EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0

The ERP, Enterprise Resource Planning, adapted to the project needs

Piloting the Advanced Manufacturing workshop 4.0

02

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TABLE OF CONTENTS

TABLE OF CONTENTS

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Table of figures

Table of figures

Abstract

EXAM 4.0, defines and describes the main features a lab for Advanced Manufacturing education should have (EXAM4.0 , 2020). It also proposes the technological and competence frameworks for Advanced Manufacturing education in VET (EXAM4.0 Framework, 2020). Based on those descriptions, the so called **EXAM4.0 Collaborative Learning Factory** has been defined to pilot the mentioned frameworks and concepts. A central element to set a CLF are the Labs Management Systems. It is necessary to integrate PLM-MES ERP systems together with Industrial IoT solutions to assure vertical and horizontal integrations.

Enterprise resource planning (ERP) is the integrated management of main business processes, often in real time and mediated by software and technology. ERP is usually referred to as a category of business management software—typically a suite of integrated applications—that an organization can use to collect, store, manage, and interpret data from many business activities (Wikipedia, 2021).

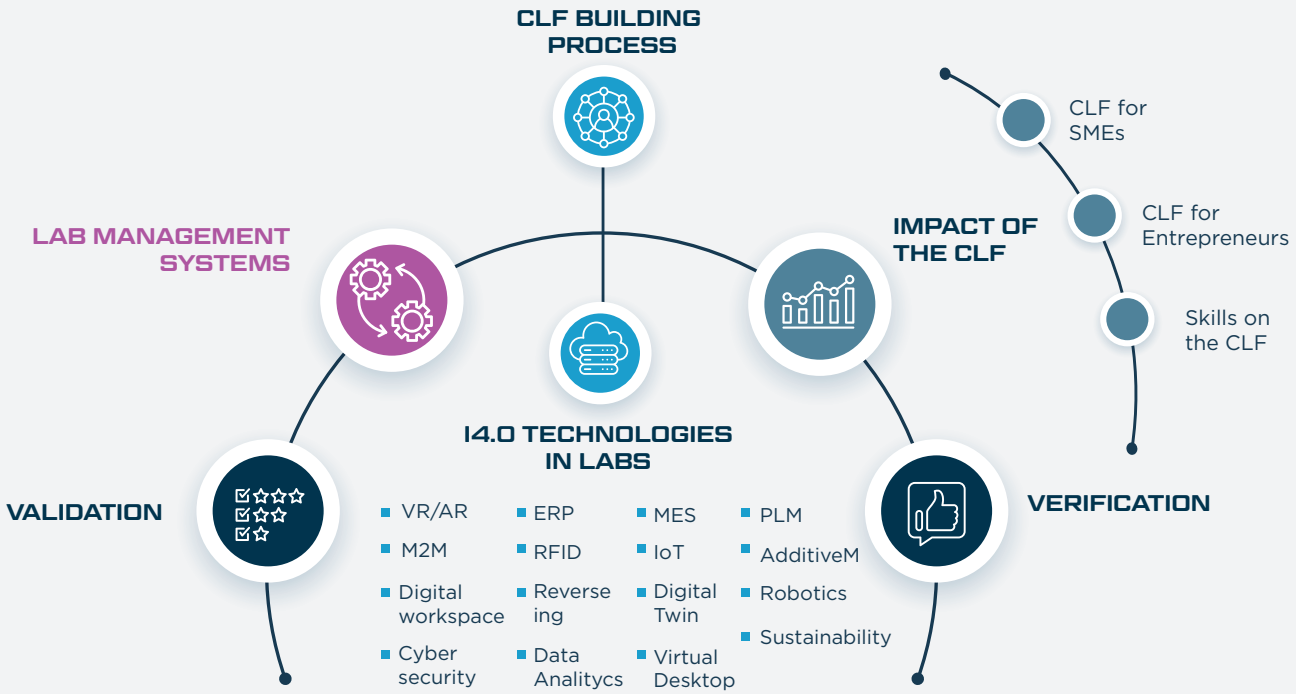
Similarly, it is possible to adopt ERP systems for resource management in VET institutions. If we focus on advanced manufacturing workshops/labs where there are production processes similar to industrial ones (e.g. in learning factories) ERP systems make sense together with other tools such as **Manufacturing Execution Systems (MES) and Project Life Management (PLM) systems.**

This paper describes a potential way of adopting ERP-PLM-MES systems in advanced manufacturing labs. Furthermore, the description is accompanied by three case studies of 3 VET centres in the Basque Country carried out as pilot activities within the EXAM4.0 action plan.

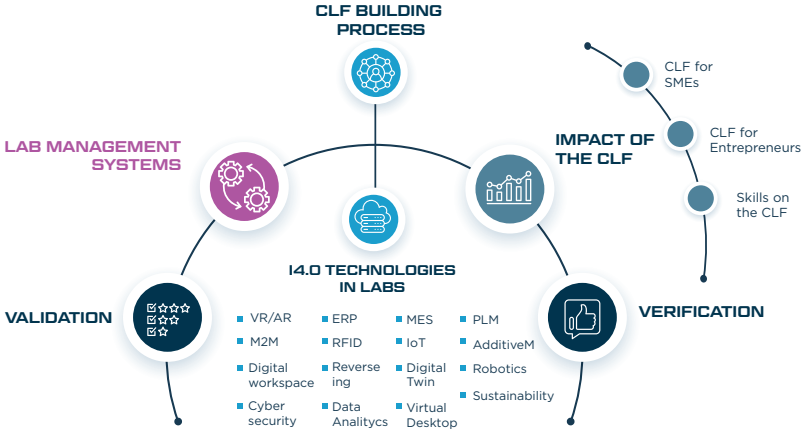
1 Introduction

Following the piloting process of Advanced Manufacturing Labs for HVET/VET through the Collaborative Learning Factory (hereafter CLF), the EXAM4.0 partners have generated a number of reports documenting the work we have carried out. The structure of the piloting process is as follows, where each “ball” refers to a specific report:

Labs for Advanced Manufacturing-CLF



In this report “labs Management Systems”, we describe the management solution we have studied and tested in partner’s labs and in the EXAM4.0 CLF. In an industry 4.0 context, the ERP solutions together with MES and PLM integration has become a central elements. (Capgemini Research Institute, 2019)



1.1. Smart factories

Capgemini Research Institute in his report *Smart factories @ scale. Seizing the trillion-dollar prize through efficiency by design and closed-loop operations from 2019*, brings the following statements:

Beyond labor productivity and asset-efficiency, the next performance leap in factories will be through end-to-end effectiveness of production systems:

- Efficiency by design: virtual design, simulation, and commissioning of factories before entering into physical operations to make processes more efficient throughout their life cycle.
- Effectiveness in operations: leveraging data and advanced analytics to reach "closed-loop" and ultimately self-optimizing operations.
- Deployment at scale: moving from an initial pilot to systematic deployment to realize the full value of smart factories

(...)

Organizations need to confront the next challenge – scaling smart factory initiatives:

- The main issues with achieving scale are challenges with IT-OT convergence and the need to develop "hybrid" capabilities and soft skills.

– *To ensure digital continuity1 and enable collaboration, effective IT-OT convergence will be critical, including digital platform deployment and integration, data readiness, and cybersecurity. Agnostic and secure multilayer architectures will allow a progressive convergence.* ***PLM , MES/SCADA, and robotics remain key components of industrial architectures****. However, the main areas of investment for at-scale deployments are IoT and manufacturing intelligence, which support data-driven operations as well as remote and mobile capabilities. (Capgemini Research Institute, 2019)*

1.2. Management of industrial processes

Manufacturing processes are composed by a number stages that must be coordinated. These stages require the careful coordination of material, resources, and information to make and deliver the product efficiently. (Seubert & Vokey, 2020)

The following is a generic list of the high-level processes within the scope of manufacturing

- Material procurement — When, how much, and from whom
- Material receipt (including incoming inspection) and storage — Frequency of delivery, where to place the delivery once it is in-house, and verification of material quality
- Material and product inventory management — All material movement within the plant
- Production planning and scheduling — When to produce and how much, which includes sequencing the manufacturing processes for the product or subassembly at both the subassembly line level and the final assembly level
- Maintenance and readiness of tooling and conveyance systems — Ongoing maintenance and calibration keeps the tooling and conveyance available when needed
- Training and readiness of operators, supervisors, and other staff — Having both the knowledge to perform the work and the right skills available when they are needed while minimizing cost
- Product quality assurance - When tests should be performed on products or materials to check the product's quality while reducing potential waste if some- thing goes wrong
- Shipping scheduling and coordination — Ensuring the product is shipped with enough time to deliver on time and minimizing shipping costs

The interaction of 3 main elements is essectial to assure the coordination of every single element that takes part on the overall production: ERP-PLM-MES.

2 Functions of ERP, PLM, MES

2.1. ERP

It automates more operational aspects of the business such as purchasing, sales, logistics, accounting, inventory and warehouse control, ordering, payroll, etc. The aim is to optimise business processes by connecting information linked to financial, production, cost or material demand management.

ERP is the set of processes that includes business and capacity planning, scheduling, and customer order management. Accounting and Human Resources are part of these processes because they represent the management of all the resources (people, material, etc.) required to execute manufacturing.

The main functions of ERP that are relevant for manufacturing are the following:

- Capacity management —For every product to be manufactured, there is a defined process. There is also a maximum number of units that can be manufactured in a given time. This will affect both the production order planning and the material procurement planning. The maximum capacity of a manufacturing plant is highly dependent on the number and mix of end products and how they are manufactured.
- Production planning — Adjusting the production plan according to changes in certain variables, including staff is a major part of the production planning process. Planning must also account for changes in the current status of the production environment as changes happen.
- Customer relationship management (CRM) — This function includes processes that ensure the customer is happy and satisfied with the end product. In addition, CRM anticipates the customer's future demand and then recommends changes to the product line accordingly with any details that would affect the manufacturing process.
- Supply chain management (SCM) — These processes ensure all materials, including raw materials and component parts, are delivered to the plant on time and adhere to the expected level of quality.

(Seubert & Vokey, 2020)

2.2. Institutions

A PLM solution administers and manages the complete life cycle of a product. It promotes the complete product digital definition in all its phases, starting with the conceptualization, going through the product design, the design of the manufacturing process, supply, manufacturing, distribution, after-sales (guarantees) and ending at the product end of life. (Ibermatica, 2020)

PLM manages intangible assets of the organisation (intellectual capital) while ERP manages tangible or physical assets.

A PLM must integrate all the software solutions used for each of the previous stages, CAD solutions for design, CAE for analysis, CAM for manufacturing, PDM for product documentation management, ERP systems for production planning and production control or MES systems

Figure 1 Source: Ibermatica

In addition to data and information, a PLM can support all the processes that a company manages:

Design Process	Manufacturing and Purchasing process	
Document management	Projects management	Outsourcing
Requirements management	Offer management	Spare parts management
Knowledge reuse	Vendor management	Technical assistance service
Change Orders (ECOs)	Quality management	Expedition
Concurrent engineering	issues management	Post sale
Etc.	Etc	

(Ibermatica, 2020)

2.2.1. Benefits of a PLM System

Product Life Cycle Management (PLM) is a fundamental enabler in any company that wants to tackle a ***Digital Transformation.***

The Products are increasingly complex and the suppliers are more global and geographically distributed. A PLM drives and ***automates digital processes*** inside and outside these companies, improving communication, collaboration and control of transactions with their providers.

A PLM provides ***flexibility*** for the organization and allows the optimization of the daily activity of each of the phases of the product development. This flexibility increases the capacity for innovation, both in products and in manufacturing processes.

A PLM system will ***improve productivity***, since it facilitates the automation of the management of product data and its integration with other business processes such as ERP for production planning and MES systems for manufacturing execution management

A PLM system ***avoids information*** silos that exist in companies due to the use of specific tools for specific processes not integrated between them. This ability to integrate all the relevant information of a product allows companies to ***make better and more informed decisions.***

(Ibermatica, 2020)

2.2.2. Impact of a PLM system in the Industry 4.0

The Industry 4.0 defines new technologies and manufacturing methods.

Collaborative methods, critical to achieving distributed manufacturing, process integration, and automation, are perfectly modelled in PLM systems.

On the other hand, technologies such as Digital twin or Big Data for data analytics need PLM systems for their support and exploitation. (Ibermatica, 2020)

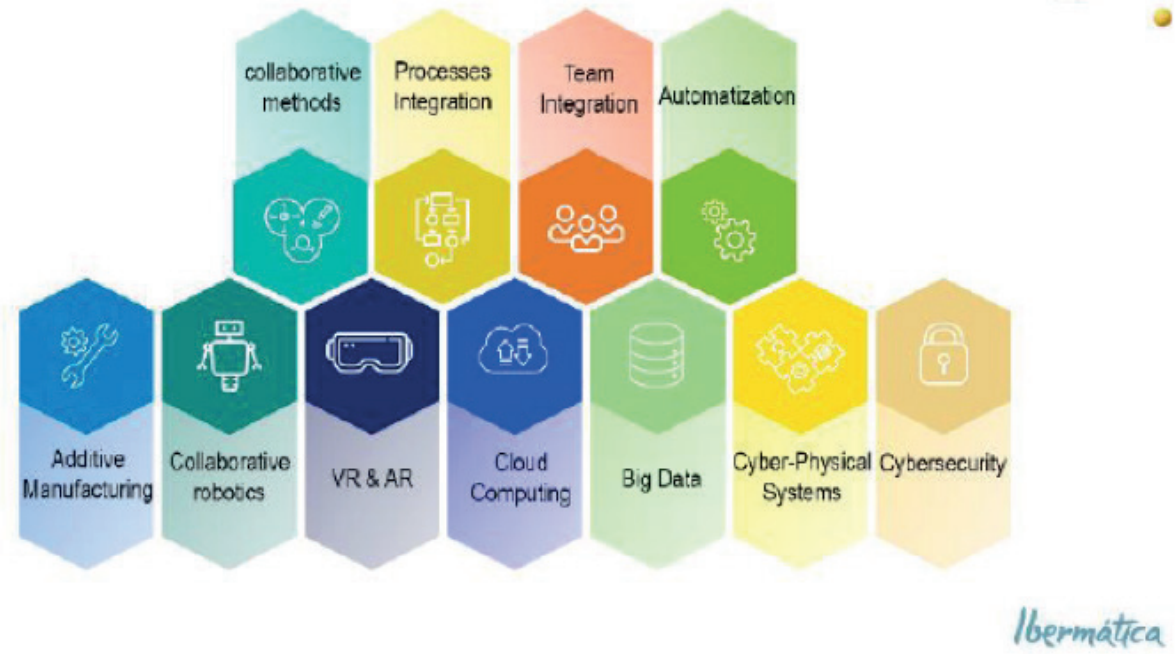


Figure 2: Internet of Things-Industry 4.0 Source: Ibermatica

2.2.3. Contribution of the PLM to EXAM4.0 CLF

Communication and collaboration

The most basic roles of the 3DEXPERIENCE platform provide users with all communication and collaboration capabilities, spaces to share information, and document viewers in the cloud.

In addition, it has tools for the communication of ideas: possibility of making 3D sketches, presentation of ideas, etc.

PLM capabilities

The roles of product life cycle management (PLM) in the cloud, in addition to adding all the communication and collaboration functionalities, add capabilities such as:

- Revisions Management
- Document Management. States of maturity.
- Workflows
- Product structure management (BOMs)
- Management issues
- Engineering changes management
- Projects management
- Task management
- Others

Figure 3: PLM capabilities in a CLF Source: Ibermatica

Engineering

In addition to connectors with most CAD / CAE systems on the market, the 3DEXPERIENCE platform has roles with 3D modelling applications in the cloud. It can also work natively with CATIA and SolidWorks for design and with SIMULIA for simulation in the cloud.

Functions extension

There are many roles within the 3DEXPERIENCE platform that can add functions to the CLF, such as:

- CNC programming
- Digital Twins
- Simulation of manufacturing processes
- Virtual reality, augmented reality
- Others

(Ibermatica, 2020)

2.3. MES /MOM

Also denominated Manufacturing Operations Management (MOM), MES are systems used in production to track and document the transformation of raw materials into finished products. MES works in real time by integrating plants or lines with equipment, controllers, operators to enable control of multiple elements of the production process (e.g. consumption, personnel, machines and support services).

MOM is a holistic solution that provides visibility into manufacturing processes in order to optimise efficiency. MOM consolidates quality management, planning and sequencing, production execution and other processes. (Jara Labrador, 2021)

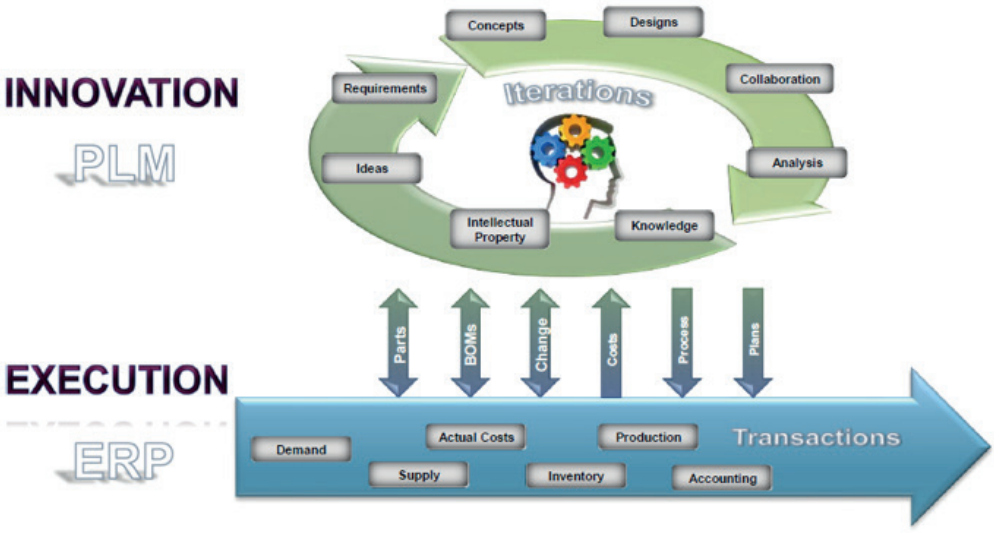


Figure 4: PLM-ERP links Source: siemens

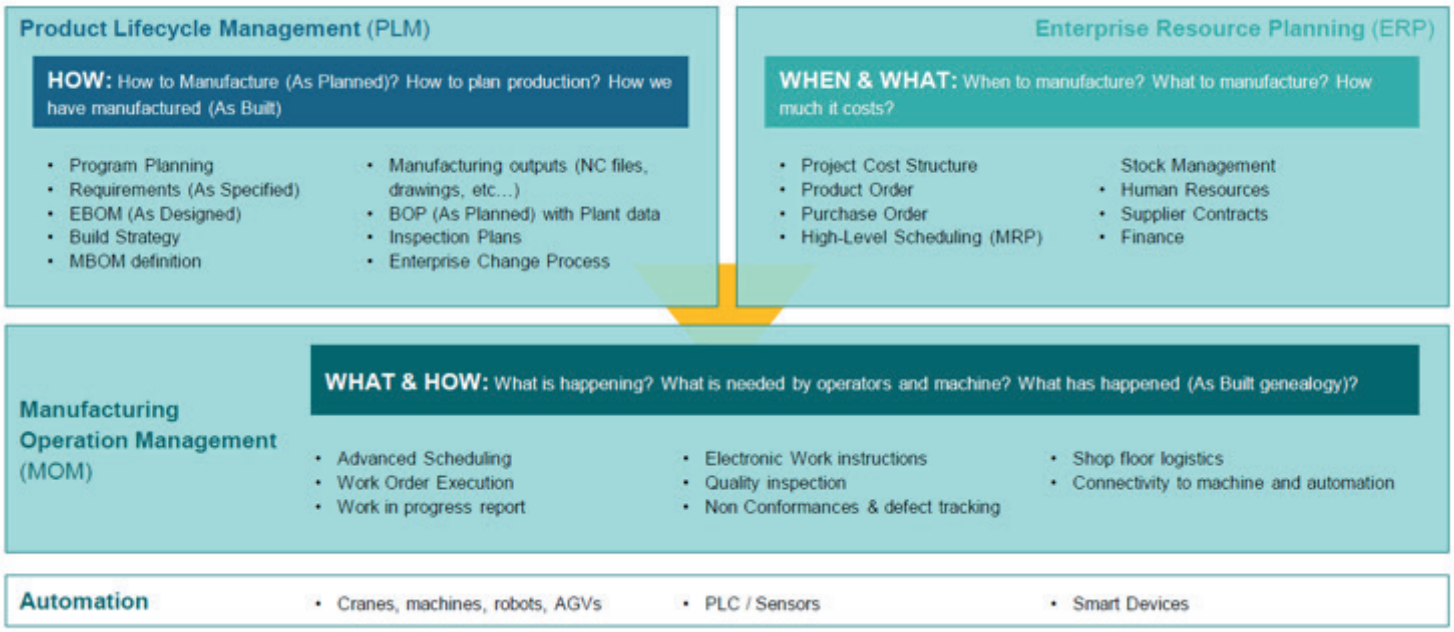


Figure 5: Functions of PLM-ERP MES Source: Siemens/EOI

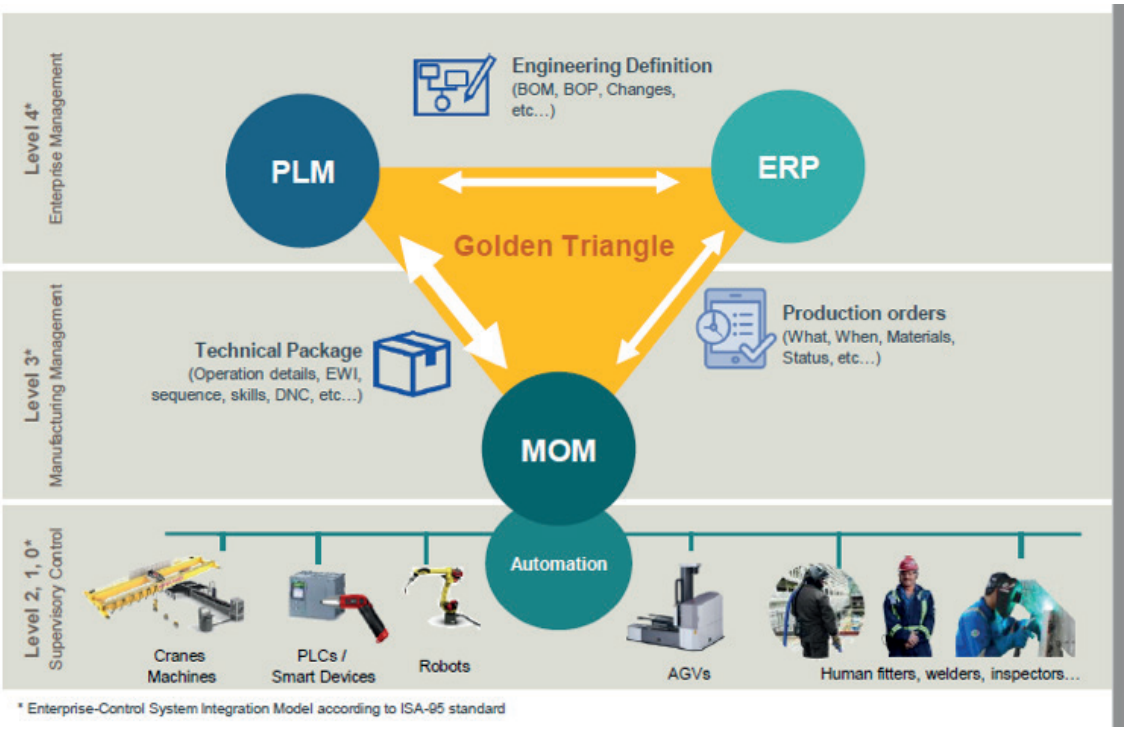


Figure 6: Golden triangle: PLM-ERP-MOM (MES) Source: Siemens/EOI

Several reports describe the central function of PLM-ERP-MES systems in Smart Manufacturing's systems architectures. Independently of the type of manufacturing process used those systems have a central function in those environments. In the following image (Capgemini Research Institute, 2019) we can see the link between engineering- operations and enterprise and how different elements interact.

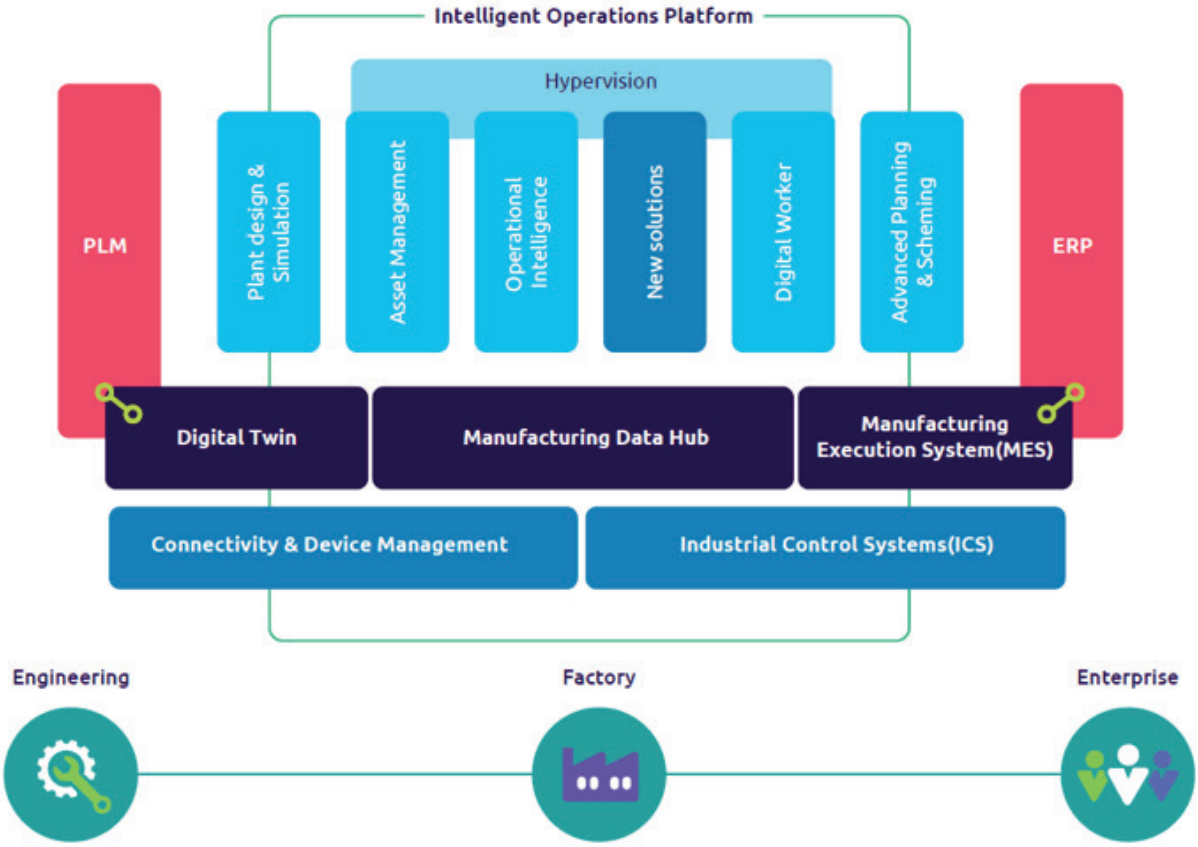


Figure 7: PLM-ERP-MES in Smart Factories Source: Capgemini

In the following image, Smart factory operations leveraging digital technologies are illustrated (Capgemini Research Institute, 2019). Once again, it is interesting to note that at an operational level PLM-MES-ERP systems are the backbone of the approach.

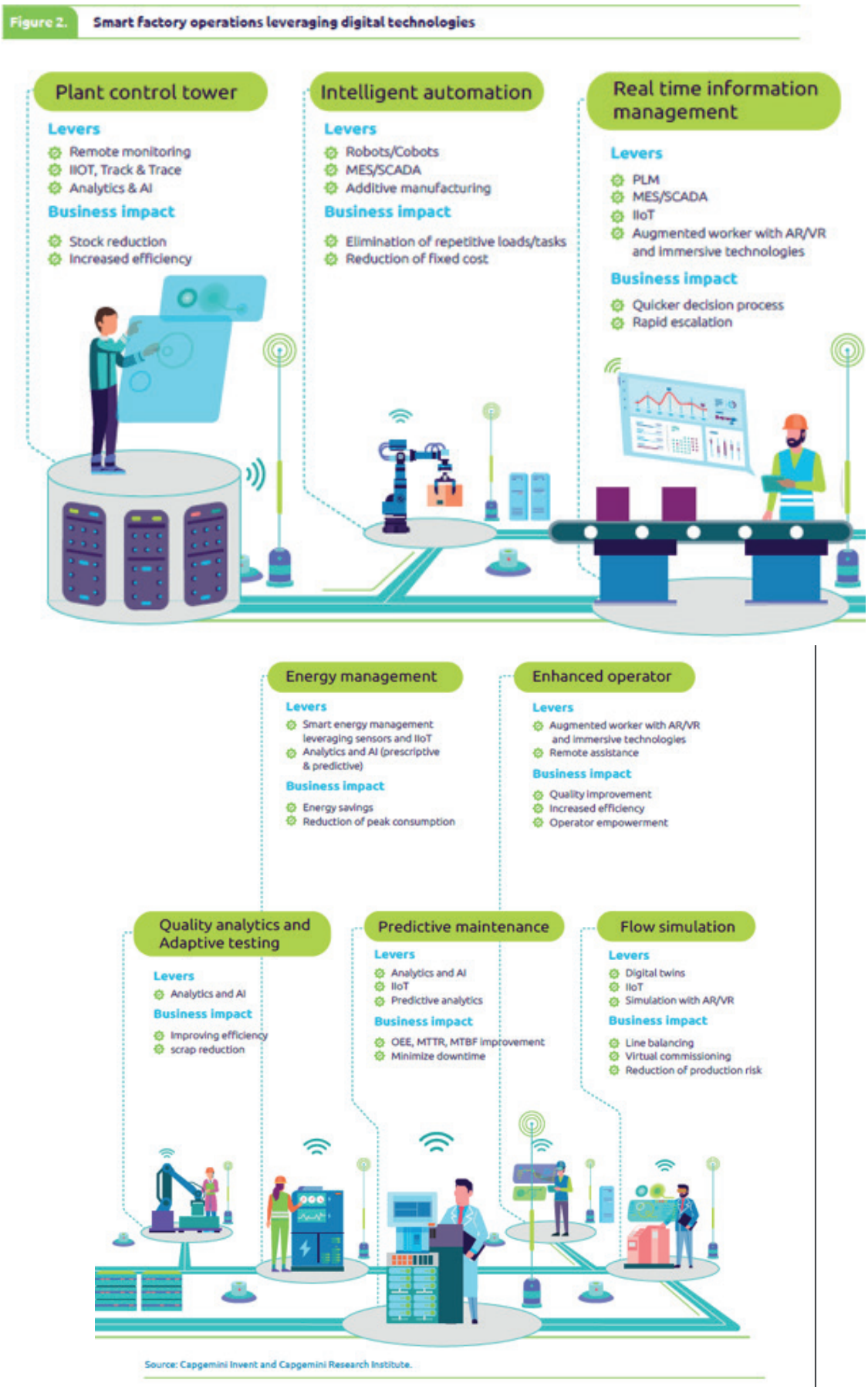


Figure 8: PLM-ERP-MES in Smart Factories Source: ©2019 Capgemini Smart factories@ scale

In the report. IoT in production Big Changes ahead in manufacturing by Roland Berger Gmbh (Roland Berger Gmbh, 2020) there is also an interesting description of the product life cycle management process and the IoT. The image shows at what levels the PLM-ERP-MES interact in the process.

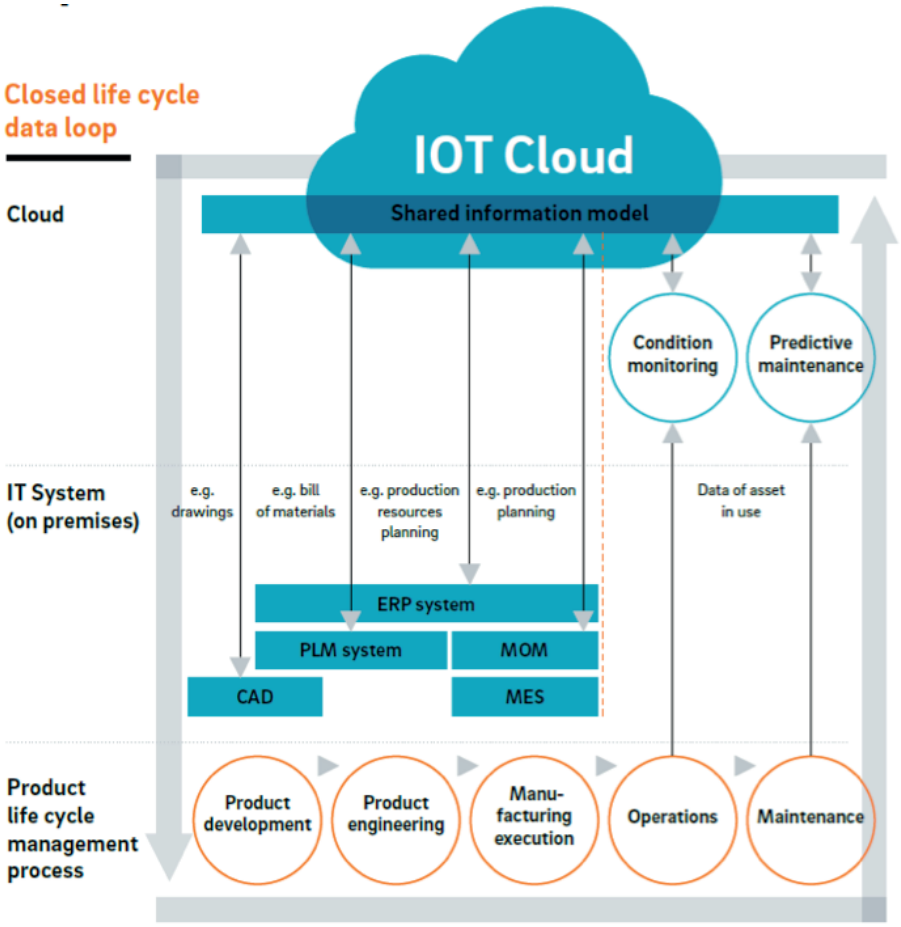


Figure 9: IoT and product life cycle management process Source: Roland Berger

3 ERP-PLM-MES systems in VET's AM labs

The purposes and motivation of integrating ERP-PLM- MES systems in VET infrastructures, labs or workshops are different from those from industry. Indeed, even from an educational perspective in a VET context, we can see ERP-MES-PLM systems for different purposes. The first distinction would be;

a) the ERP-MES-PLM are the target of the learning/training. So it is content based approach where VET centres offer training/courses related to those solutions.

b) ERP-MES-PLM are used as operational tools by learners. It is a context-based approach where VET learners are using the solution as a part of their daily tasks.

In this section, we will show the potential contribution of ERP-MES-PLM solutions in VET for didactical purposes.

3.1. FUNCTIONS OF ERP-PLM-MES system in VET labs

We distinguish two distinctive function for ERP-MES_PLM implementations at VET level:

- **ERP-MES-PLM as a training subject**
  - MES in scale learning factories (FESTO, SMC & others)
  - MES Real size Learning factories

- **ERP-MES-PLM as operational tool in VET**
  - ERP-MES for VET labs management
  - PLM in active methodologies (PBL, CBL and others)
  - ERP-MES-PBL integrated in VET and in Collaborative Learning Factories

3.1.1. ERP-MES-PLM as a training subject

ERP- MES- PLM solutions already exist as a topic or content in many Advanced Manufacturing study programs in many countries. Students get familiarized with the programming and set up of the solutions as they work with other equipment, usually from the mechatronic fields: PLCs, robots, actuators, sensors etc. There are some commercial products, mechatronic modules for automation purposes where MES systems are integrated, (a.e. Festo didactic MES (MES4, 2021):, SMC MES (Ed-MES, 2021) and others. Some ERP and PLM providers also have their educational licences. We need to distinguish between solution providers who are offering their standard products to educational institutions (educational licenses) and solutions developed for didactic uses.

In the last few years solution providers are creating many new advanced didactic equipment, featuring the latest Industry 4.0 technologies integrated on their didactic modules. VET centres have the opportunity to train their students on the technologies with relatively affordable prizes.

We can also find experiences where ERP-MES-PLM solutions are used with didactical purposes in the Learning Factory environment. These physical learning factories can be supported by means of digital factory systems and tools (ERP, MES, etc). Most physical learning factories have some kind of digital systems implemented (Abele, 2019)

3.1.2. ERP-MES-PLM as operational tool in VET

Among the VET institutions studied within the EXAM4.0 project it is not common to find VET/HVET institutions that have integrated ERP-MES-PLM solutions in the functionalities of VET labs (and even organizations) for operational purposes. The motivation to such integration would be to create digitalized environments (labs) where all users, teachers, trainers, students and researchers are obliged to use digital systems and tools for their everyday performances, independently of the study program, task, level etc that they are carrying out in such facilities.

The idea behind this approach is that students will use the same kind of digital tools (ERP-MES-PLM) that they will find in advanced manufacturing companies once they enter the labour market. Besides that, once the VET centres implement the digitalized systems, the students will be able to exploit the data created by themselves to improve their learning performances. The case studies shown in sections 5 to 8 are examples of how to put into practice the approach.

3.2. Piloting ERP-MES-PLM in EXAM4.0

In EXAM4.0 we have defined and described the main features that a lab for Advanced Manufacturing education should have. (EXAM4.0 , 2020). We have also proposed the technological and competence frameworks for advanced manufacturing education in VET (EXAM4.0 Framework, 2020). Relaying on those descriptions, we have defined the so called EXAM4.0 **Collaborative Learning Factory** (EXAM4.0, 2021) in order to pilot the mentioned frameworks and concepts. We have described the piloting process in the document 5.4 Evidence on performance of EXAM4.0 Advanced Manufacturing labs: Recorded data.

The reader will find the definition of EXAM4.0 CLF in the Collaborative Learning Factory approach for VET provision in Advanced Manufacturing (EXAM4.0, 2021) document.

The CLF that is going to be launched has divided its production process into 4 stages (product design, process engineering, production and assembly) as can be seen in the following image. Within these stages, the PLM-MES-ERP systems will have a relevant role to assure the operative of the system. As it is shown in the image the MES could be incorporated in more than one of them, but for now it will intervene in the production part.

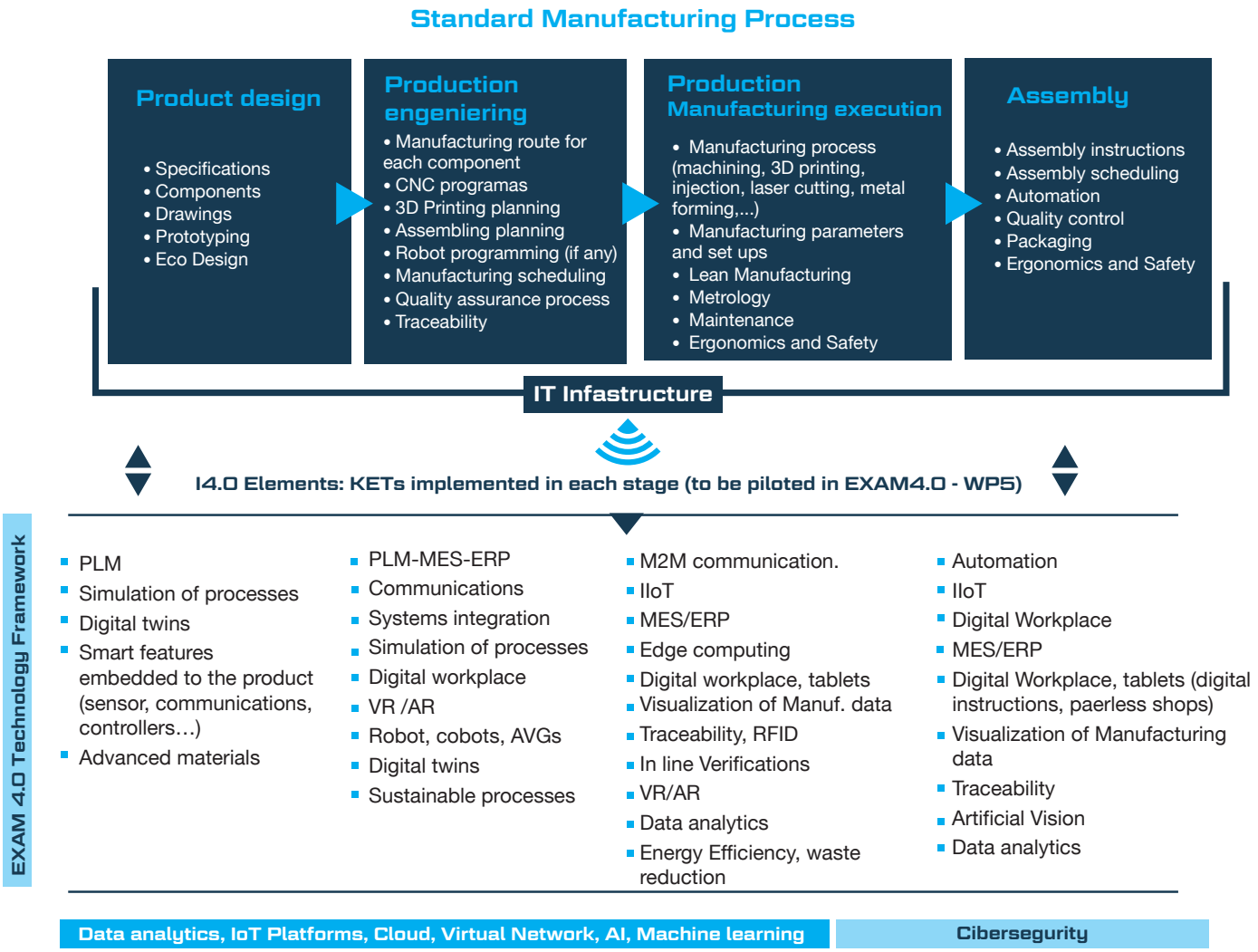


Figure 10: EXAM4.0 CLF's value chain

In the production process of these plates, the following information will be collected:

- User who has reserved the machine.
- Machine reserved hours.
- Machine running/standby hours.
- Drawing and CNC programs that are being used.
- Tools the user is using.

4 USE CASE ERP at BIDASOA VET centre's AM LAB

4.1. Introduction

Enterprise resource planning (ERP) is a process used by companies to manage and integrate the main operational processes of their businesses. Many ERP software applications are important to companies because they help them implement resource planning by integrating all of the processes needed to run their companies with a single system. An ERP software system can also integrate planning, purchasing inventory, sales, marketing, finance, human resources, and more.

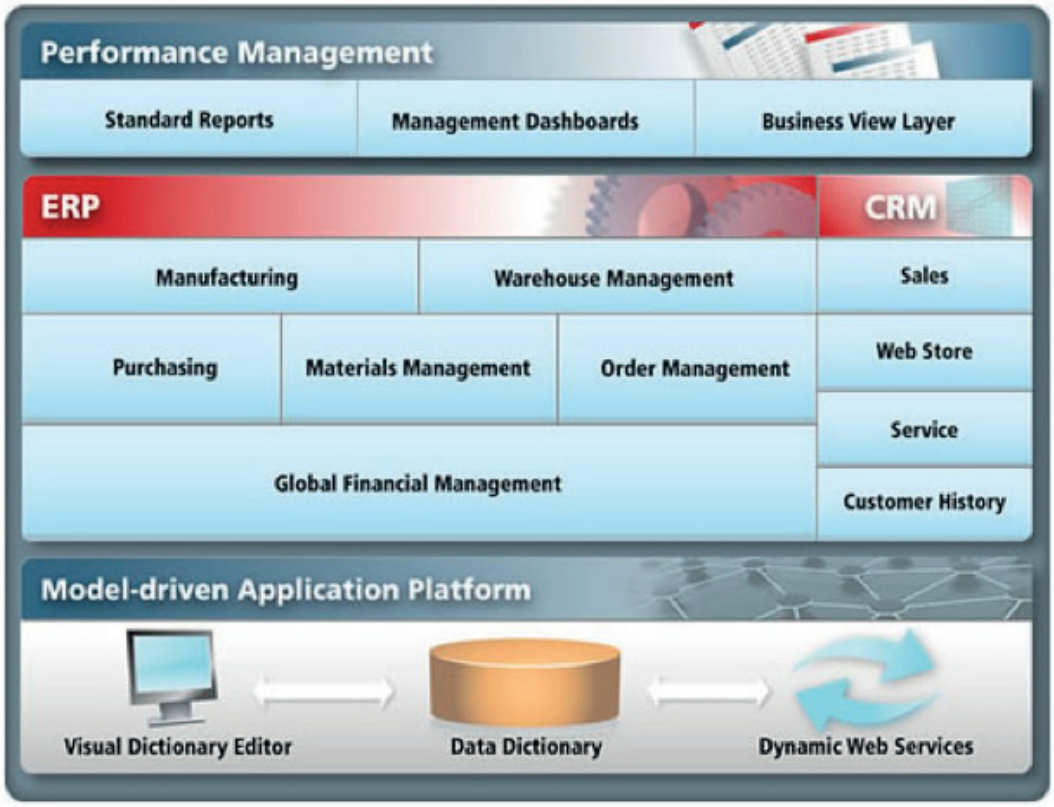


Figure 11: Compiere ERP Source; "SocrateOpen - Highly Adaptable, ERP & CRM Enterprise-Class Applications" by BITSoftware is licensed under CC BY-ND 2.0

ERP provides an integrated and continuously updated view of core business processes using common databases maintained by a database management system. ERP systems track business resources—cash, raw materials, production capacity—and the status of business commitments: orders, purchase orders, and payroll. The applications that make up the system share data across various departments (manufacturing, purchasing, sales, accounting, etc.) that provide the data. ERP facilitates information flow between all business functions and manages connections to outside stakeholders.

4.2. Piloting ERP-MES-PLM in EXAM4.0

At the moment, the ERP is used in the Mechanics department, as a management tool for the department and as an educational tool for the learning of the students of Mechanics.

- Department management: The tool is used in different aspects within the Mechanics department, aiming at centralizing everything.
- Occupation of spaces: the teaching staff can see the occupation of the different spaces used by the department in real time.

In addition, as far as the Mechanics workshop is concerned, it is not only possible to know which group of students is there, but also who is at each machine.

Figure 12: Resources booking schedule Source: author's own creation. CIFP Bidasoa

Stock management and purchasing:

With Odoo we control both the stock of tools and the stock of raw material. This way we know the situation in real time and when we reach the minimum number of materials, the person in charge will contact the distributor to buy what is needed.

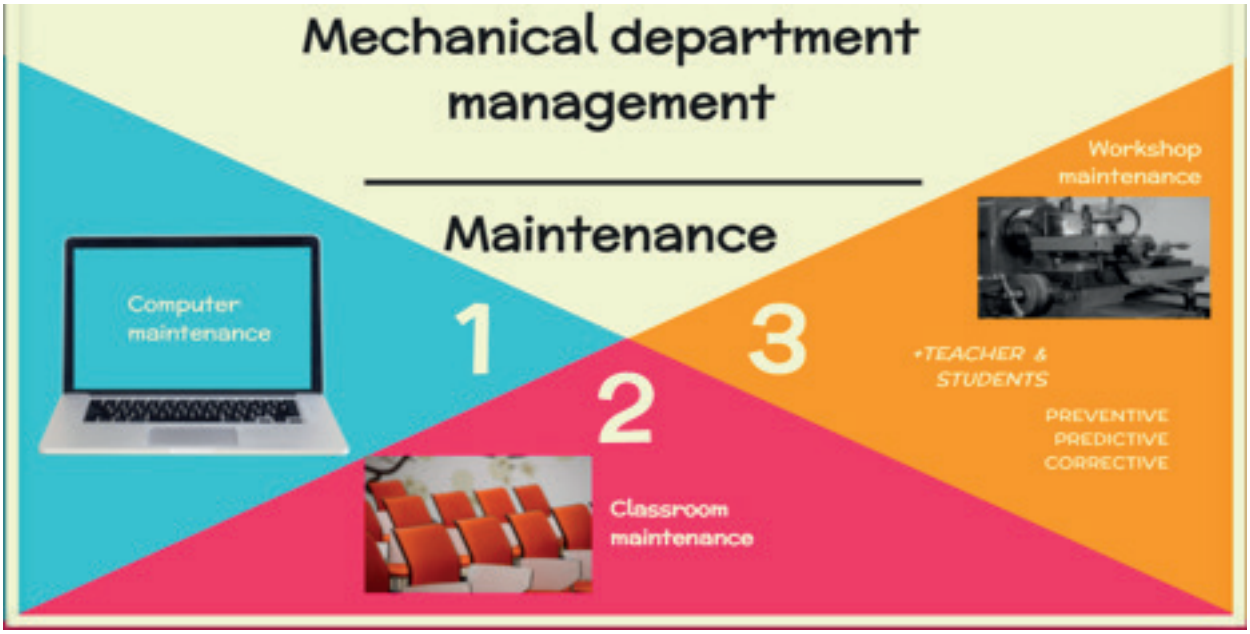


Figure 13: Maintenance types at CIFP Bidasoa. Source: author's own creation. CIFP Bidasoa

Maintenance:

Within the maintenance section we have three types of maintenance:

- IT maintenance: All breakdowns, needs ... that occur in computers, tablets, screens, software ... are managed through Odoo reports. We can follow up from the moment a maintenance action is requested until it is done, who has done it, when it has been done and how much time and money it has cost to carry out this maintenance.

This type of maintenance is aimed at teachers, as part of the work to be carried out in order to train students.

- Classroom maintenance:

In this case, actions were requested to be carried out in their classrooms, for the correct development of the activities.

- Workshop maintenance
  - Preventive
  - Predictive
  - Corrective

Preventive and predictive maintenance are carried out with the students, so that they acquire the necessary knowledge for the development of these skills.

From time to time, students carry out preventive maintenance work on the machines in accordance with the manufacturers' recommendations.

In this case, three tasks are carried out on all the lathes. We can specify how often these actions should be repeated and which group of students will do them.

Corrective maintenance: when machinery or parts break down in the students' training activity.

At that moment, depending on who has detected the need to fix something, there are two possibilities:

1. They fix it, if they have the necessary knowledge, and create a report so that there is a record of what problem the machine has had, how it was solved, what material was needed, the cost of the repair...

2. They make a maintenance report, so that the person in charge fixes it or manages the breakdown, so that when it is solved, there is a record of what problem that machine has had, how it has been solved, what material has been needed, the cost of that repair...

Data exploitation:

The ERP offers a data volume we can analyse and use for the processes improvement, resources optimisation, breakdowns causes for instance.

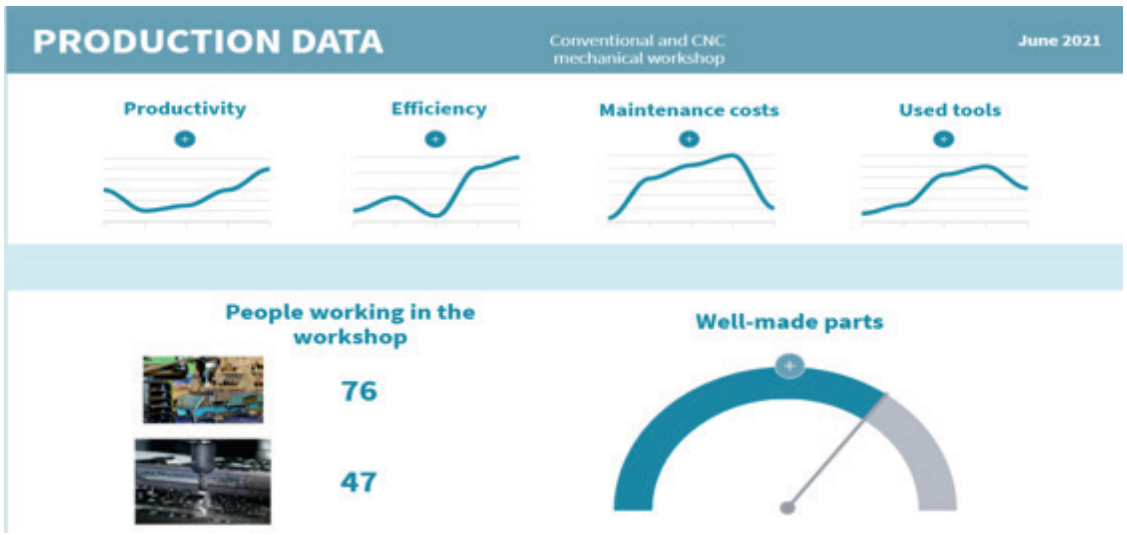


Figure 14: Available data from the ERP system Source: author's own creation. CIFP Bidasoa

4.3. Educational tool for teaching/learning development:

Two models are distinguished within this section, the first is the impact that Odoo ERP has for students in the learning process and the second is how teachers manage the tool to make learning more meaningful.

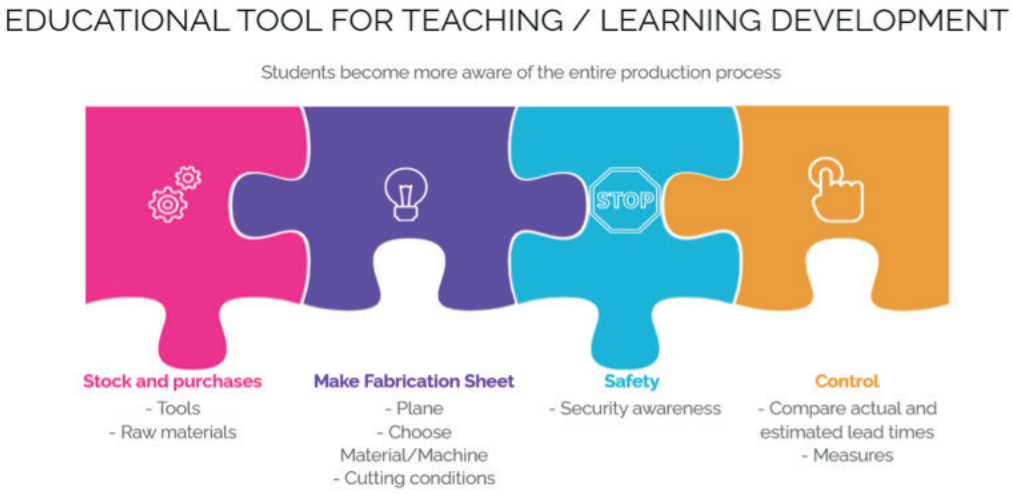


Figure 15: ERP functions at VET labs: Source: author's own creation. CIFP Bidasoa

4.3.1. As students:

Students become more aware of the whole production process. Not only of the machining part of the piece, but they take into account different aspects before they can go to the workshop to make the piece.

A) Before going to the workshop:

- **Stock and purchases:** Students can see in real time what the situation of the warehouse is, if they have the tools and materials necessary or if they need to place a purchase order. Students also participate in the purchase follow up, materials reception and storage.

- **Making a production sheet:** In order to make the manufacturing sheet, students must take into account different aspects of the process:

  - **Choose the machining process:**
    - Conventional
    - CNC

- **Draw up a plan of the part to be manufactured:** Before creating the manufacturing sheet and checking the availability of the materials, the students must create and upload the part plans to Odoo.

- **Machine reservation:** Once they have the right material to manufacture the product, they analyse the state of the machines (breakdowns, occupation...) and reserve the one they need for the day and time they are going to be in the workshop.

- **Selection of the operation to be carried out:** After selecting the machine, Odoo will only propose the operations that can be performed on this machine.

- The operation to be performed is detailed, so that once in the machine you know what to do.

- A sketch or plan will be created explaining the operation to be performed.
    - In the same operation, the time it will take to carry it out must be estimated or calculated.
    - The cutting conditions to carry out the operation, as well as:
    - Cutting speed of the tool.
    - Depth of the pass
    - Feed rate per tooth
    - Number of passes
    - Length to be machined
    - Start/end diameter
    - The tools required for this operation
    - How this workpiece is to be clamped
    - With which instrument this operation is to be controlled:
    - What measurement is to be checked.

- **Control sheet:** To end the process, the control sheet must be created so the measurements can be checked once the part is finished, in order to consider the manufacturing of the part as well performed. In this sheet you must take into account the process, the tolerances... to define the control sheet.

In this way they analyse better and are more aware of the process.
Once they have finished the manufacturing sheet, they send it to be corrected, so that the teachers can approve it before it goes to the workshop.

B) In the workshop:

The students place their tablets in the machine previously reserved, and must fill in what is requested by the ERP.

- Raw material to manufacture
- Personal protective equipment

Once they have these elements, they start working, and Odoo starts to count the time needed operation by operation, so that when the student finishes one, he/she must enter this information in the system, whether it is the measurements achieved or the change of operation.

If during the operation there has been something that has stopped the production, the cause of this must be indicated.

As mentioned in the section on department management, in the workshop the students are also an active part of maintenance.

C) Once production has finished

The students have to fill in the control sheet.

Depending on the type of measurements and the instruments needed, students will have to use either the workshop or the metrology laboratory where different measuring instruments are available, so they will have to choose the appropriate one for this task.

- Time comparison:

Once the part is finished, Odoo gives us the real time used for the manufacturing of the part, which can be compared with the estimate of the manufacturing sheet.

In the same way that the real manufacturing time is obtained, the machine tool and working times can be calculated in order to determine the total actual cost of the manufactured part.

4.3.2. Teacher's role:

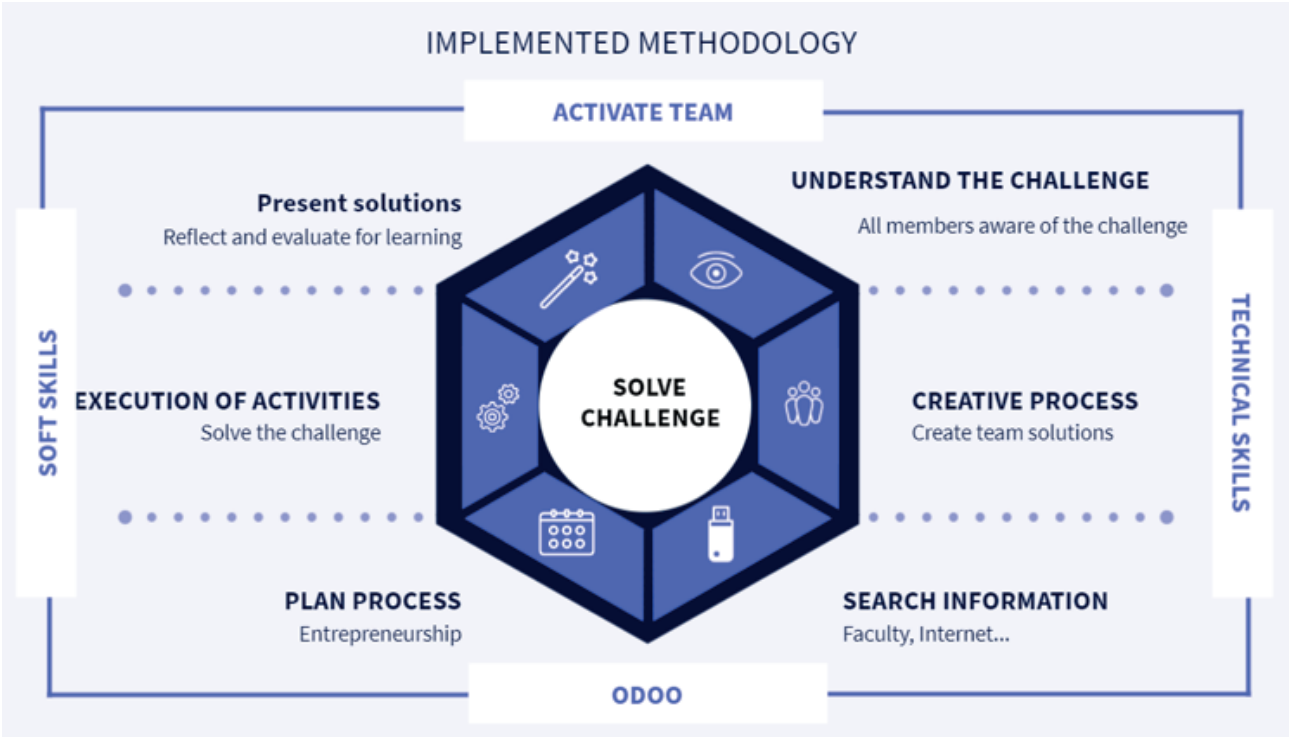


Figure 16: ERP integration in VET provisio methodologies.
Source: author's own creation. CIFP Bidasoa

At **CIFP BIDASOA** we work with the **ETHAZI** methodology, (challenge based learning methodology) and we use Odoo ERP as a platform for the challenges development.

Teachers create a structure based on challenges so that students can develop the learning process.

The **ERP** gives them the option of planning their work, to organise themselves better and solve the challenge on the scheduled time. In addition to planning, they can have a list of activities and classify them according to their status, pending, in-process, or done.

Within this framework of challenges, **cross-cutting and technical competences** are distinguished, which we can also classify within the ERP. Therefore, as they progress in the challenge or complete it, we will be grading the competences acquired. This methodology is based on collaborative work, which is why students are divided into groups. In Odoo they work collaboratively so that they create their project, their planning, their manufacturing sheets...

Once the manufacturing sheet has been created, any member of the team can access it in the workshop, no matter who has worked on it in class.

- Acceptance of the Manufacturing Sheet

Once the students have finished the manufacturing sheet, they send it to be validated by the teaching staff, who, after correcting it, may accept it or reject it. If it is accepted, a manufacturing order is created and the workshop can be accessed. If it is not accepted, the workshop cannot be accessed and must be modified.

- Control of the manufacturing process

The teachers can see in real time the situation of the workshop. Which machine is occupied by which student, which operation is being carried out by each student, the productivity of that student, the cause of the stops they are carrying out, whether they are really following the pre-established steps...

4.3.3. Pedagogical implications of the use of ERP-MES-PLM systems in VET labs Competences/Skill addressed with ERP

The competencies acquired with Odoo ERP can be classified into two groups: Technical and transversal competences.

A) Technical competences:

These competences are the ones that are most closely related to the technical content to be acquired in the learning process of the students, in our case Machining Technicians, Production Programming Staff and Industrial Design.

- **Machining Technicians:**
  - Greater awareness of the production process, from raw materials to part verification.
  - More detailed manufacturing sheet: having to enter more information about the manufacturing process means thinking about how to do it, why?
  - Cost of the work: to be aware that from the moment they start working until they finish their day, time is an important factor, whether it is machine time, worker time, material time, tool time, etc.
  - Production scheduling
  - Production scheduling option.
  - Status of the warehouse, tools
  - Management of raw material orders.
  - Relationship with different suppliers.
  - Data analysis
  - Analysis of causes
  - Improvements to be made in the production process.
  - Calculation of costs and time.

B) Transversal competences that are worked with Odoo-ERP.

- **Teamwork:**
  - Collaborative tool, team members can plan their work and all have access to production sheets, control sheets....

- **Digital:**
  - Understand the data obtained, manage it, draw conclusions.
  - Get used to virtual working environments, due to the type of students we have they are not very used to it.
- **Personal:**
  - Autonomy, initiative, critical spirit, to be aware of the importance of good planning and to see how the decisions taken in the process affect them.
  - Also once the process is finished, after analysing the data obtained, to be able to draw conclusions that help us to improve.
- **Communication:**
  - Communication between different people, the one who plans the production with the one who executes.
  - Being aware of the importance of the different explanations (both verbal and written) that are given within the production process and that can help to achieve a better result.

4.4. Collaboration opportunities (among partners) that brings the use of ERPs (together with other tools such as PLM,MES, Cloud, IoT, DTs..)

The Collaborative Learning Factory concept has given us the opportunity to get to know different schools, companies, students and ways of working.

Thanks to this concept, we have created a network in which different groups try to find a solution to a problem or challenge.

In our case, Odoo ERP is giving us the space to collaborate with different educational centres, so that we are solving problems and taking advantage of the opportunities it offers us.

At school, we have detected the need to sensorise the machines so that the process is more controlled (the machine does not start if it is not certified that the students are wearing the safety elements) and more data is obtained, which will help us to make decisions that improve the students' learning process. To this end, we are already analysing the possibility of involving other cycles of the centre to collaborate in this task.

Furthermore, when presenting our new learning model in companies, it has been very well accepted, as companies see that students obtain a global vision of the production process, which they can then transfer for the benefit of the companies.

4.5. The response of students, teachers

Students have widely accepted the use of Oddo-ERP. They have a better understanding of the whole process. In this way they see the logic of the different modules they are taught and do not see them out of context.

In addition, the fact that they have a tablet on the machine to help them visualise the process motivates them, as they are familiar with this type of device. It helps them understand what they have to do and within the ERP itself, they can carry out all the steps necessary to perform the different tasks.

The teaching staff is being more reluctant to change, as they have to learn how to handle the software, they have to manage the electronic devices, teach the students, make them aware of the importance of all the steps... and so far, we have not achieved the necessary involvement.

However, teachers who use it are happy, because they see that the pupils acquire another perspective, which they did not have until now. Moreover, other competences are involved, making the process more enriching.

4.6. Obstacles and Foreseen Risks

The need for new machinery that facilitates the collection of data and automatically makes the process safer and easier for everyone. The machines we currently have in the centre are quite old, and the process of automating them is difficult and costly.

Personal and material resources, which make the warehouse a place in continuous renovation (broken tools, tools out of place...), orders of material and necessary tools.

Personnel involved with order and cleanliness required and with the continuous renewal of the ERP, as it has to be fed and renewed as the situation of the workshop changes.

Untrained staff in new technologies but with a desire to be trained.

4.7. Next steps foreseen

Transfer and training day for the teaching staff of the Mechanics department, with the aim of achieving greater involvement on the part of the teaching staff and greater use of the ERP as an educational tool in the 21/22 academic year.

Acquisition of new machines to facilitate the process.

Use of ERP Odoo, by all the teaching staff, as a management tool for the Mechanics department, so that all the movements and tasks carried out are recorded and generate data that can be analysed.

5 USE CASE IMH's LAB MES in Labs digitalization

5.1. Definition and application of "ERIS" MES in industry

A MES system (Manufacturing Execution System) is an advanced system that allows to manage in a comprehensive way the production processes in the plant, controlling in real time the status of production and measuring the productivity of the plant and its overall efficiency.

In the CIFP IMH LHII we are in the process of integrating a MES called "ERIS" that will allow optimizing production processes, saving economic costs, improving the conditions of the people who operate the machine, making all the information on the machines available to them, at any time and from any device.

It is a machine tool monitoring system with numerical control in the plant and a service system for the manufacturing processes, offering information of high added value during and after them.

This platform is an interconnected and feedback data system (machine-CNC-APP) without the need for an added PLC, capturing data directly from the CNC, to know what is being manufactured, how, by whom and in how long the entire process will finish. All this with notifications of incidents to any mobile device.

All this allows the increase of the plant OEE, offering:

- Monitoring of plant machines in real time.
- Control of indicators through an HMI, RPM, consumption, Tª, X, Y, Z, ...
- Machine statuses and incidents (Execution, Preparation, Maintenance, Shutdown and Alarm).
- Notices of alarms of the machine and forecast of incidents due to excess time without response.
- Representation of the timeline by machine, as well as the necessary tools.
- Estimated times of the CAM, estimated by a predictive algorithm and real of all the processes.
- Viewer of estimated completion times updated in real time according to the development of the process.
- Analytical and predictive system to calculate execution times for each machine.

- Visualization of the data obtained in a graphic, simple and interactive way.
- Project management with the possibility of importing projects from CAD, CAM and ERP.
- Visual and interactive Task Planner for Projects and Manufacturing Orders.
- Control of tools and their situation.
- Monitoring and control of machine maintenance (corrective, preventive and predictive).
- Business Intelligence with all the information obtained for decision-making, OEE, technical indicators, quality indicators, ...

5.2. Apps of MES:

1.- Monitoring and data capture of all machines, in real time and directly from the CNC, avoiding human errors during data collection to obtain accurate and reliable data without the need for intermediate devices such as PLCs.

Figure 17: monitoring of machine data
Source: https://www.zitu.net/es/soluciones/eris

- Accurate and real-time data, displayed graphically, easily and interactively. At a single glance, you can analyze the status of your machines, incidents and alarms, estimated completion time, manufacturing orders in execution, etc.

Figure 18: montitoting of the production data from each machine
Source: https://www.zitu.net/es/soluciones/eris

2.- Weekly / monthly / annual summaries to consult the weekly, monthly, annual performance of each machine in a graphic, visual and interactive way. The status of the machine, the time the machine has been in each status, the OEE of the machine, alarms and the reasons for losses during production, etc. are displayed on a timeline.

3.- Assignment control to identify at a glance unjustified stops by both machine and operator. Thus, the operator may be required to justify the stops without justification. In this way, knowing the reasons for the losses, corrective actions can be taken and future stops derived from the identified reasons can be prevented.

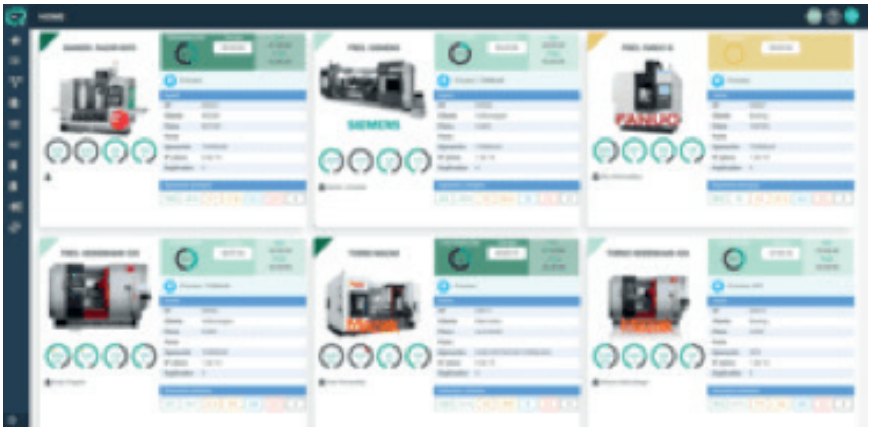


Figure 19: Production scheduling Source: https://www.zitu.net/es/soluciones/eris

4.- Data analytics to translate the large volumes of your organization's data into useful information, unifying MES and ERP analyzes, connecting machine data with company management data on a single platform. They can be compared and related, making the most of their potential, obtaining a global and reliable vision of the organization, presenting the results visually through graphs, making them available to managers and workers.

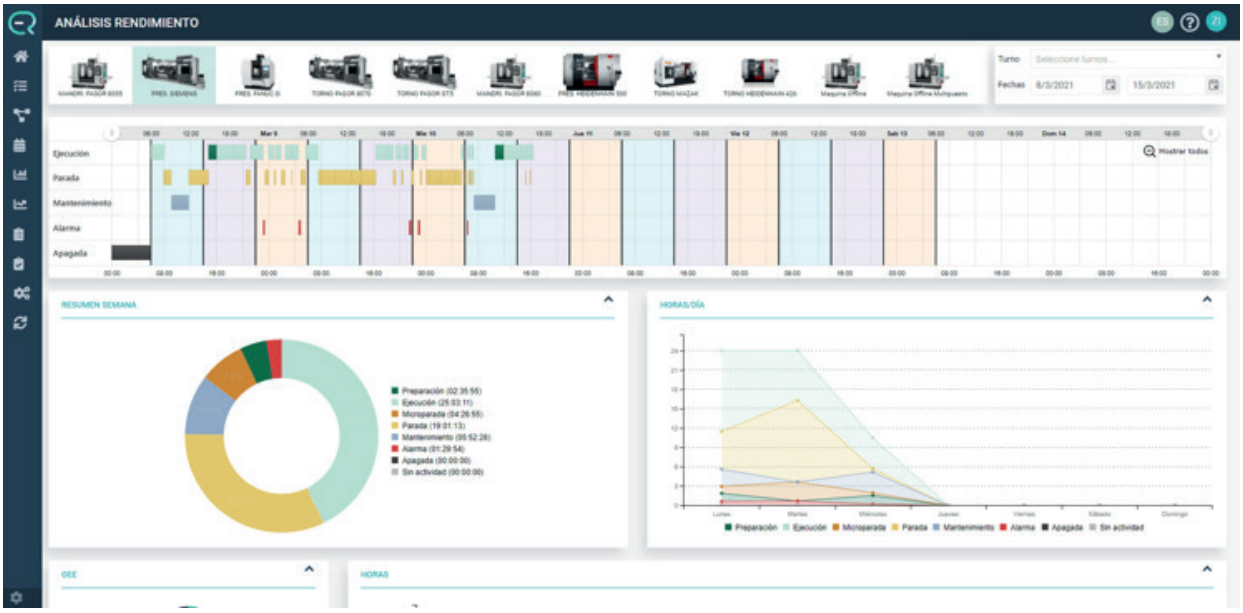


Figure 20: Data analytics and production scheduling
Source: https://www.zitu.net/es/soluciones/eris

Machines, production cells, production lines and even work shifts can be compared with each other, analyzing the information based on international OEE productivity measurement parameters and KPI's in real time, being able to find out why a high rate of productivity.

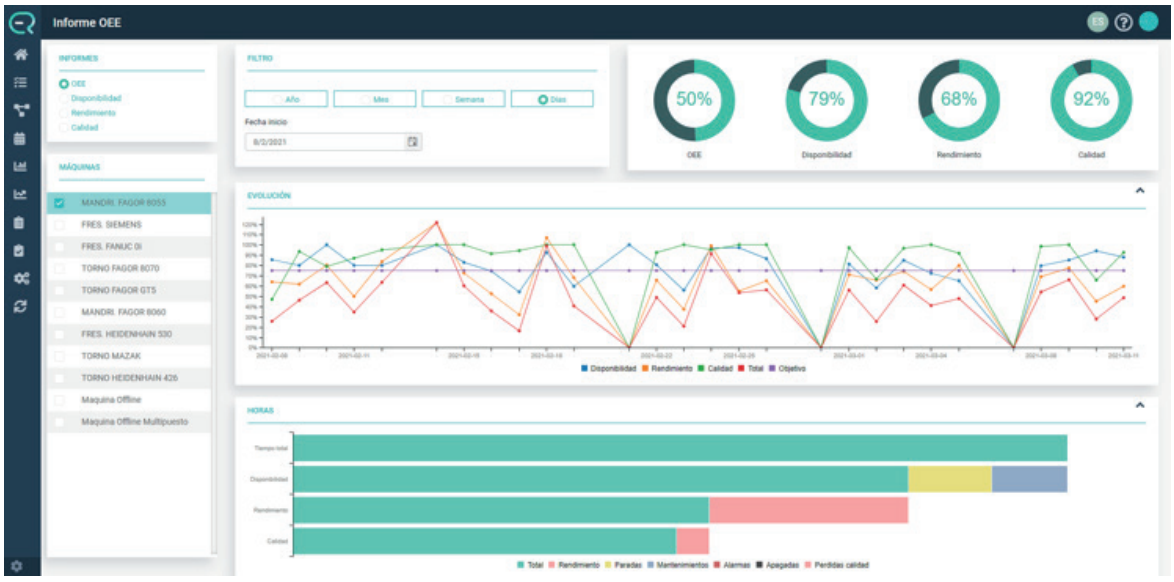


Figure 21: Data analytics and production scheduling
Source: https://www.zitu.net/es/soluciones/eris

Deviations in the offer made to a client can be analyzed, being able to detect the reasons for inefficiency as well as opportunities for improvement, optimizing production costs, detecting losses in efficiency, energy and productivity at any level of the production chain.

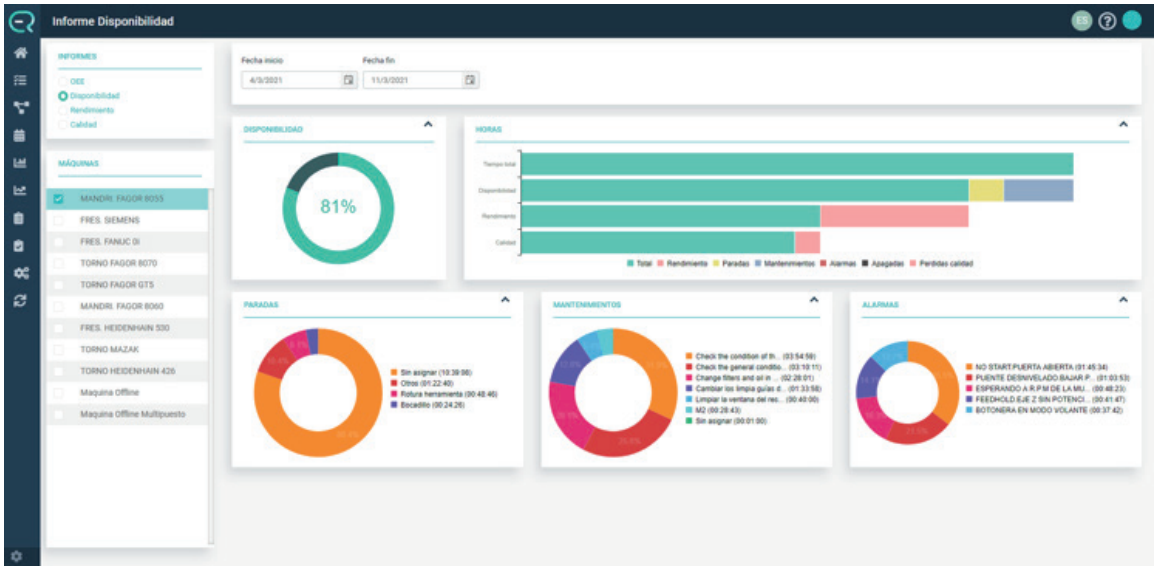


Figure 22: Data analytics and production scheduling
Source: https://www.zitu.net/es/soluciones/eris

It is possible to make a comparison of the behavior of the machines and the operators in the different jobs and detect strong and weak points in the production chain for optimization.

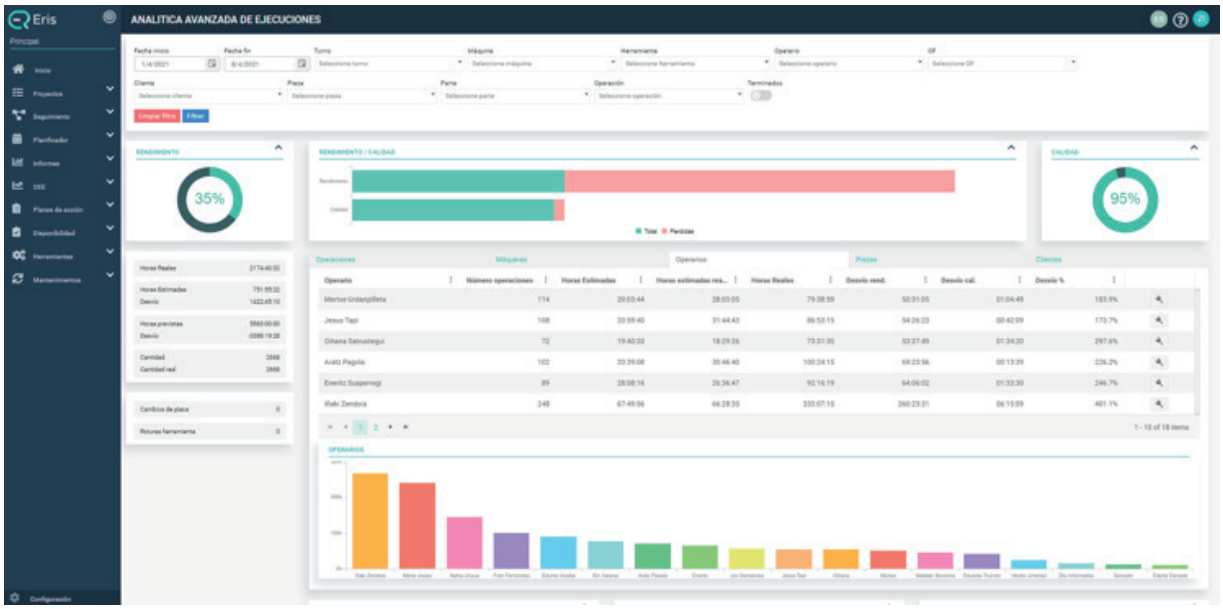


Figure 23: Machine behaviours comparison
Source: https://www.zitu.net/es/soluciones/eris

Deviations in the quality area can be analyzed with respect to customer requirements, verifying the deviation of each control guideline defined for each job or part

5.- Production planning based on information from the ERP and the situation of the production chain in real time through the MES, detecting trends and carrying out simulations using artificial intelligence.

Figure 24: Image Source: https://www.zitu.net/es/soluciones/eris

Long-term planning to obtain a global vision of the workload for the coming weeks in such a way that there is the capacity to react to different problems and know if you can meet the deadlines required by a new client.

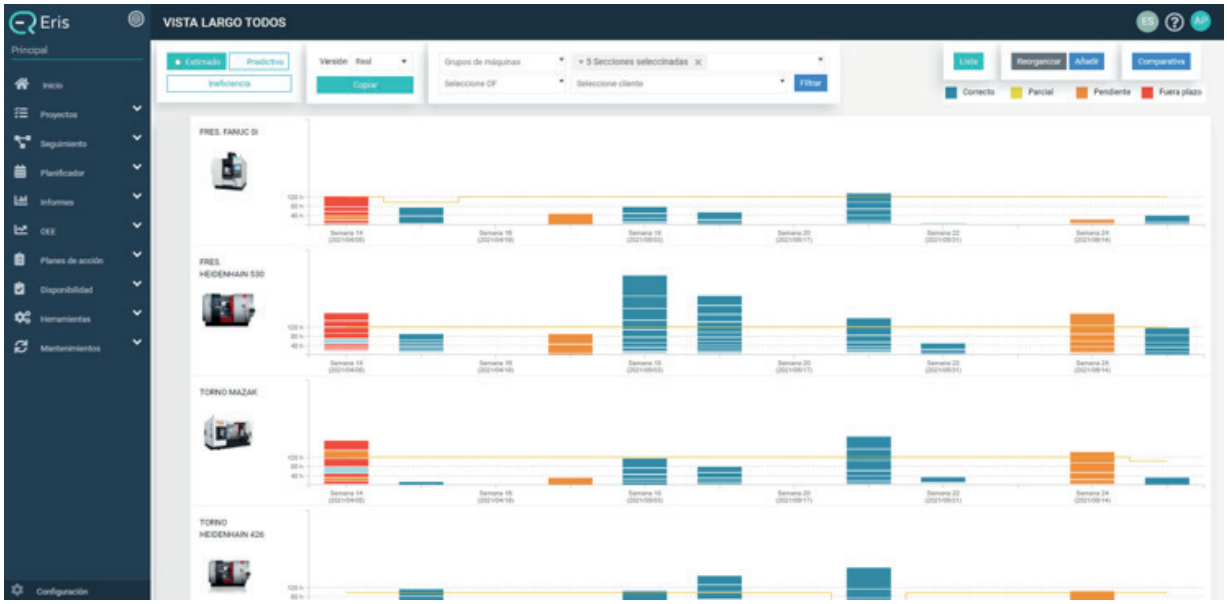


Figure 25: Long term production planning
Source: https://www.zitu.net/es/soluciones/eris

Short-term planning with the ability to react quickly to incidents that arise in real time. Operators will receive alarms with changes immediately.

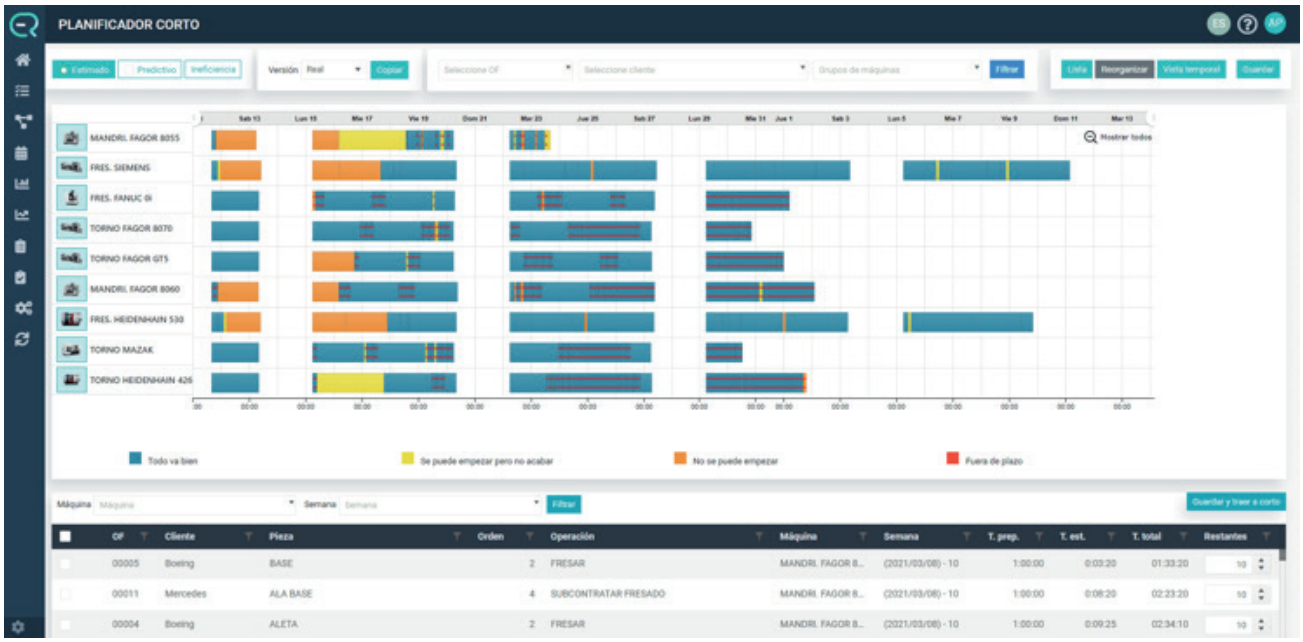


Figure 26: Short term production planning example
Source: https://www.zitu.net/es/soluciones/eris

6.- Control and management of tools: you will know at all times the real stock of your tools, their location and what tools are in each machine in real time and you will be able to consult the history of each tool; in which machine it has been used, for how long, what operations it has carried out, what materials it has machined, estimated useful life time, etc.

Figure 27: Source: https://www.zitu.net/es/soluciones/eris

In addition, it is able to connect with smart tool cabinets, thus achieving a single point from which to obtain all the information related to the production processes.

Figure 28: Source: https://www.zitu.net/es/soluciones/eris

7.- Maintenance management: ERIS maintenance management module integrates a complete CMMS software in which maintenance activities can be carried out in a way that minimizes unscheduled machine downtime and increases machine availability.

Preventive maintenance of the software will reduce corrective maintenance activities to a minimum. In addition, maintenance cost is reduced since the tasks to be carried out will be less expensive than corrective maintenance.

Predictive maintenance is a reality. ERIS AI enables predictive analytics applied to aggregated data to recognize patterns and generate insight in the form of dashboards and alerts.

In this way, decision-making to determine when to carry out maintenance tasks will be more accurate, it will make it possible to anticipate breakdowns by avoiding machine stoppages and schedule spare parts purchases.

Figure 29: Maintenance tracking and support: Source: https://www.zitu.net/es/soluciones/eris

5.3. Integration of a MES in IMH's labs

In this section we will try to explain how a MES system can be implemented in the workshops of vocational training centers.

The implementation of a MES system requires that each of the machines we want to connect to be able to communicate with the software we have chosen. The machines and equipment, through Wi-Fi communication, transmit all the data they have to a database located in the cloud via CNC.

We have communicated the following workshops:

- All the CNC machines corresponding to the TKGUNE workshop, whose objectives are to offer technological innovation services to SMEs and to be a training space for our 2 specialization programs in Industrial Mechatronics and in Production Programming in Mechanical Manufacturing.
- All CNC machines and, for now, 6 conventional machines by integrating PLCs to communicate with the MES corresponding to the general workshop whose general objective is the development of the teaching-learning process of the vocational training cycles.

It is important to clarify that when incorporating a MES into workshops of vocational training centers, the information that we would like to obtain from the machines and the way to exploit them will be different from the way the industry does because the teaching processes-learning require a different management than production companies in the aspects of a training center.

We would be able to get information from:

- Traceability of learners, machine usage, tools, performance indicators.
- Machine use information for scheduling, planning and also maintenance.
- Monitoring of students performance, state of project's and task execution at real time.
- Tools control.

The learning factories implemented in VET labs are a good way to reach the industrial applications of the MES solutions listed in the previous section in learning environments.

- Collection of data for processing by another team.
- Traceability.
- Intelligent stock control.
- End of process notice.
- Implementation of just-in-time systems.
- Automated maintenance.
- Procedure for requesting spare parts.

5.4. Benefits of to the use of MES in EXAM's CLF

Among the benefits that we find when inserting MES in EXAM CLF are:

- Massive remote control managed through the use of applications. All machinery and equipment is visible at all times and in real time, being able to control its operation and detect or solve problems.
- Cost reduction promoting operational efficiency, lowering production and logistics costs.
- Automation of processes due to artificial intelligence. The processes will become more and more automatic, avoiding the errors of manual operators.
- Better monitoring by obtaining information (status, consumption, etc.) in real time.
- Maximum use of resources, making them more efficient.

Competences addressed with MES

The insertion of MES elements are going to help on developing competences as:

- Schedule productions, production planning, quality control and measurement procedures, maintenance planning.
- Prepare the procedures for the assembly and maintenance of equipment, defining the resources, the necessary times and the control systems.
- Supervise and / or execute the machining, assembly and maintenance processes, controlling the times and the quality of the results.
- Supervise the programming and tuning of numerical control machines, robots and manipulators for machining.
- Determine the necessary provisioning through an intelligent warehouse.
- Ensure that manufacturing processes conform to established procedures. Applied metrology.
- Manage the maintenance of resources in their area.

6 USE CASE USURBIL's LAB: Functions of an ERP in VET

6.1. Objective

The objective of this project is to test and validate the use of a ERP system in an Advanced Manufacturing USE CASE, such as the DIGITAL WAREHOUSE lab, created in USURBIL with the aim of developing a successful practical HVET/VET lab.

6.2. Description of the case, Function of the ERP at Usurbil

Smart warehouses are considered to be the evolution of automated warehouses. This happens because they use automatic and independent machinery, management software and technologies such as Big Data to be more efficient and more productive when storing goods and products, preparing orders or receiving goods.

In particular, intelligent warehouses enable companies to save time in assembly processes, save costs through automation, provide more relief for employees and prevent many accidents in the workplace.

The technologies used in Digital Warehouses are: automation and robotics. There are basically two main concepts: industrial robots, and cobots or collaborative robots. Both were introduced in industrial production lines years ago, but today they are common in other areas of the company such as logistics.

The application of an ERP system such as Odoo in this warehouse guarantees that:

- Costs are considerably reduced due to compact storage.
- There is maximum stock control and order picking is carried out quickly.
- The management of incoming and outgoing goods saves space, time and money.
- Production increases and does not come to a standstill, which improves the company's - performance.
- Improved product lifecycle within the supply chain, resulting in greater stability and profitability with customers.

6.3. Technical aspects of the solution

In this section, we address how a Digital Warehouse managed with the **Odoo ERP** can be incorporated into HVET / VET school labs. We describe different options and applications.

1.- Raw Material Stockage: Material is distributed in the form of a beehive, and allows us to identify and locate the different types of material by shape and size.

Figure 30: Raw material warehouse Source: CIFP Usurbil

2.- Raw material Cutting: raw material is cut by a **cnc saw connected to the ERP system**. The automatic CNC saw identifies the type of material, shape and size, and also the lengths and number of cuts to be made. Thus, the ERP manages the inputs and outputs of the material into the WAREHOUSE.

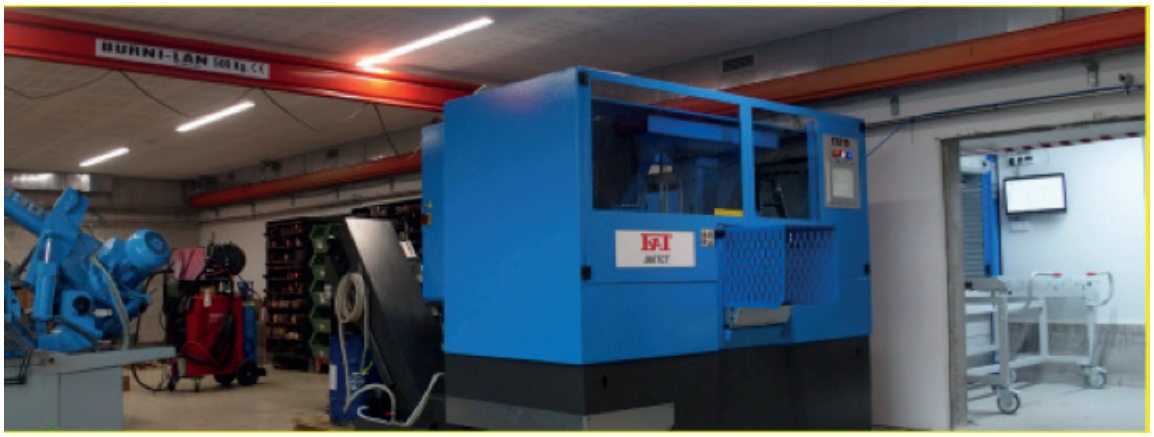


Figure 31: CNC saw Source: CIFP Usurbil

3.- Storage and distribution of the cut material with a collaborative robot A collaborative robot, also connected to the ERP, will move the cut material to their corresponding drawer on the automatic vertical palletized warehouse. This robot has a laser that identifies the piece, and so with the help of its claws it will move it to its position in the drawer into the predefined placement. The robot's movements are controlled by a tablet, and can be visualised in real time from a webcam.

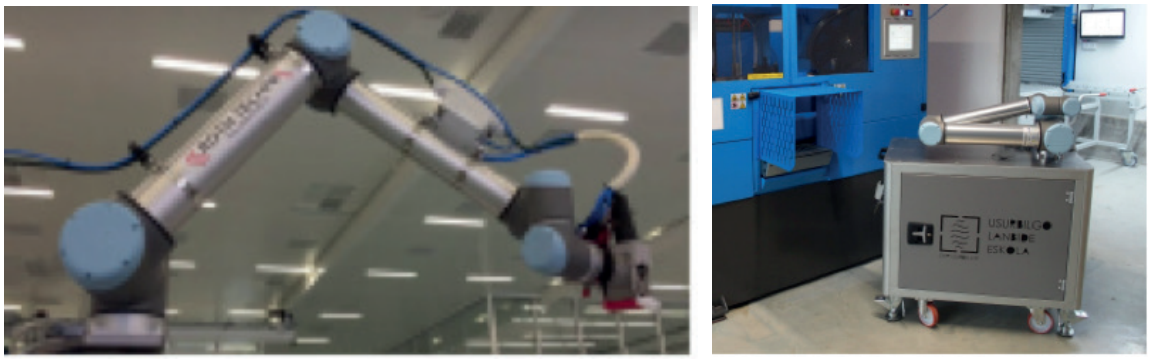


Figure 32: COBOT for material feeding Source: CIFP Usurbil

VIDEO OF THE PROJECT:

https://www.youtube.com/watch?v=N0lUQshWrL8

4.- Vertical palletized warehouse. The parts cut on the saw will be stored in a vertical palletized warehouse with the help of the collaborative robot. This warehouse is directly **connected to the ERP**. Each item in the storage shall be assigned a **drawer number and a position** in a specific pallet. Every time an order is placed, a laser light will identify the position where the element is located, making it easier to locate it. At the same time it will control the minimum stockage of parts in the drawers.

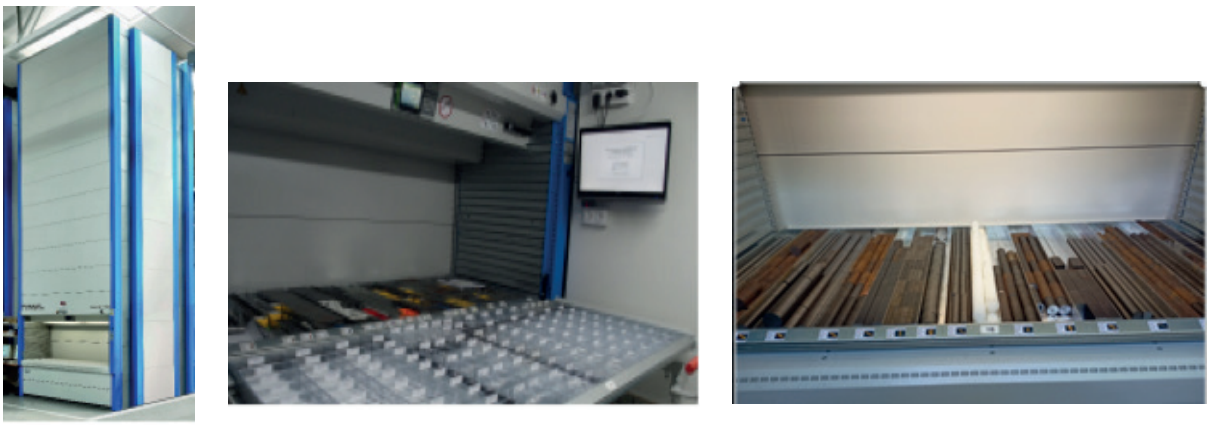


Figure 33: Automatic warehouse for raw material Source: CIFP Usurbil

5.- Intelligent tool storage. We have an intelligent warehouse where all the tools are **RFID coded** for the control of the common tools in the workshops. The tools in this warehouse are distributed in such a way that each one has its own drawer number and position. This warehouse is also **connected to the Odoo ERP**. Each student will have a **personal RFID identification code** that must be used to enter the warehouse. Once the system has detected the person who has entered, it will identify in the same way the exit of the student and the tool he/she has taken out with his/her name. This way, at any time, we can have full **control of the use of all the tools in real time**, i.e. we can identify the tools that are used the most, the ones that wear out the most, and we can also keep track of maintenance.

Figure 34: Tool warehouse Source: CIFP Usurbil

6.4. Pedagogical implications of the use of ERP-MES-PLM systems in VET labs Competences/Skill addressed with ERP

Student training and networking are USURBIL's main tools to bridge the gap between technological change and education. At USURBIL we train students and provide them with resources so that they can bring the innovations taking place in society to the classroom as quickly as possible. In this way we believe that by working as a network we give a faster and more effective response to changes.

The insertion of a Odoo ERP based Digital Warehouse is going to help on developing **competences** such as:

- Prepare the procedures for the material provision, defining the inputs and outputs, orders and control systems.
- Supervise the condition of tools and their maintenance processes, controlling the quality of the results.
- Supervise the programming and tuning of collaborative robots integrated in the process.
- Be autonomous in the planning and launching of a work order.

6.5. Collaboration opportunities (among partners) that brings the use of ERPs (together with other tools such as PLM,MES, Cloud, IoT, DTs..)

This project has brought together some internal collaboration opportunities with other school departments:

- with the Administration department, in Odoo ERP managements.
- with automatisation & robotics, in the field of machine sensorification and parameter monitoring.
- with robotics, running the collaborative robot.

6.6. Implementation

This project helped us in the creation of an integral 4.0 stock management system, run by Odoo ERP system.

Functionality from the entry of raw material to the finished product, as well as having control over all consumables and spare parts for mechanical manufacturing spare parts in an agile and online management.

This system will manage the warehouse of raw material stocks, spare parts, hardware, production process, traceability, equipment, manuals-documentation-history of machines. In conclusion, all the stock of mechanical manufacturing will be managed optimally.

The application of this project will help us to manage the resources available in a real and more digital way.

It will also require the integration of habits and disciplines necessary for the proper functioning of the system.

Some useful information that we get thanks to Odoo ERP is:

- Real stockage control.
- Training and creation of documentation for teachers and students in robotics.
- Acquisition of new disciplines and habits for the maintenance of the system.

6.7. Benefits of to the use of a ERP based Digital Warehouse in EXAM4.0 project:

OPTIMIZED SPACE

Warehouse management systems optimize warehouse flow by analyzing the best use of floor space based on the task and material characteristics. The use of space and floor plan analysis is used to determine how space should be best used and provides opportunities for reducing waste – waste of premium floor space and waste of time for locating products.

INVENTORY VISIBILITY

Using a warehouse management system will also provide visibility of accurate, real-time inventory levels. This enables a company to more securely estimate supply and avoid backorders, which leads to more satisfied customers.

TRACEABILITY

It offers the possibility to react immediately in the event of a food safety incident, crisis or alert, by carrying out a rigorous step-by-step approach, identifying process failures in the supply chain and enabling relevant actions to be taken to avoid complete damage to production.

BETTER USE OF RESOURCES

Use of resources such as raw materials and tooling is optimized because of the Odoo ERP-based automatic control. Wasting of material is minimised as each student is assigned the optimum material quantity to carry out the learning process. Tool usage is also controlled and rationalysed, and its maintenance is optimised.

REDUCE COSTS

This optimum use of raw material and tooling leads us to reduce costs, save energy and therefore, protect the environment. Teaching time is also reduced.

6.8. The response of students, teachers

Students and teachers are in general very happy with the new ERP based Digital Warehouse, because we have used a methodology that students will find after in the best manufacturing companies, and so benefits in the learning environment are obvious.

6.9. Obstacles and Foreseen Risks

Obstacles came mainly in the definition of the concept and in the implementation of the design. The work done by teachers has been hard, but we would like to emphasize the compromise and implication of teachers and students in the project.

6.10. Next steps foreseen

This Odoo ERP will be implemented also in the rest of the storage systems and machines of the school's manufacturing LAB.

It can be used as a reference for SME and other schools that visit us.

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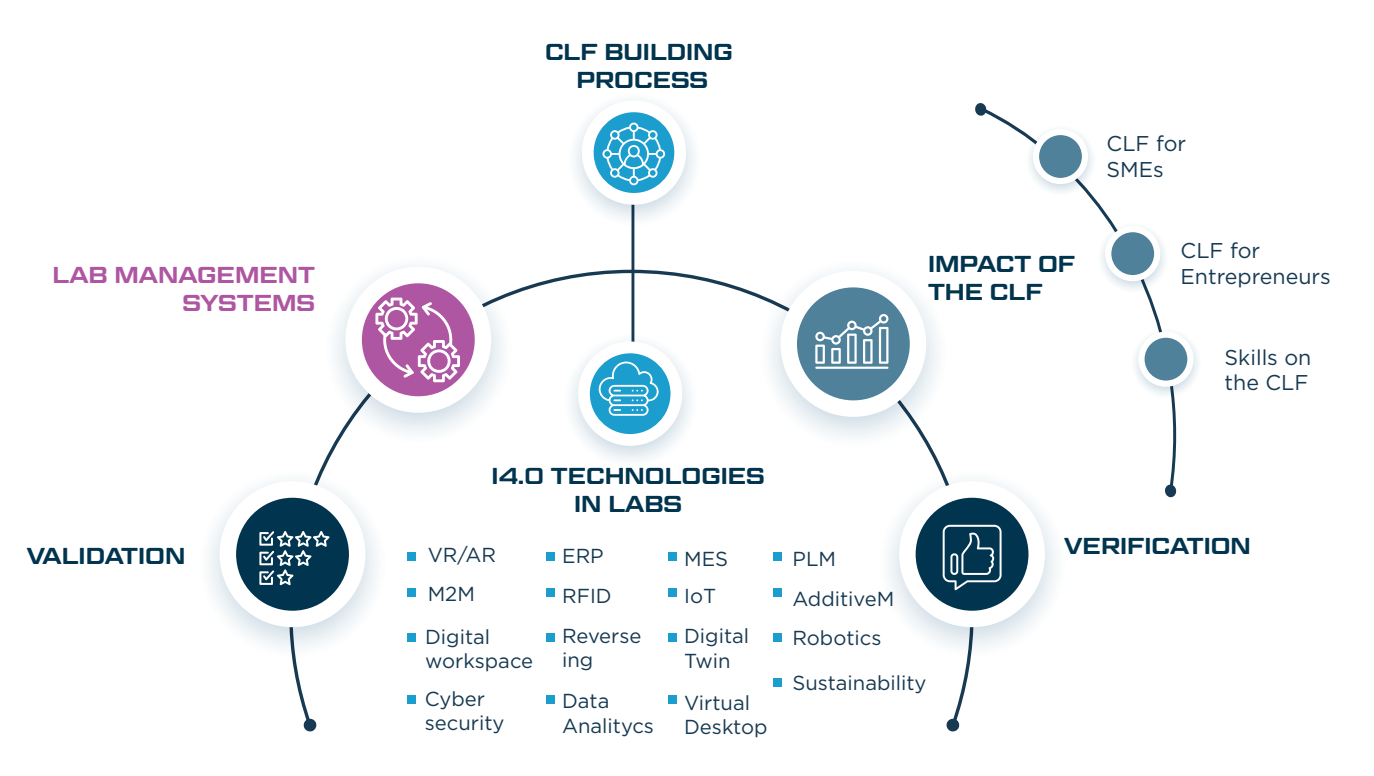
EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0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LAB MANAGEMENT SYSTEMS
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VR/AR
M2M
Digital workspace
Cyber security
ERP
RFID
Reverse ing
Data Analitycs
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Digital Twin
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