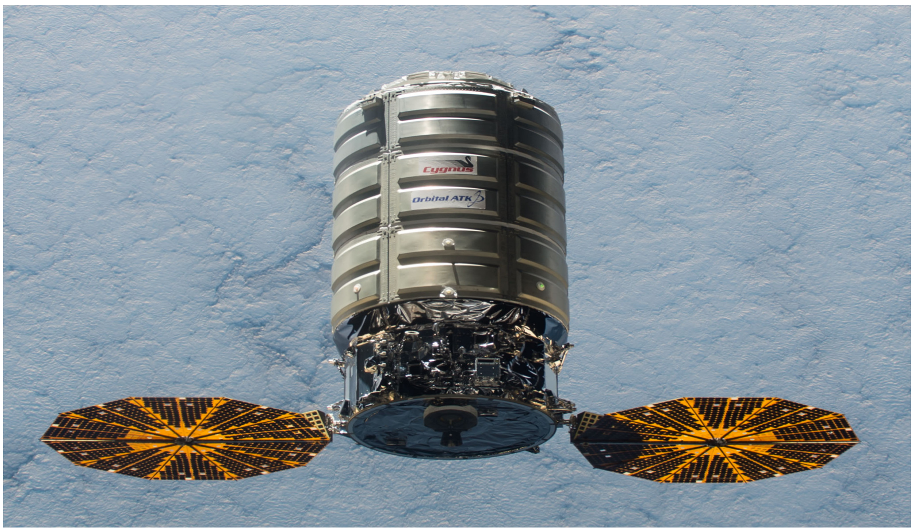


Figure 3.4. Cygnus spacecraft

Chapter 4

A personalized MES and its integration with other systems

4.1 Information System As-Is situation

Analyzing the As-Is situation of the Company Information System, the immediate observation is its inefficiency, as there is a simultaneous use of various software tools to fulfill a wide range of similar operations. This lack of integration creates an unwieldy fragmented workspace. The current situation is explained in Heiko Meyer's "Manufacturing Execution Systems" book, in which he states that "The use of various software tools without any coordination is widespread, and the reasons as to why such scenarios arise are generally similar: for an urgent task, a system is installed that is tailored to exactly that task. In parallel, a similar system arises in another area. After some time, software tools become established in many areas of the company fulfilling similar and overlapping tasks" [**6**].
This situation is unsustainable both from an ergonomic and economic standpoint.
Regarding the first issue, organisational rules and working methods associated with a specific software tool are different across the Company sites. This is due to corporate guidelines which are non-binding, requiring the implementation of a software, but without stating how it has to be used. Furthermore, longstanding and recent projects are running on different systems which have completely different procedures and encoding. This creates confusion on the course of actions to be taken. As concerns the economic implications of such an architecture, the maintenance and license costs tend to scale up linearly in relation to the number of software tools used. For this reason, the overall cost of the current architecture is not sustainable. Moreover, data consistency is difficult to ensure because of their decentralized management system.
Delving deeper into the Information System network, there follows a list of the software tools currently used:

- 3IT, the PDM used for Thales Alenia Space France projects;
- EMIS, a completely in-house developed software, heritage of Aeritalia, that was used as the ERP in the past and which is currently used as the PLM to long lasting programs. This software is used only in Torino site;
- WAND, a personalized PTC Windchill-based solution currently used as a PDM by both France and Italy;
- Ficheyes, used for flaw and non-conformity recording and management;
- SAP, the current Company ERP software. As of now, it fulfills a very limited number of operations;
- Dassault Systèmes CATIA V5, the Company CAD software;
- ENOVIA V5, a Dassault Systèmes integrated PLM package, that is the interface between CATIA V5 and WAND.

Among the items listed above, 3IT and Ficheyes have no linkage with any other application. This is critical, as there is no way to see registration errors if not by searching directly inside systems repositories. However, these two software tools are outside the scope of the analysis, because their integration into the new architecture is not, for the time being, scheduled.
Lack of interconnection gives rise to paper-based transmission of information, with the corresponding waste of time in non-value added activities, along with all subsequent activities required in the event of problems.
Lastly, the current Information Systems environment is used as a distributed data repository and this increases the chance of printing out-of-date information which can entail catastrophic damages if discrepancies and errors are not noticed within a very short time frame.

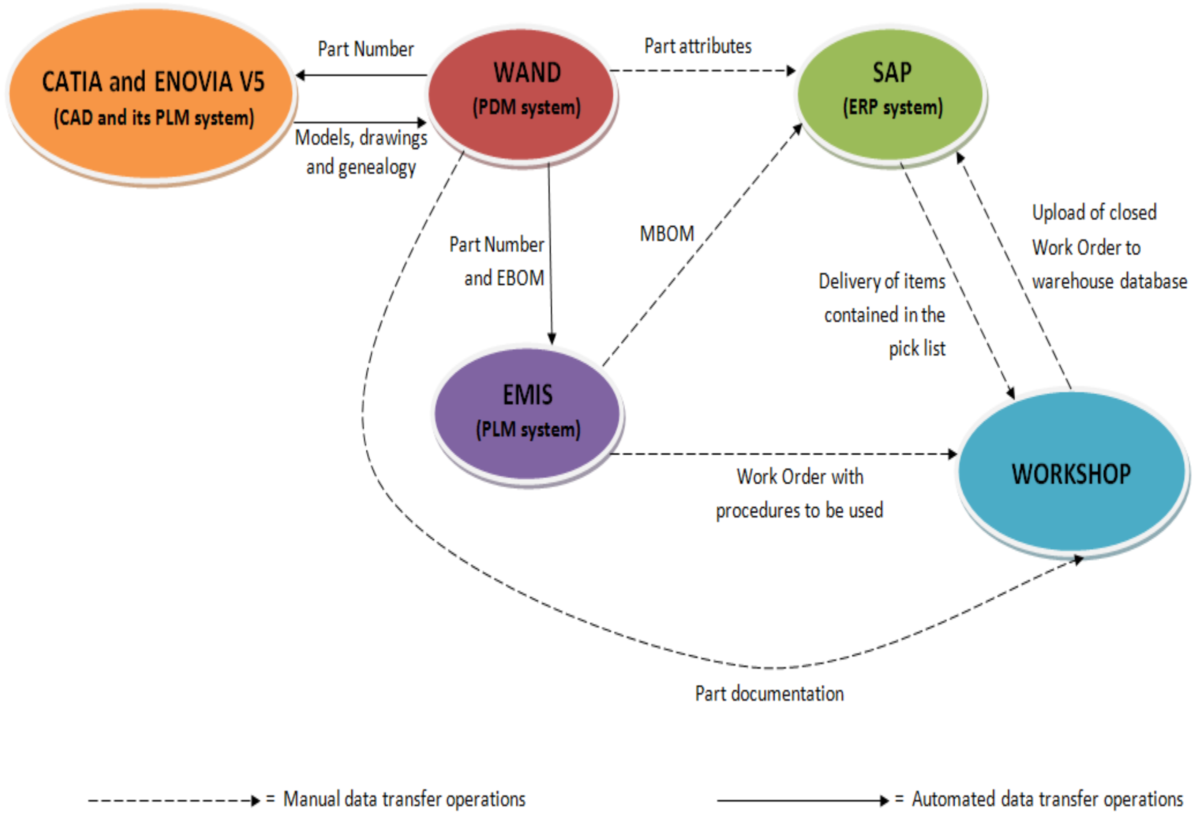


Figure 4.1. As-Is Knowledge Management System architecture

The above figure represents a modern sequence of parts data transfer among software tools. Everything starts with the creation of a new part number in WAND, which can either be very simple (e.g. a component) or very complex (e.g. a primary structure). Its complexity is defined by the EBOM structure, which is a representation of the components and quantities needed to make the required part. Once the part has been generated by the Design Authority, the interface between ENOVIA and WAND ensures that the EBOM structure associated with the part is found in ENOVIA with the same code.

At this point, designers can start creating models and drawings associated with the part number on CATIA V5. Once the technical work has been finished and freezed, the part structure in ENOVIA is updated with drawings and models that have been linked to the part number, and finally it is "published" on WAND through the same interface with a reverse loop. This way, the structure in WAND is updated with documents coming from design and documentation signature validation workflow can be started. In any case, this step is not covered in detail because it is outside the scope of this analysis.

As soon as documents have been approved and their state is set to released, inside the WAND framework part related EBOM state and maturity can be set to released and production, respectively. The workflow discussed thus far is kept identical in the new Information System architecture, as the two systems (i.e. ENOVIA V5 and WAND) are already interconnected and the transmission of data among them is automated.
Alongside the EBOM realization on WAND, the production control office starts inserting part EBOM data manually on SAP, even if the structure has not been released yet. This way, the planning orders for part components are created and purchase orders for materials and standard components, which are known to be freezed, are issued.
Shifting the focus to EMIS, its one way data transfer from WAND automatically generates a copy of the EBOM structure in this framework and ensures alignment of the part structure state between the two. Once the part EBOM on EMIS is in the released state, the correspondent MBOM can be created. This is done by the production engineering department and its structure is based on the components actually needed to manufacture a product. It is important to highlight the absence of drawings and other documents related to the MBOM structure in EMIS.
Other operations to be done in this system include:

- The creation of a Manufacturing Operations Sheet, containing a list of sequential work instructions to be carried out in order to correctly obtain the part. This document is linked to the MBOM and it is written by the production engineering department;

- Once the previous task has been completed and the MOS state has been set to active, an EMIS W/O for a certain MBOM can be activated. This is done by the production control office and this decision is taken during weekly production meetings, in which all offices are involved and where the short term planning of the production area is defined.

As illustrated in the next page, EMIS is a dated software with a very complex user interface.For this reason, its issue has been chosen for the end of the year alongside implementation of a MES.

Figure 4.2. EMIS Bill of Material interface

From now on all operations are carried out manually.
The first one is the printing of the work order (W/O) issued in EMIS. This is done by the production control unit, which is also responsible for the following steps:

- Extrapolate drawings to be associated to the EMIS work order through a reverse loop, firstly finding in WAND the EBOM associated with the MBOM of interest and then downloading and printing drawings related to that EBOM;

- Insert MBOM data on SAP MRP package. This operation was previously implemented using the EBOM structure on WAND to plan the material needs and the time at which the production should be started to meet delivery dates. Once the MBOM structure has been released, data on MRP is updated and the planned order becomes a SAP W/O. In any case, this is a fictitious W/O, because it is only used to get the warehouse pick list. Once the items contained in the pick list have been collected and placed in a picking position outside the warehouse, the SAP W/O is closed. This way, the part inside the MRP appears completed, although it's production has not started yet.

The last step required to start the in-house production is the delivery of the following units to the workshop area:

- The bundle of items situated in the picking position, which are collected directly from workshop operators;
- The EMIS work order and part drawings printed before, which is carried out by the production control unit.

The EMIS work order is then compiled manually and, once it has been closed, the final product is stored in the warehouse. The registration of the part is carried out through the designate workstation and the batch number associated to that part is the same as the just-closed EMIS work order.

4.2 Activities on software tools

4.2.1 PLM data cleansing and new functionalities

In order to create an integrated digital environment where WAND, DELMIA Apriso and SAP are interdependent, the first step required is to check the accuracy of data collected in the PLM system. Doing this prevents problems that might arise from initial incorrect and unreliable data.
For this reason, data cleansing has been undertaken in WAND, mainly focusing on the HE-R1000 project (the pilot project used to evaluate and design the new system framework). This operation concerned bills of materials, units of measure and materials associated with components.
Alongside this first critical issue, several changes to system functionality and organisational rules have also been made:

- Management of Manufacturing Bill of Materials (MBOM) structures, previously done through EMIS. This has been made possible by changes to MBOM functionalities, which ensure a correct definition of this framework. Initially, Manufacturing Bills of Materials were generated as carbon copies of the corresponding Engineering Bills of Materials. It's now possible to integrate additional manufacturing documents, such as Manufacturing Operations Sheets, construction specs, templates and loading files for production tools.

It should be noted that MOSs were used during the transitory phase to enable correspondence with the EMIS environment, but they are now substituted by routing documents, which are created in WAND and then compiled in an additional DELMIA Apriso software called Process Builder. Routing documents in WAND are empty, but their state is automatically updated following the state advancement on Process Builder, enabling the issue of work orders from SAP only for parts linked to active routing files;

- Material specs are now linked directly to construction components and not to their constituent sub-components. This way, WAND has effectively been integrated with EMIS, the part list field of which was initially empty, not showing materials specs because of data loss during their interfacing. This was important to manage the transitory phase, during which MBOM structures were developed in WAND but the subsequent phases still required EMIS employment;

- Once the first Manufacturing Bill of Materials version of a part has been released, its revision involves development of the previous framework, allowing documents integration or data correction. In this way, the reference Engineering Bill of Materials remains the same for both MBOM versions.
  On the other hand, an EBOM revision automatically generates a brand-new MBOM, carbon copy of the most recent EBOM structure. This is automatically equipped with manufacturing documents from the previous MBOM version. For this reason, method engineers have to decide whether EBOM revision affects the previous MBOM framework and, of this is the case, the new MBOM documentation must be changed;

- Usually, the EBOM framework contains engineering documents and material entities (e.g. Aluminum 7075), while the MBOM is used to select commercial shapes (e.g. a two inches plate) which are then linked to previously required material specs. This follows organizational procedures, where the engineering department identifies an appropriate component material as a result of structural analysis and the production engineering unit selects the most convenient raw material shape to obtain the final part.
  Nevertheless, in some specific cases (e.g. carbon fibers) the material commercial shape is selected directly by the engineering department. This is because some materials have unambiguous commercial shapes, leaving no doubts in their selection;

- Estimated quantities associated with material usage must be declared in the MBOM framework. This also applies to bulk materials, because the MRP do not issue requirements for materials whose quantities have not been estimated in the MBOM structure. Through this operation, the MRP present the entire list of material requirements. At this point, the production control unit decides whether to issue a purchase request for these materials too or not, depending on their availability as bulk items. This is why procurement responsibility on bulk materials is shifted to the production control department, following the proper workflow;

- A new "On Hold" command to manage notification of expected design changes has been introduced. It is located in the EBOM view by selecting the drop down menu on the top. Through this command, it is possible to issue an alert for a certain production part (i.e. it has maturity production and MBOM state released) for which an expected EBOM revision has been considered.
  This works as follows: when the revision of a part EBOM has been scheduled and the engineering department wants to suggest a block on the production of new not up-to-date components, it can advise the production control office via the "On Hold" command. When a work order is close to being activated on the MRP, the production controller receives a warning regarding "On Hold" parts and decides, together with the production engineering department, whether it is mandatory to stop production until a new version has been issued or not.
  As concerns work-in-progress parts, the "On Hold" command has no impact and their production is completed anyway. To stop them, a CCB is necessary where a final ECO decision is authorized;

- Creation of the "phantomize" command to be used by the production engineering department. This is essential, as it lets users generate Manufacturing Bills of Materials compliant with components effectively produced, deleting intermediate levels in case these are not manufactured. This way, intermediate levels in the Manufacturing Bills of Materials can be "ghosted", so that work orders related to these parts are not issued from the MRP, because they are not actually manufactured.

To identify shortcomings in the software, a trial and error methodology has been used. Firstly, a conceptual map of desired system functionalities has been realized, identifying discrepancies between the current system and the comprehensive one.

Moreover, the Information Technology unit has implemented changes in WAND Acceptance, a PLM test area. These new features have been verified by the production engineering project group.
Where the aforementioned additional functionalities tested in WAND Acceptance was evaluated positively, they have been implemented in the WAND production environment to become part of corporate procedures. On the other hand, if the solutions tested in WAND Acceptance were not considered of practical use, the IT unit worked to find another process that meets design requests.
Clearly, since the system has been redesigned to accomplish new corporate procedures, the list of changes introduced by the IT unit has been continuously updated, with lots of unplanned requests that have sprung from daily work on the system.

4.2.2 MES preliminary operations

The Company Manufacturing Execution System is DELMIA Apriso, a solution proposed by Dassault Systèmes specifically for the aerospace industry.
Activities on this environment fall into two main modules:

- Process Builder, which is an application for defining dynamic, integrated, and reusable execution processes. A Process is a digital model of an actual existing bundle of operations that an enterprise employs to make components. Process authors use this module to produce parts routings;
- Execution, which is the MES used to manage work orders and manufacturing activities.

In light of the actions carried out in order to use the system, it is important to outline the way routings are built. Each process is broken down into a sequence of activities, executed by agents, which consume resources and produce an output. DELMIA Apriso has divided processes into a hierarchy of entities, as shown in the following figure.

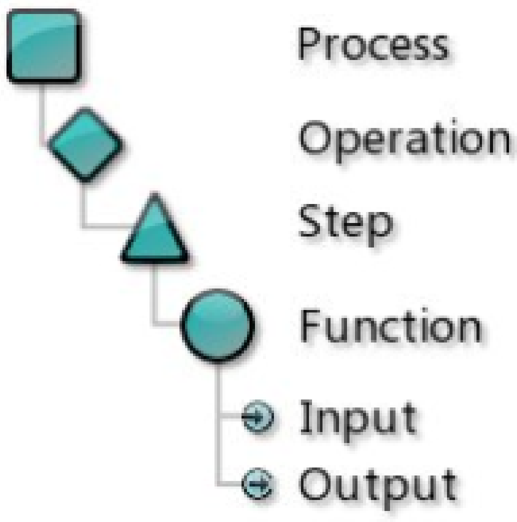


Figure 4.3. DELMIA Apriso Entities

An operation is a section of the manufacturing process performed on a work center by resources that consume materials. Usually, it is performed by one person in one place at one time.
An operation can be either standard or not, depending on its specificity with regard to a part routing. If an operation is considered standard, it can be reused in different routings just by modifying parameters or characteristic ranges, while specific operations are constructed directly in a part routing and cannot be reused in other situations. Depending on the process, operations can be scheduled in parallel or sequentially.
Each operation has one or more steps, depending on its complexity. A step is a detailed description of a given task and is linked to one or more work instructions, which are the real technological content required to complete a specific task.
Lastly, input/output functionalities can be linked to steps where data insertion or reception is, respectively, required.
To use the Execution module, several actions have been accomplished and others are still under completion:

- Creation of .csv files for users, skills and work centers. These are then uploaded in Process Builder in specific repository folders, to allow their selection during routings definition. Differently, tools and machines are extrapolated from a specific Company database and inserted in the corresponding repositories.

  Another aspect that can be inserted in routings is quality specifications. A specification is a group of characteristics that collectively defines an acceptable process, operation or step;

Work Center Code	Description	WC Type (WC-WorkCenterType-HumanLabor, WC-WorkCenterType-MachineLabor, WC-WorkCenterType-ProcessLabor, WC-WorkCenterType-ExternalLabor)	Company Code	Facility Code	Department Code (max ch. 40)	Building
10.00	QC manufacturing quality control	WC-WorkCenterType-HumanLabor	ALS	57	10	TO
10.01	QC laser tracker	WC-WorkCenterType-HumanLabor	ALS	57	10	TO
12.00	QC incoming inspection	WC-WorkCenterType-HumanLabor	ALS	57	12	TO
16.00	QC AIT quality control	WC-WorkCenterType-HumanLabor	ALS	57	16	TO
22.00	Electrical / harness workshop	WC-WorkCenterType-HumanLabor	ALS	57	22	TO
24.00	thermal hardware workshop	WC-WorkCenterType-HumanLabor	ALS	57	24	TO
25.00	CFRP workshop	WC-WorkCenterType-HumanLabor	ALS	57	25	TO
25.01	CRFP ISO5 CR workshop	WC-WorkCenterType-HumanLabor	ALS	57	25	TO
26.00	sandwich panels workshop	WC-WorkCenterType-HumanLabor	ALS	57	26	TO
27.00	inserts and panels finishing	WC-WorkCenterType-HumanLabor	ALS	57	27	TO
28.00	OSR bonding workshop	WC-WorkCenterType-HumanLabor	ALS	57	28	TO
33.00	AIT mechanics	WC-WorkCenterType-HumanLabor	ALS	57	33	TO
34.00	AIT functional	WC-WorkCenterType-HumanLabor	ALS	57	34	TO
36.00	AIT EGSE	WC-WorkCenterType-HumanLabor	ALS	57	36	TO
37.00	AIT fludic	WC-WorkCenterType-HumanLabor	ALS	57	37	TO
38.00	AIT alignement	WC-WorkCenterType-HumanLabor	ALS	57	38	TO
41.00	painting workshop	WC-WorkCenterType-HumanLabor	ALS	57	41	TO
43.00	surface treatments	WC-WorkCenterType-HumanLabor	ALS	57	43	TO
46.00	dye penetrant inspection	WC-WorkCenterType-HumanLabor	ALS	57	46	TO
48.00	autoclave	WC-WorkCenterType-MachineLabor	ALS	57	48	TO
50.00	external supplier	WC-WorkCenterType-ExternalLabor	ALS	57	50	TO
61.00	VPPA Variable Polarity Plasma Arc Welding	WC-WorkCenterType-MachineLabor	ALS	57	61	TO
62.00	FSW Friction Stir Welding	WC-WorkCenterType-MachineLabor	ALS	57	62	TO

Figure 4.4. A snapshot of the work centers .csv file

- Creation of standard operations and work instructions. In the latter repository there are also Health Safety Environment products having no description on how to apply them. Each one of these products contains an hyperlink, which redirects users to a web page describing product instructions and conditions of use.
  The whole set of work instructions is uploaded on Process Builder through an input mask and saved in a specific repository, which can be consulted during routings construction;

- Creation of users/skills and users/work centers excel matrices, which are uploaded in Process Builder, although their values are required in Execution environment. A person enters the Execution module using his/her credentials and then, once logged in, a dashboard showing available operations is displayed. Operations are filtered for each user following the two aforementioned matrices.
  The users/skills table, instead, has been built using an ILUO methodology, which consists of assigning letters based on the knowledge level of each user. An "I" evaluation represents a training situation, while the "O" corresponds to the highest level. This scale is reflected in different employee classes on Process Builder, which are then assigned to users and which may be required to perform specific operations or steps.
  The users/skills matrix also contains skills on DELMIA Apriso and SAP, giving users authorizations on specific software functionalities;

Skill Description	Class	CdC >>	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351	T351
TEST EQUIPMENT MECHANICAL TECHNICIAN	MATERIAL AND TESTS															L					
TEST EQUIPMENT ELECTRICAL TECHNICIAN	MATERIAL AND TESTS																				
TEST EQUIPMENT STRAIN GAUGE INSTALLATION	MATERIAL AND TESTS																				
TEST LOAD APPLICATION OPERATOR	MATERIAL AND TESTS																				
TEST CONDUCTOR	MATERIAL AND TESTS																				
TEST DATA HANDLING	MATERIAL AND TESTS																				
MECHANICAL TECHNICIAN	MECHANICAL WORKSHOP																				
SANDWICH PANEL INSERT INSTALLATION	MECHANICAL WORKSHOP				L	U	L	L		U	L			U		L		U		L	
KAPTON / SSM BONDING	MECHANICAL WORKSHOP					U				U				U				L		L	
HEATERS BONDING	MULTIDISCIPLINARY																				
AVIONIC PANELS FINALIZATION	MECHANICAL WORKSHOP					L		I		U	I			U				L		L	
COLD BONDING	MULTIDISCIPLINARY																				
HEAT PIPES INSTALLATION	MECHANICAL WORKSHOP					U	I	I		U	I			U						L	
CFRP LAMINATION	MECHANICAL WORKSHOP					L				L				L							
SANDWICH PANEL ASSEMBLY	MECHANICAL WORKSHOP					L				U				U						L	
SANDWICH PANEL REPAIR	MECHANICAL WORKSHOP																				
CFRP REPAIR	MECHANICAL WORKSHOP																				
AUTOCLAVE OPERATOR	MECHANICAL WORKSHOP			U												U					
LATHE OPERATOR	MECHANICAL WORKSHOP			U	U								U								
CERUTI LATHE OPERATOR	MECHANICAL WORKSHOP			U									L								
RAMBAUDI MILL OPERATOR	MECHANICAL WORKSHOP			U	L								U								
DYE PENETRANT INSPECTION	NON DESTRUCTIVE INSPECTION											U									U

Figure 4.5. A snapshot of the users/skills matrix

- Empty routing files coming from WAND are visualized in the Process Builder interface, where they can be filtered by different attributes (e.g. site). The initial state of the routings is "Design in Progress". A method engineer edits the structure, starting from operations then detailing operations through steps and, finally, linking work instructions to each step. Once completed, the routing is saved and its state is updated to "Prototype". At this point product assurance officers and senior method engineers can validate or reject it. When the routing is validated, it becomes "Active" and can be used to manufacture the related part. Clearly, a routing can be set to "Active" just in case all its building blocks are "Active" too, following parent-child relationships.

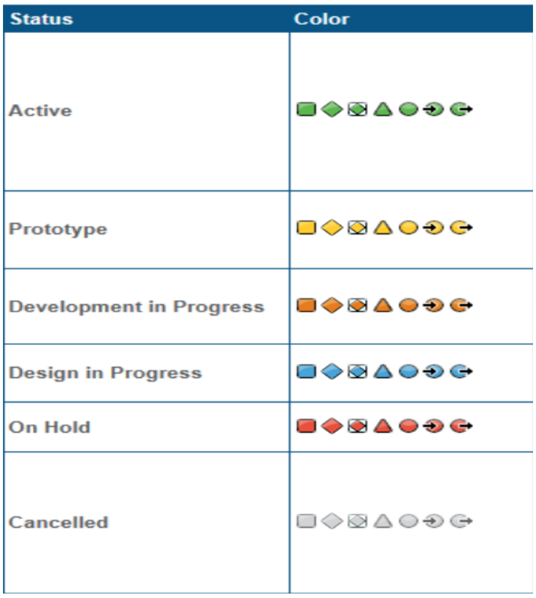


Figure 4.6. Entity status types

4.2.3 ERP changes to support the new system

On SAP, which is the Company ERP, just one major variation to the standard version has been necessary.

Analysis of the new system highlighted a problem during the supplier selection process. For this reason, a new sequence of activities has been established:

1. The engineering department builds the routing file for a part number. If there is an external supplier mechanical operation, this is assigned to a generic work center, which is not linked to a real supplier;

2. Once the production control office generates a work order through the MRP, this is linked to the previous routing, without detailing which supplier has to be selected;

3. The purchase office then assigns the external operations to a specific supplier, issuing a purchase order. At this point, the generic work center on the SAP is replaced with that of the selected supplier, which is already registered in the system as a supplier attribute;

4. Finally, part number routing on MES is automatically updated through a SAP/MES interface, replacing the operation generic work center with the one referred to the selected supplier coming from the SAP.

This way, all suppliers entering MES Execution with their credentials will find the list of operations assigned to their work center.

This variation has solved a major decision authority conflict. In fact, without this change, the production control department would have been responsible for supplier selection, leaving no choice to the purchase office, which is the department in charge of this operation.

4.3 Information System To-Be situation

The figure below provides an integrated overview on the actions and roles of each system in the new Information System.

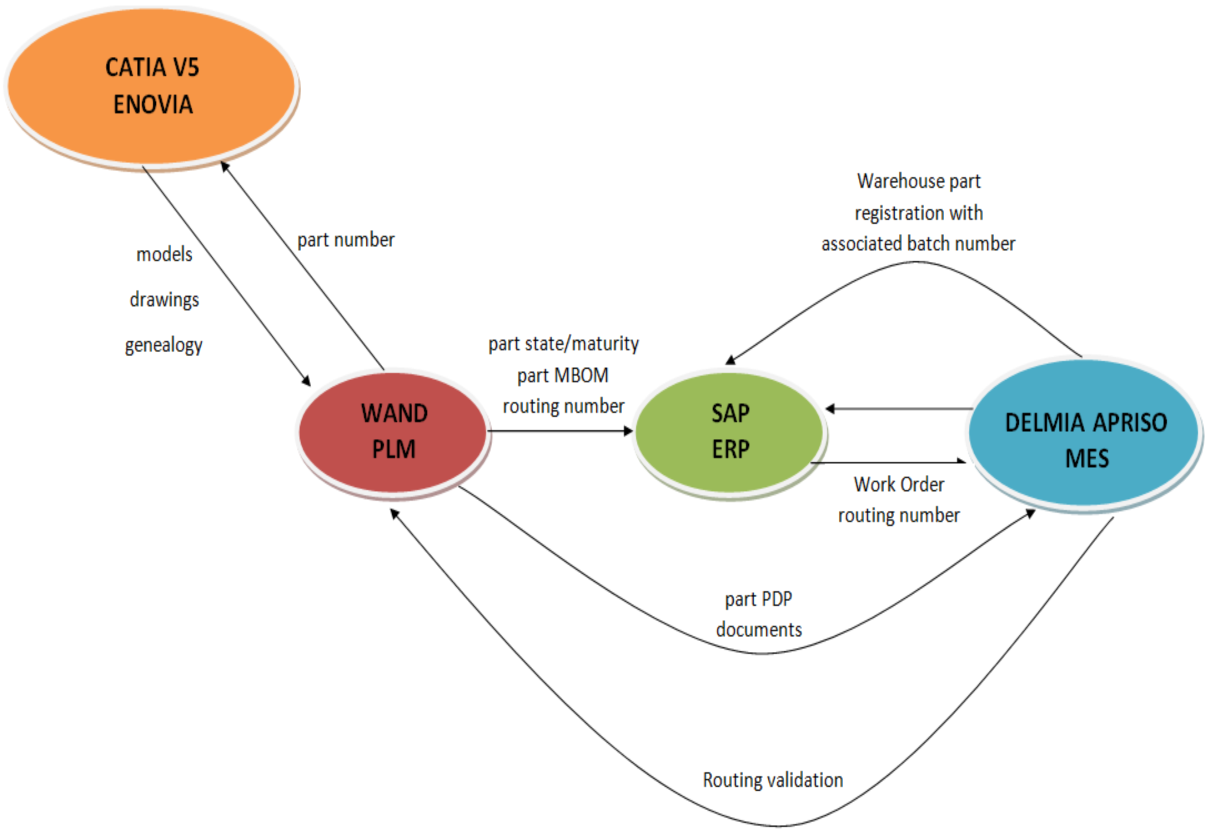
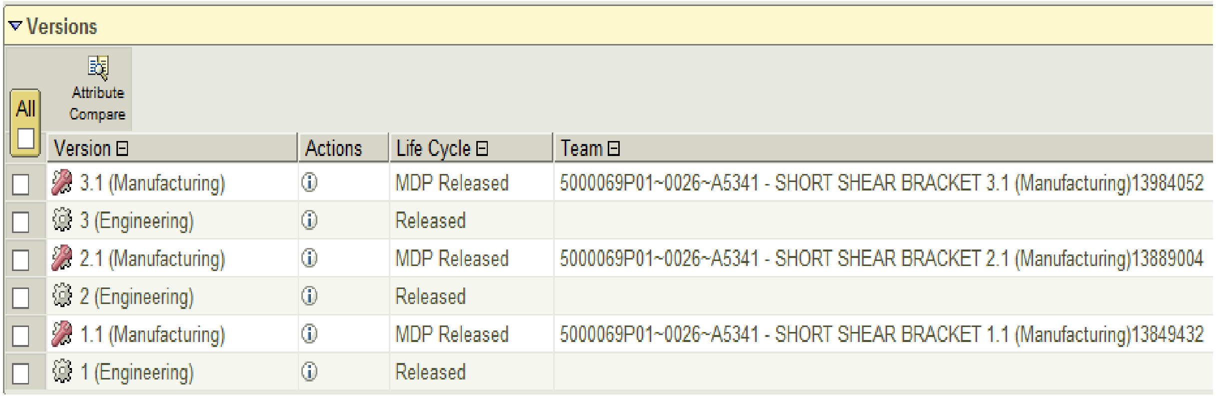


Figure 4.7. To-Be Knowledge Management System architecture

As mentioned in the "Information System As-Is situation" section, the initial information flow between Enovia and WAND is kept identical as it is both efficient and tested.
Apart from that, all other system functionalities have been changed.
In WAND, after a part EBOM has been represented and its state has been set to Released (i.e. its design is frozen) it is possible to build the related MBOM. Its structure is initially a carbon copy of the corresponding EBOM, which must be integrated with construction documents (e.g. routings) and material commercial shapes. Moreover, the MBOM can also be modified to represent manufacturing procedures, using the "phantomize" command.
The whole iteration history of a part is available on the system, allowing users to identify different versions and changes that occurred both at EBOM and MBOM levels.



Versions

Attribute Compare

Version	Actions	Life Cycle	Team
3.1 (Manufacturing)	ⓘ	MDP Released	5000069P01~0026~A5341 - SHORT SHEAR BRACKET 3.1 (Manufacturing)13984052
3 (Engineering)	ⓘ	Released	
2.1 (Manufacturing)	ⓘ	MDP Released	5000069P01~0026~A5341 - SHORT SHEAR BRACKET 2.1 (Manufacturing)13889004
2 (Engineering)	ⓘ	Released	
1.1 (Manufacturing)	ⓘ	MDP Released	5000069P01~0026~A5341 - SHORT SHEAR BRACKET 1.1 (Manufacturing)13849432
1 (Engineering)	ⓘ	Released	

Figure 4.8. Iteration history dashboard

A key change has been made to WAND employment regarding parts state and maturity. In the past, they have been used as if they were a single attribute, without representing their different objectives. In fact, parts EBOM states were set to released as well as maturities to production simultaneously. This has been modified, separating their employment. It is now possible to complete actions on the MRP once parts EBOM have been released, disregarding maturity values.
Two subsequent processes are dependent on WAND data.
The first one concerns the ERP. Once a part number MBOM has been released, its structure and routing number are passed to SAP. Moreover, the part maturity is also transferred to SAP. Regarding the latter, maturity can assume one out of three possible stated: development, pre-production or production.

- In case part maturity is set to "development", the MRP state is "X1", meaning that it is possible to plan components requirements based on the part MBOM;
- If part maturity is set to "pre-production", the MRP state is "X2", meaning that it is possible to issue items purchase orders by carrying out the procurement activity. The structure used as reference is the part MBOM;
- If part maturity is set to "production", the MRP state is "X3", meaning that it is possible to emit a work order for the part number. To do this task, it is also mandatory to have an active routing for the selected part.

As far as MES Process Builder is concerned, it receives part routings codes from WAND, which appear as empty files. They are linked to corresponding part numbers and contain part documents (i.e. drawings and models). The production engineering department represents part construction processes through entities (i.e. operations, steps and work instructions) and, once work cycles have been validated, routings become active. This information is then sent back to WAND, where part routing document states are updated.

Work orders issued by SAP are then transferred to the MES Execution dashboard. It is important to highlight that the technical content for each work order is received from Process Builder. Once the last operation of a certain W/O is finished, this information is sent to SAP, where the work order is closed and a batch number is registered. Both these operations are completed automatically.

The final task is carried out in SAP, where the warehouse location of the aforementioned batch number is manually assigned by a warehouse operator.

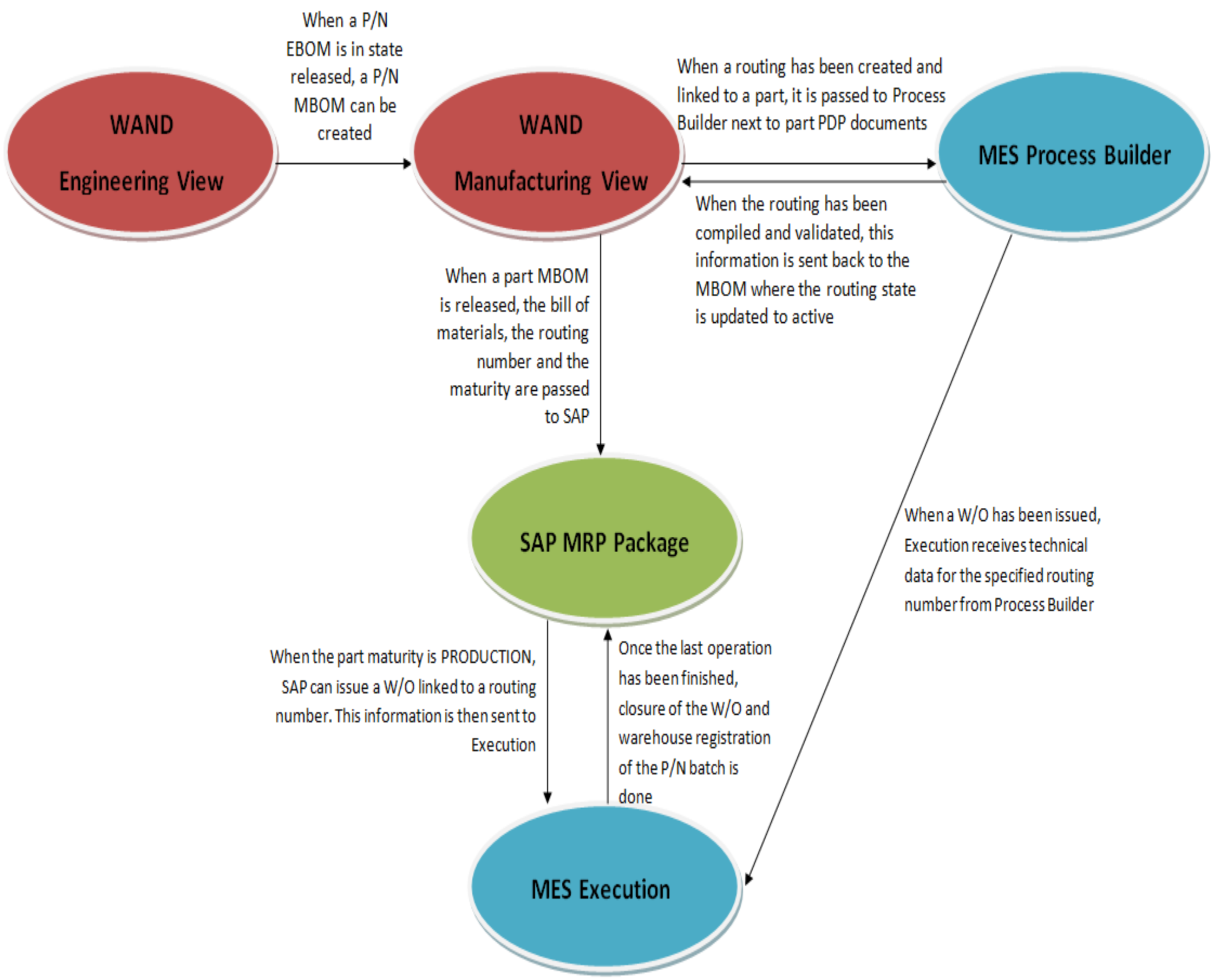


Figure 4.9. Information Flowchart

4.4 Data exchange solution adopted in the new system architecture

To ensure intercommunication among systems, data exchange is carried out via Genio, an Extract, Transform and Load (ETL) tool.
Data is extracted from heterogeneous sources and it then processed and transformed into a proper storage format. Lastly, it is uploaded into the target database.
This middleware is used to share different file formats, pulling out data from one system database and placing it in another one.
For example, MES receives and transmits data through XML files, while SAP uses a different file format for this purpose, which is called Intermediate Document (IDoc).
Genio is set up to implement data exchange procedures at selected time intervals. With regard to the Company situation, interfaces are executed each hour, which is enough to ensure a proper data consistency across the entire system architecture.

4.5 A future advantage deriving from MES through a cost analysis perspective

4.5.1 Manufacturing operations involved in the study

To carry out the analysis, four workshop activities have been initially taken into consideration:

- **Inserts disposition**, which is a manual operation required on honeycomb panels to satisfy structural requirements stemming from mathematical analysis. Inserts can be placed either in through holes or in blinded ones.
  To keep it simple, the procedure consists in drilling holes on the panel and then placing inserts there. Once this task has been done, a special glue is poured in the area between the honeycomb and the inserts through one of the two small holes in the inserts head. When the area has been filled up, the glue starts exiting from the other small hole, indicating completion of the process;

Figure 4.10. Some structural inserts with visible head holes

- **Optical Solar Reflectors (OSR) positioning**, which is a manual operation. It is used as a coating to ensure a passive thermal control for satellites and spacecrafts. Their functionality is to reflect solar radiation while simultaneously dispersing external radiators heat;

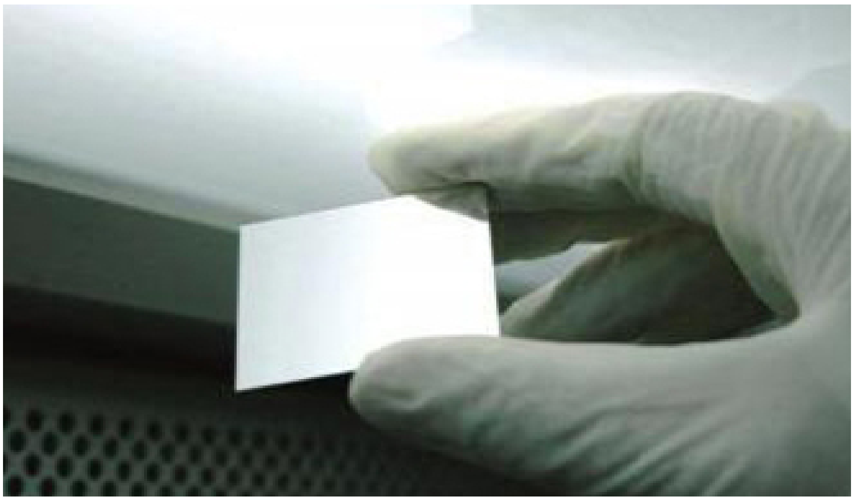


Figure 4.11. An Optical Solar Reflector

- **Orbital welding**, which consists on a welding head with 360° rotation around a static workpiece. An arc welding process is usually used; more specifically, the latter employs a Tungsten Inert Gas (TIG) technique using non-consumable electrodes.
  In orbital welding the process is controlled by automatic systems and it is run with little intervention from the worker, whose main task is supervising process parameters.
  This process was developed to address the issue of manual worker errors and is mainly used for components requiring high quality;

Figure 4.12. Orbital welding operation

- **Assembly**, which refers to a variety of operations having different working processes (e.g. mounting, fasteners, riveting, harnesses installation, hardware structural bonding). All assembly operations are performed in the workshop area according to an established workflow.

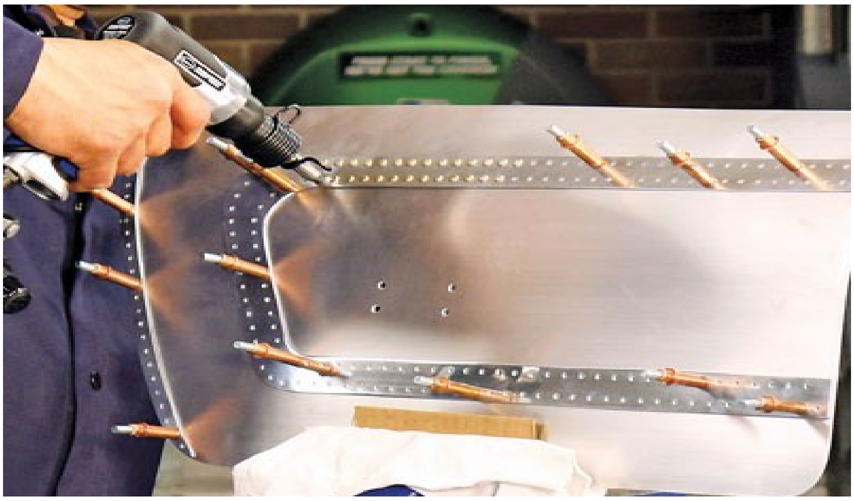


Figure 4.13. Riveting operation

4.5.2 From data collection to managerial insights

The analysis starts with the FPY data. This is a Company report containing operations performance, stating whether operation outcomes have been positive or negative. It is drawn up each year, and it contains OK and non-OK operations for each month.
Each operation that has not been accomplished correctly will require an additional process to fix the problem.

CCPI-ITALY P&T	FSW			OW			BRAZING			ASSEMBLY			OSR			INSERTS		
	cm	Trend	FPY	weld	Trend	FPY		Trend	FPY		Trend	FPY		Trend	FPY		Trend	FPY
JAN	880	100%	100%	7	88%	88%	0	na	na	36	100%	100%	930	100%	100%	938	100%	100%
	880			8			0			36			932			942		

Figure 4.14. First Pass Yield structure

Now, it is important to list the assumptions that have been made in order to perform a seemingly realistic analysis:

1. Withe the full 2019 data FPY available (with operations recorded until the end of August), while having only the 2018 performance ratios concerning OK operations over the total number for that year, the total number of 2018 registrations has been assumed equal to the number of registrations from January to August 2019, multiplied by $\frac{12}{8}$ (i.e. assuming a constant average number of monthly registrations from January 2018 to August 2019);

2. Operation rework time distributions have been estimated with the support of different workers' experiences. Through this process, it was decided to represent these times using Weibull distributions. The following formula represents the probability density function of a Weibull random variable:

$$f_X(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{4.1}$$

   To align this distribution with operation rework times, it has been shifted to the right, avoiding the occurrence of incompatible rework times (e.g. a too-small rework time cannot be obtained, because of working tool procurement and preparation);

3. A coefficient representing non-registered operations has been chosen. Set to 1.1, it has been employed to take operators' inattention or forgetfulness into consideration in recording data on the FPY.

It is now possible to outline the work that has been carried out.
Firstly, 2018 non-OK operations were computed by multiplying the total number of estimated registrations by the performance ratio. This was done for each of the four considered operations.
The 2018 non-OK operations were added to the ones occurred in 2019. At this point, their sum was multiplied by 1.1 in order to take unregistered non-OK operations into account.
This procedure provided starting data for the analysis.

	OSR positioning	Inserts disposition	Orbital Welding	Assembly
not ok operations taking into account also unregistered operations	18	53	88	52

Figure 4.15. Reworks for each operation category

Passing to MATLAB, Weibull distribution parameters have been estimated for each of the four categories alongside a distribution shift to ensure data compliance with workers' experiences regarding rework times. This was the only available work procedure, because of rework time data shortage.
Following experts insights, OSR positioning, Inserts disposition and Orbital welding rework times have very little variability. On the other hand, assembly rework operations, because they form a category containing a lot of different processes, are variable time activities.
Moreover, each non-OK assembly registration may imply rework operations on many components as each assembly consists of an aggregation of parts.
For these reasons, it was decided to leave aside the final estimated costs for OSR positioning, Inserts disposition and Orbital welding and focus on the one concerning assembly rework operations.
The Probability Density Function (PDF) and Cumulative Distribution Function (CDF) representing assembly rework times distribution are shown on the following page.

The λ parameter, which represents the scale of the x-axis values, has the effect of stretching out the PDF. Since the area under a PDF curve is a constant value of one, the y value associated to the modal value will also decrease with the increase of λ.
With regard to assembly rework times, λ has been set to 32, a very high value representing the process variability.
The k parameter, which represents the shape of the curve, has been set to 1.4. This means that the modal value is close to the smallest rework time, but the two does not coincide. In this case, the modal value is between 23 and 24 minutes, while the smallest rework time that can be obtained is 10 minutes.
Once more, λ and k parameters along with the shift value have been established thanks to workers' know-how. Specifically, the two distribution parameters were determined via a two-step procedure: firstly, several PDFs have been represented, each with a different pair of parameters (i.e. λ and k). Then, workers were asked which PDF best represents the assembly rework time distribution. The PDF which have received the greatest approval was used, along with its parameters.

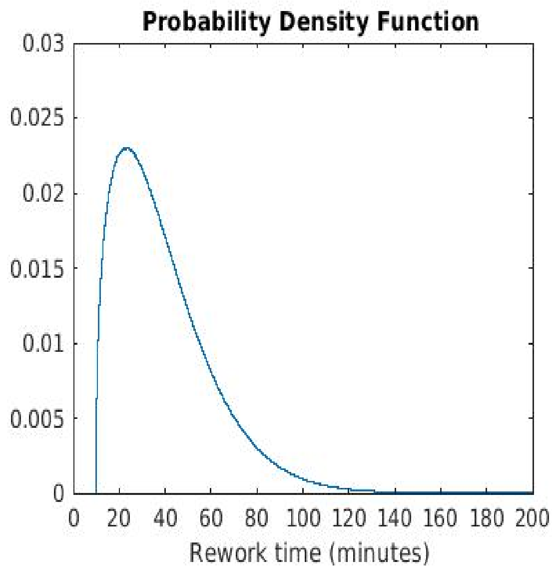


Figure 4.16. Assy rework time PDF

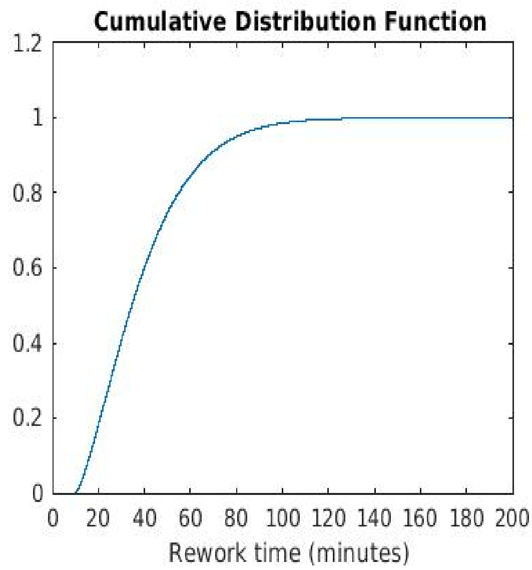


Figure 4.17. Assy rework time CDF

Once the distribution was identified, two assembly rework cost scenarios were conducted, the first being carried out using discrete cost intervals, the second conducted using a more interesting approach.

- The first rework cost scenario starts with the simulation of 5 random samples for the 52 assembly rework times. The sum of the rework times was computed and then divided by 60, obtaining the total rework hours for the period January 2018 - August 2019.

Nevertheless, these 5 values refer to the overall number of rework hours just in case each non-OK assembly operation required one single rework, but that is not the case. For this reason, a discrete set of reworks number for each operation has been estimated thanks to the workers' experience. Three values were considered: a minimum (i.e. 1), a maximum (i.e. 15), and an average (i.e. 8). This way, three sets of overall rework hours were obtained according to the discrete set of reworks number considered.

Finally, given that each working hour costs the Company €50, the direct labor cost have been computed for each of the three cases.

TOTAL MINIMUM REWORKS HOURS	33,4	34,8	29,6	34,0	35,1
TOTAL AVERAGE REWORKS HOURS	266,8	278,2	237,1	271,8	280,5
TOTAL MAXIMUM REWORKS HOURS	500,3	521,6	444,6	509,6	525,9
TOTAL MINIMUM COST FOR REWORKS	€ 1.667,5	€ 1.738,6	€ 1.481,9	€ 1.698,7	€ 1.753,0
TOTAL AVERAGE COST FOR REWORKS	€ 13.340,4	€ 13.909,0	€ 11.855,3	€ 13.589,8	€ 14.024,2
TOTAL MAXIMUM COST FOR REWORKS	€ 25.013,2	€ 26.079,3	€ 22.228,7	€ 25.481,0	€ 26.295,5

Figure 4.18. Assembly reworks costs in the first scenario

As shown, cost magnitude varies significantly depending on the number of reworks set associated to each rework time.

- The second reworks cost scenario is based on an intuitive assumption, which has been confirmed by workers: the longer the single rework time, the smaller the number of reworks to be done. This consideration is not applicable to the small single rework time, where the associated number of reworks can be either very high or very low.

  For this purpose, a simulation of 50 random samples for the 52 assembly rework times was performed, along with a simulation of 50 random samples for the 52 values representing the number of reworks associated with each corresponding single rework time.

  The following figures are useful to better grasp the connection between rework time and the number of reworks for an assembly operation.

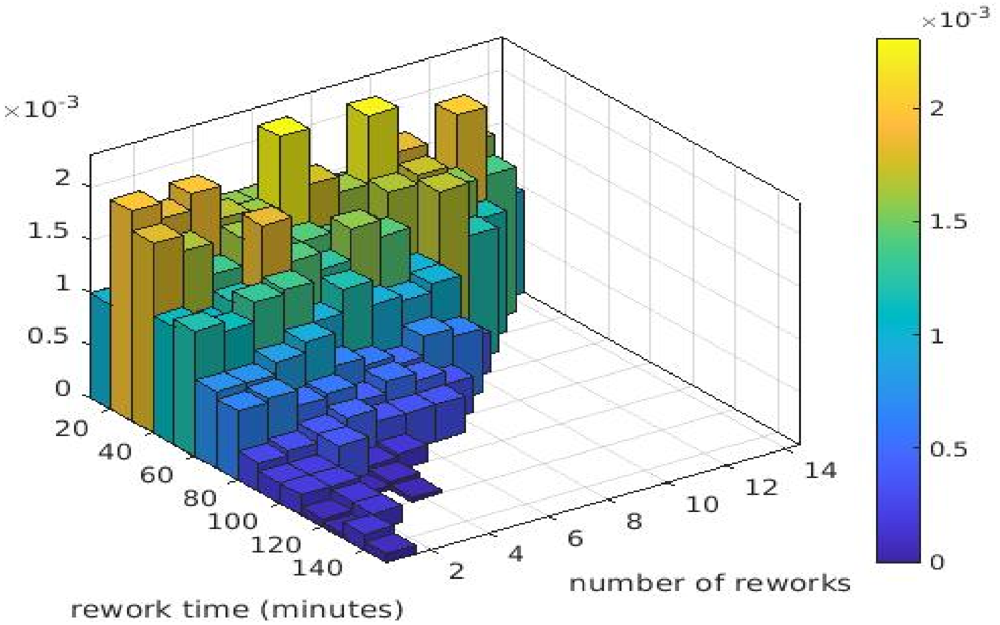


Figure 4.19. Histogram representing assembly rework time PDF

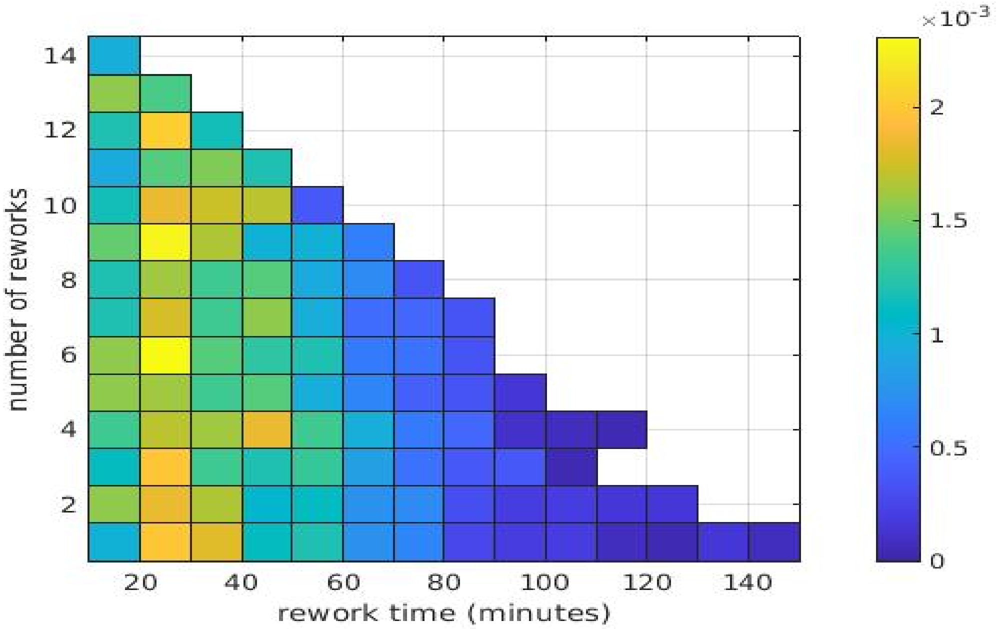


Figure 4.20. Number of reworks dependency on single rework time

Given this assumption, a single value was obtained for the overall rework hours. This was made possible by using the Excel SUMPRODUCT functionality, which multiplies corresponding components in the two arrays (i.e. rework time and number of reworks) and returns the sum of those products.

Lastly, given that each working hour costs the Company €50, the direct workers cost was computed. Unlike the first scenario, in this case the variability of the reworks cost is not exceptionally high, although it is not negligible.

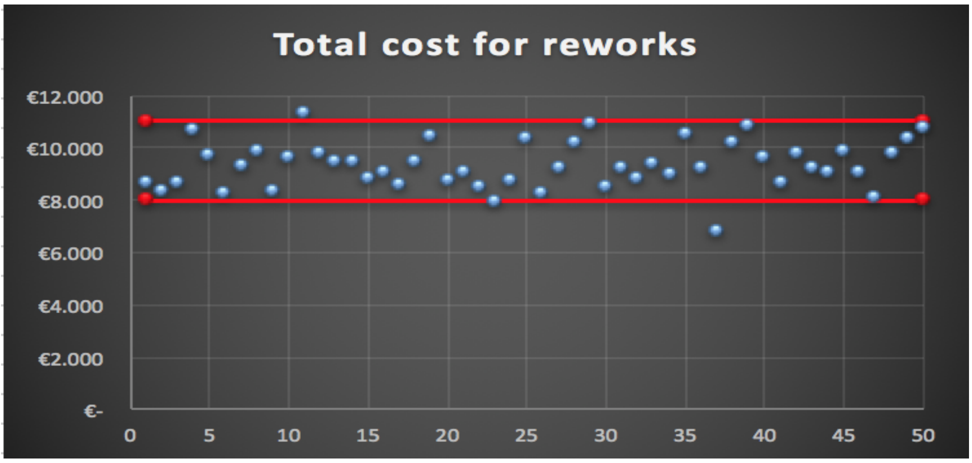


Figure 4.21. Assembly reworks cost in the second scenario

As a final consideration, it is important to highlight the little importance that has been given to the economic meaning of the estimated reworks cost. In fact, although it may be seen as a small value for a large company, this cost does not represent the overall expense associated with rework operations, but only the workshop operators' share. For this reason, the overall reworks cost can be much higher than the one computed. Additionally, it is on its own a highly variable cost, involving several cost categories (e.g. the cost of people involved in solving non-conformances or problems encountered during assembly operation).

This clarification is important to understand the goal of the analysis, which was not focused on finding the total cost for assembly rework operations, but, rather, on assessing direct reworks cost variability.

Summarizing, the analysis was carried out to shed light on the importance of having a MES system that allows reworks time to be recorded with extreme accuracy and to create real time snapshots and graphs to assess the current situation.

This is critical, because managerial decisions require much more than mere ballpark figures; in fact, they demand very precise data.

4.6 Discussed improvements to better manage production orders and to spread system applicability

The startup system implementation pursued three main objectives:

- Reducing work orders completion times;
- Ensuring better communication among departments;
- Doing away with paper documentation.

Following meetings with DELMIA Apriso managers, new available functionalities have been proposed to satisfy Company requirements. These are currently under investigation to evaluate their applicability:

- A production cockpit window to better allocate resources in the short period, in case the Company is running out of time because of orders congestion.
  This can be very helpful for the workshop manager, who can be enabled to modify the master schedule in such situations;
- In order to meet Assembly Integration and Test (AIT) unit requirements, enabling its effective use of the MES, a possible solution has been identified.
  The proposal requires the creation of test articles which would be added to the MBOM structure of a certain part. These items refer to testing configurations, which fall outside the actual manufacturing structure.
  Once the test article numbers have been created on WAND, their procedural flow would be the same as ordinary part numbers. The only difference resides in the issue of work orders for these test articles, which is done directly on MES Execution. This procedure, which does not employ SAP and thus does not create problems due to erroneous additional requirements, makes it is possible to manage these articles in a compatible way with other part numbers.

Chapter 5

Case study

5.1 HE-R1000 mechanical structure

HE-R1000 is the pilot project used to evaluate the application of the new MES system in the corporate Information System architecture. For an explanation of the purpose of this project, see the "Core business of the Torino site" subsection.
In brief, this is a mechanical platform with the purpose of being used in different projects, because of its modularity.

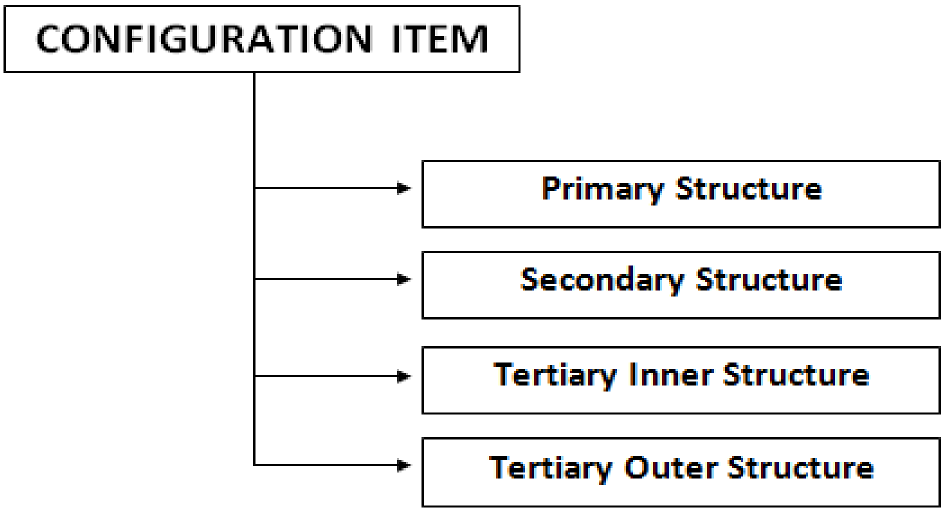


Figure 5.1. HE-R1000 mechanical structure

As shown in the figure above, the configuration item (i.e. the top assembly referred to the whole structure) has 4 main components:

- A primary structure, employed to give mechanical stability to the configuration item;
- A secondary structure, used to support other systems (e.g. sensors and antennas);
- A tertiary inner and outer structures, which contain complementary parts that do not refer either to primary and secondary structures.

Delving deeper into HE-R1000 primary structure shows it consists of 134 part numbers (indicating the quantity of items required to obtain it).

One of these parts is the component that was used to evaluate the data flow among WAND, DELMIA Apriso and SAP. It is the Bottom Platform Assembly.

5.2 Information flow throughout the new Manufacturing Management System

The purpose of this section is to visually represent the information flow outlined in "Information System To-Be situation" section. This is done referencing to the Bottom Platform Assembly.

As a preamble, it is important to mention the unavailability of the interface between WAND and ENOVIA because of professional secrecy. Accordingly, the first exhibits represent the EBOM and the MBOM of the Bottom Platform Assembly.

Name	Actions	Number	Version	State	Quantity	Line	Part Maturity
BOTTOM PLATFORM ASSY		5000009A01~0026~A5341	1.19 (Engineering)	Released			PRODUCTION
ADHESIVES		M02A076ND1A999089	1.3 (Engineering)	ACTIVE	28 each	165	PRODUCTION
BOTTOM PLATFORM INS LAYOUT		5000011A01~0026~A5341	2.7 (Engineering)	Released	2 each	11	PRODUCTION
BLIND THREADED		SL10837M4-7M/X	3.4 (Engineering)	ACTIVE	2 each	991	PRODUCTION
BOTTOM PLATFORM SANDWICH		5000049A01~0026~A5341	2.3 (Engineering)	Released	1 each	11	PRODUCTION
POTTING		M02E016NC9A999088	2.3 (Engineering)	ACTIVE	6 each	164	PRODUCTION
RECESSED SLEEVE INSERT		5000109P01~0026~A5341	2.2 (Engineering)	Released	4 each	913	PRODUCTION
SPECIAL INSERT ASSY		5000100A01~0026~A5341	1.10 (Engineering)	Released	10 each	906	PRODUCTION
SPECIAL INSERT ASSY		5000102A01~0026~A5341	1.7 (Engineering)	Released	2 each	907	PRODUCTION
SPECIAL INSERT ASSY		5000094A01~0026~A5341	1.6 (Engineering)	Released	10 each	901	PRODUCTION
SPECIAL INSERT ASSY		5000092A01~0026~A5341	1.6 (Engineering)	Released	20 each	900	PRODUCTION
WITH HELICOIL INSERT		ENN398-04-12	1.4 (Engineering)	ACTIVE	24 each	992	PRODUCTION
BOTTOM RING ASSY		5000120A01~0026~A5341	1.8 (Engineering)	Released	2 each	21	PRODUCTION
BOTTOM_RING		5000074P01~0026~A5341	2.2 (Engineering)	Released	1 each	11	PRODUCTION
HC L6 TD MJ4X0.7 MM		LN9499-02060	1.8 (Engineering)	Valid for BOM Production	2 each	21	PRODUCTION
BOTTOM UNION BRACKET		5000084P01~0026~A5341	2.2 (Engineering)	Released	2 each	29	PRODUCTION
7075 T73 SHEET TH5 MM		M07A006A10A154307	2.4 (Engineering)	Valid for BOM Production	0.11 kilograms	11	PRODUCTION
BUTT STRAP		5000085P01~0026~A5341	2.3 (Engineering)	Released	4 each	23	PRODUCTION
7075 T3 SHEET TH6 MM		M07A006A10A154396	4.4 (Engineering)	Valid for BOM Production	0.015 square meters	11	PRODUCTION
CENTERING CLEAT ASSY		5000182A01~0026~A5341	1.4 (Engineering)	Released	8 each	31	PRODUCTION
CENTERING CLEAT		5000181P01~0026~A5341	2.3 (Engineering)	Released	1 each	11	PRODUCTION
HC L7.5 TD MJ5X0.8 MM		LN9499-03075	1.12 (Engineering)	Valid for BOM Production	1 each	21	PRODUCTION
P-224 WIDTH 25.4MM		M04D004N00A999653	1.7 (Engineering)	Valid for BOM Production	0.01 as needed	210	PRODUCTION
PANEL INSERT ASSY		5000121A01~0026~A5341	1.5 (Engineering)	Released	8 each	27	PRODUCTION
HC L6 TD MJ4X0.7 MM		LN9499-02060	1.8 (Engineering)	Valid for BOM Production	4 each	21	PRODUCTION
PANEL INSERT		5000082P01~0026~A5341	2.2 (Engineering)	Released	1 each	11	PRODUCTION
S M5X0.8-14-14		LN29950J0514B	1.7 (Engineering)	Valid for BOM Production	80 each	514	PRODUCTION
S MJ6X1-14-14		LN29950J0614B	1.7 (Engineering)	Valid for BOM Production	16 each	614	PRODUCTION
S MJ6X1-18-18		LN29950J0618B	1.7 (Engineering)	Valid for BOM Production	4 each	618	PRODUCTION
UPPER CLEAT ASSY		5000119A01~0026~A5341	1.9 (Engineering)	Released	24 each	25	PRODUCTION
HC L7.5 TD MJ5X0.8 MM		LN9499-03075	1.12 (Engineering)	Valid for BOM Production	1 each	21	PRODUCTION
UPPER CLEAT		5000076P01~0026~A5341	2.2 (Engineering)	Released	1 each	11	PRODUCTION
W COUNT ID5.2 OD10 T1		DIN65209-05M	1.29 (Engineering)	Valid for BOM Production	80 each	500	PRODUCTION
W COUNT ID6.2 OD12 T1.5		DIN65209-06M	1.13 (Engineering)	Valid for BOM Production	20 each	600	PRODUCTION

Figure 5.2. Bottom Platform Assembly EBOM structure

Name	Actions	Number	Version	State	Quantity	Line	Part Maturity
BOTTOM PLATFORM ASSY		5000009A01~0026~A5341	1.1.2 (Manufacturing)	MDP Released			PRODUCTION
ADHESIVES		M02A076ND1A999089	1.1.1 (Manufacturing)	MDP Released	28 each	165	PRODUCTION
BOTTOM PLATFORM INS LAYOUT		5000011A01~0026~A5341	2.1.3 (Manufacturing)	MDP Released	2 each	11	PRODUCTION
BLIND THREADED		SL10837M4-7M/X	3.1.1 (Manufacturing)	MDP Released	2 each	991	PRODUCTION
BOTTOM PLATFORM SANDWICH		5000049A01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	1 each	11	PRODUCTION
POTTING		M02E016NC9A999088	2.1.1 (Manufacturing)	MDP Released	6 each	164	PRODUCTION
RECESSED SLEEVE INSERT		5000109P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	4 each	913	PRODUCTION
SPECIAL INSERT ASSY		5000100A01~0026~A5341	1.2.2 (Manufacturing)	MDP Released	10 each	906	PRODUCTION
SPECIAL INSERT ASSY		5000094A01~0026~A5341	1.2.2 (Manufacturing)	MDP Released	10 each	901	PRODUCTION
SPECIAL INSERT ASSY		5000102A01~0026~A5341	1.2.2 (Manufacturing)	MDP Released	2 each	907	PRODUCTION
SPECIAL INSERT ASSY		5000092A01~0026~A5341	1.2.2 (Manufacturing)	MDP Released	20 each	900	PRODUCTION
WITH HELICOIL INSERT		ENN398-04-12	1.1.1 (Manufacturing)	MDP Released	24 each	992	PRODUCTION
BOTTOM RING ASSY		5000120A01~0026~A5341	1.1.2 (Manufacturing)	MDP Released	2 each	21	PRODUCTION
BOTTOM_RING		5000074P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	1 each	11	PRODUCTION
HC L6 TD MJ4X0.7 MM		LN9499-02060	1.1.2 (Manufacturing)	MDP Released	2 each	21	PRODUCTION
BOTTOM UNION BRACKET		5000084P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	2 each	29	PRODUCTION
7075 T73 SHEET TH5 MM		M07A006A10A154307	2.1.2 (Manufacturing)	MDP Released	0.11 kilograms	11	PRODUCTION
BUTT STRAP		5000085P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	4 each	23	PRODUCTION
7075 T3 SHEET TH6 MM		M07A006A10A154396	4.1.2 (Manufacturing)	MDP Released	0.015 square meters	11	PRODUCTION
CENTERING CLEAT ASSY		5000182A01~0026~A5341	1.1.1 (Manufacturing)	MDP Released	8 each	31	PRODUCTION
CENTERING CLEAT		5000181P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	1 each	11	PRODUCTION
HC L7.5 TD MJ5X0.8 MM		LN9499-03075	1.1.2 (Manufacturing)	MDP Released	1 each	21	PRODUCTION
P-224 WIDTH 25.4MM		M04D004N00A999653	1.1.2 (Manufacturing)	MDP Released	0.01 as needed	210	PRODUCTION
PANEL INSERT ASSY		5000121A01~0026~A5341	1.2.2 (Manufacturing)	MDP Released	8 each	27	PRODUCTION
HC L6 TD MJ4X0.7 MM		LN9499-02060	1.1.2 (Manufacturing)	MDP Released	4 each	21	PRODUCTION
PANEL INSERT		5000082P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	1 each	11	PRODUCTION
S M5X0.8-14-14		LN29950J0514B	1.1.2 (Manufacturing)	MDP Released	80 each	514	PRODUCTION
S MJ6X1-14-14		LN29950J0614B	1.1.2 (Manufacturing)	MDP Released	16 each	614	PRODUCTION
S MJ6X1-18-18		LN29950J0618B	1.1.3 (Manufacturing)	MDP Released	4 each	618	PRODUCTION
UPPER CLEAT ASSY		5000119A01~0026~A5341	1.1.2 (Manufacturing)	MDP Released	24 each	25	PRODUCTION
HC L7.5 TD MJ5X0.8 MM		LN9499-03075	1.1.2 (Manufacturing)	MDP Released	1 each	21	PRODUCTION
UPPER CLEAT		5000076P01~0026~A5341	2.1.1 (Manufacturing)	MDP Released	1 each	11	PRODUCTION
W COUNT. ID5.2 OD10 T1		DIN65209-05M	1.1.2 (Manufacturing)	MDP Released	80 each	500	PRODUCTION
W COUNT. ID6.2 OD12 T1.5		DIN65209-06M	1.1.2 (Manufacturing)	MDP Released	20 each	600	PRODUCTION

Figure 5.3. Bottom Platform Assembly MBOM structure

In addition, it is important to show a part attributes screenshot, containing the list of additional part features. The displayed figure is referred to the Panel Insert Assy (component number 5000121A01 in the just exhibited Bottom Platform Assembly MBOM), which has been "phantomized" to represent the Bottom Platform Assembly manufacturing cycle, where this intermediate assembly is not realised.

Additional Attributes

Attribute	Value
Control Export License	N
Description	PANEL INSERT ASSY
ENOVIA Code Dati Sensibili	EVP000000011867
ENOVIA Version Dati Sensibili	---
Fracture Critical	false
Incoming Control Requirement	N
Management By Project	P
Note	P151 - MARKING AS PER SP P520 - CLEANING METHOD F P521 - CLEANLINESS LEVEL P522 - PROTECTION HANDLI
Part Typology	Assiemi - Assieme Meccanico
Phantom	true
Reason For Change	New Emission
Track Management Index	L
TradeClass	AEB13
Part Maturity	PRODUCTION

Figure 5.4. Panel Insert Assy "Phantom" attribute detail

At this point, an empty routing document is created and then linked to the Bottom Platform Assembly MBOM. Lastly, it is found among the part related documents with state "In Work". For what concerns the Bottom Platform Assembly, there is another associated document containing drawings and files of the CAD models.

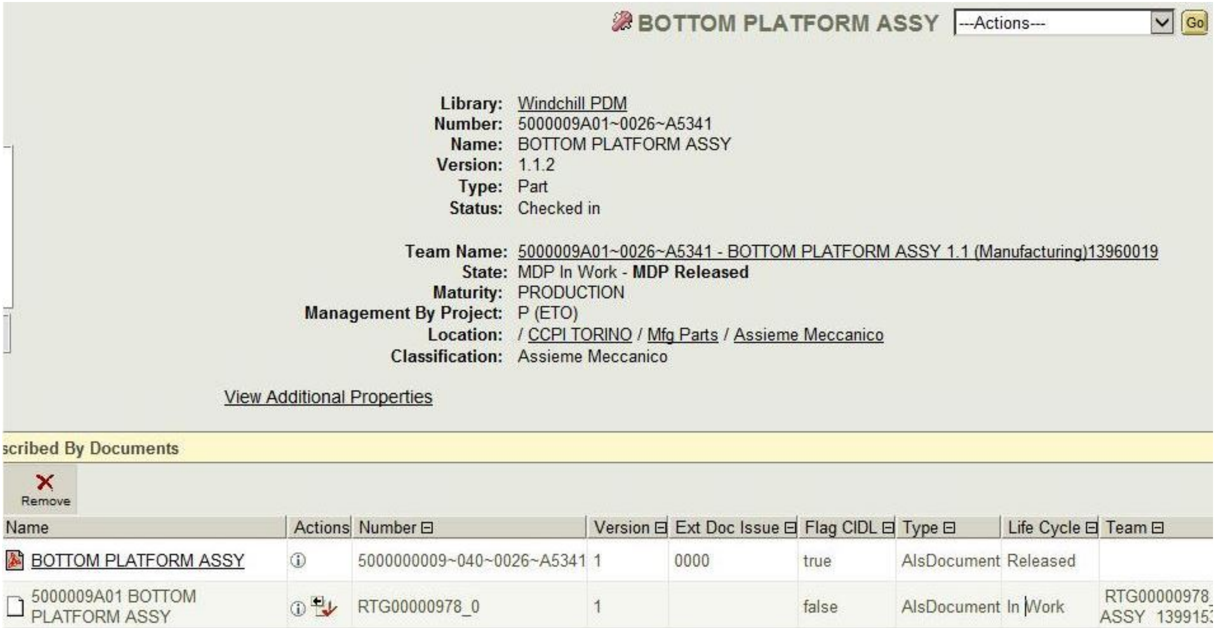
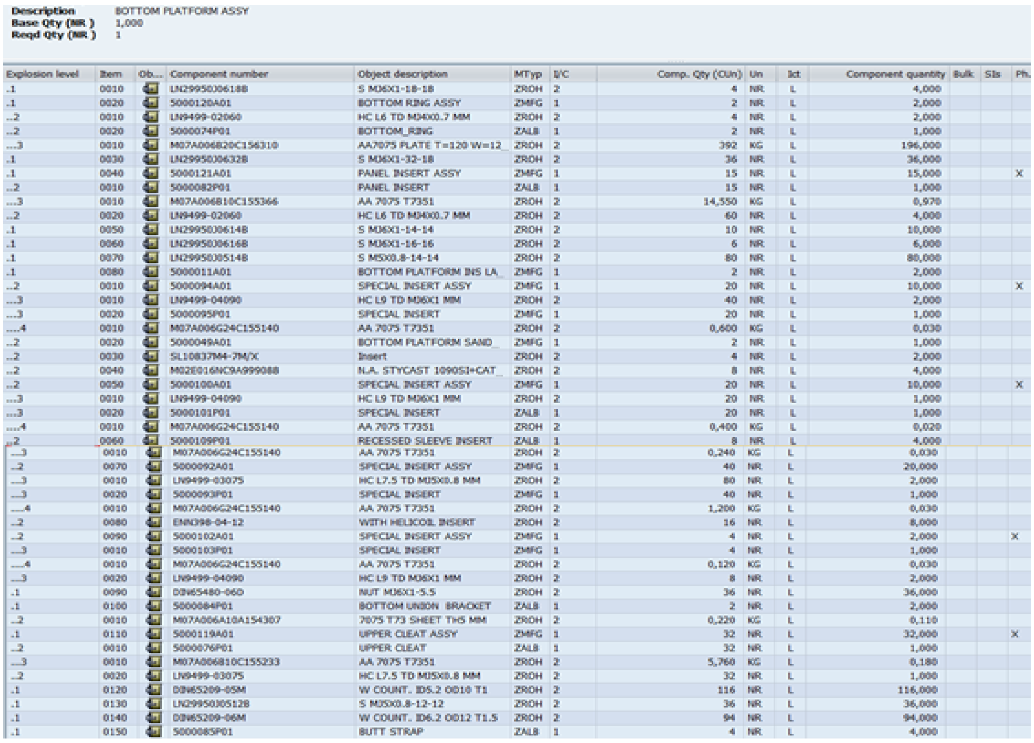


Figure 5.5. Bottom Platform Assembly related documents

Shifting to SAP, the Bottom Platform Assembly BOM structure is found in one of its modules.



Description BOTTOM PLATFORM ASSY
Base Qty (NR) 1,000
Reqd Qty (NR) 1

Explosion level	Item	Ob...	Component number	Object description	MTyp	I/C	Comp. Qty (CUn)	Un	Ict	Component quantity	Bulk	SIs	Ph.
.1	0010		LN29950J0618B	S MJ6X1-18-18	ZROH	2	4	NR	L	4,000			
.1	0020		5000120A01	BOTTOM RING ASSY	ZMFG	1	2	NR	L	2,000			
..2	0010		LN9499-02060	HC L6 TD MJ4X0.7 MM	ZROH	2	4	NR	L	2,000			
..2	0020		5000074P01	BOTTOM_RING	ZALB	1	2	NR	L	1,000			
...3	0010		M07A006B20C156310	AA7075 PLATE T=120 W=12_	ZROH	2	392	KG	L	196,000			
.1	0030		LN29950J0632B	S MJ6X1-32-18	ZROH	2	36	NR	L	36,000			
.1	0040		5000121A01	PANEL INSERT ASSY	ZMFG	1	15	NR	L	15,000			X
..2	0010		5000082P01	PANEL INSERT	ZALB	1	15	NR	L	1,000			
...3	0010		M07A006B10C155366	AA 7075 T7351	ZROH	2	14,550	KG	L	0,970			
..2	0020		LN9499-02060	HC L6 TD MJ4X0.7 MM	ZROH	2	60	NR	L	4,000			
.1	0050		LN29950J0614B	S MJ6X1-14-14	ZROH	2	10	NR	L	10,000			
.1	0060		LN29950J0616B	S MJ6X1-16-16	ZROH	2	6	NR	L	6,000			
.1	0070		LN29950J0514B	S M5X0.8-14-14	ZROH	2	80	NR	L	80,000			
.1	0080		5000011A01	BOTTOM PLATFORM INS LA_	ZMFG	1	2	NR	L	2,000			
..2	0010		5000094A01	SPECIAL INSERT ASSY	ZMFG	1	20	NR	L	10,000			X
...3	0010		LN9499-04090	HC L9 TD MJ6X1 MM	ZROH	2	40	NR	L	2,000			
...3	0020		5000095P01	SPECIAL INSERT	ZMFG	1	20	NR	L	1,000			
....4	0010		M07A006G24C155140	AA 7075 T7351	ZROH	2	0,600	KG	L	0,030			
..2	0020		5000049A01	BOTTOM PLATFORM SAND_	ZMFG	1	2	NR	L	1,000			
..2	0030		SL10837M4-7M/X	Insert	ZROH	2	4	NR	L	2,000			
..2	0040		M02E016NC9A999088	N.A. STYCAST 1090SI+CAT_	ZROH	2	8	NR	L	4,000			
..2	0050		5000100A01	SPECIAL INSERT ASSY	ZMFG	1	20	NR	L	10,000			X
...3	0010		LN9499-04090	HC L9 TD MJ6X1 MM	ZROH	2	20	NR	L	1,000			
...3	0020		5000101P01	SPECIAL INSERT	ZALB	1	20	NR	L	1,000			
....4	0010		M07A006G24C155140	AA 7075 T7351	ZROH	2	0,400	KG	L	0,020			
..2	0060		5000109P01	RECESSED SLEEVE INSERT	ZALB	1	8	NR	L	4,000			
...3	0010		M07A006G24C155140	AA 7075 T7351	ZROH	2	0,240	KG	L	0,030			
..2	0070		5000092A01	SPECIAL INSERT ASSY	ZMFG	1	40	NR	L	20,000			
...3	0010		LN9499-03075	HC L7.5 TD MJ5X0.8 MM	ZROH	2	80	NR	L	2,000			
...3	0020		5000093P01	SPECIAL INSERT	ZMFG	1	40	NR	L	1,000			
....4	0010		M07A006G24C155140	AA 7075 T7351	ZROH	2	1,200	KG	L	0,030			
..2	0080		ENN398-04-12	WITH HELICOIL INSERT	ZROH	2	16	NR	L	8,000			
..2	0090		5000102A01	SPECIAL INSERT ASSY	ZMFG	1	4	NR	L	2,000			X
...3	0010		5000103P01	SPECIAL INSERT	ZMFG	1	4	NR	L	1,000			
....4	0010		M07A006G24C155140	AA 7075 T7351	ZROH	2	0,120	KG	L	0,030			
...3	0020		LN9499-04090	HC L9 TD MJ6X1 MM	ZROH	2	8	NR	L	2,000			
.1	0090		DIN65480-06D	NUT MJ6X1-5.5	ZROH	2	36	NR	L	36,000			
.1	0100		5000084P01	BOTTOM UNION BRACKET	ZALB	1	2	NR	L	2,000			
..2	0010		M07A006A10A154307	7075 T73 SHEET TH5 MM	ZROH	2	0,220	KG	L	0,110			
.1	0110		5000119A01	UPPER CLEAT ASSY	ZMFG	1	32	NR	L	32,000			X
..2	0010		5000076P01	UPPER CLEAT	ZALB	1	32	NR	L	1,000			
...3	0010		M07A006B10C155233	AA 7075 T7351	ZROH	2	5,760	KG	L	0,180			
..2	0020		LN9499-03075	HC L7.5 TD MJ5X0.8 MM	ZROH	2	32	NR	L	1,000			
.1	0120		DIN65209-05M	W COUNT. ID5.2 OD10 T1	ZROH	2	116	NR	L	116,000			
.1	0130		LN29950J0512B	S MJ5X0.8-12-12	ZROH	2	36	NR	L	36,000			
.1	0140		DIN65209-06M	W COUNT. ID6.2 OD12 T1.5	ZROH	2	94	NR	L	94,000			
.1	0150		5000085P01	BUTT STRAP	ZALB	1	4	NR	L	4,000			

Figure 5.6. Bottom Platform Assembly BOM on SAP

It contains components information, such as quantities and units of measure. It also specifies which components have been "Phantomized", as it is shown in the last column of the following figure (e.g. look at Panel Insert Assy part, having number 5000121A01). Finally, a column having as header "Bulk" is used to represent bulk materials, which are to be chosen by the production control unit.
Nevertheless, it is not possible to issue a work order until the part routing is in state "Released". This need requires the construction of the part routing.
Initially, the empty routing file is found on Process Builder thanks to its interface with WAND.

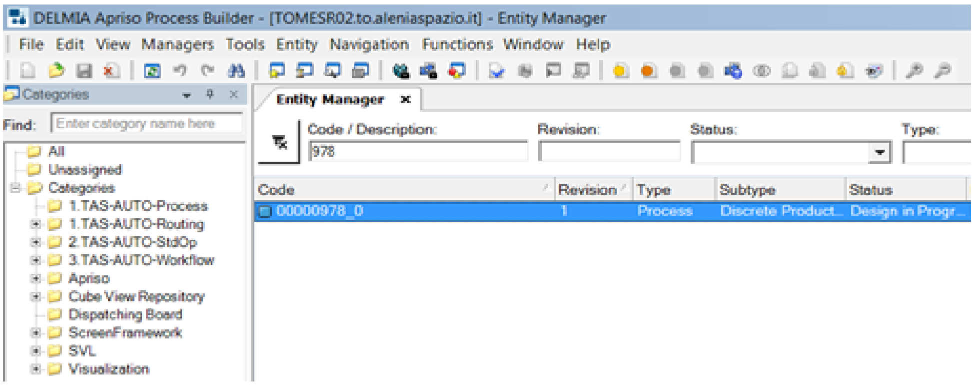


Figure 5.7. Routing to be compiled

Then, it is compiled with operations representing the Bottom Platform Assembly manufacturing cycle. As it is shown in the leftmost list in the figure below, several additional elements are included in the part routing, such as a work center for each operation, skills required to accomplish a specific operation and procedures linked to operations where they are going to be used. Moreover, each operation has one or more steps to which must-have characteristics can be linked.

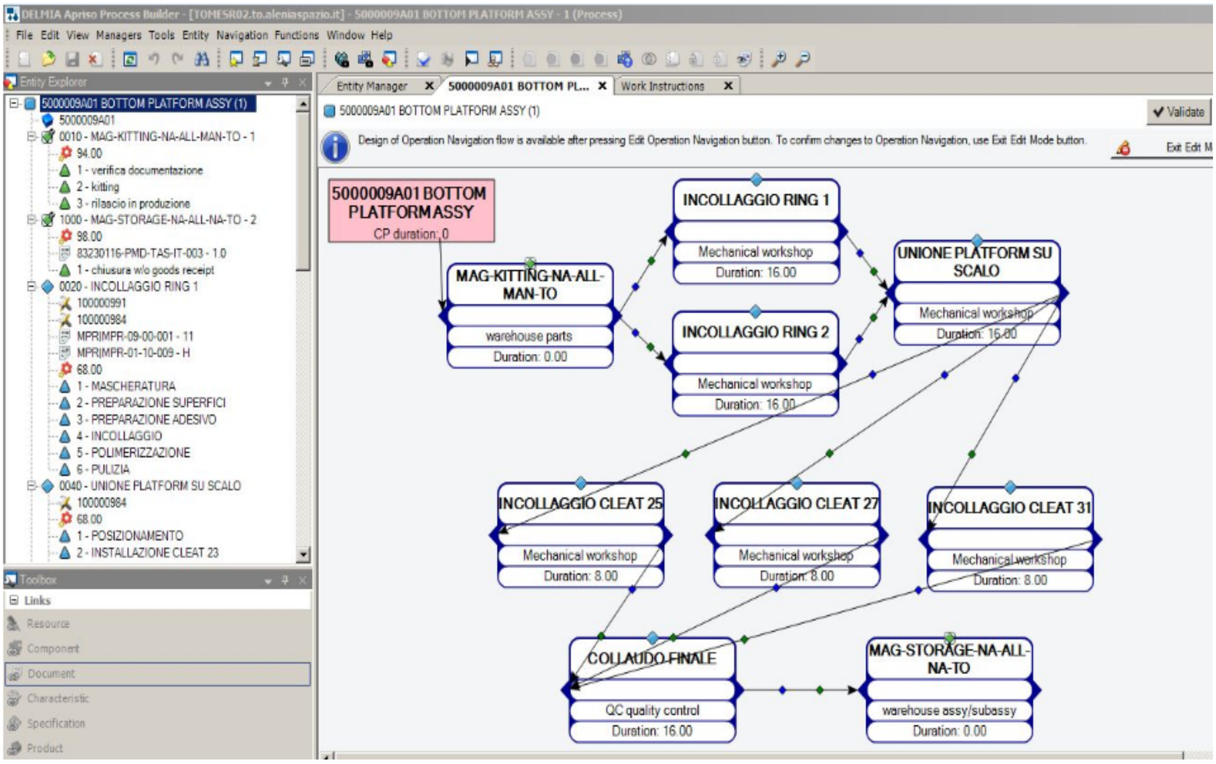


Figure 5.8. Bottom Platform Assembly flowchart

Steps represent the building blocks of the routing, being the technological contents to effectively obtain the Bottom Platform Assembly. Differently from operations, steps can only be executed sequentially.

The steps of the "Unione platform su scalo" operation are displayed below.

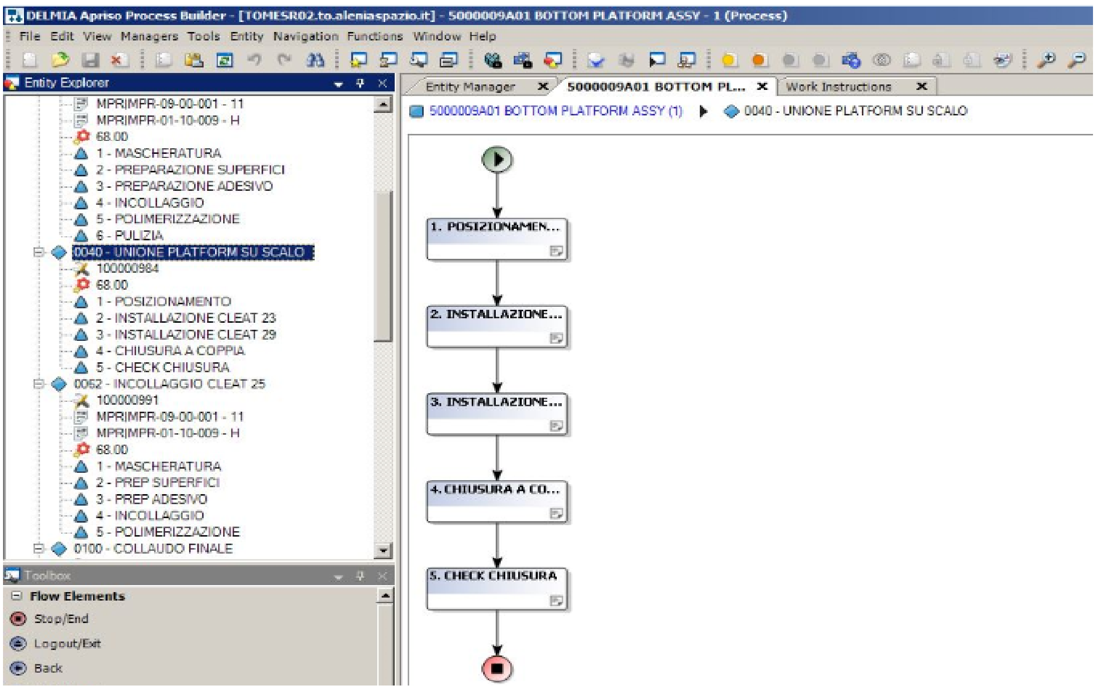


Figure 5.9. Routing operation steps

Once the Bottom Platform Assembly routing has been compiled and validated by the selected checkers, its state is updated to "Active". Then, thanks to the interface between WAND and MES Process Builder, the routing state is updated to "Released" in the part MBOM on WAND and the part work order can be now issued from SAP.

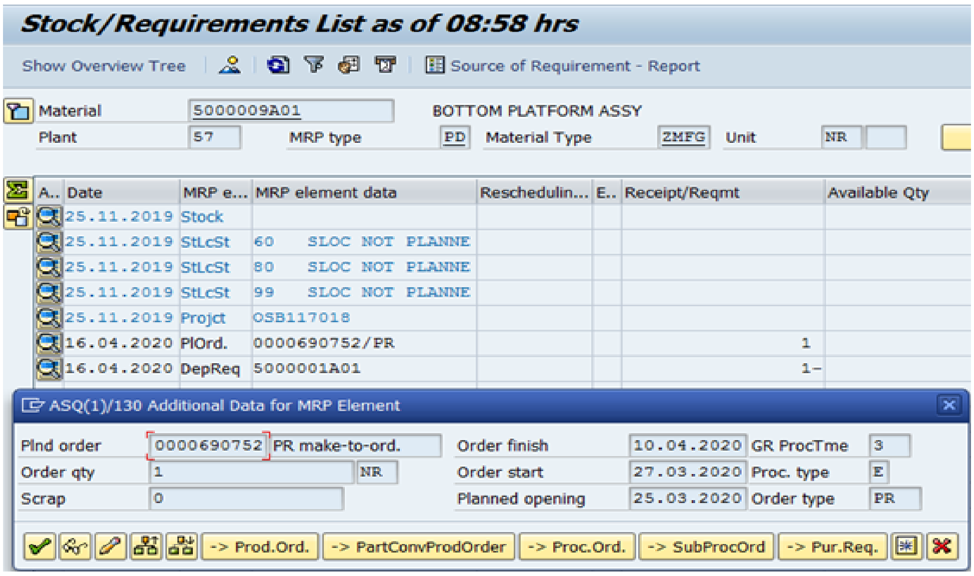


Figure 5.10. Bottom Platform Assembly work order dashboard

The work order is then displayed on MES Execution, where the available operations of the part routing are highlighted in green.

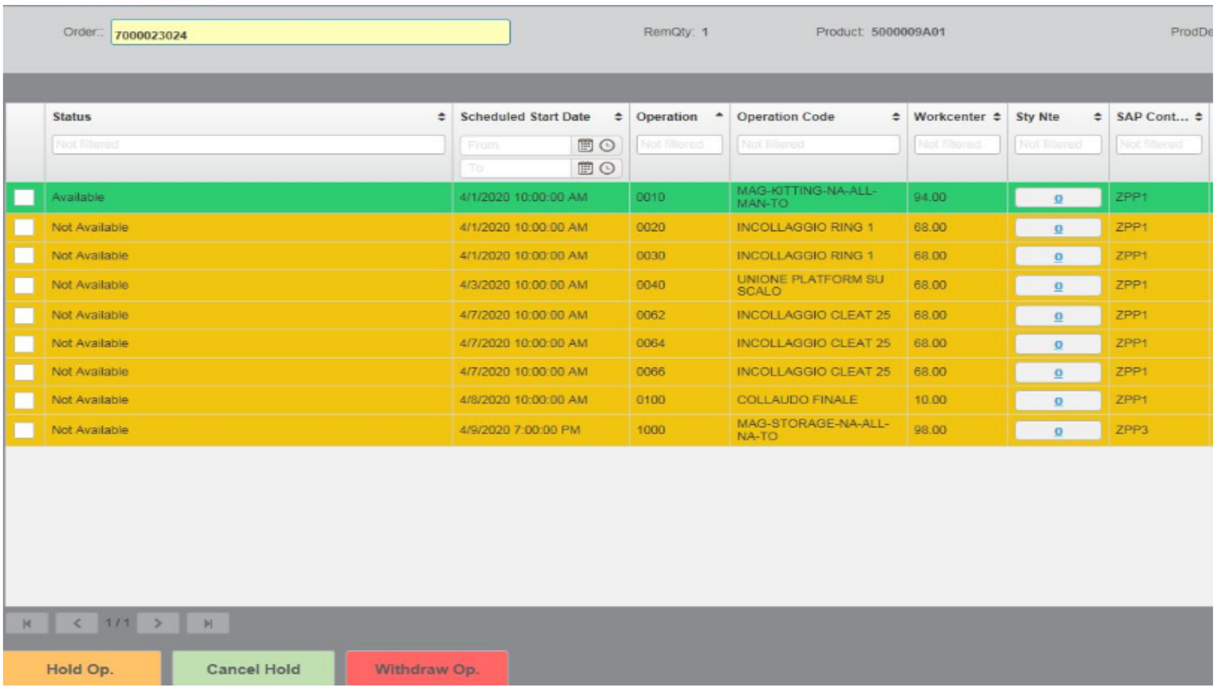


Figure 5.11. Work order operations box

To visualize the MES user interface it is shown a detail of the "chiusura a coppia" step. On the left there is the description of the tasks to be executed, while on the right it is exhibited the planned and actual working time for the "Unione platform su scalo" operation. Moreover, on the bottom right there is the declaration of good or scrap components, which selection is available once the final step of an operation has been performed.

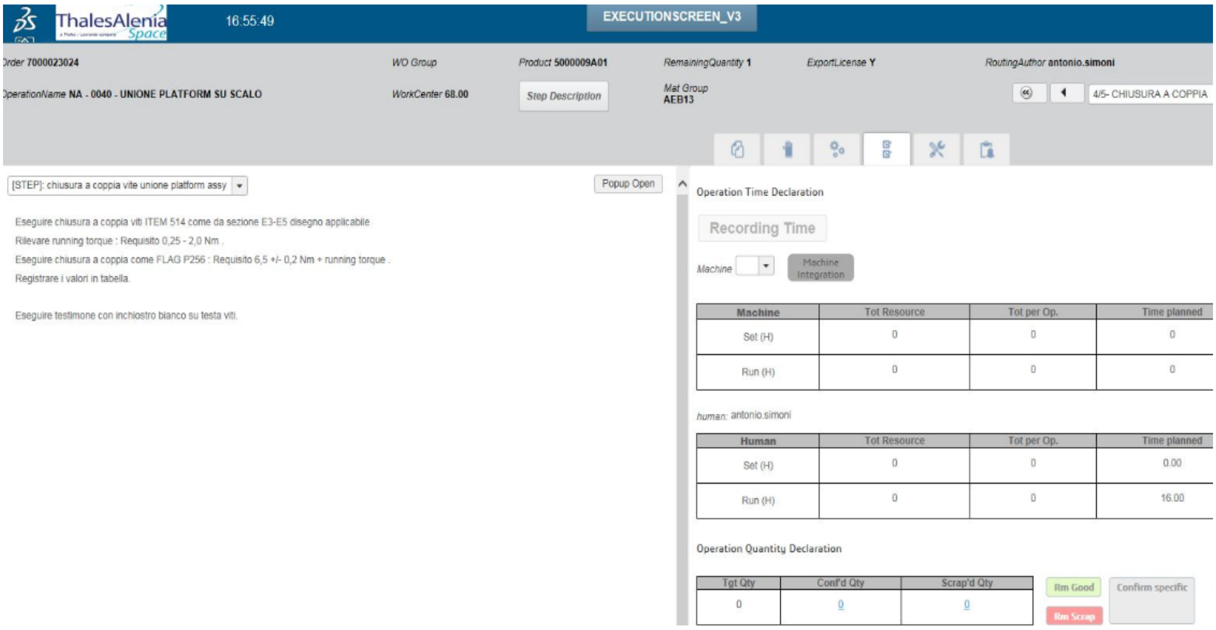


Figure 5.12. User interface for the "Chiusura a coppia" step

To complete the MES Execution analysis, it is also shown the last step of the last routing operation (i.e. "chiusura w/o goods receipt"), which requires the verification of the finished part and its declaration as a good or scrapped one.

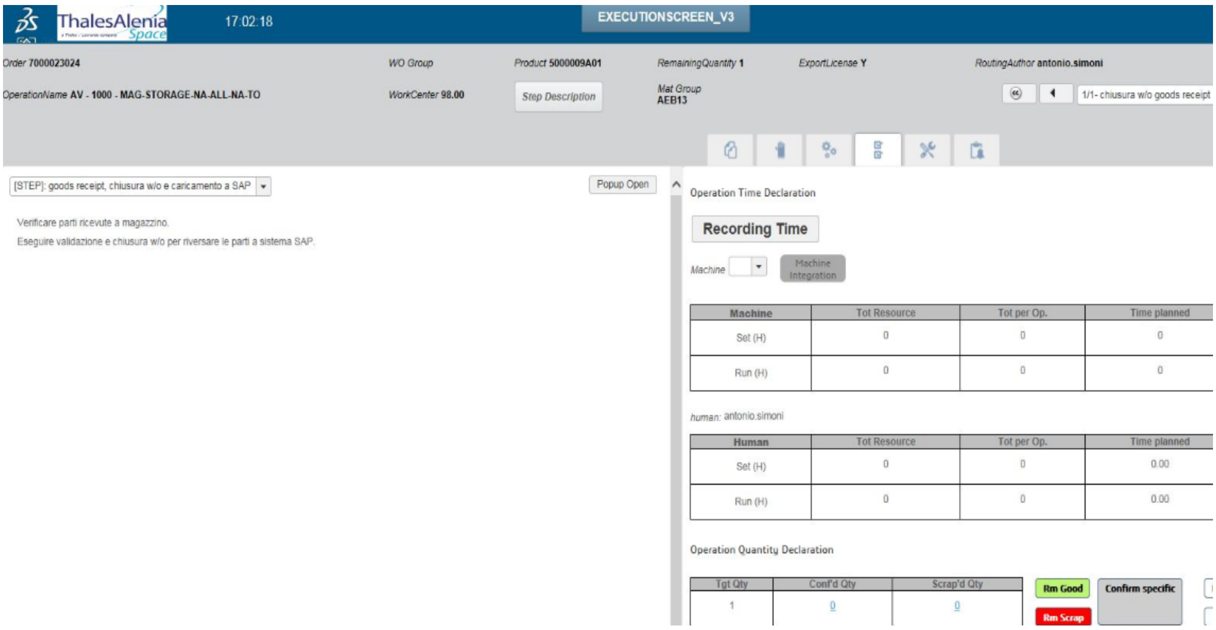
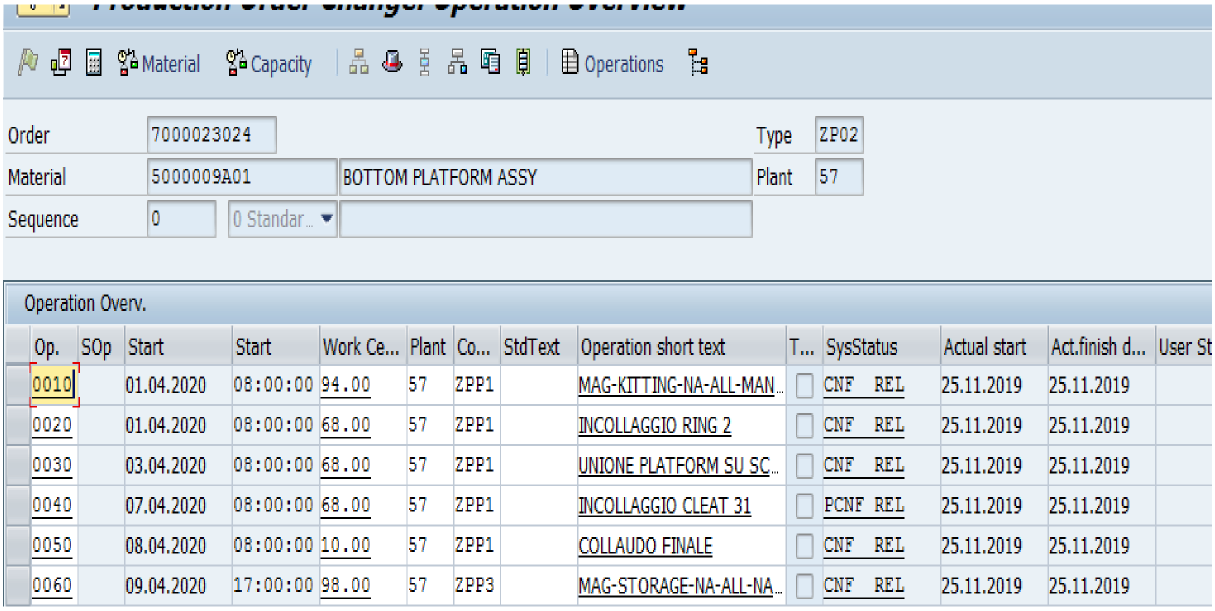


Figure 5.13. Last routing operation

Switching again to SAP, three last exhibits are considered.

The first one is referred to the W/O status, where all operations are listed and classified with their starting and ending times. In this case, being analyzed at the end of the routing, all operations have been performed and they are classified as confirmed.



Op.	SOp	Start	Start	Work Ce...	Plant	Co...	StdText	Operation short text	T...	SysStatus	Actual start	Act.finish d...	User St
0010		01.04.2020	08:00:00	94.00	57	ZPP1		MAG-KITTING-NA-ALL-MAN...		CNF REL	25.11.2019	25.11.2019	
0020		01.04.2020	08:00:00	68.00	57	ZPP1		INCOLLAGGIO RING 2		CNF REL	25.11.2019	25.11.2019	
0030		03.04.2020	08:00:00	68.00	57	ZPP1		UNIONE PLATFORM SU SC...		CNF REL	25.11.2019	25.11.2019	
0040		07.04.2020	08:00:00	68.00	57	ZPP1		INCOLLAGGIO CLEAT 31		PCNF REL	25.11.2019	25.11.2019	
0050		08.04.2020	08:00:00	10.00	57	ZPP1		COLLAUDO FINALE		CNF REL	25.11.2019	25.11.2019	
0060		09.04.2020	17:00:00	98.00	57	ZPP3		MAG-STORAGE-NA-ALL-NA...		CNF REL	25.11.2019	25.11.2019	

Figure 5.14. Work order advancement on SAP

The second one is a dashboard representing the closure of the work order on MES and the automatic generation of a batch number for the Bottom Platform Assembly, which is then used to assign a warehouse location to the part.

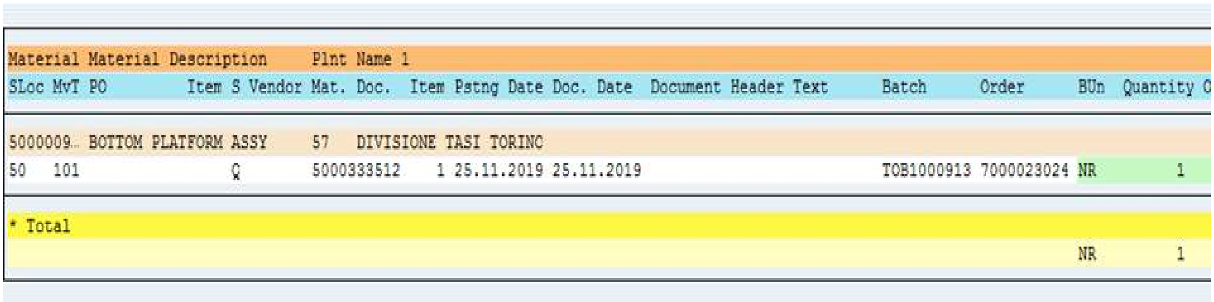


Figure 5.15. Batch number and part storage declaration after work order completion

As it is shown from the previous exhibit in the leftmost side, the storage location is automatically set to 50, which means that the part is left in the production line. To change the storage location, a manually operation is required and is done on SAP by a warehouse operator. In this case, the Bottom Platform Assembly is left on the line and no manual operation has to be done in this regard.

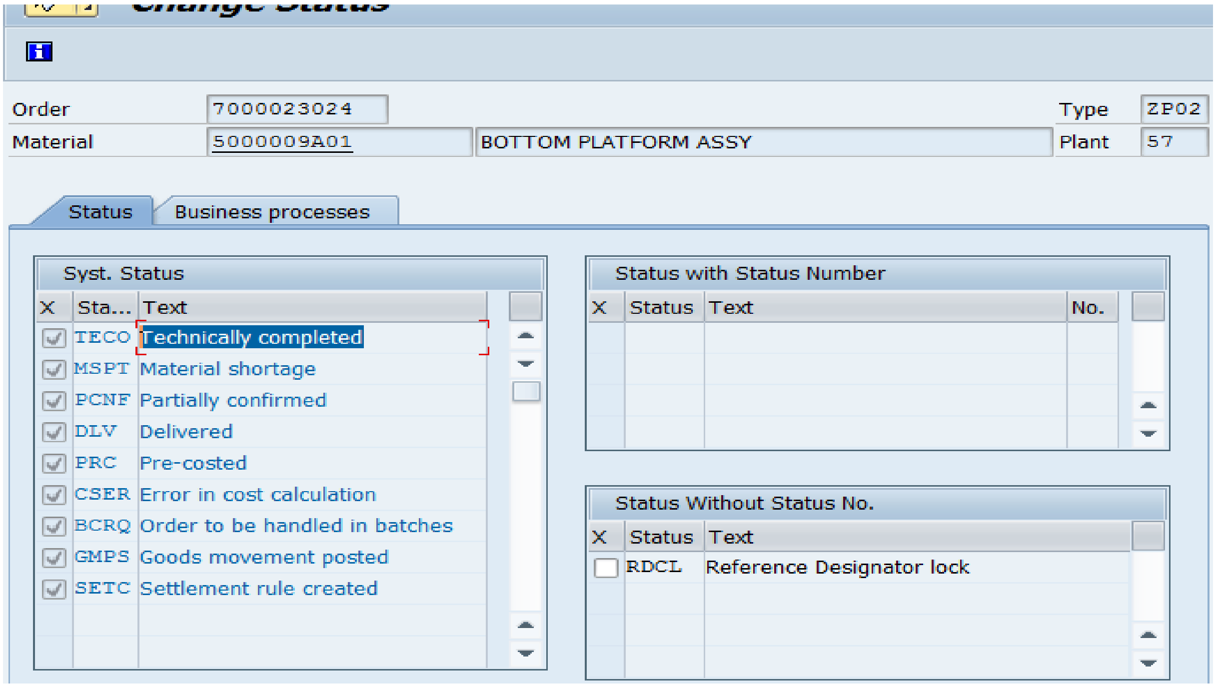


Figure 5.16. Bottom Platform Assembly final status report

Finally, the above screenshot represents the only manual operation throughout the whole information flow. It is the final document reporting the Bottom Platform Assembly status.

Chapter 6

Conclusions

The purpose of this work was to address the Manufacturing Execution System integration into the Information System architecture of a company leader in the aerospace Industry. The idea was to start from the context, outlining Industry 4.0 and other ideas that have given rise to the widespread adoption of this application, and then going into detail explaining pros and cons of the system itself.

Finally, the case study in which I have been involved was described, analyzing the starting Knowledge Management System architecture and the operations required to integrate the Manufacturing Execution System inside it. A visual representation of the information flow for the Bottom Platform Assembly manufacturing process was also included.

A critical issue in the Manufacturing Execution System development has been the need of finding a compromise among different offices requirements, which were usually in conflict both on the system functionality and on the task responsibility allocation.

As a final consideration, it is important to highlight the problem of organisational inertia in the adoption of this new technology.

In fact, people are not prone to change their mindset and way of working because of longstanding routines. This create a barrier to process changes. For this reason, the adoption of the new Manufacturing Execution System has been delayed for months and at the moment only a share of the Company employees (mostly less established and proactive ones) is effectively using it.

The work carried out has been long and time consuming, requiring frequent meetings among different offices and a great cooperation. The Manufacturing Execution System is still under development and additional features will be added during next months, following the evolutionary nature of the software functionality.

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