Improving Manufacturing Execution Systems Modelling: a pattern collection and classification approach

Moisés Vasconcelos Rodrigues Torres Coelho

Master's Dissertation

Supervisor from FEUP: Prof. Pedro Amorim

U. PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Mestrado Integrado em Engenharia e Gestão Industrial

2021-06-28

Abstract

Facing a specific context of a Manufacturing Execution System (MES), an action research approach was used to solve the problem at hand: identify the best way to create patterns and characterise them. At each factory where an MES is applied, a whole adjustment and modelling work is previously done for that particular implementation. Thus, it was necessary to identify such patterns to improve this recurring process. For that, design patterns were used, which led to obtain a final structure to present the identified patterns. This structure, consisting of two tools, a mind map and a patterns framework, allows a quick and punctual use, but also a more in-depth and detailed observation of the modelling solutions. Feedback was obtained from the company where this project was integrated, being positive regarding the results presented. The approach adopted and the methods applied were well framed and presented good results.

Resumo

Perante um contexto específico de um Manufacturing Execution System (MES), foi usada uma abordagem de *action research* para resolver o problema em questão: identificar a melhor forma de criar padrões e caracterizá-los. A cada fábrica onde é aplicado um MES, é feito previamente todo um trabalho de ajuste e modelação para essa determinada aplicação. Viu-se então a necessidade de identificar tais padrões para melhorar este processo recorrente. Para isso, recorreu-se a padrões de design que levaram a obter uma estrutura final para apresentar os padrões identificados. Esta estrutura, consistindo em duas ferramentas, um mapa mental e um quadro de padrões, permite um uso rápido e pontual, mas também uma observação mais detalhada e pormenorizada das soluções de modelação. Foi obtido um feedback por parte da empresa onde se integrou este projeto, sendo ele positivo face aos resultados apresentados. A abordagem adotada e os métodos aplicados foram bem enquadrados e apresentaram bons resultados.

Acknowledgements

I have to be thankful for the strong support and all the help provided by my brother, Samuel.

A big thank you also goes to Leonor, the company's supervisor, who was always interested in helping me and corrected me a lot, in small and large details.

I want to express gratitude to professor Amorim by his advises and his availability during all the project.

Finally, a I must also show my appreciation to Critical Manufacturing for supporting young academics and for the monetary incentive.

Contents

Abbreviations

CM MES – Critical Manufacturing Manufacturing Execution System

DS – Deployment Services

ERP – Enterprise Resource Planning

FG – Finished Goods

GUI – Graphic User Interface

LP – License Plate

MES – Manufacturing Execution System

MTS – Make-To-Stock

MTO – Make-To-Order

PO – Production Order

SFG – Semi-Finished Goods

WIP – Work-In-Progress

List of Figures

1 Introduction

Each passing day is a new step towards modernization, that leads us to new realities. Concerning the industry, this modernization, nowadays, is called Industry 4.0. As its name implies, this is the fourth industrial revolution and, if in the previous revolutions the great innovation drivers were steam, electricity, and electrical automation, this one is due to the ICT (Information and Communications Technologies). These technologies allowed the Cyber-Physical Systems (CPS) concept to appear and together with the Internet of Things (IoT) led and still lead to the progress of this new revolution. With this technological basis it was possible to have customized and flexible mass production, this being one of the main motivations of the focus on this evolution (Rojko, 2017).

Cyber-Physical Systems combine both the computation and the physical processes as well as the integration of both. The magic behind this comes from the connectivity of the computers with the physical events and objects, as they interact with it constantly, sending and receiving information that can be changed as fast as the process goes on. This continuous communication between the two worlds, permitted by the networks that links all the parts of the system, allows loops of feedbacks where one side is affected by the other and vice-versa (Lee, 2008). The IoT concept is also strongly connected to this revolution. Some say that it started with the radio-frequency identification (RFID), but soon evolved to something more. Once the perception of the limit of human capability and its high expenditures to save and record data was realized, the concept gain substance and meaning. So, this just brought the idea of setting the "things" to collect data for us (Ashton, 2010), opening a new window to progress. Nowadays, the concept is translated physically in the integration of sensors, actuators, RFID tags, and communication technologies (van Kranenburg et al., 2011). In few words, Dorsemaine et al. (2016) defined IoT as the "group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate".

Bringing these two main concepts together (CPS and IoT) enable Industry 4.0 to become a reality in the manufacturing sector. There are several types of information systems operating in this field and they can be ranked according to their level. In the Figure 1, one can see the different levels from the shop floor up to the enterprise resource planning level. The Manufacturing Execution System (MES) is one of the pyramid systems that contributes to the revolution and its position allows to receive the detailed information from the shop floor, to process it and to show the useful data to the user or transmit it to the upper-level systems. In other words, it is the bridge between ERP (Enterprise Resource Planning) and equipment automatic control system (Gao et al., 2015).

Ugarte et al. (2009) defines the objective behind a MES to be the optimization of the manufacturing processes and resources. Yet, inside this big goal, there are a wide range of applications that contribute to this purpose. From the basic and simple traceability and genealogy of materials to the production scheduling. All these features contribute to a more valuable digital world, making the industry even more efficient.

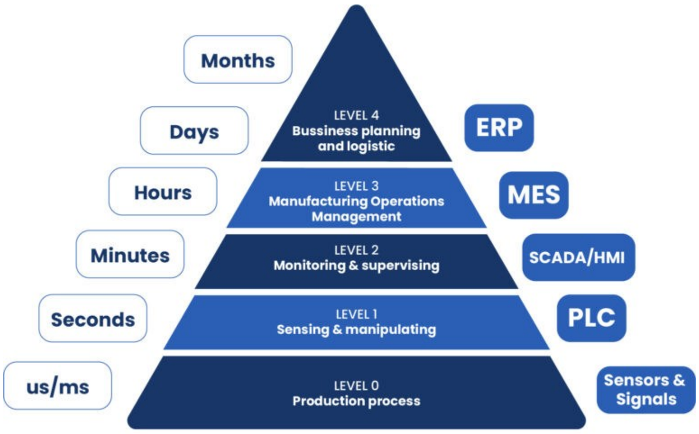


Figure 1 - ISA 95 system levels

1.1 Critical Manufacturing and the CM MES

> *Critical Manufacturing (CMF) is dedicated to empowering manufacturers of complex, high tech discrete products with a manufacturing execution and intelligence system to achieve their goals. It is ready for the future whether it is called Industry 4.0 or something else. It scales to the operations, gives clear insight and guidance on any desktop or mobile device, drives visibility of production and its costs across the supply chain, and is easy to implement on an existing infrastructure. As a result, CMF's state-of-the-art products and services enable you to drive down cost, flexibly meet market demands, and ultimately achieve greater agility, visibility, and reliability (*Critical Manufacturing - Critical Manufacturing | Company Overview*, n.d.).*

Critical Manufacturing follows its mission driving business value through the convergence of intelligence, operations, and automation technologies, seeking its vision for the future: making Industry 4.0 a reality for all manufacturers.

CMF provides a wide range of solutions into a single product. It is called CM MES and as the name reveals, it is a manufacturing execution system applicable to discrete product manufacturers. It was built by the company and stills in constant development such as the information technology (IT) industry demands. Besides the creation and improvement of their product, CMF also deploys its own product on the costumers' plants pursuant to their needs and requirements. CM MES is composed of several modules, from the core function, such as resource tracking or batch traceability, to integration with other systems and quality control, among many other functionalities. From customer to customer, the features and settings required change, and to make the product suitable for every case, the product itself allows to build customization on it, complementing the out-of-the-box features.

1.2 Project context and motivation

To deploy the product (CM MES) on the customers, there is a specific department, called Deployment Services (DS). It is in charge of implementing the MES, modelled as the client wants (according with the selling conditions). In order to have the final product ready to be used *in loco*, it goes through a long process, being the most relevant stages in this context:

requirements analysis, modelling design, modelling development, verification, and deployment. To do this work, there is a project team, composed by people with different roles. For each project there is a different team, although, one person can be working on several projects at the same time. The average project duration is around six months to one year. Since each project is different from all the others, the modelling applied for one is particular for that case and finding the best modelling solution is a challenging task, because it requests a good expertise of the product. This knowledge of the CM MES and know-how to implement is found mainly on the personnel of the DS department. Their understanding of previous projects or past work experience, allied to a high knowledge sharing and a great team assistance spirit, are the base of each worker's expertise. However, every time someone enters to the DS department, or as a deployment partner, he has a long path to do to gain that know-how. Meaning that they could not improve and accelerate their learning process from some operational manual or guidelines. Here is one of the reasons that motivated this project: the lack of standard modelling solutions and how to implement them. With regular staff recruitment in mind, the need for such tool is strengthened. Even for experienced workers a tool like this may be very useful to simplify their work. Therefore, good accessibility to already implemented solutions and a consistent record of good solutions would bring value to the company. Furthermore, with the help of the vast experience of some collaborators in the different industrial segments of CMF's customers, indications of common characteristics between the various deployment projects were found, which also motivated this project: how to identify, in a systematic way, common problems and their solutions.

Product development is carried out by another department, the product department. This department is constantly working to improve the CM MES by fixing bugs or adding new features. Even though they are two separate departments (product and deployment services), they need each other, either to build specific features for customers or to learn how the product is used by the customers. Aligned with this idea, this project could also reveal more useful information for the product department.

1.3 Project objectives

The objectives of this project are related to the reasons given above. With these reasons in mind, the goal is to work with the deployment teams to extract standard implementation solutions (patterns) identified in completed or under development projects. These patterns will then be catalogued and structured in a way that they can be used easily. In addition to pattern recognition, it is important to identify the conditions under which each pattern occurs and to establish possible relationships with various characteristics of the customers, be they the type of industry, the manufacturing process, the type of equipment used, or others. By identifying these dimensions, it would make it easier to apply the patterns to new projects.

The final objective of this project is to create an organized and categorized catalogue of patterns which will act as a database of best-practices when modelling production processes of different types in Critical Manufacturing MES. Building a catalogue will provide several benefits for the company. With such a consolidated base of standard solutions, Critical Manufacturing's proposed solutions will be more consistent and of higher quality. The process of collecting customer requirements would be optimized thanks to a structure that functionally integrates the patterns, the conditions under which they occur and the relationships they present, allowing a more effective communication with customers. This tool will also help make future project effort estimates more accurate, since an estimate based on standard implementations will always be more certain than custom-designed solutions.

In terms of research matter, the problems that arise are: how should this information be collected, what information should be taken into account, how to structure and present the results in a useful and user-friendly way.

1.4 Method followed in the project

Firstly, the way the product, CM MES, is organized was assimilated and minimal knowledge of how it works was obtained. After this learning, several relevant topics of the product were known, topics that would then be the target of analysis. In order to understand the type of data that one would be dealing with and to devise a way to handle them, one started by choosing a topic, collecting some documentation related to that topic from various projects and then proceed with the data treatment. The documentation alone was not enough, so interviews with project members were essential, representing the main data input. From there, more topics were analysed, and results were emerging. This characterises the action research approach that guided the development of the project. The study of the topics and their characteristics also included an analysis of these by industry segment. As a form of evaluation of the proposed solution, feedback was collected from several people in the company, serving at the same time as suggestions for improvement.

1.5 Dissertation structure

To provide a better and structured reading, the dissertation was divided in chapters and sub-chapters following a logical thread. The chapter 2 introduces the theoretical background considered as baseline for the method followed. The third chapter serves to explicitly define the problem at hand as well as all the context it involves, be it the format of the information to collect or the features of the product. The chapter 4 presents the methodology followed and how the flow path to the results was done. The chapter 5 shows the results achieved with the correspondent explanation and to finalize, chapter 6 sums up the main conclusions and points out improvements and future work.

2 Literature review

This chapter serves to show the state-of-art around the subject of this project and which scientific knowledge served as background for the methodology and for the proposed solution. In the first sub-section the topic of action research will be addressed, which served as an approach to the problem. In the second, the topic of design patterns, which inspired the creation of the proposed framework, will be explored. To finish, a small paragraph will sum up the reasons of this literature review.

2.1 Action research

The term action research was first used within social change after World War II by Kurt Lewin (Azhar et al., 2010). Later, several scholars studied action research, which according to Azhar et al., "is not a specific method or research; rather it is an approach". From these scholars, who eventually encompassed several areas in their studies, from social sciences to information systems, several definitions and explanations of what action research is have emerged. Baskerville & Wood-Harper (1998) say it is based on a combination of theory and researcher intervention in order to solve problems. Naoum (2001) places the researcher at the centre of this approach, being the one who understands the situation, identifies the problem, proposes improvements, and reflects on the results obtained. As Rezgui (2007) and Avison et al. (1999) see it, action research is a unique approach in the sense that, through change and reflection, it connects research with practice. In a given context, with a real and immediate practical problem, the aim of this approach is to construct and/or test theories to solve that problem, according to Azhar et al. (2010). Finally, Hinchey (2008) defines action research as a cyclical process of fact-finding guided by those within the subject. Despite the diversity, the whole general idea that everyone ends up idealising is notable: an approach that does not focus on producing conceptual knowledge, but rather practical results (Azhar et al., 2010).

There are many studies following this approach with respect to small-scale problems, however, those concerning complex real-life problems where it is applied are more appreciated (Avison et al., 2018). Despite all the subjects that may be involved, information systems draw attention for the applicability of action research to it. Lau (1997) identified and analysed several studies using action research from various categories, highlighting here, the areas of information systems analysis and implementation (Burstein & Gregor, 2002). In this context, Avison et al. (1999) even mentions that information systems can be an example of the benefits of an action research approach, listing five of them.

As previously stated, this is an approach that is based on iterative processes, with the interaction between researchers and practitioners (Kock et al., 2017). Azhar et al. (2010) presents it as having a five-stage cycle: diagnosis, action planning, action taking, evaluation and learning specification.

2.2 Design patterns

According to the Cambridge Advanced Learner's Dictionary & Thesaurus (*PATTERN | Meaning in the Cambridge English Dictionary*, n.d.), a pattern can be defined as "a particular way in which something is done, is organized, or happens" or "any regularly repeated arrangement, especially a design made from repeated lines, shapes, or colours on a surface" or even "something that is used as an example, especially to copy". Assimilating these definitions is a good starting point for facing the problem at hand. However, it is by far not enough to process the issue that the project will raise. The first step that one would intuitively consider, would be to understand what kind of standards one will be dealing with. However, according to Dixon (2012) the search for patterns is something that cuts across several domains, from the hard sciences to the humanities, leading to a rethink of this initial perspective. And as seen, the definitions of patterns do not differ so much from one another, which makes one believe that the design of patterns in one area may well serve as a basis for another.

In 1977, Alexander et al. (1977), in his book, described techniques of town planning, architectural designs and building construction thus developing the discipline of design patterns (Noble, 1998). Johnson (1992) claims that Alexander's work and his idea of "pattern language" was meant to be used not only by architectural specialists, having, instead, an applicability in several areas. After Alexander's book, many others made use of his work and adapted it to their specific field (Beck et al., 1995). Gamma et al. (1994) himself made the connection between what Alexander said and the applicability of it in his area of object-oriented programming. Gamma et al. (1994) presents a compilation and catalogue of a plethora of design patterns in object-oriented software. This programming domain saw in design patterns a promising approach for system developments, especially object-oriented systems (Zimmer, 1995). According to Gamma et al. (1994) the difficulty of creating a flexible and reusable design is so great that it becomes "impossible" to achieve it the first time. In this sense, many experienced designers tend to reuse solutions already written, making the necessary adjustments, thus revealing the value of patterns and their catalogues.

Some advantages of design patterns on the subject of object-oriented programming have been identified by Gamma et al. (1993) and Zimmer (1995) as: providing a common vocabulary for communication between designers; providing a means to reuse design knowledge as a base of experience; and reducing learning time.

Gamma et al. (1994) states that a design should be designed with focus on the problem at hand, but inclusive enough to be applied to future cases. Gamma et al. (1993) characterizes a design pattern as a micro-architecture, with few applications, thus tending towards a small size and scope. Beck et al. (1995) defines design patterns as a peculiar way of recording those designs that fit well in certain situations and can be applied again in the future.

As it was possible to see, there are several characterisations for action research, and there are areas where it is more effectively applied, such as information systems. The strength that led to the choice of this approach is the fact that, in this project, it was subject to the intrinsic knowledge that the company members had and the unfamiliarity of the system by the external actor. Being the MES an information system it was important to understand the relevance of this type of approaches in this branch and how their methods are carried out. As exposed, the design patterns are something not linked to a single area, showing itself as an interdisciplinary topic and hence these have served as a basis for this project. Furthermore, the literature presented on Gamma's patterns makes clear the similarities between this area and the implementation and modelling of MES. It is also impossible to ignore the very connection between both within the information systems sphere.

3 Problem contextualization

The first thing that is necessary to know in order to understand this report, is how the CM MES works and to what each functionality relates to. After that, a more detailed overview of the available data to analyse will be made.

From now on, whenever the term MES is mentioned, the intention is to refer to the system itself and for specific cases, the CM MES.

3.1 Product features

The CM MES is organised into several categories that encompass all its functionalities. The most used and important for this project is Business Data. This category includes all the entities (with or without a physical representation) that virtualize the manufacturing environment. Next, the various entities mentioned throughout this document are identified and explained:

Facility – corresponds to a physical shop floor location, which can have several areas.

Area – an area is a logical grouping of steps and resources which may have a corresponding physical location. Always belongs to a facility.

Product – represents a set of desired characteristics of a material, e.g., a specific model to be produced. To create a product, it is necessary to define some settings such as the default flowpath (flow and initial step where it will start its process), determining where the materials will be placed after creation. It is possible to see a screen snip of a product GUI in Figure 2.

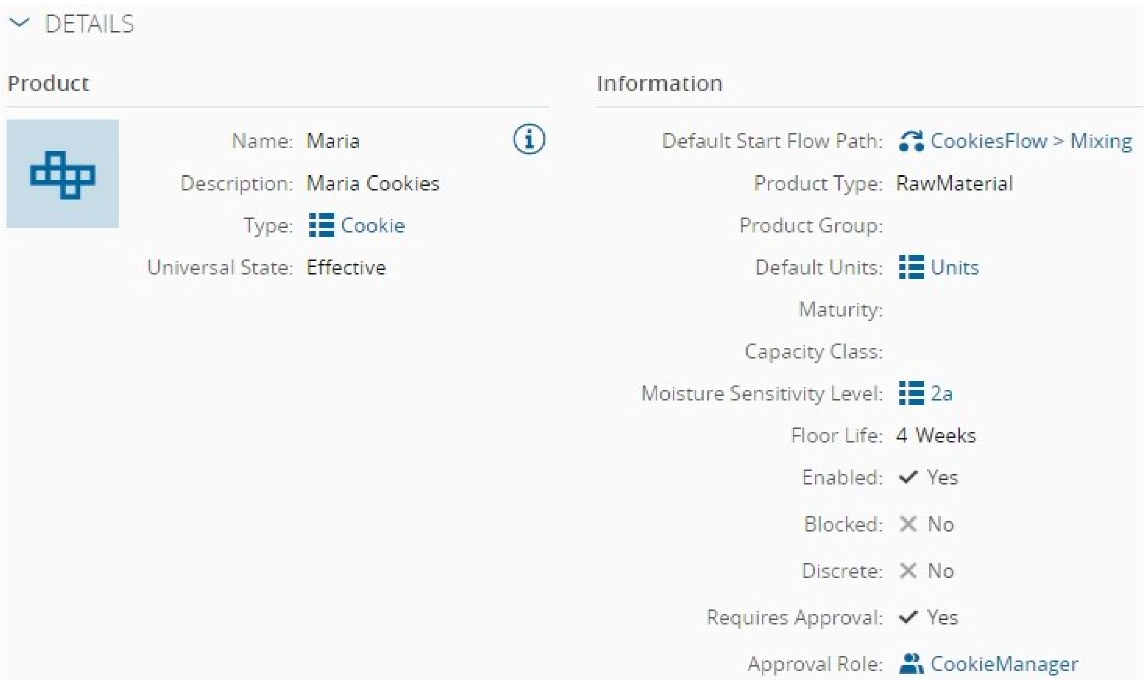


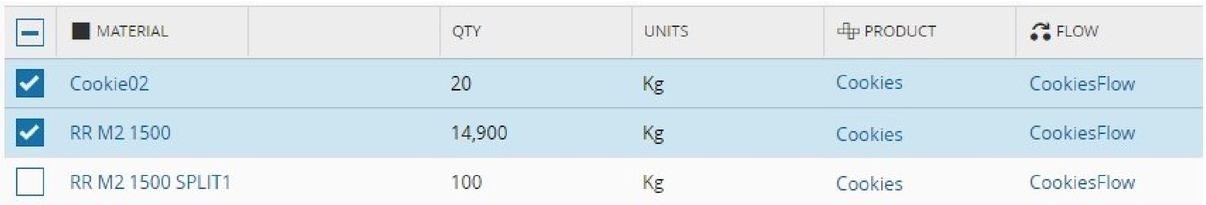
Figure 2 – GUI of a product entity example

Material – the material corresponds to the physical object that takes place in the plant; it can represent raw material, inventory, or work-in-progress; it always needs to have associated a product, to specify what that material is or will be and is permanently at a facility, step and flow; each material needs to have the units specified (kg, litters, units, etc.) and its quantity; a material can represent an aggregation of materials (as lots, batches, wafers, etc.). Figure 3 shows possible materials configurations. A material can contain various sub-materials.

Figure 3 - Schematic example of a material configuration

Resource – represents any entity that participates in the processing or storage of the materials, such as equipment or personnel; it provides a service and is located in an area; a resource can also contain sub-resources.

Step – represents a manufacturing process operation and is the smallest trackable process unit for work-in-progress (WIP) materials. Figure 4 shows the materials, on a step, with its quantity, units, which product is and the flow it is following.



MATERIAL	QTY	UNITS	PRODUCT	FLOW
Cookie02	20	Kg	Cookies	CookiesFlow
RR M2 1500	14,900	Kg	Cookies	CookiesFlow
RR M2 1500 SPLIT1	100	Kg	Cookies	CookiesFlow

Figure 4 - GUI of a step with materials and their properties

Flow – the flow is the ordination of steps (or flows) that constitutes the route/path that each material will follow; it can be of a single route, or have optional or alternate paths, for example; a flow can be used by several materials at any given time. Because steps and flows can be repeated in a given flow, the unique position on the step in a flow is determined by a flowpath.

Bill-of-Materials (BOM) – the bill-of-materials contains all the products and respective quantities that must be consumed by a target product at a given step; the BOM must have defined the product it concerns to and should identify each step where the consumption takes place, through the BOM context; the BOM context defines the BOM applicable to a given step based on a set of predefined criteria.

Production Order (PO) – it is the virtualisation of a real production order, represents a given product demand through one or several materials. The system tracks all the production order materials, their quantities, and their state (*InProgress*, *Completed* or *Delivered*). The Figure 5 explains how each state is reached.

Figure 5 - Material states in the context of a PO

Container – is an object which holds materials within it, with defined positions or not.

Each entity may be changed and operated in CM MES based on a set of business actions. Figure 6 illustrates a material's simple state model. In terms of material's traceability, the most relevant actions for the rest of the dissertation are:

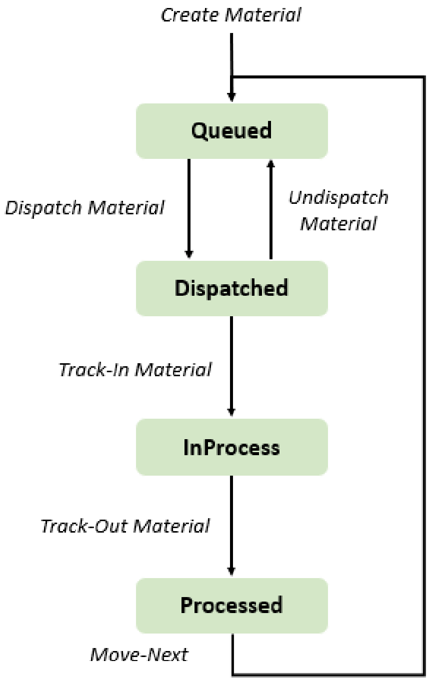


Figure 6 - Simplified material state model

Dispatch – used to assign a *queued* material to a certain resource; it acts as a material reservation for a given resource.

Track-in – used to track-in a material, meaning it will start a process at a given resource; the material must be in *dispatched* state.

Track-out – used to track-out a material from a resource, indicating a completion of the process; the material must be *InProcess*.

Move-next – places a given material in a new step in the *queued* state; the new step corresponds to the proceeding step defined in the flow; the material must be in the *processed* state (or *queued* if the step is *pass-through)*.

Ship – used to move a material from one facility to another.

Split – splits a material into two or more materials; it is used mainly for logistic purposes. The material being split is named as main material and the other as new material.

Merge – merge two or more materials into one; the one that will absorb is the main material and the other are the child materials; they must be of the same type, product, and be in the same step.

Record Loss – it registers a loss of quantity of a given material; a predefined reason must be chosen.

Terminate – this action applies to many entities with the purpose of declaring a given object as terminated; it makes the object "invisible" on normal conditions (not allowing most actions), instead of deleting it.

Assemble – assembles source materials (raw or components materials) to a given production material; assemble operations are enforce through the BOM defined for the step where material is at. Four types of assemble supported:

> *Explicit* – each component to use needs to be manually identified; quantity of production material is not affected by consumptions recorded.
>
> *ExplicitAdd* – similar to the previous but the production material quantity is affected by the consumptions by the ratio defined in the BOM.
>
> *AutomaticAtTrack-in* – components are not explicitly identified one by one; the consumption is done by the system at the moment of track-in based on a predefined list of components attached to a consumable feed of the equipment performing the step.
>
> *AutomaticAtTrack-out* – similar to the previous but the consumption is only done at track-out.

Attach – it serves to attach a consumable material to a consumable feed. Required in case of using automatic material assembling.

Combine – it is similar to an explicit assemble action with the exception that does not require BOM context.

There are also relevant business actions done at the Production Order:

Assign – assign one material or more to a given production order; the material must have the same product of the PO to count for its target.

Release (PO) – defines a PO as *released,* allowing it to have materials assigned. The starting and end dates must be defined.

Close (PO) – defines a PO as closed, preventing future material assignments to the PO; it can only be triggered if all materials assigned to that PO are completed and if the target quantity was achieved.

The Figure 7 outlines the state model of a PO and the actions between them.

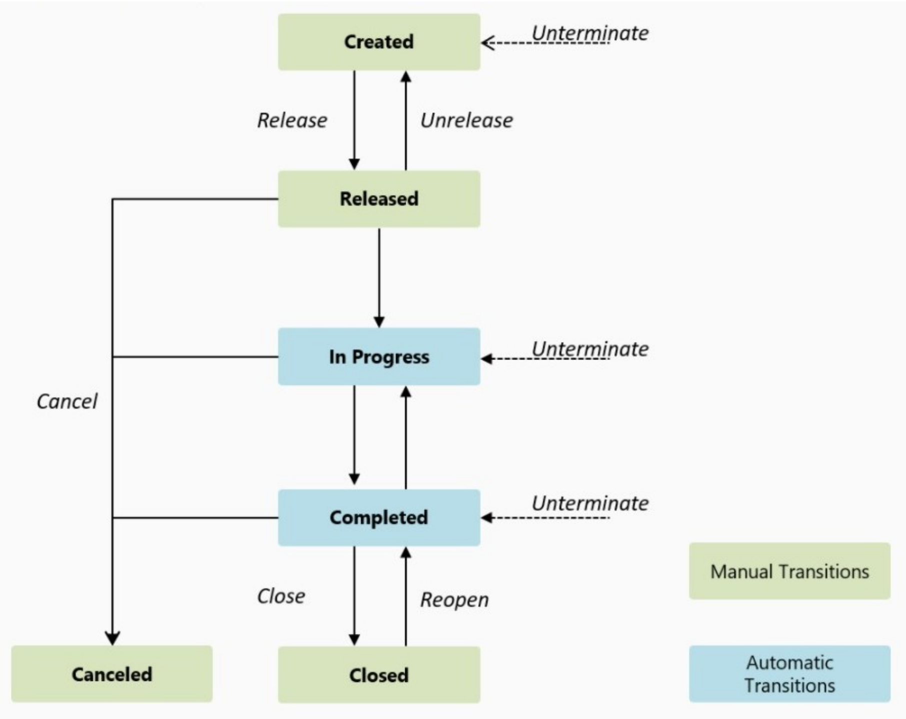


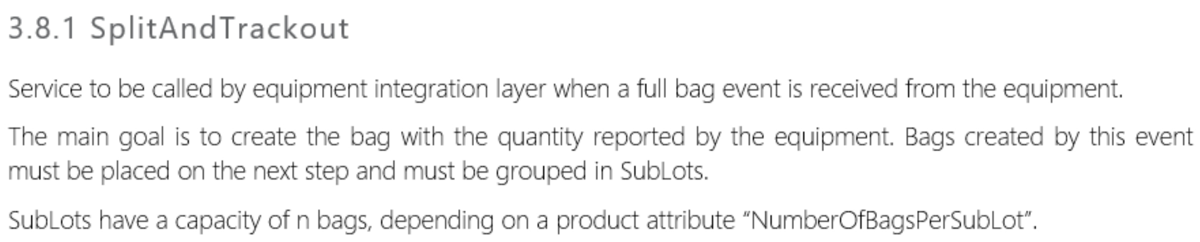
Figure 7 - Production Order state model

3.2 Data recognition

The starting point for this project was a list of topics. This list, previously created by the company, included several subjects that, according to the company's experts, could lead to potential patterns. Some topics were more specific, and others were broader.

The first places to collect data for the patterns study were the company's documents. For each project that would be approached, the documents that would have information related to the topic in study were identified.

There are several types of documents. Technical specification documents serve to provide a functional way to understand how each requirement was implemented, identifying the MES objects involved. These documents are intended as a more technical documentation of the work performed in the implementation and are primarily intended for use by technical teams or advanced users of MES. This type of document contains a lot of information, but only a part of it may be interesting for the study. The customization artifacts chapter and the technical specifications one are the chapters that mainly contain relevant data, and are presented in text, tables, and bullet points format. These data include, in general, explanations of the functionalities or the objectives of the customisation in question, the conditions under which it takes place, the input and output objects, assumptions and the specification of the adopted design. In Figure 8 and Figure 9, it is possible to view two examples of those excerpts. However,


3.8.1 SplitAndTrackout

Service to be called by equipment integration layer when a full bag event is received from the equipment.

The main goal is to create the bag with the quantity reported by the equipment. Bags created by this event must be placed on the next step and must be grouped in SubLots.

SubLots have a capacity of n bags, depending on a product attribute "NumberOfBagsPerSubLot".

Figure 8 - Snip from a technical specification document: text example

from project to project different specifications are addressed, and the way they are written is also different. The documents of this type, as said, are more technical documents, so they sometimes contain unknown references that limit their understanding.

3.8.1.2 Output Object

Output object properties	Description
public Material Bag{ get; set; }	Bag created during the split and trackout service.
Public Material SubLot {get;set;}	SubLot where the created bag was placed. This can be an existing sublot or a new one.

Table 29: Output Object

Figure 9 - Snip from a technical specification document: table example

Blueprint is another type of document produced by implementation projects. This type of document is created at the beginning of the projects, with a first global idealisation of the solution. Their purpose is to record the entire manufacturing context and all customer requirements, as well as an overview of the concepts and strategies of all functional areas in which the MES is involved. A blueprint should serve as a communication vehicle between CMF and the customer.

Another characteristic of written data is that it is not all in the same digital format. Many of the documents are found according to the same template, text document, but in the case of older projects it is likely that they do not follow the same template and for more recent cases they are already embedded in the MES, i.e., accessible through a browser.

Another means of data collection was dialogue with members of the deployment teams. People from each of the projects under study were indicated. People who would have sufficient knowledge to address the topic in question, and more specifically the manufacturing context, the requirements, and the solutions that that project contemplates. It was expected that each of these people would have this type of knowledge, thus allowing the necessary information to be obtained on how it is done, why it is done, and the consequences of the modelling applied in each specific case.

4 Methodology

This chapter presents and explains the methodology undertaken for this project. The project itself is quite particular since it concerns CMF's own product and so the methodology chosen was tailored with the context.

Taking into consideration the duration of the internship and the complexity of the product under study, it would be impossible to contain all the modules of the CM MES within the scope of the project. Therefore, some topics were pointed out, by experienced personnel, which already suggested the presence of patterns. Although the topics were always referent to some subject regarding the CM MES, they could have different coverages.

To tackle a project of this nature an appropriate methodology had to be chosen, so an action research approach was adopted. Following Azhar et al. (2010), action research helps to improve the competencies of stakeholders, through a cyclical process of feedback assessment. In view of the objectives of this project, which basically aim at an improvement of the implementation process by the workers, and given the particular conditions presented, the action research approach seemed the adequate one to be followed. However, until this conclusion was reached, several methods were put under study, which also revealed the cyclical and iterative nature of this approach. Focusing on the goal of discovering and creating patterns, the analytical method focused on machine learning analysis, although this idea quickly lost momentum. Eventually some analytical techniques were used, which were mixed with the next method of design patterns. The latter, as its name indicates, is a method that defines patterns (or giving other names: architectures, solutions) that serve as a model for the creation of something. It is with this same intent that this method was applied, allowing to achieve the identified objectives and to validate the whole structure proposed in the present context.

4.1 Analytic method

The first intention in view of the project objectives would be an analytical analysis to discover patterns. In order to test and find out if this was the best method to apply, one started by choosing a topic from the list available and analysing it. Some projects that might contain information relevant to the subject were listed, and thereafter, the respective documents were collected and the member of the team to be contacted for clarifications was identified.

Regarding the analysis of the first topic, in this case the Partial Track-out, firstly the technical documents of each project were read (a total of seven projects analysed for this topic) in order to understand what this topic was about and how it fitted into the projects; a way to understand the reality of the supposed pattern on the terrain. After this first contact, the particularities that would characterise the various solutions were identified.

It was verified that the topic had a small coverage in what concerns the number of modelling matters that it includes. Despite all the information collected from the documents, this was not sufficient to understand the context where the partial track-out took place, be it the equipment used, the reasons why that solution was applied, or other modelling details that sometimes were not pointed out in the accessed written records.

It was thought to distribute a small survey to the project teams in order to collect some information about the companies and their plants, and therefore, to be able to relate that with the modelling solutions and identify patterns. Information such as how is the production oriented (MTO/MTS), what type of manufacturing processes they apply (discrete/job shop/etc.) or the even the production volume were in the survey. However, during dialogues with some of the projects' members, it was collected, or tried to collect, some answers and feedbacks to evaluate and adjust the survey questions. What was concluded was that the subjects that the questions addressed were quite variable for each company, meaning that they could have different manufacturing processes depending on the product or on the production line, or the collaborators would not have enough knowledge to answer. Thus, it was not worthwhile to find such relations in a global sense, instead these relations were studied for each pattern and written in a more comprehensive way for the modelling process.

After trying to understand how to apply a model to this data in order to identify patterns, based, for example, on keywords, it was concluded that this would not be a very efficient approach given the existing conditions and the required objectives.

However, an analysis that could and was studied was the relationship of the modelling characteristics with the industry segment. This analysis, besides being possible given the existence of a classification of each project at that level, would bring great advantage to the company since the architecture of the deployment services department is divided by those segments.

Another very common technique in the field of analytics is the separation of a dataset to train and test a model. Based on this technique, it was proposed to the company to make an evaluation of the proposed final framework to serve as a validation of the "model". It was possible to obtain feedback from the MES Consultants. These are workers who operate on the MES modelling and end up also being target users of this solution.

4.2 Design patterns method

The approach was then changed, trying an analysis based more on the design patterns defined by Gamma et al. (1994). This way, directing the analysis to a more subjective format and based on the experience of the teams, one started to contact the representatives of the projects. With some base knowledge of the topic, obtained from the technical specifications, some questions were prepared to guide the interviews. However, the most important of this process of data collection through dialogue is the evolutionary and cyclical factor. In other words, following the strategy of the action research approach, after each interview new conclusions were drawn and the questions for the next interview were improved and narrowed. For the remaining projects this cyclical method was continued, as well as for the following topics (consumables and production orders): examining technical documents, formulating questions, interview one project, identifying characteristics and creating more targeted questions, as shown in Figure 10.

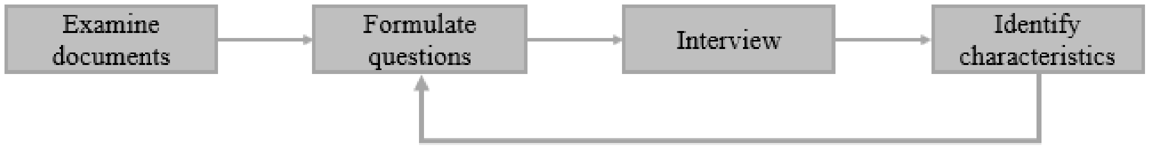


Figure 10 - Cyclical process to extract data

As regards the definition and characterisation of patterns, after the various previous approaches, the format chosen was based on Gamma et al.‘s (1994) template for design pattern. The template encompasses sections such as: pattern name and classification; intent; also known as; motivation; applicability; structure; participants; collaborations; consequences; implementation; sample code; known uses and related patterns. Yet, this definition, not having exactly the same nature of the solutions under study, was adapted. An iterative process took place, where modifications were made as more knowledge on the subject and more information was obtained to build the standards. In the same manner as happened with the interviews, at each pattern, at each analysed characteristic, the current format was re-evaluated, together with the company, and adjusted in the weak points, continuing the process with new patterns. We started from the template already referenced and after successive changes we obtained the final structure, which will be explained in the following chapter. In addition to the classification of the patterns according to these procedures, the idea of an auxiliary scheme emerged during the process to facilitate the perception of the topic (if it is broad enough) and to present a graphical idea of the relationship between the solutions. In other words, to bring together the various options that a worker could choose when faced with a modelling problem. This idea materialised in a schematic mind map which will be explained later. Once again, following the action research approach, with each topic/pattern that was defined adjustments were made to the previous structure in order to obtain a tuned final solution.

5 Results

Throughout this chapter, the proposed structure that will meet the objectives of this project is presented. In addition to the detailed explanation of this structure, the results of the analysis of each topic are also shown. The feedback and consequent evaluation by the company is presented in the last sub-section of this chapter.

It is important to highlight that what is presented here as MES modelling options are **possible** solutions and not the only ones, since the number of projects analysed is small and because as object of study were only assigned projects that were characterized as propitious to bring better conclusions in terms of customizations.

5.1 Framework

Given all the conditions surrounding this study and taking into account the objectives of the project, a solution was conceived. This solution was achieved through the various topics that were investigated. This solution consists of a framework composed of two elements: mind map and pattern frame. Each of them will now be explained.

5.1.1 Mind map

This mind map is a structure in root format that organises information related to the topic. It presents in a light and intuitive way relevant questions that arise around the topic in question, relating the various named solutions. As shown in Figure 11, the mind map is organised in the following way: the featured topic, which is divided into categories, with these branching into items representing, more or less specific, solutions. This format aims at a quick and easy use of this tool.

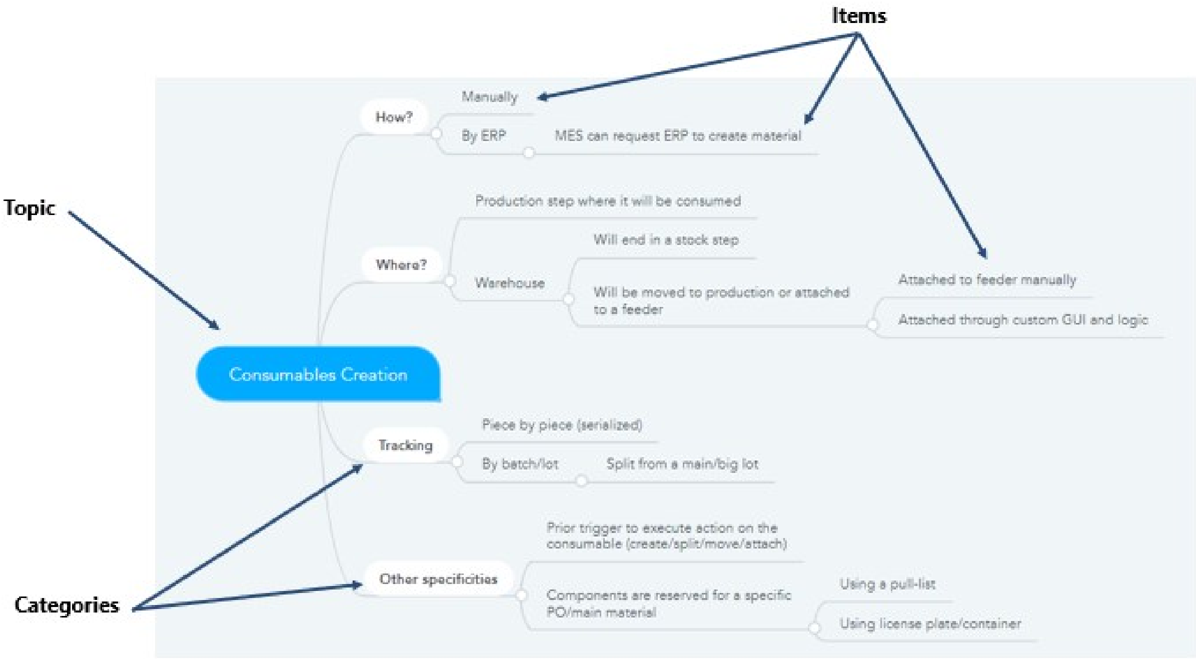


Figure 11 - Mind map example explained

5.1.2 Pattern frame

To complement the mind maps and for topics that are too specific, a pattern frame template was created. It consists of a grid composed by several boxes, each one corresponding to a trait of the pattern. Through these various traits, each implementation solution, generalised as a pattern,

Pattern name BOM from ERP [PO]	**Main characteristics** ERP integration; PO's main BOM
Motivation After the definition of a new production order, the bill-of-materials of the PO needs to be defined and sent to the MES.	**How to recognise it?** Is there a ERP system in the company? Is the ERP the master data system? Are there variations of the BOM per PO?
Applicability Type: integration Applicable to: receive the PO's BOM and split to add to the steps' context; receive it and validate against the BOM already in the MES.	
Implementation Inputs: --- Integration with ERP. It should be the same integration of the PO creation; the BOM that comes from the ERP is normally for the whole process (operations), having the reference where each component will be assembled; the BOM in the MES side can be divided in smaller BOMs per assembly step or a single one; the mapping between the consumption steps in MES and ERP assemble operations must be taken into consideration, either by attributes at the step level or sub-flows; MES step's BOM context must be updated accordingly; to ensure BOM Context is applicable to PO, one can add a key column to identify the POs and ensure that when resolved the BOM context takes PO into consideration; or one can use the PO materials instead and ensure that splits also copy the BOM context entry.	
Consequences Pros: does not need manual input or via master data loader for every new BOM; good in cases with high variability of the BOM's per POs. Cons: may be hard to map the components for the steps; harder customization.	**External systems** ERP
Known uses Industry segment: --- Projects:	**Related patterns** "Route" from ERP [PO]
Remarks: > should be give attention to the source step of each consumable, some assumptions may be needed. >	

Figure 12 - Pattern frame example

is defined and characterised. The traits include useful and important instructions for those who will use this tool, each of which is explained below.

Pattern name – identifies the name, being unique for each pattern; the brackets, “[ ]”, represent the topic where it is embedded.

Main characteristics – highlight the main characteristics of the pattern, working also as key words.

Motivation – recognize what is the principal motivation for the pattern, the reasons or needs why it is done.

How to recognize it? – along with motivation, it helps the recognition of situations where the pattern may fit or may be needed; the questions should be written consistently (positive answers if appliable).

Applicability – specifies when and where the pattern can be applied; also classifies the pattern type (what it represents in the MES, e.g. integration or attribute).

Implementation – specifies the details of how the pattern can/should be implemented; also reveals the inputs needed for the pattern to work.

Consequences – presents the pros and cons of a solution like that pattern, mainly comparing with its alternatives.

External systems – shows which external systems may be associated with the pattern.

Known uses – names some projects that have implemented that pattern; it may indicate in which industry segment the pattern is mostly used.

Related patterns – identifies which patterns could be related with that one; they can be alternative solutions, subsequent solutions, or other patterns that are commonly used at the time of that one.

Remarks – space to add relevant information that does not fit the other fields.

5.2 Topic analysis

As initially mentioned, the topics under study may have different levels of coverages. For the three that were analysed, the first one, partial track-out, would concern a specific solution and therefore resulted in only one pattern frame, while the other two already allowed the creation of a mind map and subsequent pattern frames. For the sake of variety, the second topic, consumables, was only studied at the mind map level, and the third one, production orders, has already covered the mind map and several pattern frames, thus allowing the evaluation and comparison of the various levels of information.

During this section, the several projects will be described, designated as cases for confidentiality reasons. The section is structured by topics and within each are presented the cases analysed, the main conclusions drawn from the combination of the characteristics identified in each project, a mind map of the topic and details of certain specific solutions that have shown interest to explain better. The consumables topic is divided in two sub-topics. All cases studied relate to the topic in question, and only pertinent issues related to it were addressed.

The organization of the characteristics taken from each topic, as well as the analysis of their frequency by industry segment, was done through tables and an example of each can be consulted in Annex A. It is also possible to see, in the Annex A, a snip of the compilation of all the patterns created.

5.2.1 Partial Track-Out

Studied cases

- Case 1

The part of the process relevant in this case, corresponds to the beginning step of the production order. There is a batch material, that will be processed over time, but since the resource processes piece by piece, at a certain time it will be needed a separation of those processed units from the rest of the batch. At this moment, the partial track-out is done, with components assembling included, and the split material will be moved to the next step where exists a material (or it will be created at the first split) to which the split material will be merged. When all the quantity from the initial batch is processed and merged to that new material with the processed units, this one can moved forward.

- Case 2

There is a lot (material) that will be processed in a step (the "PO material"), but the output are sub-lots. Every time there is a track-out, anticipated of a split, the processed units will represent a bag, which will be attached to a sub-lot that will move forward independently. The limit of bags on one sub-lot may be defined. The production order main material (initial lot) is terminated. The inputs are sent by the equipment through an integration entry.

- Case 3

Starting with the production order correspondent batch, the downstream process will be done on smaller pallets. To achieve these conditions without waiting for the completion of all batch, a partial track-out is done, resulting in smaller batches of type pallet. This is happening in the first step of the flow of the production order. An advantage for the customer is that he can report the finished pallets to other systems, allowing the pallet to be moved onward without waiting for the rest of the batch.

- Case 4

There are three main steps/machines. Each one with several consumables. Flow: two steps/machines will send the result to another one, as consumables also, being the beginning steps of the PO. The machines by themselves determines which pieces were finished in good state and which are scrap, but this information needs to be introduced by the operator in the system. The good ones are counted to be tracked-out. Process integrated with the ERP. At every partial track-out (split and track-out), an automatic label is printed. The partial track-out happens for a determined quantity, so that new material is moved onward to feed the consumption point for the next step, instead of waiting until the end of all order. There is a time control of the interval for each split and track-out, which is much easier in this way because is all registered in a single entity.

- Case 5

Production starts with a bulk material, based on the PO. They have a central line with machines and other lines for manual operations. At the end of those manual workbenches, they only move the material forward to the next step when the whole batch is processed. For the customer, it is important to register the number of units done by each operator and the time they took. When a shift ends, if the operator had not finished the batch in-hand, he needs to split the batch and track-out one part of them to report the units completed by him and leave the rest dispatched for the next operator.

- Case 6

It has a similar process to the Case 4 in one process, and another one more like the Case 5, yet with a slight difference. Regarding this last process, the tracking is made for the whole line, not for every operation. It is modelled in one step only. The split and track-out can be used for shift change reasons, but the main difference is that when the operators are tracking-out a material, they need to indicate how many consumables were used and from which batch were taken. So, this particularity needs to be fitted in the custom GUI when doing a split and track-out.

- Case 7

In this project, the partial track-out happens between the winding and pre-assembly operations. Each operation corresponds to one step, and physically they are connected by a conveyor that allows a continuous flow of materials from one to another. Even though the stream is piece by piece, by several reasons from the customer side, it is not possible to model in only one step. The materials that get out from the first step are originated from an assembling operation. In the MES the material on the winding step is in the form of a batch, thus, because of that and the fact that the modelling is made in two steps and the processed materials of one goes directly to the other, it raises a problem on how to handle on MES the already processed units. Since the costumer wants to have the system modelled as close to reality as possible, the necessity of doing splits and track-outs regularly appeared. The solution of tracking every piece/unit was not worth it because the actions on the MES are to be taken manually (by an operator) which would make unviable a solution like that. To solve the problem, when the operator goes to the interface, he performs the partial track-out to move the processed units given by the resource to the next step. Every time a material from the same initial batch is tracked-in on the second step, it is merged with the other material already there. It will result in having three batches along this process: one at the winding step in-process, another at the pre-assembly also in-process and the other one that will be between these two, corresponding to the quantity that was split and tracked-out and will merge the remaining units. Something that may happen is a shift change. When it occurs, the operator should track-out the completed units from the second step, performing another partial track-out, and on the next shift when all quantity is processed and tracked-out, both materials are merged again into one (the production order lot) before moving to the following step. The only identified entity is the lot, that must be in process in two steps and with the possibility to move quantities on demand frequently.

5.2.2 Consumables

Creation

Main conclusions

- Most of the consumables are created after trigger of the ERP.
- Most are identified as a batch/lot.
- Some are created in the warehouse area and others in the production, upon a global release (with PO/BOMs/consumables/etc.) from the ERP.
- It is common for the consumable created in the warehouse to end in a stock/supermarket step (not source step neither feeder) waiting to be consumed.
- Sometimes it is required to reserve a certain piece or batch of consumables for a specific PO or material.
- At times, the consumables are created right in the step where they will be consumed.
- It could also happen that a trigger occurs previously to the consumption of the consumables so that these could be processed in time.
- In case of big initial lots of consumables, it could come to occur a split from that one, so the lot is kept in the traceability.

Mind map

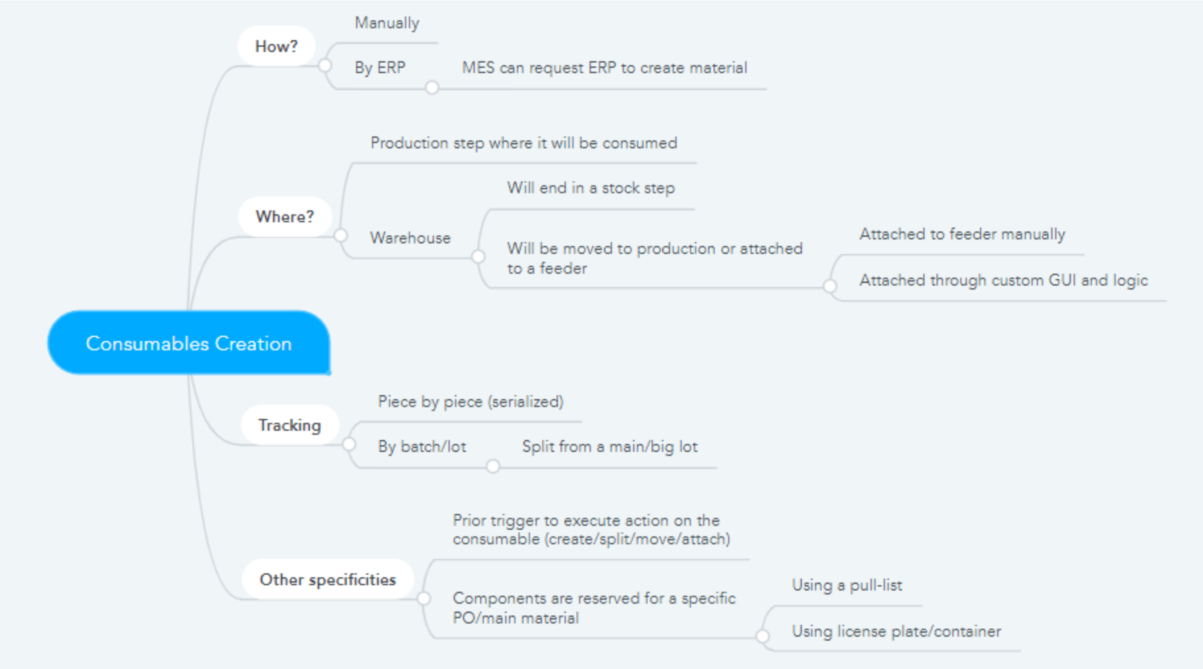


Figure 13 - Consumables creation mind map

Relevant questions that come to light when talking about the creation of consumables are: how are they created? Where? What type of tracking is done?. To represent these questions and their answers, a mind map is presented. Following, we explain the mind map since it is made with few words.

- How?
  They are created manually by an operator, that inputs the data needed, or by order of the ERP. In the last case, it could take place that MES requests ERP to send the order to create the material.
- Where?
  Consumables are created or in a production step, right where they will be consumed, or in the warehouse area. It happens, after the raw materials pass through some flow path or not, for them to end in a stock step (also called supermarket step, where they just stay waiting for being grabbed for consumption), but also, in some cases, they will be redirected to a step in the production area or attached to a consumable feeder. This attach can be made manually or by a customized GUI (with its own custom logic).
- Tracking
  The type of tracking applied to the consumables were serialized and by batch/lot. This means that in a same case it could happen that one material would be tracked as a batch and another one as a single piece. For those tracked by batch, they could be originated from a bigger lot, via split.
- Other specificities
  Other relevant modelling worth to emphasize are: the trigger by a material in a previous step that would drive the execution of an action on the consumable, for example, it could trigger its creation or the attach to a feeder; and the existence of a relation between the main material and its consumables that would assign these to be used/assembled only in that material. Two cases of this relation are the use of pull-lists and license plates or containers.

Studied cases

- Case 8

The ERP sends the information to MES of the entrance of the consumables in a stock room and these materials (batches) are created in MES in this step. Later, they are confirmed by an operator in a custom GUI, moving them to the next step (it could be some components preparation process or not) and finishing in the consumable feeder source step.

- Case 9

In a first case, the raw material is created (in the same step where it is consumed) and assembled automatically by the code, after the operator identifies the material (lot number, heat lot number and others) when executing the track-out.

In a second case, when facing an assembly line, the MES has a trigger point given by the main material (before the assembly moment), in which it will trigger a message to the ERP with a Pull-list (list of materials and quantities of the various BOMs of the main material). The pull-list will be associated with the warehouse materials that will be consumed by that main material (strictly by that one). When the Pull-list is sent **to the ERP**, the materials are created and remain in a step in the warehouse until they are moved to another step of stock waiting to be used. Identification is done material by material, each containing the right quantity for assembly.

- Case 10

The creation of consumables is led entirely by the ERP, which sends a message to the MES with the necessary information. There is also the possibility that MES requires to the ERP (for lack of material) permission to create components. The material for the start of the process is created in the initial step, in batch and with the various sub-materials ('wafers'), waiting to be consumed. Other consumables are also created in the steps where they will be consumed and identified by batch/lot.

- Case 11

There are different cases in this project: WorkScan, SupermarketScan and SupermarketAuto.

WorkScan - The ERP creates a License Plate (this will correspond to a container in the MES) with the various consumables to be used in a specific PO. This License Plate is then sent to the MES, which creates the container and the respective materials contained therein (with the original batch references), in a stock step waiting to be consumed. These materials are identified piece by piece and they are linked to their PO.

SupermarketScan (solution still under development) - The ERP updates MES about the batches, and respective quantities, that are sent to the "supermarket shelves", a step that will serve as stock for the operators to use. These materials are identified by batches and thus created like that in MES.

SupermarketAuto (solution still under development) - There is no identification of the batches in this case (due to the mixing of them), but the materials are created as in the previous case.

- Case 12

The materials arrive at the warehouse and the ERP sends to the MES the batch reference of each product and the material is then created (a new product is also created if it does not yet exist) on a warehouse step. After operator action, the material would move to the consumable feeder (attached). Along with this ERP message, the BOM is also sent for this PO product and the corresponding entity is created in MES. There was an intention to track liquid consumables but given the nature of the MES nothing was modelled in this regard.

- Case 13

The creation of the components starts with the operator creating large batches. After reading a barcode (with the quantity) in a special GUI, the following logic will happen by customization: split the batch according to the quantity; move to the source step and attach to the consumable feeder. It works this way with all components.

Details of some features

When there are raw materials that need to be reserved for a specific PO or main material, the solution can go across different names, like pull-list or license plate. To ensure this requirement, a possible solution could be the creation of a container with its own identifier and the materials inside it; these materials are connected to the specific PO (for example). Another option is to associate a pull-list (list with the names of the materials needed) to the specific material and then get the materials for the assemble checking the pull-list and the materials in a stock step.

For cases when a big lot of raw materials is registered in the MES and this have not the appropriate size for the following processes in the plant, one solution in consideration is the split of the big lot into smaller batches. In this way, the reality is closer to the modelling and the traceability is kept.

Consumption

Main conclusions

- Most of the consumptions are done at the track-out, automatic or by customization.
- Both *explicit*/*explicitAdd* and automatic, as types of assembling, are commonly applied.
- When using Pull-lists or License Plates, in the moment of consumption, the materials associated to these attributes are always checked against the BOM.
- Additionally, for the License Plate case, the operator confirms that the LP on MES is the one he is using.
- There is a case where the production process (with several steps) is modelled as only one step, and the consumption is made only once as the material ends that process.
- Combine is also one option used to consume the consumables without the need of a BOM and it also keeps the genealogy.
- In a case where there is equipment integration (IoT), the assemble is done when the material is *InProcess*.
- Another case to consider is when there are work cells, which integrate a step and simultaneously have their own steps.

Mind map

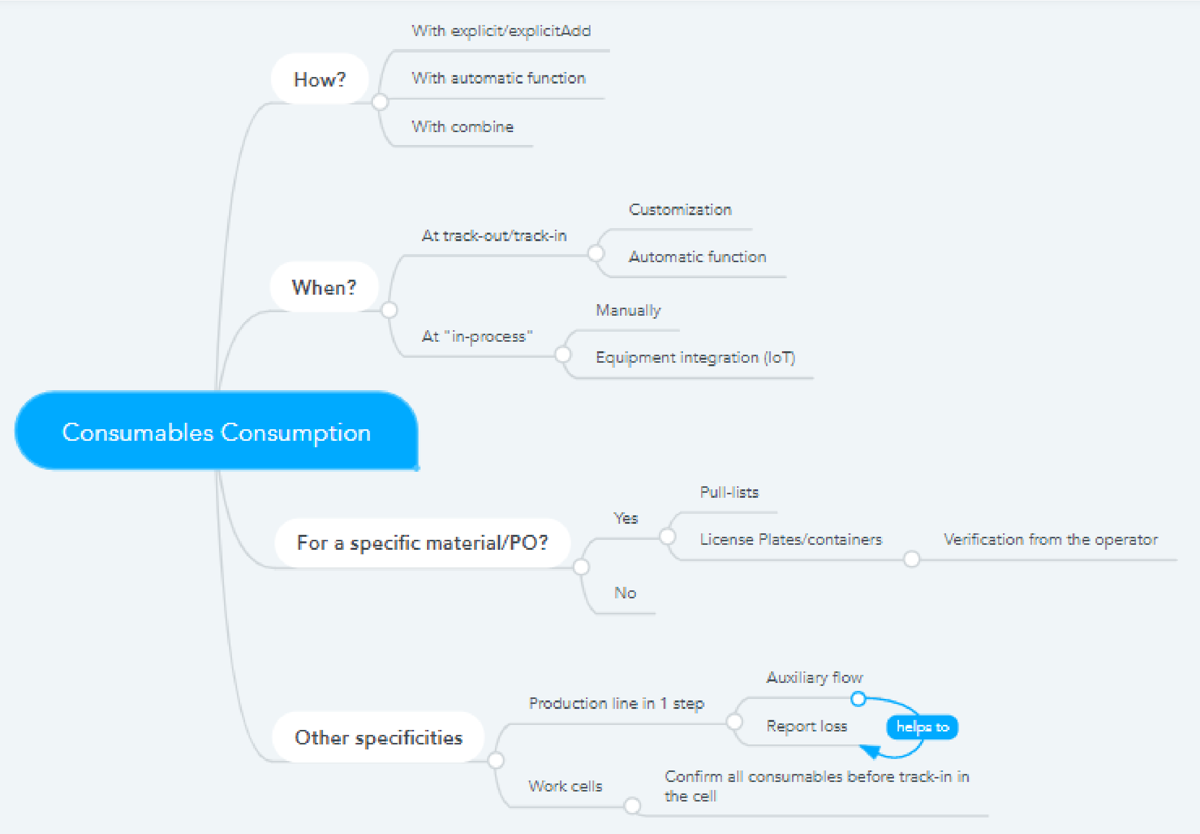


Figure 14 - Consumables consumption mind map

The Figure 14 presents a mind map regarding the consumption of the consumables in its several dimensions.

- The consumables are assembled to the main material with the automatic or *explicit*/*explicitAdd* functions but are also consumed with the combine feature, that also keeps the genealogy but does not require a BOM context.
- Concerning the moment of consumption itself, it happens right after the track-in or right before the track-out. To go on this way, the process must occur using the automatic assembling function or through a customized logic. The consumption may occur as well during the “in-process” state, being this the procedure for a manual assemble or an assemble in case of integration with equipment, also called IoT.
- An important difference to point out when consuming is if the material/PO should be assembled with a specific consumable or not. In positive case, the solutions applied were the pull-list and the license plate techniques, the last containing an extra verification from the operator that ensures that the license plate from where he is consuming is the same in the system.
- Other relevant specificities that drew attention to were: the case of a production line (having several consumption points) modelled only in one step, where it was also created an auxiliary flow to help reporting losses; and the case of working cells, where the operator checks all the consumables for the cell before the track-in of the main material in the cell’s steps (more detailed explanations about these two cases in “Details of some features” section).

Studied cases

- Case 14

A production line with multiple consumption points is modelled in MES by a single step, with only one BOM (with all the components for that line). When tracking out a main material all consumables referenced in the BOM are consumed through the combine. In case a loss is reported, it is necessary to designate the point in the line where this happened (through custom GUI), indicating in an auxiliary flow (which contains the various steps within that production line and their respective mini-BOMs), so that the MES collects the materials from the mini-BOMs prior to that step, inclusive, perform the consumption (in this case, combine) of only those consumables and then record the loss in the main material.

- Case 15

In the first case, as mentioned in the other sub-topic, the consumables are consumed automatically (by customization) when the track-out is done (explicit method).

In the second case, the main material has the Pull-list associated with it (custom attribute), which indicates the exact components to consume for that material (reason why it has to be customized). When the track-out is done, MES will automatically select the consumable materials that are on the Pull-list (checking against the BOM of the step) and assemble them (explicit).

- Case 16

In most cases, consumption is done through integration with equipment (IoT), which happens during the "in-process" state, and the MES records the component's usage and the assembly.

- Case 17

In Workscan case, through customization, when the operator performs track-out, the MES automatically performs the assembly. However, the operator has to validate the License Plate (LP) that he is using and the MES consumes the materials from that LP (also confirming with the BOM), after verifying that it is destined to the PO in process (PO has consumable materials that are in containers, these containers with the associated LP).

In the supermarkets cases there is no modelling yet.

- Case 18

Component consumption is normally done with the out-of-the-box features of MES.

- Case 19

There are two cases. The first happens in the first step of production, where an *ExplicitAdd* of the material is made.

In the second case, there are two cells, within a step, and with several "mini-steps" included in them. The consumables for these cells are all presented (according to the BOM) to the operator to confirm them as being ready to be used, i.e., being in the consumable feeders, before the track-in is done (not impeding). The assembles within these cells are done by *AutomaticAtTrack-Out* for each "mini-step".

Details of some features

One issue taken as pertinent to break down and explain better is the modelling of a production process with several resources and consumable points, with a fast output rate. The problem noticed here was the already referenced output rate and the need to track the operators in the resources. The solution that came out for this problem was the aggregation of all the steps into one, since it would be unfruitful to have the operators to interact with the MES for every piece and in every step, and the creation of an auxiliary flow that would be completely disconnected of the rest of the plant. This auxiliary flow, having represented all the steps of the production line, allowed to have the traceability of who were in which resource, in which time and also helped to ensure that the right consumables were used in case of a loss. To explain this better, we need to know firstly how the consumption is done. Thereby, a normal procedure would be:

a material enters the "big" step (track-in) and when is ready to end the last processing the track-out is actioned and automatically, by customization, before executing the actual track-out, all the consumables in the BOM of that step are assembled (or in this case combined). Well, when a loss of any main material is reported before the track-out, a problem arises. To be more exact concerning the consumables used in that material lost, the auxiliary flow will help in the way that the operator can identify in which step of production the loss happened (in a custom GUI) so the customized logic can grab the step identified by the operator, search in the BOM which materials were consumed until that step, including, do the consumption of those, in this case, combining the materials, and only after that report the loss of the main material (with the consumables aggregated with it). The reason why is used the combine function is because the BOM in the BOM context is set as reference, since it was built to have in the step column the names of the steps of the auxiliary flow and not the name of the "big" step (this would be the normal approach for a BOM context).

Another relevant situation is the existence of work cells and its modelling. In the case analysed, there were two cells with several steps inside and several consumption points as well. What happens in the real plant is that most of the times, one worker would do various tasks in that cell, supporting the requirement of showing to the operator, before starting a process, all the consumables that would be needed for all the steps inside the cell, so that he could prepare them before starting the job, minimizing this way non-value-added time.

5.2.3 Production Orders

Main conclusions

- Every case studied had an integration with ERP, concerning the POs.
- In most of them, the ERP also sends the BOM for the product in the PO.
- The majority of the projects create the materials after the PO.
- And the bigger part defines one material with the total quantity.
- Most of the cases have the PO closed automatically.
- The flowpath used is commonly inherited from the product.
- It was not identified any significant relation between the industry segments and the modelling characteristic.

Mind map

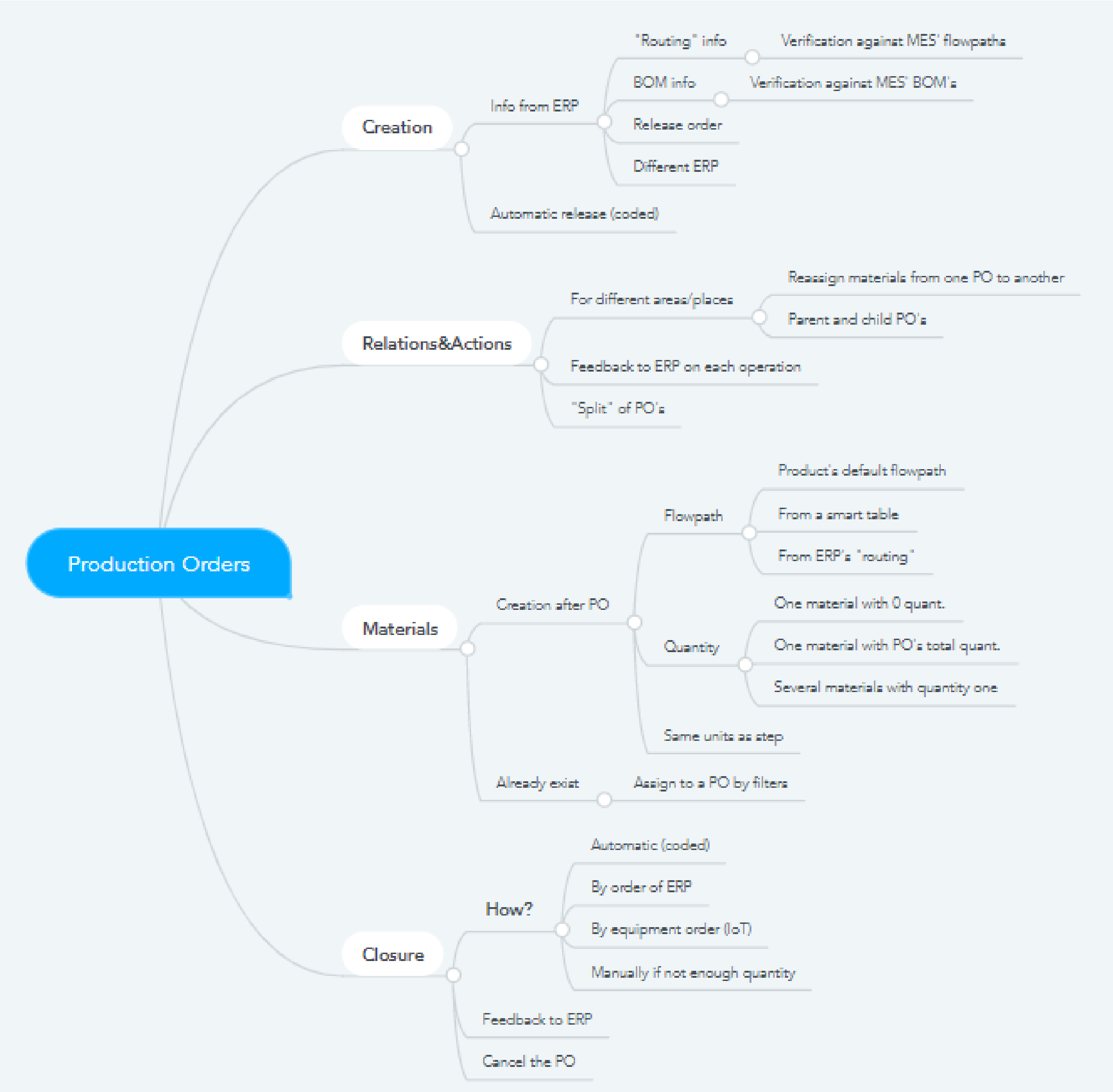


Figure 15 - Production Order mind map

The mind map presented depicts the modelling approaches regarding production orders. The four major concerns are: the creation, the relations and actions, the materials, and the closure. When talking about the creation of the production order, the customization related can be for the case when the information for the creation comes from the ERP, by integration. On this regard, beside the mandatory data for the creation of the PO, it can be also received from the ERP the "routing" information (normally represents the key operations needed for that product, but it does not necessarily resemble to the MES flows) and also the BOM information for that product. These extra data can be used for verification with the entities created in MES à priori. Likewise, from the ERP it can be received the order to release the PO. Still in the subject of ERP integration, there is a special case for when the ERP has a very different structure and for that reason it requires almost a total integration customization.

Some relations that deserve attention, concerning customizations, are the fact of having POs for different areas or production lines, that can imply materials' reassignment to POs or a relation of parent and child POs; the requirement of having to send a feedback to the ERP on each operation done on a material assigned to a PO, including the reference of that PO; and the case of split of POs, that is not a real action of split, but its essence is the same because it will be created a new one (with a relation somehow with the other) with the quantity specified and the other will be decreased in that quantity also.

Talking about the materials that should be assigned to the PO, there are occasions where they already exist, and for the specific case when there are several POs in the list to be concluded, they can be assigned applying filters to that list of POs, in order to choose one. On the other hand, most of the times, the materials are created after the release of the PO. Regarding this subject, three characteristics deserve attention, being them the flow that the materials are going to follow, the quantity that each have and how many are created and its units. The flowpath applied can be the default flowpath defined in the product that will be produced for the PO; it can be the one defined in a smart table after resolving the table with, for example, the production line and the facility; or it can be based on the ERP's "routing" information. About the quantity, many of the solutions modelled create one single material (at the beginning), some with zero quantity and others with the total quantity of the PO. Other solutions include the creation of several materials, normally as many as the total quantity of the PO, with unitary quantity each. For the units of the materials created, they can be, if not chosen by default, the same as the units of the step.

Concerning the closure of the PO, it can be done by code, so without manual action; after order from the ERP to close it or, for the cases where there is a lower tolerance and the PO's quantity is not achieved, manually. It may be relevant a feedback to the ERP informing the closure of the PO. And in cases of need, a cancellation with condition may well happen.

Studied cases

- Case 20

In this factory, production is done continuously, non-stop, which leads to a particular case: since materials are not created in bulk nor have any information regarding their PO, instead of choosing the materials that will be assigned to the PO (or created for it), the materials created will "choose" a PO to which they will be associated. New POs are frequently created, which have a start date and an end date (the latter is just a reference). Through integration with ERP, which sends the order to create the POs, the MES receives all the data, creates them and releases them right then and there. The POs are then on a list, waiting to have the materials associated with them and subsequent finalization. On the materials side, which are constantly created with the formation of the raw rim, a PO is assigned. However, there are several POs on the list, which leads to the need for criteria to choose one. The POs that are already closed and those that do not belong to the area and product in question are filtered out, then the remaining ones are sorted in order from most recent to oldest (according to start date) and the PO to which the next material will be assigned is chosen. For each new material, this process is repeated. The ERP sends several POs to various production points, i.e., to produce several products in different areas. Some of the POs will be followed by others, which causes the "finished" materials from one to move to the beginning of another. The reassignment of materials between POs is due to three reasons: the ERP receives the order to close the old PO; the materials arrive in a new area that is no longer included in the flow of the old PO, but in a new one; a change in priorities where a new PO with a more recent start date is created. After one of these reasons is given, there will be a reassignment of the material to the new PO, but only when an operation is triggered on that material (track-in, move-next, assemble, etc.). The choice of the new PO always follows the criteria explained above. Once the MES receives a closing order from the ERP, it is stored in a table so that it can proceed when there are no more materials in the middle of the process, that is, not completed in that PO. There is no configuration regarding BOMs.

- Case 21

There is integration with the ERP. It sends the PO data (quantity and product) plus the BOM for that PO's product to the MES. There is only one flow, and the range of products is quite low. POs are usually in very large quantities (tens of thousands). The PO is created and then the corresponding material is created, with the entire quantity, in the step indicated in the default flowpath for that product. There are no dependencies between POs. Their closure is automatic when all the respective sub-lots (derived from the main material created initially) are shipped.

- Case 22

There is a hierarchy of POs. There is one parent PO and several child POs, which represent the layers, which are the different components produced. The components can have an expiration date. These layers are produced independently and will ultimately be aggregated to form the FG, according to the BOM (layers are represented in the BOM as consumables). The MES ensures that only layers from the children POs of that parent PO can be consumed. ERP integration is in place. A requirement was made to track each operation of each step, associating it to the corresponding PO and then send it to the ERP. The products are created previously, in a different integration. The BOM comes together with the PO. The units of the PO will be the same as the initial step given in the route, coming from the ERP.

- Case 23

Case 23 reveals value for study because it has integration with an ERP system, but a not so common system, Navision. For this very reason, the structure and architecture of the integration had to be thought and written practically from scratch, not using tables or other MES entities (as is done in other cases), but building the code with queries to obtain the necessary information. For modelling, the ERP launches the POs to the MES, which creates the respective entities. First the synchronization of the products is done and later, in the same synchronization, the information of the BOMs and the POs are transferred. Materials are created after the POs, with zero quantity. POs can be created for FG or for SFG, and there is no relationship between them. Regarding the end of the PO, when the required quantity is reached, automatically, through code, the PO is closed. It can eventually be opened again to remove a material from it, either because of the need for rework, or because the material must be given as scrap or some other defined reason.

- Case 24

In this case there is also integration with ERP. The project is still at a very early stage and therefore not all solutions for the requirements have been defined, nor have the requirements been fully raised. At first, the materials will already be created when the POs are passed to the MES and will be assigned later. The ERP sends to the MES through the integration the name of the PO, the product, and the quantity to be produced. From there, MES associates the POs to the materials in the respective flows and steps according to the product. All the logic and rules regarding the dependency and order of the POs are handled by the ERP, but for MES they are independent, and no rules are contemplated. The POs will be automatically closed (by code) as the required quantity is reached. At the time of this closure, this notification will also be sent to the ERP.

- Case 25

There is integration with ERP, which sends the product, the quantity to be produced, the BOMs and the route, which encompasses the operations that this product will go through. In MES, these operations correspond to sub-flows with one or more steps. The various operations that the product will go through vary according to the PO/product, however, each operation is always the same and is already defined in MES a priori. Upon receiving such route, MES will aggregate the respective sub-flows to a parent flow. After creating the PO, the materials that will belong to it are also created. This can happen in two ways. One, more frequent, in which only one material is created with the total quantity of the PO, and another in which as many materials as the quantity of the PO will be created at the same time, each with unit quantities, that is, in a serialized manner. A split PO may occur, on the ERP side, which in turn will also imply an adjustment on the MES side. This adjustment consists in creating a new PO with the quantity that was split and reducing the quantity of the old one, and this information is sent by the ERP. This rule is still under development, but it will also be necessary that these POs are related in some way. Likewise, there may be a relationship between POs for cases in which one will handle the materials of the other. To cancel a PO, the procedure will be to reduce the quantity of the PO to zero, however, it is necessary that the consumables defined for that PO are already at zero or finished. At the end of the line, the material is shipped and when this moment occurs, if it is the last material in the PO, the PO will be closed (automatically). The modelling regarding losses has not been thought through yet.

- Case 26

There is integration with the ERP. It sends the product and the quantity to be produced. It also includes the production line and the facility where the PO concerns, the planned start-end date, the due date, the material type to be created and the BOMs. In this project, per the customer's request, the POs should be called Manufacturing Orders (MO). The PO is created. Using a smart table (created on purpose), which contains the relationship between the flow to the PO and the products and production lines, the corresponding flow and therefore the initial step are taken. If there is no corresponding information for the production line, MES assigns a flowpath by default. With this, the material for the PO is created, containing the entire PO quantity. The dates sent by the ERP are only for reference, for information purposes, although there may be further developments on this subject. There is another smart table that includes sub-resources options that you can choose for each PO, within that production line. There are no dependencies between POs. In this project there is integration with the equipment (IoT) in some lines. In these cases, the equipment itself recognizes when the PO has reached the required quantity and sends the MES the order to close the PO. Where there is no IoT, or in case this function has been disabled, this closing has to be done manually.

- Case 27

There are only 5 integrations in the whole project. One of them is from ERP to MES, where the PO information is sent with the product and quantity. The product identifies the default flowpath and the step where the material for the PO will be created. This material contains the entire quantity needed by the PO. There are four other integrations, from the MES to the ERP, at each move-next that is made; at each scrap that is registered; at each assembly and whenever there is a shipping of material. Likewise, when the PO material is shipped (there is only one, in principle), it is automatically closed. As far as losses are concerned, there is no rule that limits the closing of the PO, so many losses can be registered. There are no dependencies between POs.

- Case 28

There is integration with the ERP, which sends the PO data (product, quantity, and dates) to the MES, including the BOM and route. These last two are used to check with the entities already created in the MES a priori if there is consistency, otherwise it would give an error. It is also up to the ERP to send the PO release order to the MES. As soon as the release is executed, a zero-quantity material is created in the default flowpath step for the product in question. This material will follow its course, where it will go through various assembles that will add quantity to units (*explicitAdd*). There is no dependency or relationship between POs. The closing of the PO is done automatically and is reported to the ERP.

- Case 29

There is integration with the ERP, which sends the PO data (product, quantity, and dates) to the MES including the BOM and route. These last two are used to check with the entities already created in the MES a priori if there is consistency, otherwise it would give an error. It is also up to the ERP to send the PO release order to the MES. As soon as the release is executed, a zero-quantity material is created in the default flowpath step for the product in question. This material will follow its course, where it will go through various assembles that will add quantity to units (*explicitAdd*). There is no dependency or relationship between POs. The closing of the PO is done automatically, as soon as the quantity of the PO is reached (and that there are no uncompleted materials). In case this quantity is not reached due to any losses, it will have to be closed manually.

- Case 30

This case has a particularity. The production process is based on a raw material that is transformed along the flow, however, in the MES a material was modelled that always has the same name and changes product. Precisely because of this product change, several POs are required for the entire process. POs are then created for each different "product" of this material.

5.3 Company's feedback

In order to have a more encompassing and cross-cutting validation of the proposed structure, the company's MES Consultants were asked to look at the mind maps and pattern frames and comment on the structure, applicability, and design of the solution. Some questions were created in order to guide the collection of opinions. The questions focus on issues like the usefulness, understandability, and scope of the framework. It is possible to see these questions in Annex B. Five responses were obtained and, in general, all pointed in the same direction. The main conclusions drawn were:

- The framework is presented in a user-friendly way, however it could be improved in what concerns text through bullet points or tags for quick access and through the use of colours to identify each topic. Linking the mind maps to the pattern frames or present quick information about each item was also hinted.
- The information was overall clear, although it could use more direct names in the pattern frame traits like "pattern recognition" instead of "how to recognise it?".
- Mind maps address the main issues, according to respondents, but do not cover all the problems that may arise.
- The information presented and the very way it was presented brought results, in the sense that it raised different points of view or revealed details that had not been thought of in a real project situation.
- Regarding the importance of the framework for the modelling process, the answers were congruent and emphasised the value of a structure like this. Advantages such as a better learning path, leveraging knowledge from past solutions, and more value drawn from customers within the time available were highlighted.
- Overall, with the present amount of information, the content is understandable, but for better and faster perception it was suggested to add diagrams to the pattern frames.

6 Conclusion and future research

This dissertation focused on identifying and creating patterns for MES modelling and, at the same time, on the whole process up to this result. The aim was to figure out formats to present the patterns and to organize that information in order to characterize and identify them in such a way that it would be useful for current use.

This process was based on an action research approach, which allowed for gradual and progressive data collection; gradual because it was done through interviews with members of each project studied, for each topic under analysis; progressive because each interview besides serving its purpose of capturing information, also fostered the learning and integration in the context of the MES system.

The approach taken also made it possible to attempt various methods that would enable the creation of better standards or the model of these. An analytical method was initially adopted, seeking to relate the various features of a given topic to each other or to other factors. However, this attempt was quickly aborted due to the whole context of data arrangement, data gathering and the defined objectives, which would make this solution costly in terms of time and not very advantageous for the company. With the development of the analysis through the analytical method, perceptions and ideas were created culminating in a design for the application and creation of standards. This final design, called the framework, is aimed at MES modelling topics and consists of two tools. The first is a mind map that allows a quick contextualization of the topic and recognition of the main issues to consider in an implementation process, as well as several solutions. The second tool, based on object-oriented design patterns, shows in a non-succinct but schematic way what characterises a given solution. It identifies why it exists or how this pattern can be recognised, where it can be applied and under what conditions, provides details of how it should be implemented in the system and also exposes advantages and disadvantages that this solution may present. Furthermore, it includes, derived from a specific analysis, in which industry segment this solution can be most relevant or most found.

All the work regarding the three topics of the MES was developed and at the end it was delivered to the company to evaluate and return an appraisal about the structure, which was generally positive. Some improvements and suggestions were pointed out. It is possible to say that the approach chosen was fruitful, since the results were appreciated by the company.

Although it appears that the objectives were met, it was recognised that there was much work that could follow on from this project. Namely, to investigate further the way records of each project are made, trying to link this structure with new cases that arise, in order to automatically, or more easily, update the existing patterns or create new ones. Another study that could complement this one, enters the temporal field and should investigate the impact that customizations have on each project, highlighting the cost-benefit of making such features available out-of-the-box in the MES system.

References

Alexander, C., Ishikawa, S., & Siverstein, M. (1977). *A Pattern Language: Towns, Buildings, Construction*. Oxford University Press.

Ashton, K. (2010). That ' Internet of Things ' Thing. *RFID Journal*. http://www.rfidjournal.com/article/print/4986

Avison, D. E., Davison, R. M., & Malaurent, J. (2018). Information systems action research: Debunking myths and overcoming barriers. *Information and Management*, *55*(2), 177–187. https://doi.org/10.1016/j.im.2017.05.004

Avison, D. E., Lau, F., Myers, M. D., & Nielsen, P. A. (1999). Action research. *Communications of the ACM*, *42*(1), 94–97. https://doi.org/10.1145/291469.291479

Azhar, S., Ahmad, I., & Sein, M. K. (2010). Action Research as a Proactive Research Method for Construction Engineering and Management. *Journal of Construction Engineering and Management*, *136*(1), 87–98. https://doi.org/10.1061/(asce)co.1943-7862.0000081

Baskerville, R., & Wood-Harper, A. T. (1998). Diversity in information systems action research methods. *European Journal of Information Systems*, *7*(2). https://doi.org/10.1057/palgrave.ejis.3000298

Beck, K., Coplien, J. O., Crocker, R., Dominick, L., Meszaros, G., Paulisch, F., & Vlissides, J. (1995). Industrial experience with design patterns. *Proceedings - International Conference on Software Engineering*, 103–114. https://doi.org/10.1109/icse.1996.493406

Burstein, F., & Gregor, S. (2002). *The Systems Development or Engineering Approach to Research in Information Systems: An Action Research Perspective*. https://www.researchgate.net/publication/2899126

Critical Manufacturing - Critical Manufacturing | Company Overview. (n.d.). Retrieved May 26, 2021, from https://www.criticalmanufacturing.com/en/company/overview

de Ugarte, B. S., Artiba, A., & Pellerin, R. (2009). Manufacturing execution system - A literature review. *Production Planning and Control*, *20*(6), 525–539. https://doi.org/10.1080/09537280902938613

Dixon, D. (2012). Analysis tool or research methodology: Is there an epistemology for patterns? In *Understanding Digital Humanities*. https://doi.org/10.1057/9780230371934

Dorsemaine, B., Gaulier, J. P., Wary, J. P., Kheir, N., & Urien, P. (2016). Internet of Things: A Definition and Taxonomy. *Proceedings - NGMAST 2015: The 9th International Conference on Next Generation Mobile Applications, Services and Technologies*, 72–77. https://doi.org/10.1109/NGMAST.2015.71

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). *Design Patterns Elements of Reusable Object-Oriented Software*. Addison-Wesley. https://doi.org/10.4324/9780203583159-18

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1993). Design patterns: Abstraction and reuse of object-oriented design. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *707 LNCS*, 406–431. https://doi.org/10.1007/3-540-47910-4_21

Gao, Q., Li, F., & Chen, C. (2015). Research of Internet of Things applied to manufacturing execution system. *2015 IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems, IEEE-CYBER 2015*, 661–665. https://doi.org/10.1109/CYBER.2015.7288019

Hinchey, P. H. (2008). *Action Research Primer*. Peter Lang Publishing Inc.

Johnson, R. E. (1992). Documenting frameworks using patterns. *Conference on Object-Oriented Programming Systems, Languages and Applications*. https://doi.org/10.1145/141936.141943

Kock, N., Avison, D., & Malaurent, J. (2017). Positivist Information Systems Action Research: Methodological Issues. *Journal of Management Information Systems*, *34*(3), 754–767. https://doi.org/10.1080/07421222.2017.1373007

Lau, F. (1997). A Review on the Use of Action Research in Information Systems Studies. In *Information Systems and Qualitative Research*. https://doi.org/10.1007/978-0-387-35309-8_4

Lee, E. A. (2008). Cyber physical systems: Design challenges. *Proceedings - 11th IEEE Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing, ISORC 2008*, 363–369. https://doi.org/10.1109/ISORC.2008.25

Naoum, S. G. (2001). Dissertation research and writing for construction students. In *Dissertation Research and Writing for Construction Students*. https://doi.org/10.4324/9780080467047

Noble, J. (1998). Classifying relationships between object-oriented design patterns. *Proceedings - 1998 Australian Software Engineering Conference, ASWEC 1998*, *1998-Novem*, 98–107. https://doi.org/10.1109/ASWEC.1998.730917

PATTERN | meaning in the Cambridge English Dictionary. (n.d.). Retrieved June 26, 2021, from https://dictionary.cambridge.org/dictionary/english/pattern

Rezgui, Y. (2007). Exploring virtual team-working effectiveness in the construction sector. *Interacting with Computers*, *19*(1). https://doi.org/10.1016/j.intcom.2006.07.002

Rojko, A. (2017). Industry 4.0 Concept: Background and Overview. *International Journal of Interactive Mobile Technologies (IJIM)*, *11*(5), 77–90. https://doi.org/10.3991/ijim.v11i5.7072

van Kranenburg, R., Anzelmo, E., Bassi, A., Caprio, D., Dodson, S., & Ratto, M. (2011). The internet of things. *1st Berlin Symposium on Internet and Society*.

Zimmer, W. (1995). Relationships between Design Patterns. *Design*, *1*, 345–364.

ANNEX A: Final and intermediate results

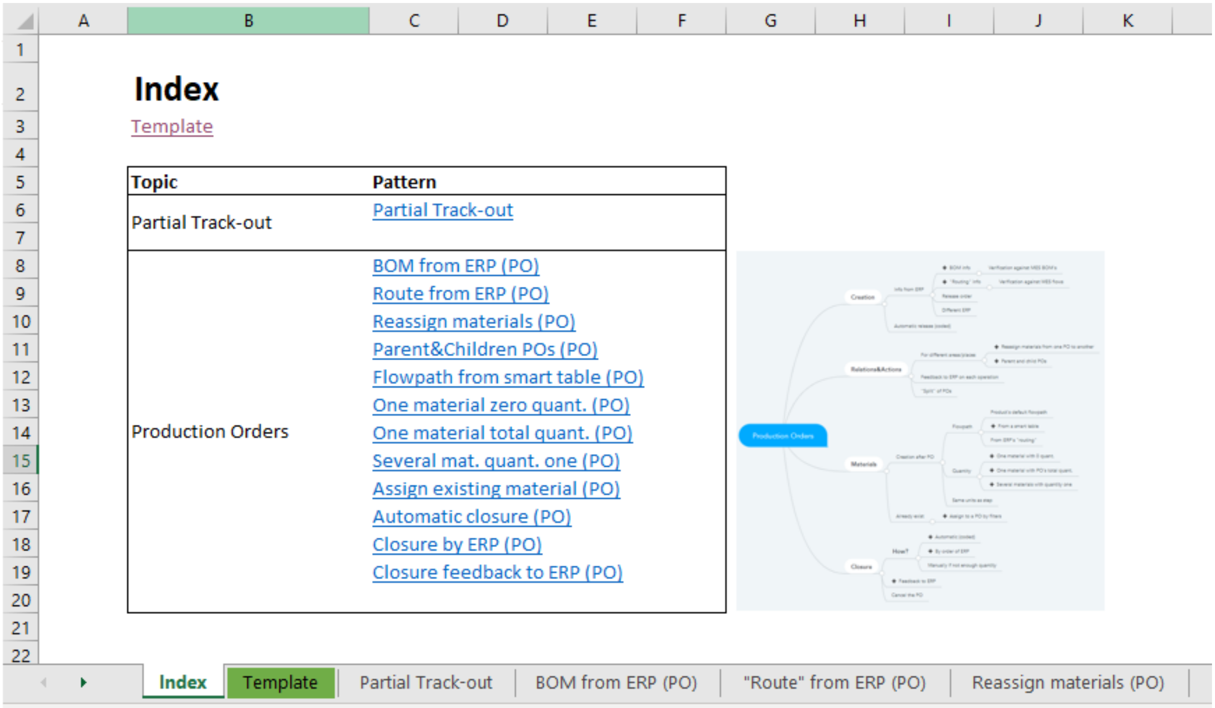


Figure A.1 – Screenshot of the final pattern collection

Semi-Conductor	%	Medical devices	%	Eletronics	%	Other	%	**Total**
1	10%	3	30%	2	20%	4	40%	10
0	0%	0	0%	0	0%	1	100%	1
0	0%	2	29%	2	29%	3	43%	7
0	0%	1	25%	1	25%	2	50%	4
0	0%	1	50%	1	50%	0	0%	2
1	20%	3	60%	1	20%	0	0%	5
0	0%	0	0%	0	0%	1	100%	1
0	0%	1	50%	1	50%	0	0%	2
0	0%	0	0%	0	0%	1	100%	1
0	0%	3	43%	1	14%	3	43%	7
1	50%	0	0%	0	0%	1	50%	2
0	0%	2	50%	0	0%	2	50%	4
0	0%	1	33%	1	33%	1	33%	3
0	0%	0	0%	0	0%	1	100%	1
0	0%	0	0%	1	100%	0	0%	1
0	0%	0	0%	1	100%	0	0%	1

Figure A.2 – Screen clipping of an industry segment analysis example

Creation	Project	Case1	Case2	Case3	Case4	Case5	Case6	Case7
	Industry segment	Medical devices	Other	Eletronics	Other	Other	Eletronics	Medical devices
Identified characteristics	**Frequency**							
ERP "creates" materials	5	X		X	X	X	X	
GUI custom to move raw material (RM) (inside wa	2	X						X
RM created where is consumed	2		X	X				
RM reserved to a specific PO/material	2		X		X			
Tracking piece by piece	1				X			
Tracking by batch/lot	6	X	X	X		X	X	X
Previous trigger to do action on consumable (creation/split/move/attach)	1		X					
MES request ERP to create RM	1			X				
Attach to feeder manualy	1						X	
RM created manually	1							X
RM created in WH (without stock step)	1	X						
RM created/moved to stock step	3		X		X	X		
Split do lote de RM	1							X

Figure A.3 – Screen clipping of a topic characteristics example

ANNEX B: Guide questions to MES Consultants

Questions that were provided to the MES Consultants to guide in a feedback evaluation:

- Was the framework user-friendly?
- Was the information clear?
- Did the mind maps cover all the problems that you could face regarding the topic?
- Was there any detail presented here that you have not though about yet on your projects?
- Do the framework add any value to project modelling?
- For each one of the three topics (pattern; mind map; mind map and patterns):
    - o Could you understand the content only by what that topic presented?
    - o Was the structure good enough to understand?
    - o Do they need more context or any support scheme?
- Any other comment?