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Knowledge reuse and collaborative environments in industrial engineering

RESEARCH DOCTORATE THESIS

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ideas CREATE

Technology is so much fun but we can drown in our technology.
The fog of information can drive out knowledge.

[Daniel Joseph Boorstin]

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Fabio Peluso, Naples, March 2015

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Abstract

In recent years, thanks to the ICT systems, there has been a continued growth and an increasing accumulation of the available information. Managing information has become one of the key activities in any sector. Indeed, information management emerged as the core and the basis of manufacturing enterprise. The research activity mainly focused on the development of a Knowledge Based Engineering (KBE) methodology for supporting a manufacturing company, in particular railway manufacturers, in reusing company knowledge. A Decision Support System (DSS) has been developed with the scope of identifying products already designed that fully or partly fit what required by new bids. The DSS has been built within a PLM software and part of the research has concentrated on comparing the PLM suites available in the market searching for the best tool able to act the role of a centralized management dashboard for knowledge reuse. The proposed methodology involves different business units and several expertise, emphasizing the importance of a collaborative environment and the need of a methodology for design review sessions.

Contents of this thesis retrace these considerations: the second chapter reports a technology scouting on the available PLM tools; the third and the fourth chapters deal with a KBE methodology and the development of a DSS; the fifth one proposes the development of an immersive virtual reality environment aimed at deploying review sessions by design and manufacturing teams with interdisciplinary skills; at last, in the sixth chapter, it is reported a Discrete Event Simulation application as example of a procedural KBE application.

CHAPTER 1

KNOWLEDGE BASED ENGINEERING

1.1 Introduction

The development of complex systems requires a sequence of engineering and management decisions which must satisfy many competing requirements. Design is recognized as the primary contributor to the final product form, cost, reliability and market acceptance. The high-level engineering design and analysis process (conceptual design phase) is particularly important since the majority of the life-cycle costs and overall quality of the system are determined during this phase. The major opportunities for cost savings occur in the earliest phases of a product design. Approximately seventy per cent of the life-cycle costs are frozen by the end of the conceptual design phase. The key to shortening the design cycle is to shorten the conceptual design phase, which will also reduce the amount of engineering in the redesign stage. The engineering trade-off process during conceptual design is undertaken using good estimations and informal heuristics. Current traditional CAD tool support is extremely limited for the conceptual design phase. There is need to rapidly conduct design analyses involving multiple disciplines communicating together (trading off such things as performance, cost, reliability, etc.). Finally, it is necessary to be able to manage a large amount of domain-specific knowledge. The solution is to commit more resources at the conceptual design stage to reduce the cycle time by eliminating redesign. All of these factors argue for an integrated design tool and environment that can help make decisions early in the design synthesis (conceptual design) process.

An integrated design tool can enable a diverse and multi-disciplinary team of engineers and designers to achieve consensus of design intent under complex design requirements and increased design constraints. The design tool should allow the design team to examine more configurations at greater levels of detail. The problem then is to develop an architecture for a design tool that meets all of these requirements.

Reducing the time and costs of designing activities, from the concept to the release of production documents, represents a huge competitive advantage for any company. In recent years more and more importance is given to the concept of product platform, trying to conceive families of products intended for similar types of service, customized according to the specific needs, so that requirements may lay down in an automatic way the features of the required product. However, companies often lacks a structured system that allows to automatically manage the information available in the database and, therefore, to be able to reuse what has been already designed. Individual designers drive much of the design choices on the basis of their knowledge and experience and, in case of poor communication, it can happen that components already designed (or very similar ones) in the past are designed again.

The technology that allows the development of a true virtual prototype of a product is known as knowledge-based engineering, or KBE. KBE is the methodology for capturing and structuring know- ledge about a design and its design process. KBE may be used to define engineering methods and procedures. In KBE, the product structure tree (topology) is dynamic, so that KBE offers true engineering automation including application development, geometric modeling, application deployment and tools integration. Knowledge- based engineering is a programming tool used to develop a virtual prototype or a design advisor for the design of an established product in a given design domain.

Existing knowledge about a class of designs is utilized in knowledge-based engineering or design (KBE or KBD) and organized into a database format usable by computers. Detailed designs or virtual prototypes are then rapidly developed through the use of digital computing power, developed databases, and systems of rules. The product model which is developed in the KBE environment is a virtual prototype. A virtual prototype has all of the geometric characteristics or attributes of the product as well as the non-geometric attributes such as materials, mass properties, stress and deflection characteristics, etc. Once the virtual prototype is created, it can be used by the designers to evaluate the success or merit of the design configuration, and then modify it if desired. The product model represents the engineering intent behind a geometric design. The information contained in a product model includes physical attributes like geometry, material type and functional constraints. KBE is based on the use of design knowledge in the form of 'design rules'. The design rules form the kernel of an object. Design rules comprise four basic categories:

1. Heuristics: comprised of experimental rules of thumb and 'best practices.' Usually based on corporate culture design heuristics. These are of the type, If (condition is true), then (action recommended).
2. Empirical design rules: these rules are based on curve-fitted expressions that are developed from experimental data. Meta-model technology used to develop models of complex systems.
3. Legislated constraints: these are comprised of rules established by law or by engineering standards.
4. Laws of physics: based on first principles in the form of analytical or numerical models. Also known as parametric rules. These rules are usually simple algorithms that would be solved using spreadsheet models.

Design rules are used to synthesize the knowledge in the knowledge base and to establish how the knowledge is used in a given model. The design rules are used to both define and relate the attributes in a KBE model. The methods and processes of an engineer are mimicked by these rules.
Design rule types include:

- calculations
- conditionals
- look-up databases
- fixed
- variables
- references

- execute external programs
- selections
- optimizations.

1.2 KBE

In this chapter, a detailed analysis of the state of the art in the field of knowledge capture, modeling techniques and representation methods is reported. A second contribution regards the automatic design problems, such as: process and product representation, knowledge reuse and knowledge sharing, CAx/PDM/PLM integrations.
The advantages of using KBE are many: design process automation, proper application of the Best Practices, design support for the less experienced technicians, acceleration of the product development process.
The research activities were aimed at developing a tailored methodology and tools based on the study and synthesis of the existing literature for typical fields of application of the KBE. Below, the state of the art in the field of KBE systems, acquisition and formalization of knowledge, methods of development of Automatic Design (AD) tools are reported. Subsequently, some fundamental issues in the AD applications, related to the representation, reuse and sharing of knowledge are discussed.

1.2.1 State of the art

In this chapter the state of the art on the KBE discipline is reported, considering three main topics:

- methods and tools for the representation and analysis of processes;
- KBE systems and their functionalities;
- main development methodologies of KBE applications.

The first group includes the representation techniques of the product used both for the design and for the development of CAD applications. In addition, shows the techniques used in the analysis process to represent and optimize the information flow.
In the second topic, definitions about KBE are introduced and the main structures of a KBE system are shown.
In the last topic, studies conducted about KBE are presented, illustrating the main results in aeronautics and automotive, where the methodologies have been developed.
Before discussing these three issues, a discussion on the definition of knowledge as reported in International Literature is reported in next paragraph.

1.2.2 Definition of knowledge and acquisition processes

Wallace [1], in his article, defines the knowledge from the concepts of Datum, Information and Knowledge. Data can be described as "one or more symbols that represent something." The data are objective and independent from the possibility of an observer to understand its meaning. In a specific context, the data are transformed into information: if the observer is able to interpret the information, the information becomes knowledge. What transforms information into knowledge is the know-how of the observer. In fact, the more you gain experience from past cases and the study of specific literature, the more you are able to accumulate other conscientiously. Knowledge is defined, according to Wallace, as the basic building block of experience that populates the human intellect. Moreover, the acquisition of new knowledge is done through the knowledge already acquired, in the sense that makes human beings can interpret the new data and to transform them into new knowledge. In the context of mechanical design, it is important to define what kind of knowledge you can acquire and represent. Therefore, you must define how information is transformed into knowledge. Eder [2] describes the way in which knowledge is acquired. In his article he claims that knowledge is derived from information through processes of "deduction, induction, reduction / adduction, or innoduzione". Kerr [3] describes the processes of transformation of information into knowledge. Human knowledge is then the set of constructs defined by our minds. The information is cosituite by any new information that changes the structure of knowledge if interpreted in a specific context. Then the data can be regarded as objective information and knowledge are subjective. Before continuing it is necessary to put another characterization of knowledge.

It may be explicit, if represented, or implicit, if not represented.

Explicit knowledge is the general and commonly known in the particular field of application, while the tacit is the one which comes from personal experience that every designer acquires during daily activities and can also be subjective

1.2.3 Knowledge in design processes

Ishino and Jin [4] represent a complete map of functional knowledge, dividing it into domain knowledge and strategic knowledge. The first is associated with the description of the problems of engineering domain, while the second is related to processes and design choices. The two main classes are then divided into 14 categories listed below in Figure 1.1 and described in detail in the paper.

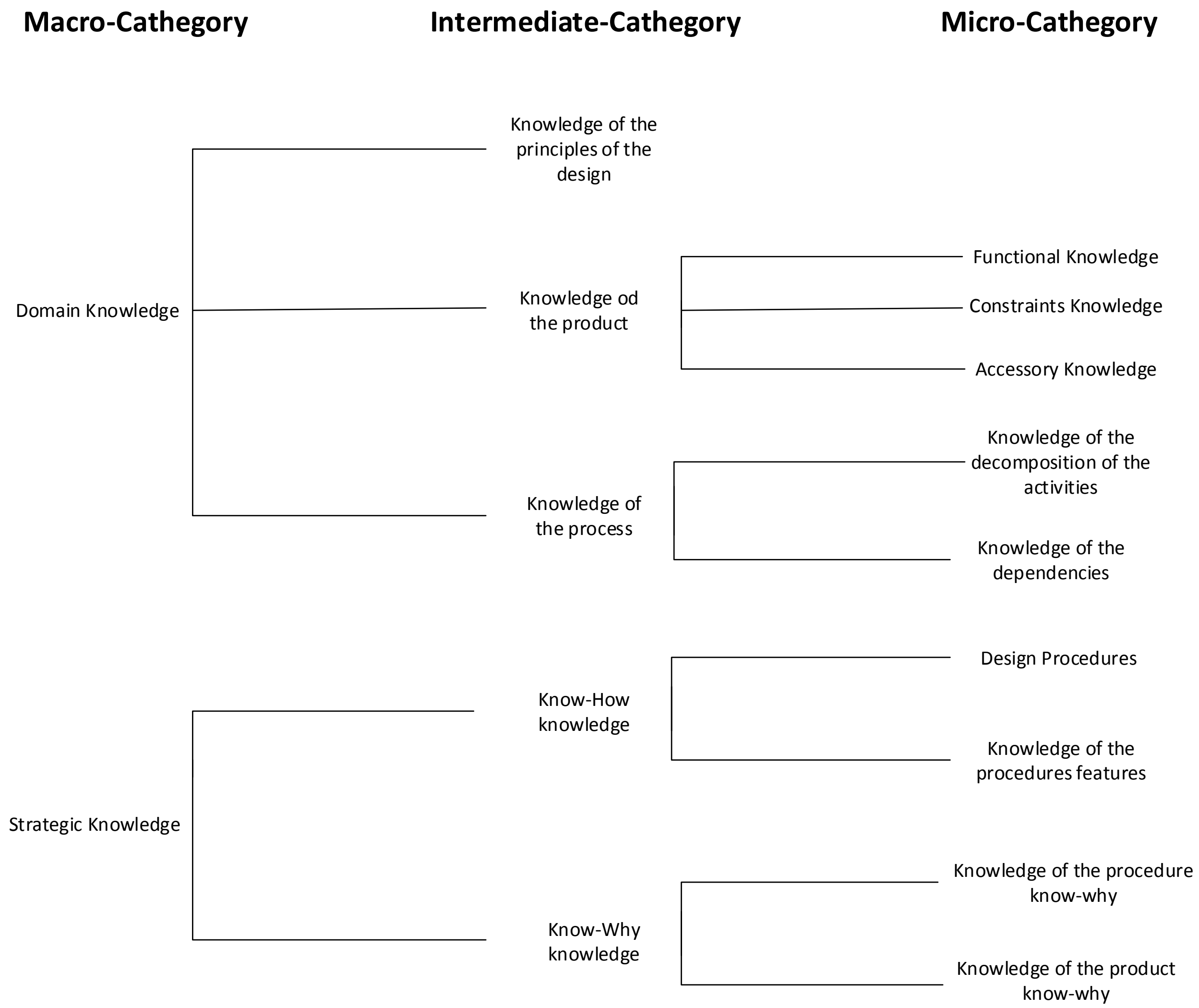

Figure 1.1 - Types of design knowledge according to Ishino e Jin

It should be noted that once again a distinction between implicit knowledge (domain) and explicit (strategic) is introduced, but this time the authors focus their attention on personal knowledge to make it available in systems design support.

1.2.4 Engineering knowledge representation methods

Engineering knowledge, depending on the representation tool, assumes different shapes, which communicate specific information targeted to the domain of the designer expertise. The information and knowledge are represented using appropriate instruments, whether they are a structured programming language or complex and articulated development environments. These tools offer a knowledge representation with greater or lesser complexity and articulation. Widely used tools aimed at supporting the design are, for example, CAD, finite element structural analysis, kinematic and dynamic analysis tools, but also spreadsheets, programming languages and shells. With these tools, a first level of representation of information and knowledge used in the design phase is obtained; it is information and knowledge limited to a specific aspect, for example geometric/topological, functional, structural strength or kinematic or dynamic. In particular, it notes the fundamental role, in industrial design, of the morphology of the components and the same can be said for the links and relationships that allow you to aggregate the parts together. Therefore, also the only virtual prototype of a product brings with it, implicitly in the form of components and links between the parties, a large amount of information and knowledge. The information and knowledge treated at this level are both type domain strategic; for example, the characteristic morphology of a shaft with sections of different diameter is determined on the basis of domain knowledge, while the value of a radius or the finish of a surface can be considered to be of strategic type, because they can be determined on the basis the specific business skills or personal. A second level of knowledge representation is present when at least two types of information and knowledge are incorporated on the product, for example those of a geometrical and topological with those of sizing criteria and verification. This latter often lend themselves well to the encoding algorithms and to the representation with structured programming languages or with spreadsheets. A typical example is given by the application of automatically sizing parts and simple assemlbies realized integrating parametric geometric models and spreadsheets; the sizing can be achieved simply correlating geometrical parameters, or by evaluating mathematical formulas more or less complex or iterating procedures and verifying the conditions laid down. Many applications in small and medium-sized companies are made following this approach. Even the integration of information and knowledge of geometric and functional (structural, kinematic and so on) is a typical example of this level. A representation of the knowledge-based algorithms is revealed, however, limited in many cases, for example in the management of systems with complex architecture or when you need to manage design variations that require different parts, as in the case it is intended to replace the functional groups with others. Also in this case, knowledge is represented by both domain and strategic, corporate or personal. A third level of knowledge representation is required when wishing to implement applications that can handle situations such as those mentioned previously, e.g. product architectures complex with variants for some parts. For these scopes the object-oriented methodology has proved particularly suitable. The potential of this approach in representing information and knowledge depends on the fact that the architecture of many products is inherently object-oriented, that is structured in entities in different hierarchical levels, different, characterized by attributes that can be determined by methods that implement rules choice or calculation procedures, sizing verification and so on. At this level of knowledge representation corresponds a more dominant role for the technological, regulatory and material aspect.

1.2.5 Knowledge representation technologies based on CAD representation

Technologies based on CAD representation prefer the graphical representation of geometric data than other types of data. As introduced earlier, they do not allow a complete representation of knowledge, though possible, but their use is very large. Geometrical data they represent are usually managed through parameterization and through the use of software tools that allow the insertion of formulas, spreadsheets or applications created specifically for the geometric model by the use of programming languages. The most common CAD systems allow, thanks to the feature-based approach, the management of the configuration of the product, such as quotas, material, the amount or the existence of features, obtaining much more structuring of the given geometry.

1.2.6 KBE systems and their functionalities

KBE systems allow to automatically configure and design a product and to formalize processes' Know-How and Know-Why and make them available to all the designers. With a KBE system, the time spent in the design, can be reduced up to 90% thanks to the following characteristics:

- Support the designer during the entire design process with error handling;
- Automation of repetitive tasks;
- Automatic search of the correct information;
- Automatic generation of CAD models and related documents.

1.2.7 Definition in literature

In literature, different definitions of KBE technology. One of the most representative is given by Javed [5], which argues that the technology KBE is "the process of combination of engineering knowledge, its methodologies, rules and best practices, with the knowledge and best practices of the design process aimed at creating models that describe the definition of the product design activities and the related engineering analyses". Stokes [6] argues that KBE approach is "the technique of the use of advanced software that reduce development time through the capture and reuse of product and process knowledge in an integrated manner."

Based on these definitions, it can be said that a KBE system is a computerized environment that guides the user to reach the domain of admissible solutions and, hopefully, to the better solution, in the same manner with which the user would have proceeded with the same resolution using its domain knowledge. The solution is reached in an automatic way, retrieving information from multiple sources, defining the structure of the final products and the dimensioning of their components. The results of operations are generally displayed in real time through interfaces that usually include software tools like CAD or FEA.

A KBE system is a solution for knowledge management that focuses on the description of product architectures and design processes through certain actions defined by rules. For example, the choice of a bearing is an event that, when activated, sets in motion a series of operations based on rules that finalize the operation: load calculations and load directions, dimension checks, choice of the component through the use of family tables from the company database, creation of the CAD model, creation of 2D drawings and documents in general. To reach these objectives, the majority of KBE systems explits the object-oriented logic with which it is possible to represent the product in the form of a hierarchical tree structure containing classes of objects representing functional groups and mechanical components which, according to the entry rules and parameters, through the use of the events mentioned above, takes the form of a product.

For example, the product "elevator" is represented by a tree structure in which there are the macro classes "lifting group", "motor" or "pulley", but also the elementary "screw", "bolt" or "cushion".

These classes do not represent a particular type of screw; rather, they represent the general set of screws and contain properties (defined as “variables”) and links to geometrical data, procedural data, rules and various documentation. According to the provided rules, the class "screw" can generate the product "M10 screw", complete with a CAD model and documentation.
A rule can be of the type shown below:

$$screw.RealDiameter = sqrt(screw.CrossSection)/ \pi \quad (1.1)$$

1.2.8 Analysis of the main aspects of the automatic design

This section discusses some important aspects in the automatic design. In particular, the issues of product representation, its reuse, knowledge sharing, software system integration are investigated. A first observation on these issues concerns the correspondence of what will be discussed in the traditional design processes. An interesting analysis of Gorti [7], states that, in traditional design process, there is often an overlap between various activities and, in particular, often is not defined when a designer is working to define the architecture of a product or is performing some procedure to choose or size components. In automatic design applications, however, this distinction has to be made to define where is the knowledge of the product rather than the process. According Gorti, literature that deals with the design reflects this showing a dichotomy between a process representation and product design. The two main features in the representation of knowledge in the application of automatic design are therefore the representation of product architectures and the representation of the design process. In addition to these two main aspects, other of them have to be taken into account: the reuse and sharing of knowledge; integration of automatic design systems with PLM systems and, in particular, PDM systems and corporate archives.

1.2.9 Product architecture representation

Representation of the product architecture, together with process representation, is the basis of the automatic design. There are several ways to represent a product. The most common method, especially in the technical departments, is to design having the bill of materials (BOM) as reference. The BOM is a list containing all the components in an assembly ordered via a unique identification code. In this list there is no distinction between components morphologically or functionally similar and there is no information about relationships and functional hierarchies between the components themselves. Despite this type of representation is largely used, it does not highlight any information of the functional or hierarchical type, and is not suitable with a product to be configured with automatic design techniques. A higher level of completeness is provided by the CAD representation, which allows to collect, organize and enrich the product information by adding hierarchical and relational information to the information contained in a bill of materials. In fact, this type of representation, allows to generate a logical structure of assemblies and subassemblies that give information of belonging and relation to other components. In addition, the representation performed with parametric CAD modelers, if integrated with appropriate instruments, also provide dimensional information and allow the management of dimensioning rules.

The parametric CAD models developed through the integration of programming languages or spreadsheets allow automatic configuration of many products. This approach, however, presents some limit when trying to configuring products with complex architectures. To overcome these limitations, by the end of the 80's, the Object-Oriented (OO) approach began to be adopted, allowing the product decomposition into parts and subparts and improving models management. The most interesting aspect of the OO approach is the ability to predict and manage model variants in a simple way, using selection rules for the components that can be easily implemented even in products with high architectural complexity.

1.2.10 Design process representation

The representation of the product is the second key aspect of the automatic design. It has to guide the designers during the phases of design and product configuration, ensuring the correct application of Best Practice business.

Chung and others [8] argue that there is a need that claims for an approach to the management of the process that is a combination of automation and human judgment.

The methods of the process representation mostly used in KBE systems, in cases where the processes are strongly determined, essentially fall into two main approaches, a) procedural and b) Object-Oriented. The first method consists essentially in performing procedures that process input information to provide the output. These procedures operate directly on the product representation systems and enclose all of those typical constructs of the programming: cycles, iterations, IF-THEN – ELSE constructs.

The other method of process representation is the OO type, where the sizing procedures and the choice of the component are implicitly written in the methods associated to the classes of hierarchical structure representing the product.

The difference between the first and the second method is the way to interact with the product model. In the first case, the model is built as the user provide the information to do so, while in the second case, a starting model already exists and it incrementally assumes the final configuration, as the input data are modified.

In both cases, however, is the widespread use of web interfaces or form type that make explicit the design procedures and simplify the application of the correct procedure by the user. The tendency is to represent the design process through the network and, nowadays, a large number of development tools allow the creation of web-based environments. In [9] there is an example of a collaborative tool that allows the overcoming of all the conflicts that arise when multiple project participants perform the same process.

1.2.11 Knowledge reuse and sharing

Related to the theme of product and process representation, is the theme of knowledge reuse and sharing. Knowledge reuse is the ability to take advantage of the results of an activity several times and without repeating such activities. In this case, once the model of the product has been created, knowledge reuse can mean the ability to extrapolate some part of the code and propose it again in other contexts. To do this in an easy manner, the modularity of the applications is fundamental; modularity can be reach with an Object-Oriented system. Knowledge sharing regards the possibility that many users can reuse the knowledge. For this purpose, the use of common databases to store applications and modules is an effective method. The trend of recent years is to create part and product libraries and functional groups that can be used by the multitude of the stakeholders. Cheung [10] also states that the reuse of knowledge is the adaptation of explicit knowledge (domain or strategic, formalized to be represented) of successful practices such as to generate new ideas. Markus in [11] considers among other explicit knowledge as the one represented by the IT technologies. He states that the concept of explicit knowledge includes:

- Methods of communication with which the designers share their observations;
- Archives where knowledge can be structured for reuse and sharing

The development of a knowledge repository requires some considerations about integration with PDM and PLM tools. This tools can check all the data and information of the entire life cycle of the product; but, although advanced, they are not able to store domain and strategic knowledge. Consequently, the role of a knowledge repository can be seen as independent and complementary to PDM/PLM systems. The first controls the explicit knowledge required to perform design tasks, such as the rules for quoting parts, architecture and procedural knowledge. The second handles the CAD parts and their related documentation, materials data, revisions and so on. KBE applications built using the elements contained in a repository of knowledge needs to communicate with a PDM in bidirectional way. A KBE system can search and retrieve specific parts from PDM and can store new parts and sub-assemblies in the database of the PDM. The knowledge stored in the archive can be reused several times, always producing a different product.

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CHAPTER 2

COLLABORATIVE ENVIRONMENTS: A RESEARCH ON THE AVAILABLE PLM SUITES

2.1 Introduction

This chapter deals with the synthesis of a research aimed to choose a product lifecycle management (PLM) tool, between the various solutions in the market, better matching the needs of using it in a knowledge based engineering (KBE) environment. The first part of the activity had regarded a technology scouting; the authors believe they have found a powerful and not expensive tool able to satisfy the need of a company who wants to use its knowledge and best practices for bringing performance and innovation in its organization. After investigating the three categories of PLM available in the market, the first conclusion is that a *PLM-centric* PLM is the better solution in a large-scale action when there is the need of managing both design-and-manufacturing data and financial-and-supply-chain data.

2.2 PLM solutions

The existing literature largely explains what PLM systems are and what are the advantages of having a PLM suite in an organization. First, these tools have to manage product data. Second, exposing information is another crucial scope. A brief definition that remarks the profitable use of a PLM in a complex and large-scale contest can be the it enables collaboration within and between enterprises [1]. A complete description of these systems can be found in the extensive literature ([2] [3] [4] et al.). In synthesis, a PLM solution supports the development of products in two ways:

- it manages the whole product information, like CAD models, documents as specifications, bills of materials, as a single product definition;
- it allows to track, to manage and to automate governance and creation processes such as portfolio management, program management, release management and change management that are often based on industry standards or customized to internal definitions [5].

The most complete definition found in the literature is the following one:
"*PLM solutions are a unique combination of software, middleware, hardware and services that put allow data to be the core of the product development process. This enables the organization to extract greater value from data, collaborate in a more effective manner, streamline processes, improve employee productivity, and set the foundation for innovation.*"[2].
It can be observed that a PLM consists of two macro-capabilities:

- <u>fundamental capabilities</u>, like check in-check out, access rights, "where-used", automatic Part Number assignment, engineering data information exposure;

- innovation capabilities, like managing and understanding Multi-CAD Data, intelligent recognition of change, Text-Based Document Crawling.

In the search for the solution to be adopted, the ones missing any of the fundamental functionalities should not be considered. Contrary, PLM innovation capabilities should be strongly considered in the scouting.

2.3 The context: collaborative environments

This research activity has born in a context of a KBE project, aimed to design a system for the management and for the efficient reuse of a company best-practices and standards. If managing change to engineering data is the primary purpose of a PLM system, then exposing that information is its secondary one. This includes finding and reusing designs, enabling access to engineering data to other departments in the company and allowing anyone in the company to interrogate such data without requiring the use of computer aided technologies (CAx) applications.
A typical manufacturing company has a software architecture at least composed by:

- several CAD tools for 3D modeling;
- different CAE tools for simulating the products;
- a simulation data manager (SDM) for managing the analyses' data;
- a PDM solution, containing the company knowledge;
- an ERP solution, for sales, service and customer relationship management.

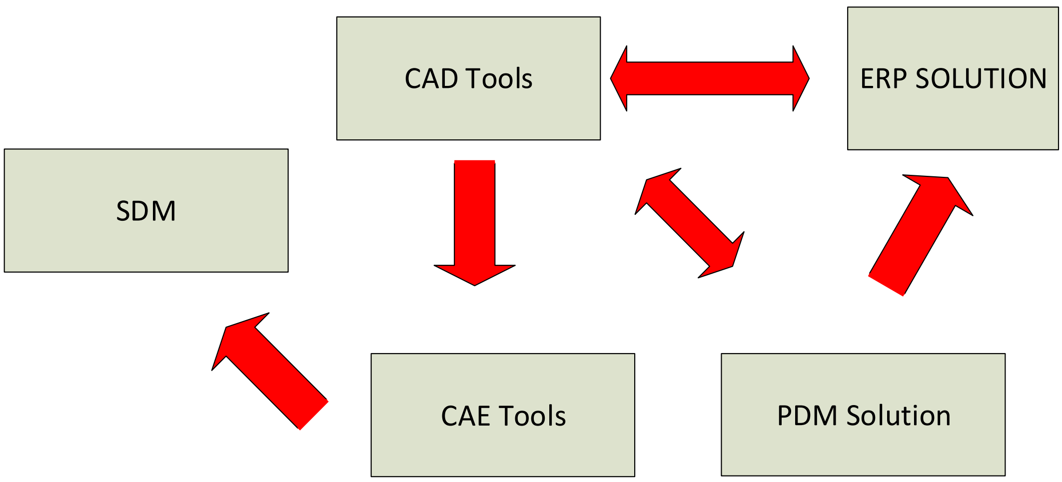

Figure 2.1.Typical software infrastructure of a large company

Nowadays, although considerable efforts have been devoted, the perfect integration and collaboration between the tens of software tool used in a big company has not been reached yet, and much time is lost every day in finding and/or collecting pieces of information. This paper describe an activity aimed to find the best PLM tool, to be inserted at the top of the software architecture in figure 2.1, acting the role of a management dashboard.
In the context of this specific case-study, the software tools were:

- Creo 2.0 by PTC, Catia V5R19 by Dassault Systemes, NX by Siemens PLM as CAD tools; these solutions are, by the matter of fact, the three major 3D modeling products existing in the market.
- Several CAE analyses tools, like Pro/Mechanica, Nastran/Patran, Comsol, Ansys, LS-DYNA and SIMPACK.
- Windchill 10.0 as the PDM solution.
- SimManager by MSC as the Simulation Data Manager.
- SAP as the ERP.

2.4 PLM: technology scouting

2.4.1 Introduction

In 2009 *The Aberdeen Group*, a technology research and consulting firm, reported a study on the PLM solutions in the market, ranking them by two characteristics [5]:

- the *Value Delivered* by vendors: the percentage of survey respondenting companies that, using their solution, achieved a Best-in-Class performance;
- the *Market Readiness* of the vendors: a parameter that measures vendor's ability to serve the market.

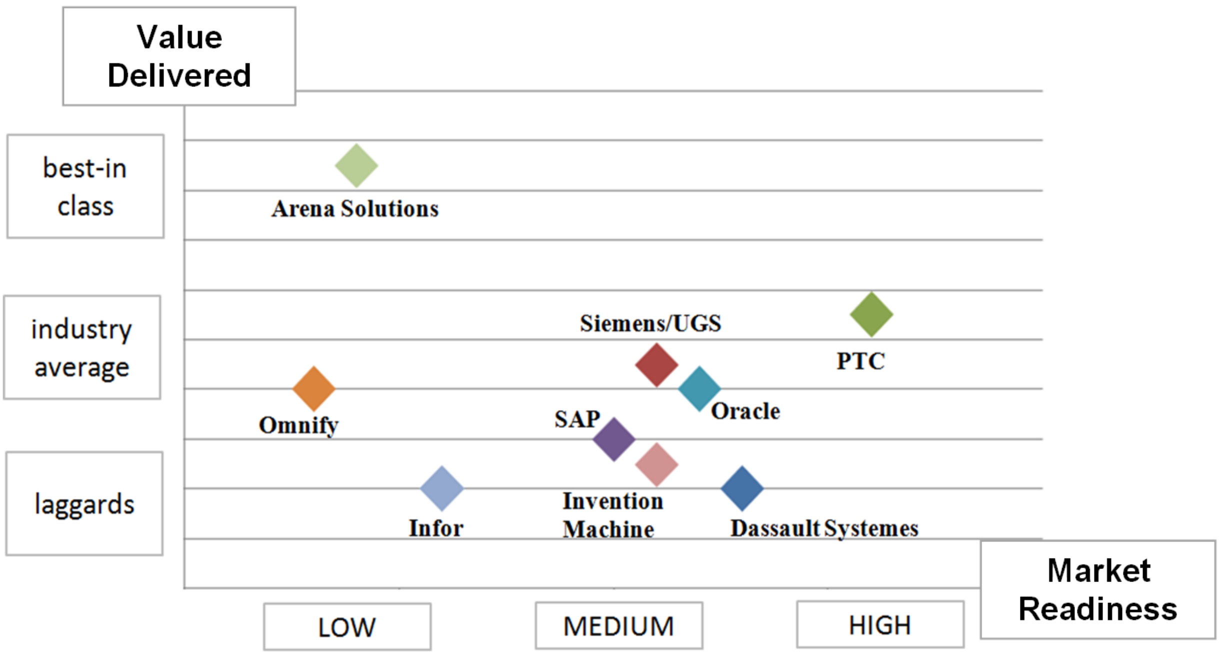

Figure 2.2. Market readiness and value delivered by the main PLM actors

Based on this research, PTC, Arena Solutions, Siemens/UGS and Oracle/Agile are the top PLM software solution providers. It could seem strange that Dassault Systemes (DS) is outside the top positions, but the reason is that until 2008 Dassault offered three distinct PLM products, having the consequence that none of these solution has progressed as much as competitors. Starting from 2009, DS has integrated the three solutions into one and probably a new study would see it near PTC and Siemens. According with the available analyses in [5] [6] [7] [8][9], the division of PLM market in terms of revenues for the principal actors of the PLM sector is reported in figure 2.3.

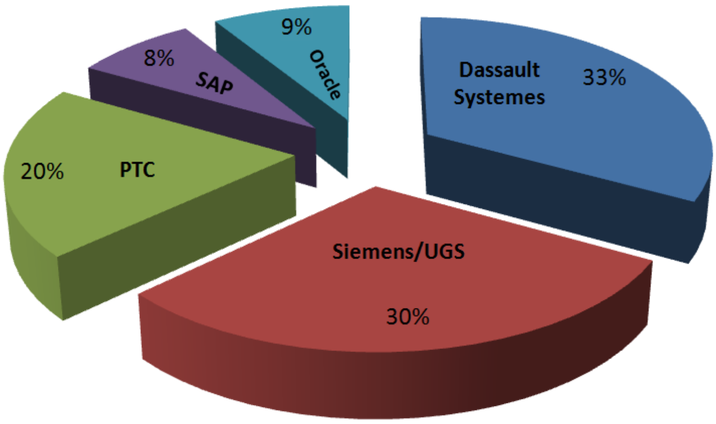

Figure 2.3. PLM market division

Below, it is reported a possible classification of the existing PLM tools:

- **A.** PLM solution in a Product Development Suite. Enovia by DS, Windchill by PTC and Teamcenter by Siemens/UGS fall into this class;
- **B.** PLM solution in an Enterprise Suite. Solutions from Oracle and Sap belong to this category;
- **C.** PLM solution as a Stand-alone Offering. Several products, by several minor PLM-vendors, appertain to this group.

2.4.2 The choice of a Stand-alone PLM solution: Collaboration Desktop

Searching on the most suitable solution to adopt, four main groups of characteristics have been analyzed:

- the ability of managing change to engineering data;
- the ability of finding, interrogating and reusing engineering data;
- the guarantee of a safe collaboration;
- native integrations and easiness of customization;
- cost, deployment and maintenance.

Typically, solutions belonging to class A are perfectly integrated with the PDM, CAD (and the whole CAx) solutions of the same suite of products. Like briefly said above, each of the major CAD vendors also has a PLM solution perfectly integrated only with its native CAD system. While this works for companies that only need to store 3D data in one file format, other companies (it can be said the totality of large companies), must manage 3D data in a variety of competing formats. To meet this need, the software vendor can provide to the buyer additional functionality to integrate competing 3D data types. These additional programs are installed with the PLM system and usually add the ability to track product structure that was created in another CAD software, and to store and manage competing file types. Users are given the opportunity to launch the competing CAD program to edit 3D models and to save the changes back into the PLM system, which is useful, but is often unwieldy compared to the same procedure with the native CAD system. Besides, within the customers, the existence of this "add on packs" create complexity for IT departments in terms of getting the added functionality working and integrated efficiently into the product lifecycle [10], Engineering process teams have to make changes to accommodate the anticipated difficulties with adding multi-CAD functionality to their current processes. The use of these procedures also annoys end-users who have to learn a new set of instructions and rules for handling the 3D data [11]. When there is the need to manage multi-CAD data, and nowadays every modern engineering organization has to exchange design data in a wide variety of CAD formats, employing a PLM system that understands one CAD format extremely well and treats all others as foreigners does not work. At last, the extensive customization needs bring, of course, high customization costs and future high upgrade costs and implementing time.

PLM solutions belonging to class B, the so-called ERP-centric, are ideal for that companies that consider manufacturing or supply chain resource planning a much more important business than product development. These solutions provide basic integration to CAD tools. Like it is reported in [12], experience has shown that if a vendor does not have its own CAx offerings, it cannot fully understand the real needs of engineering departments. For these reasons, engineering departments and R&D personnel generally are not big proponents of ERP-centric systems.

According with the considerations above, the choice fell on a Stand-alone PLM solution. Capabilities of these types of solutions can be best-of-breed because its development resources are not applied to developing integrations with other systems and applications within an enterprise system, but they are focused on developing a tool that can be quickly installed, configured and customized. In particular, three PLM-centric solutions have been investigated:

- Datastay PLM by Datastay Corporation;
- Aras PLM by Aras Corporation;
- Collaboration Desktop by Parallaksys.

Datastay PLM is a SaaS (Software as a Service) PLM solution, that is a software delivery model in which software and associated data are centrally hosted on the cloud. This feature allows customers to reduce IT support costs by outsourcing hardware and software maintenance and support to the SaaS provider. Datastay is now a part of Autodesk Inc and Datastay PLM merged into Autodesk PLM360.

Aras Innovator PLM is an Open Source solution. This allows users to download and evaluate the tool freely, but for appropriate support and for accessing to hot bug fixes, users have to pay a subscription fee. It has native integrations with all the major CAD tools.

Collaboration Desktop is a PLM solution, born in 2007, developed with the focus of obtaining a tool easy to configure and customize. It's been developed with the aim of responding to the demand of companies to integrate different CAD, without the need of difficult and costly updates and customizations. It also has text-based document crawling capabilities,that is the possibility of finding documents based on the content inside the documents.

2.4.2.1 Collaboration Desktop

Collaboration Desktop (CD) has been identified as the best platform able to deploy collaborative solutions for collaborative environments like in figure 2.4.

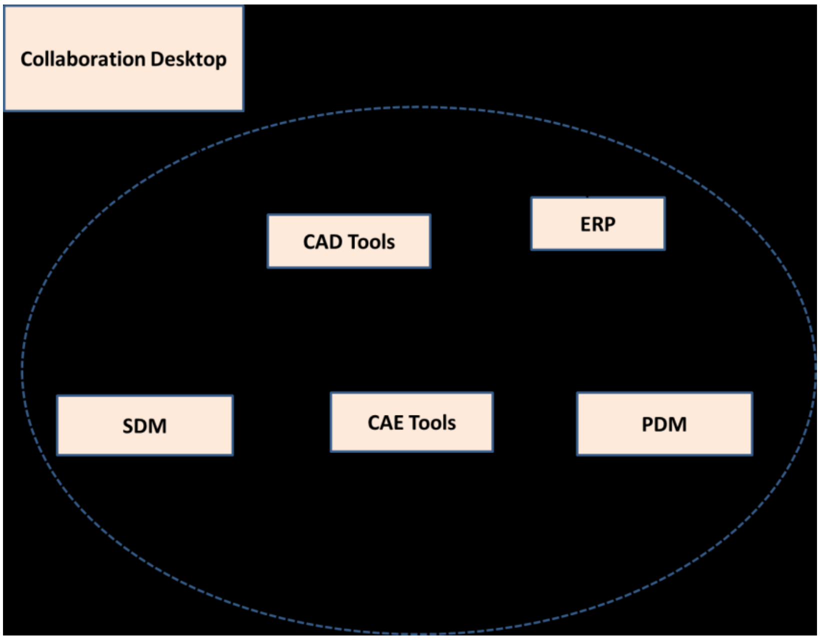

Figure 2.4.New software infrastructure with CD acting the role of integrating the others software solutions

CD is built on Microsoft .NET framework on a three-layer architecture. Developed paying much attention on integrations capabilities, its gateways, API and templates are available in order to extend the already available functionalities. It has native integrations with Microsoft Office, Project and Dynamics obtained thanks to the .Net technology and the web services based integrations with most common used Cad tools, the full interoperability with other PLM solutions and SAP R3.

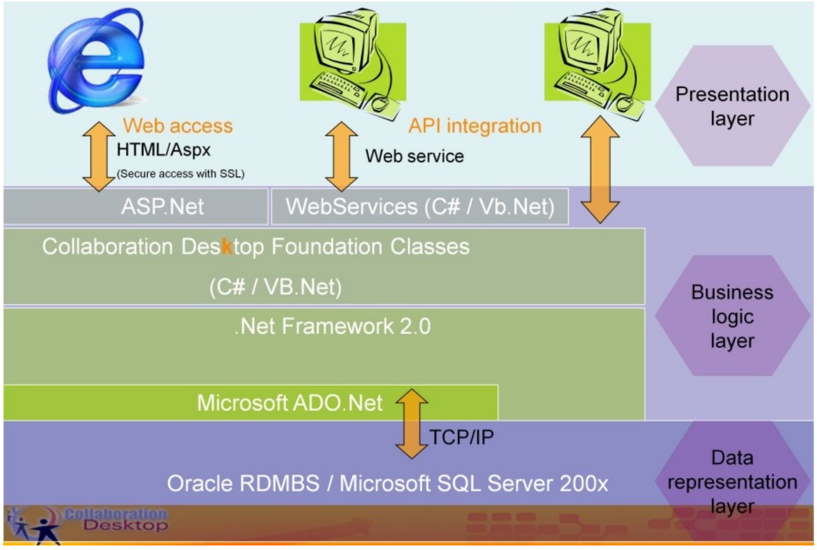

Figure 2.5. CD architecture

The main features that led to the choice of the CD suite are A) ease of use, B) easy tailored customization, C) integrations, D) quick implementation. In detail:

A. CD has an intuitive user interface, ensuring rapid adoption by users. The application is easy to use and "discoverable"; users can alone explore the environment and more advanced functionalities are "discovered" easily
B. the end-user itself can make changes to create its own views of data;
C. CD has a wide range of Off-the-Shelf components;
D. the Dynamic Business Modeler provides an interface for the definition of object types, relationship types, access policies and workflows that can be used without having to use any programming language.

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CHAPTER 3

A KNOWLEDGE BASED ENGINEERING APPROACH FOR SUPPORTING RAILWAY MANUFACTURERS FROM THE TENDER NOTICE TO THE DESIGNING PHASE

3.1 Introduction

This chapter describes the development of a KBE approach able to support railway manufacturers in their assessments on the convenience of participating in competitive tendering and, subsequently, in the offer definition and in the designing phase. The proposed approach is based on a Decision Support System (DSS) that allows an analysis, called Adopt–Adapt–Innovate (AAI), to be made, which helps the company in the search of its products that best suit the requirements of new bids. Digital pattern techniques, configuration design methods and parametric modeling are the tools proposed to optimize the process that starts with the tender notice, passes through the offer definition and ends with the design. The railway market logics, the proposed methodology and the first obtained results are described below.

3.2 KBE in manufacturing sector and the railway market

The economic downturn and the increasingly demanding markets are forcing companies to reduce wrong and unprofitable investments, and searching for means to decrease time and costs for new product development while satisfying customer requirements. In the design domain, one of the technologies that can support the decision making phase and the rapid, modular design is KBE. Many definitions of KBE exist in literature [1-3]. All of these definitions can be synthesized as follows. KBE is the use of advanced software techniques, and the study of innovative methodologies, to capture and re-use product and process engineering knowledge in an integrated way. Its fundamentals are clearly reported in [4]. As the definitions state, one of the hallmarks of the KBE approach is to automate repetitive, non-creative design tasks. As exposed in [5] not only does automation permits significant time and cost savings, it also frees up time for creativity, which allows exploration of a larger part of the design envelope (figure 3.1).

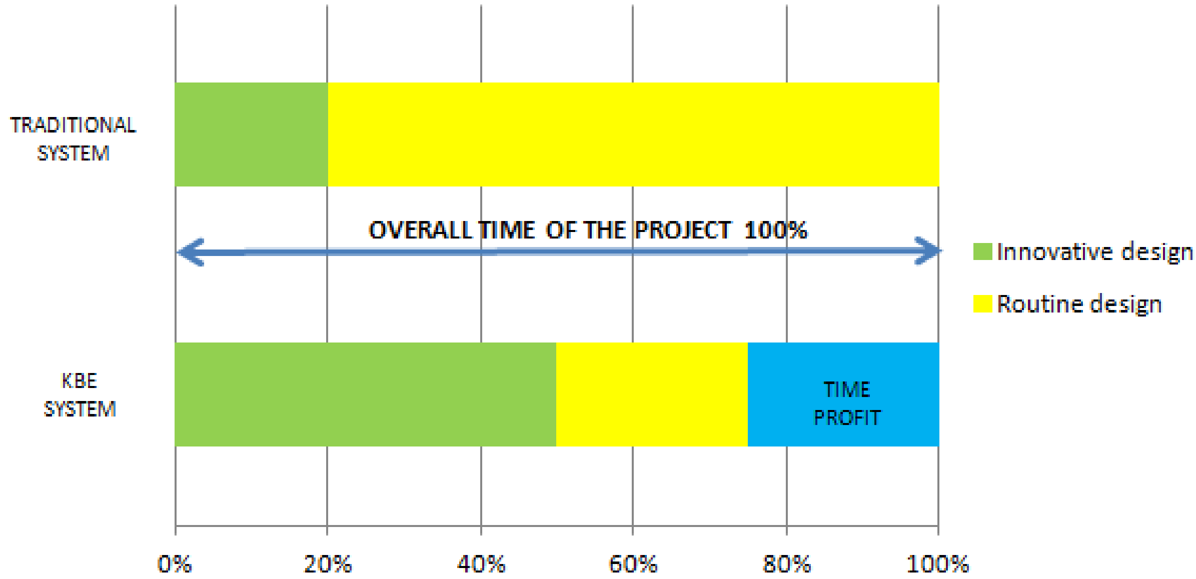

Figure 3.1: Influence of KBE usage on time of main design tasks.

Successful efforts to implement and benefit from KBE have been made in various manufacturing sectors. For instance, in [6] is described the development of a multidisciplinary system that is able to rapidly generate car designs. In the aerospace domain, there is a research [7] dealing with a system that automate design effort for blended wing bodies; [8] describes an application for the design of low pressure turbines; KBE systems are also developed for the design of manufacturing tools and processes [9][10]. By contrast, there are only few researches and applications in the railway manufacturing industry [11].

This research derives from a research born with the scope of designing and implementing a KBE system for supporting a firm acting in the railway market. The activities have been conducted in collaboration with a train manufacturer company, AnsaldoBreda.

Different from other manufacturing sectors – i.e. the automotive industry - in the railway market the producer of a train is not the actor that decides the features of the vehicle it is going to produce; indeed, this role lies with the customer and the regulatory rules of the country in which the vehicle is going to serve. In detail, the commissioning body (the customer) issues an invitation to tender (ITT) that consists, inter alia, of the train-requirements list. These requirements are organized into the technical specifications document.

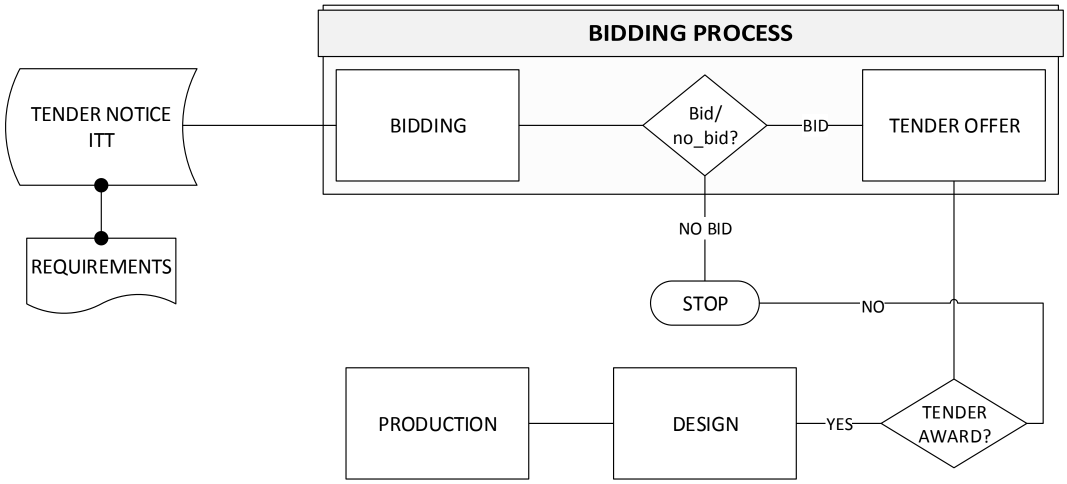

Figure 3.2: The flow chart from the ITT to the production phase.

As illustrated in figure 3.2, the process begins with the ITT and continues with the bidding process: the company makes technical and economical feasibility analyses, and chooses, in this case, to take part in the tender (bid/no bid choice); the tender offer then follows. Finally, in the case of a winning bid, there is the design and the production of the train.

3.2.1 The railway market logics

As illustrated above, in this market, the customer gives the specifications on the train while the supplier must comply with the requirements. For a company that produces trains, project development begins with participation in a tender called by a client. The invitation to tender contain the **Train Technical Specification** (TTS), which represents the collection of all the requirements imposed by the customer. In general for a vehicle / train driving the contents of a CTF can be organized as follows.

TRAIN WIDE FUNCTIONS

1.1 TRAIN OPERATION, TYPES AND FLEXIBILITY
- 1.1.1 Train Operation
- 1.1.2 Unit Types
- 1.1.3 Flexibility

1.2 MULTIPLE WORKING
1.3 UNIT FORMATION AND LENGTH
1.4 TRAIN GAUGE
1.5 DRIVER ONLY OPERATION
1.6 INTERIOR SPACE & CAPACITY
1.7 WEIGHT
1.8 PERFORMANCE

BASE SYSTEMS

1.51 INTERIOR SCENARIO DEFINITION
1.52 SIGNAGE
1.53 SECURITY & RESISTANCE TO VANDALISM
  1.53.1 Vehicle Security
  1.53.2 Vandalism and Misuse
  1.53.3 Graffiti Removal
1.54 CLEANABILITY
  1.54.1 Interior Cleaning
  1.54.2 Exterior Cleaning

CREW ENVIRONMENT

1.55 CAB
1.56 CREW AREAS
1.57 DRIVER EGRESS
1.58 EMERGENCY EQUIPMENT

From the above, it is clear the large number of requirements that a vehicle must satisfy. Starting from the TTS, the company has to decide whether to participate or not in the bidding and, if yes, to prepare a technical offer (OT).
The OT is a very delicate document because on the one hand many of the chances of success are played on the quality of the solutions proposed, on the other hand everything offered becomes challenging in case of award. So, as almost always happens, you need to optimize their choices mediating conflicting requirements.
The preparation of an OT requires a substantial design effort developed, typically, from resources specially dedicated to this type of activity.
The documentation prepared is very significant because it is necessary to provide evidence to the Client in an exhaustive and convincing that were taken into consideration all the technical aspects contained in the TTS.

3.3 The Methodology: knowledge capture, retention and re-use

In medium and large companies, a simple and efficient reuse of the knowledge base can be difficult because of the huge amount of data. An effective data management system is mandatory if the company wants to take advantages of this asset. For a railway manufacturer, as mentioned above, a new project begins with the bid/no-bid choice and possibly continues with a competitive and profitable tender offer. Typically, these tasks must be done in a fixed and short time frame and the constraints imposed by internal communication may hinder participation in the competition. In the worst case, there is the risk of participating with hasty and inaccurate analyses. Searching for a way to support these critical phases, the authors have researched on a new methodology.

3.3.1 The Decision Support System

First, a Decision Support System (DSS) has been designed into the PLM system (which is a classifier of the whole company knowledge in terms of designed/produced trains, subsystems and/or components) with the aim of realizing a “catalog” of standard products. This catalog can be examined in order to search for the component.
The data structure of the catalog consists of three objects/classes:

- At the first level of the structure there is the class vehicle: the root object of the Product Breakdown Structure (PBS); the family to which the vehicle belongs (i.e. high-speed train, automatic light metro, metro-tram) is an attribute of this class.
- At the second level, there are the subsystems: mock objects that identify a function of a train or a typical element of the organization of a train or, finally, a typical element of the assembly process of the vehicle (i.e. vehicle body, power system, pneumatic/hydraulic equipment).
- At the last level, there are the components: items of the E-BOM (Engineering Bill of Materials) characterized by classification attributes (i.e. bogie, traction motor, pantograph).

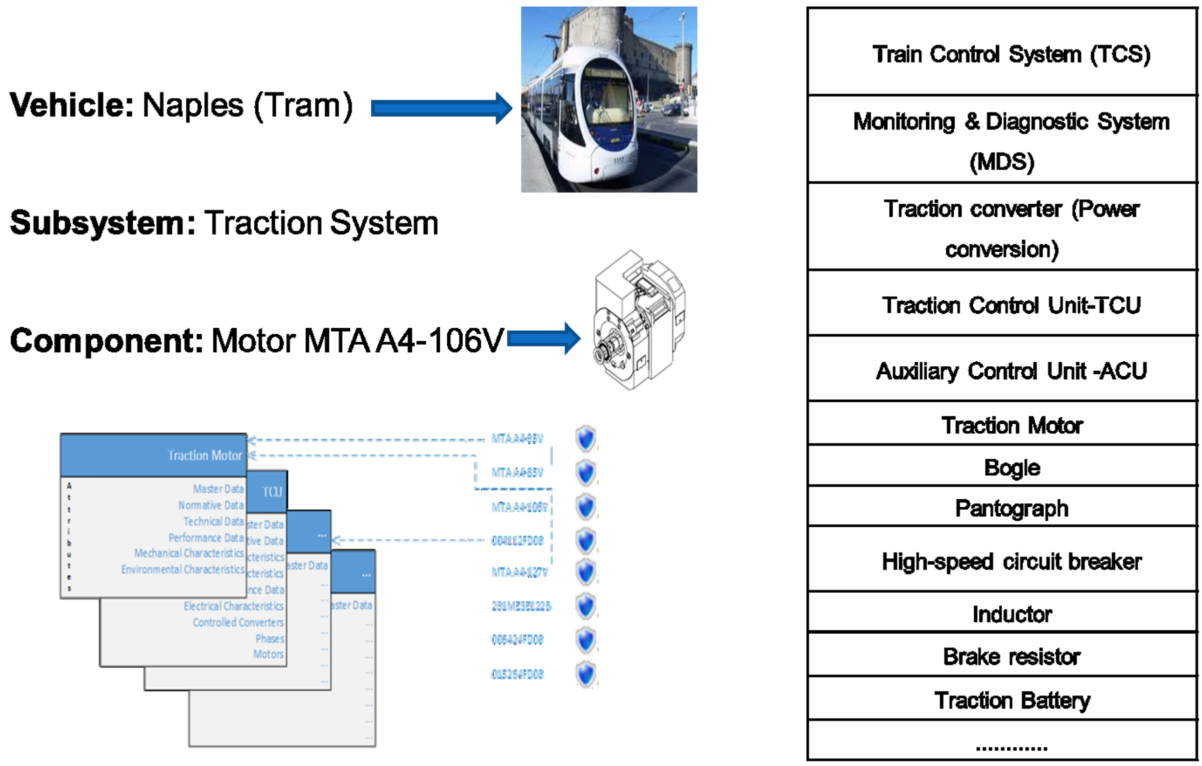

Figure 3.3. Example of the three-level classification structure

The classification has been made with attributes of various genres: master data; normative data; technical data; performances data; mechanical characteristics; environmental characteristics; electrical data; other useful data. Furthermore, every component has a link to the corresponding

Configuration Item (CI) stored in the PDM system, containing all the files and the documents related to it.

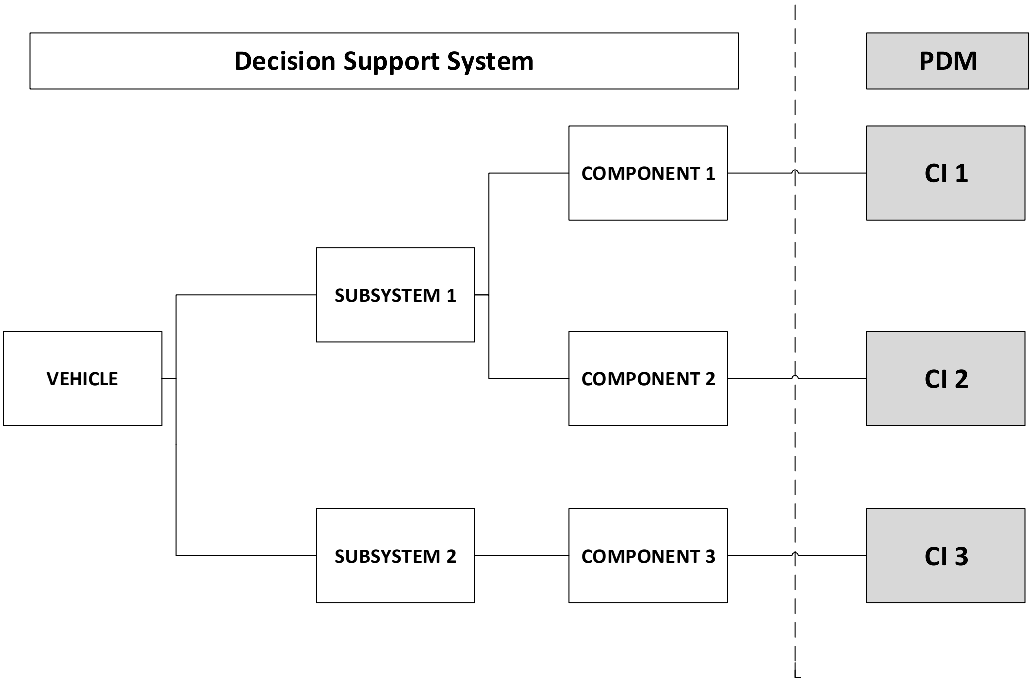

Figure 3.4. The three-level structure of the DSS and the link with the PDM

The class subsystem combines the functions of the vehicle as configured at the second level of the standard PBS, carried out on the basis of the structure of product groups as defined by 'EN 15380-2 Product group Code letters for Railway applications - Designation system for railway vehicles - Part 2: Product groups'. In figure 3.5, the three-layer data model implemented into the PLM system is shown.

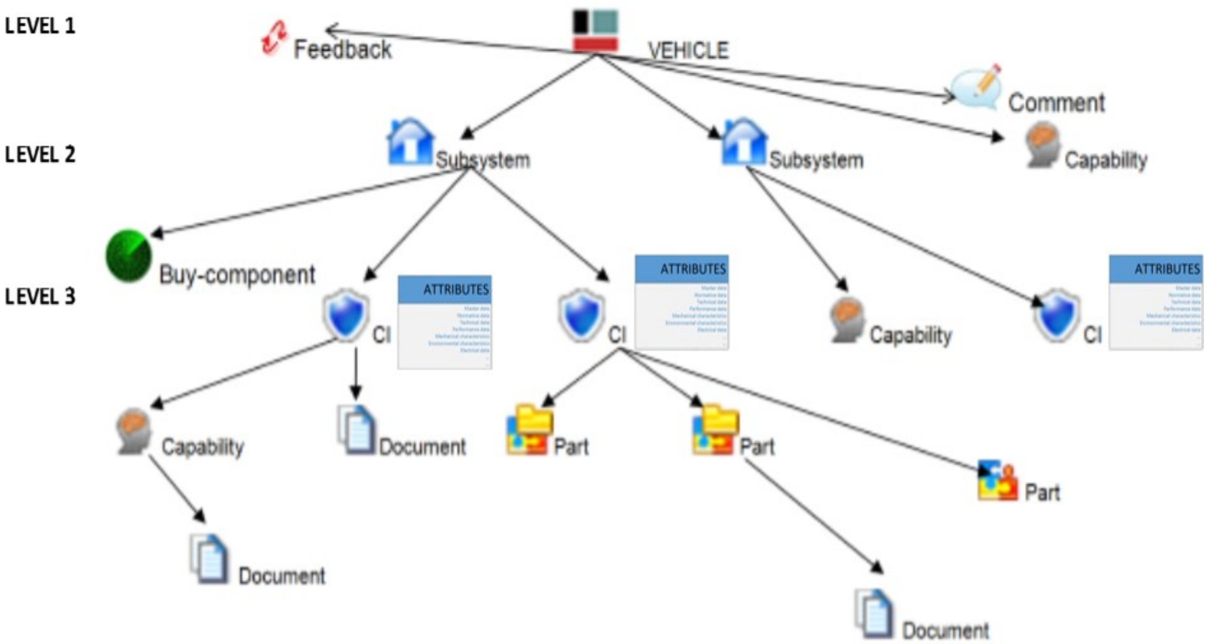

Figure 3.5: The data model of the product catalog

3.3.2 Adopt-Adapt-Innovate analysis

The workflow that, starting from the ITT, allows a vehicle/component configuration to be obtained, which is identified according to the PBS functions and to the customer needs, is:

1. a set of requirements/features (established at the level of the components) is constructed out from the technical specifications document;
2. a search is performed, into the DSS, with this set of requirements/features as input, comparing what the customer wants and what is classified in the catalog;
3. AAI analysis starts: the system returns the details of the comparison and a series of synthetic indexes of correspondence;
4. A first-proposal of vehicle/component configuration, identified according to the PBS functions and to the customer's needs, is automatically generated by the PLM system. This configuration may have some empty data fields, meaning that there is no CI in the catalog that matches the technical specifications;
5. a context of product is generated, where it is possible to manage the new product and make technical and economical analyses. This is the end of the AAI;
6. the adapting phase through the use of template CAD products (see the next paragraph) starts;
7. when the adaptation is not possible, an innovation may be necessary.

The AAI analysis, a pivotal point of the proposed methodology, works as follows. CIs referred to as "adoptable", that is, whose attributes correspond to 100% to the requirements, are automatically inserted into the configuration of the new vehicle. CIs referred to as "adaptable", that is, to be modified so that their features match the requirements, are copied onto a new CI for the subsequent changes/adaptations according to the technical specifications. Eventually, if for some item of the E-BOM the KBE system does not find any CI which matches the requirements, that is, the matching percentage is too low, the corresponding leaf node (at the third level of the PBS) is empty and it means that an innovation is necessary. Thus, at the end of the AAI, the system returns a first-proposal PBS (figure 3.6).

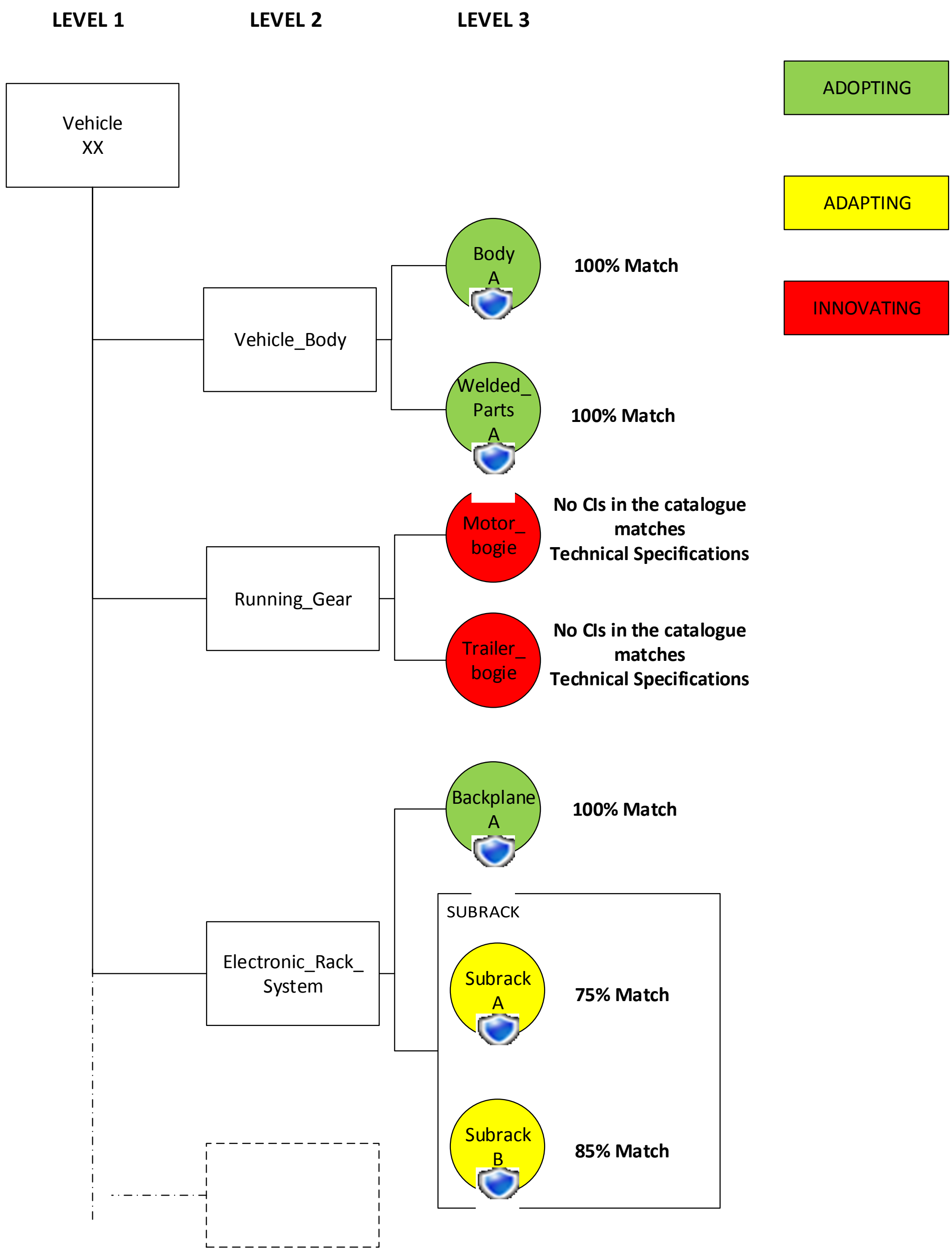

Figure 3.6: Simplified example of a first proposal vehicle configuration identified according to the PBS functions and to the customer needs.

As shown above, it may happen that some leaf node has two or more adaptable CIs. In this case, the system engineer can choose, between the proposed CIs, the most suitable one on the basis of personal technical considerations.
At the end of the AAI analysis, the company makes the bid/no bid choice.

3.3.3 AAI analysis for the electrical design of a train

A railway vehicle is essentially composed by two principal systems: the case and the bogie. The case consists of a metallic structure of steel or aluminium alloy and the activities to do on the case concern the montage of the electrical equipment, the pneumatic system, the furnishing and the auxiliary equipments. The case study described here regards the electrical equipment. In manufacturing, a case is often divided into different working zones, among which there is of course the imperial.

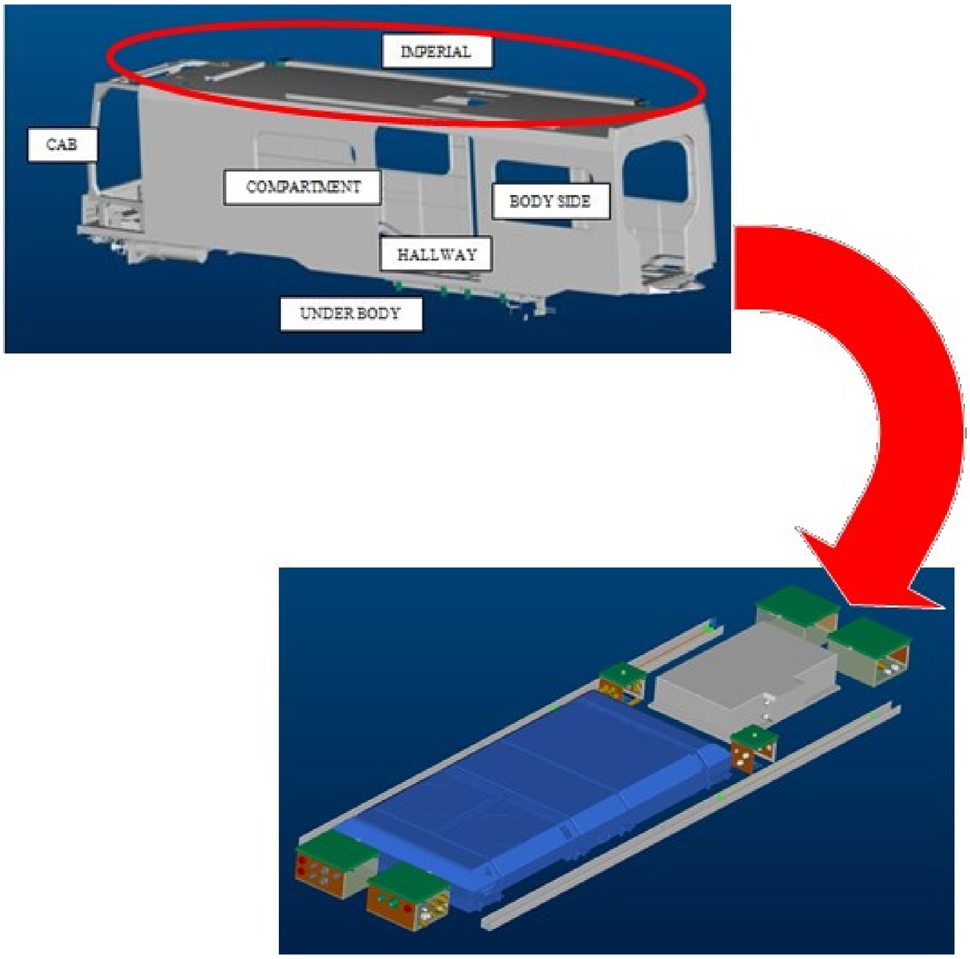

Figure 3.7: The case and the imperial

The imperial is the upper zone of the body of a railway vehicle and contains the housings for the pantographs (when present), the braking resistors on vehicles equipped with electrical braking and a series of equipment auxiliary such as HVAC modules and the static converters.
Starting from the dagrams constructed out from the Technical Specifications document, a series of requirements for Low Voltage (LV), Medium Voltage (MV) and High Voltage (HV) have been defined.

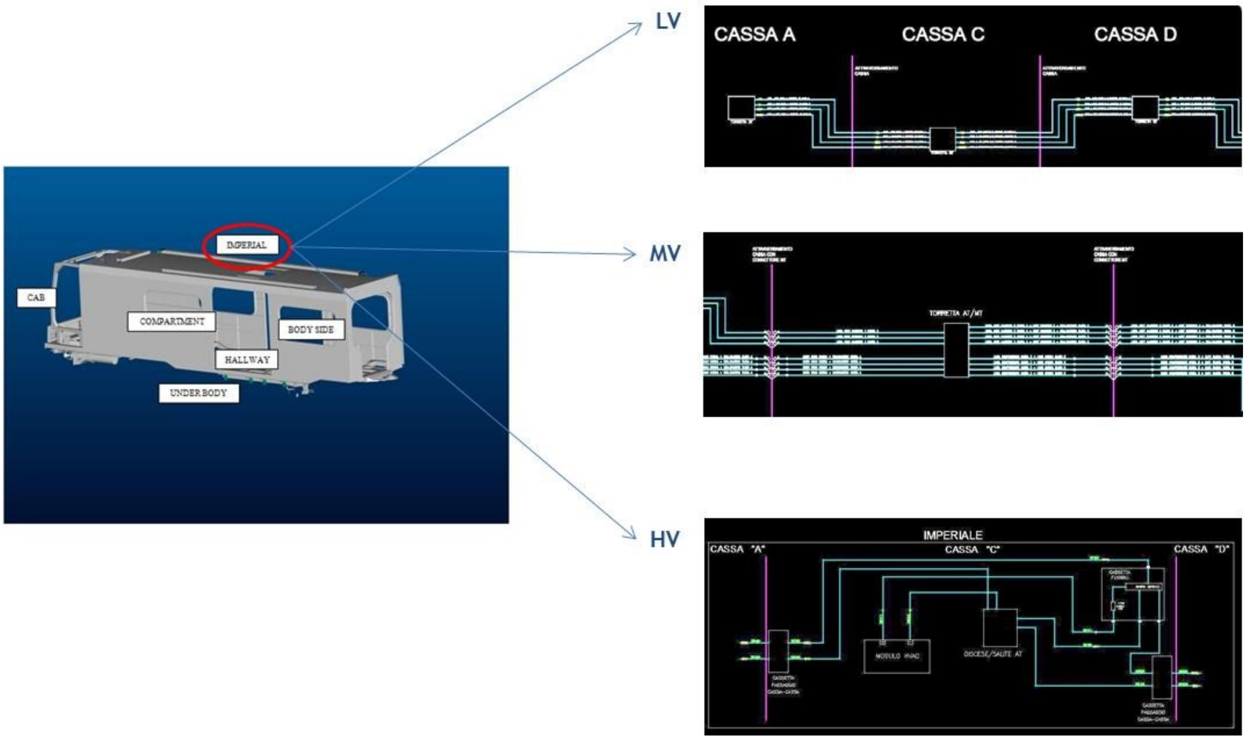

Figure 3.8: Wiring diagrams

On Based on these requirements, the DSS has been queried. The AAI analysis has given an “adaptable” outcome: five of the six zone have resulted to be adoptable, but some adaptations have resulted to be done for the imperial zone; thus, the case appeared to be adaptable.

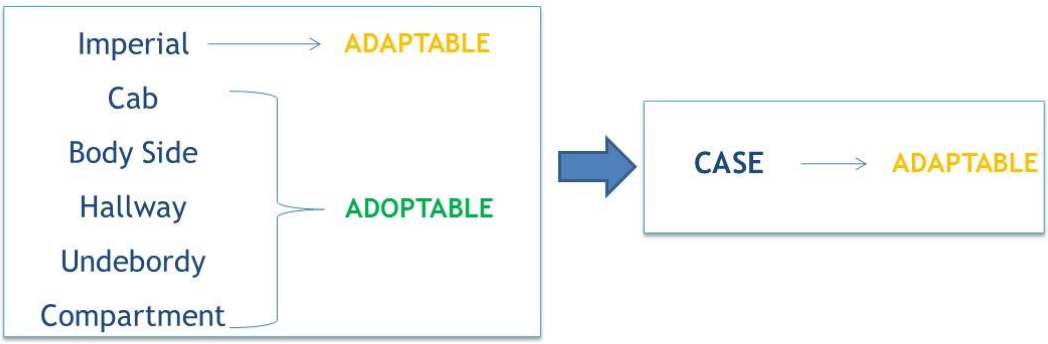

Figure 3.9: AAI’s outcome

Designers, in the adapting phase, can take advantage using a template CAD file as the type illustrated in next paragraph.

3.3.4 Adapting phase through the template product

The template product acts in the designing phase, once the tender has been won. Normally, the redesign of a product may be time consuming and can require repetitive actions. The methodology proposed in this paper suggests the use of a template product, that is a 3D mathematical model of a component that encloses or contains all the features of a whole family of products, conditional expressions (if-then-else constructs) and some technical constraints information. Starting from the template product the user can configure new products with similar but different characteristics.

3.4 The Template product case study: the rack of the Traction Control Unit

As clearly illustrated in [12], "*the challenge of reducing designing time […], especially in the context of large companies, encourages the use of methods and tools aimed to support designing activities and to re-use the company know-how"*. Inspired by the design parameterization methodology, that is *"to automatically complete new parts design through changing the parameter value of the existing design results*"[13], has been developed a *template* CAD product with the focus on speeding up the design activities. In particular, the authors concentrated on the development of a methodology and a tool that:

- contributes to reducing the time to market of products;
- is able to interact with the PDM/PLM system and contributing to its population;
- is interactive.

The *template* product case-study is born from the consideration that commercial CAD systems' ability of supporting the parametric modeling of parts is high and well known, but parametric design of assembly models is not well sustained [14]. The first assemble modeled in a template way is the rack of the Traction Control Unit (TCU); this is a product with a not high level of complexity, and whose components had a high level of standardization. These features well suited to a case-study. The developed *template* rack has a high-parametric structure; the user interacts with it through the independent variables that are related to all the other dependent parameters. Through a suitable choice of these variables the designer comes quickly to the definition of the product, all of its features and all the technical documentation required for its production: in fact, the annotations have been included into the 3D model; in this way, the user automatically generates the geometry of the assembly complete with dimensions, tolerances and all the information necessary for the production of the *component*.

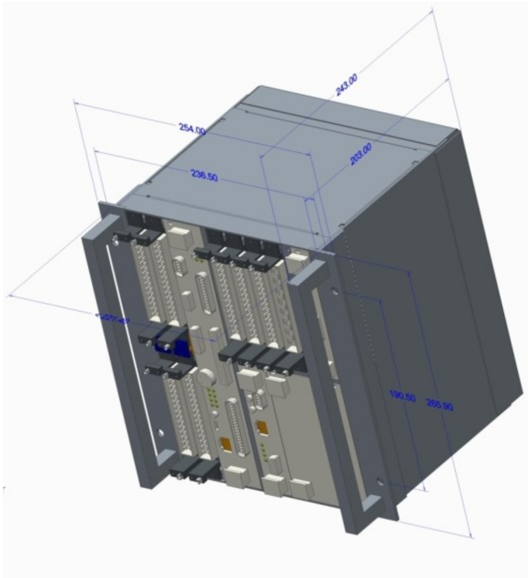

Figure 3.9: An instance of the *template* rack complete with the 3D annotation

The rack consists of several sub-assemblies and they were modeled separately and then inserted into an overall architecture that allows the user to manage the entire variability of the rack family.
The activity started with a detailed analysis of the assembly to be modeled aiming at identifying:

- the subcomponents and the features to model;
- the independent parameters that control the variability of the subcomponents and the assembly;
- the functional relationships between the subcomponents.

The *template* has been completely parameterized; in this way, the user can get any configuration of the rack simply typing input from the keyboard, without taking any action on the 3D model. It should be noted that the parameterization affects not only geometrical and dimensional parameters, but also binary parameters or strings which can manage the presence or absence of features and parts.
The CAD tool used for modeling the template rack is Creo2.0 by PTC. In detail, for obtaining the *template* product, two tools of the Creo2.0 suite have been used:

- the pro/program module;
- the family table tool.

Pro/program is a programming module. It allows users to manage and edit the strings of code that Creo2.0 generates when modeling the various parts/components; in fact, each part or assembly is associated with some lines of code and, editing the code through *pro/program* in an appropriate way, it is possible to program the model and obtaining a conditional modeling. One of the possibilities provided by this tool is to manage the parameters via questions that are asked to the user; through this approach, each configuration of the product is identified by a set of values for the independent parameters chosen. In this way, the designer has only to define the set of values and do not worry about the modeling and the creation of documentation.

The *family table* tool lets you create multiple versions of a part or an assembly, changing the values of parameters such as dimensions and managing the presence of features and components. This tool gives the designer the opportunity to populate the product catalog after he has defined the set of parameters: within the *template* has been implemented the option of saving the set of input parameters by creating an instance of the family table.
The rack of the TCU is composed by the structural unit and the electronic boards inserted into; the boards allow you to manage the functions of the vehicle related to the traction. Thus, the assembly rack has been broken down into its subcomponents:

- the subrack;
- the backplane;
- the electronic board;
- the board rail.

The subrack is the unit intended to house the printed circuit boards; the backplane, that is a plate for housing the rear connectors, is mounted inside the subrack; the boards are mounted in the subrack with the appropriate board rails.

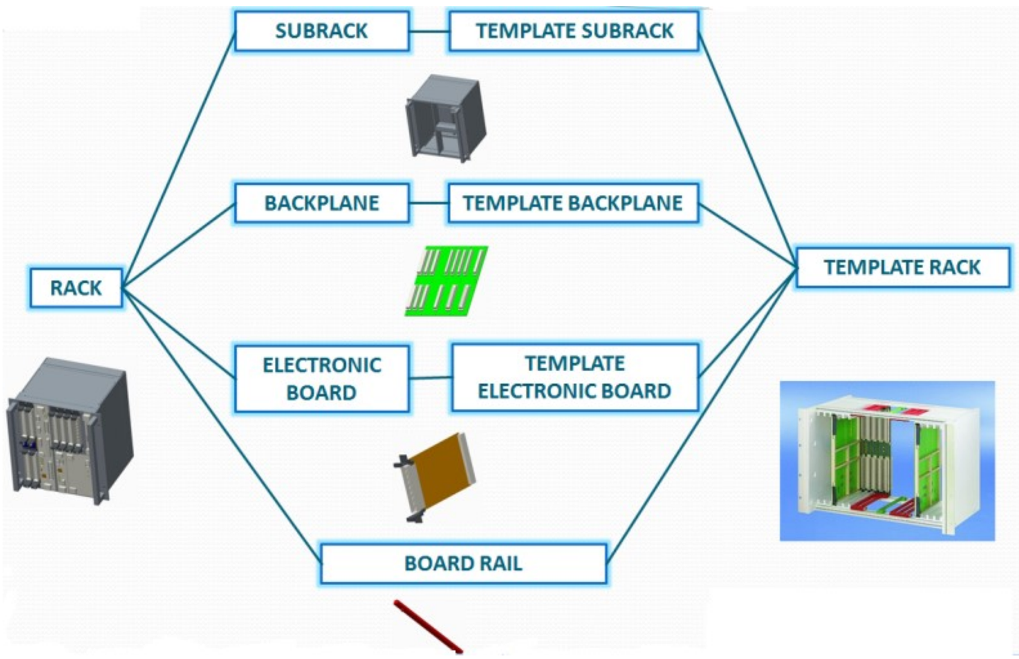

Figure 3.10: The rack and its subcomponents.

The CAD model handles the geometric variability of the subrack, the backplane and the boards and also allows positioning the boards in the assembly. The flow chart for obtaining the desired rack is reported in figure 3.11:

1. the user chooses the subrack through a series of questions/answers:
2. the system queries the library to check whether the required backplane is already present and, if not, a new backplane is generated on the base of the inputs;

3. the system queries the library to check whether the required type of board is already present in the catalog and, if not, a new board-type is generated based on the inputs;
4. the user chooses the number of boards and their position.

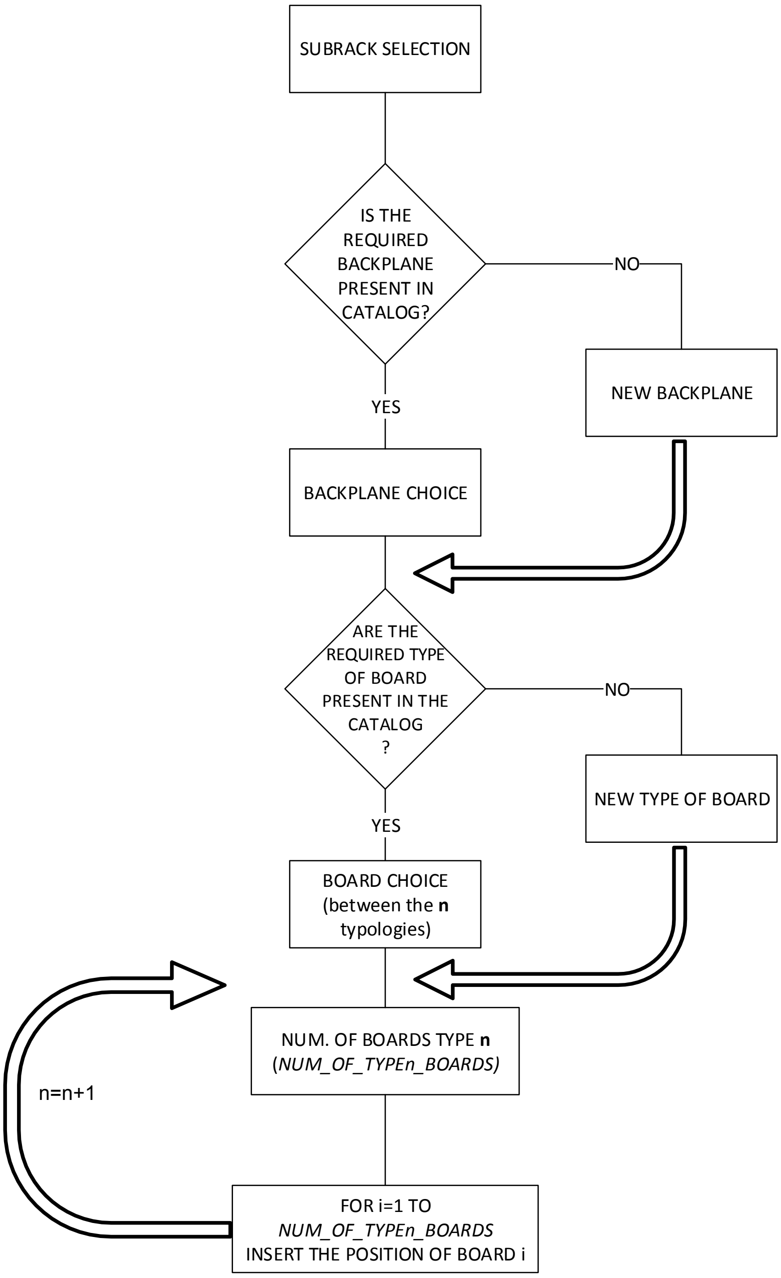

Figure 3.11: The flow chart for assembling the rack.

The inputs are put into the model via the user interface, passing by a series of questions through a sequence of pop-up windows (see figure 3.12). By simply entering these inputs the user get the whole geometric model, complete with 3D annotations and the technical documentation. So the modeling phase and production of technical documentation is reduced to the mere choice of the set of input parameters; everything else is handled entirely and automatically by the *template*.

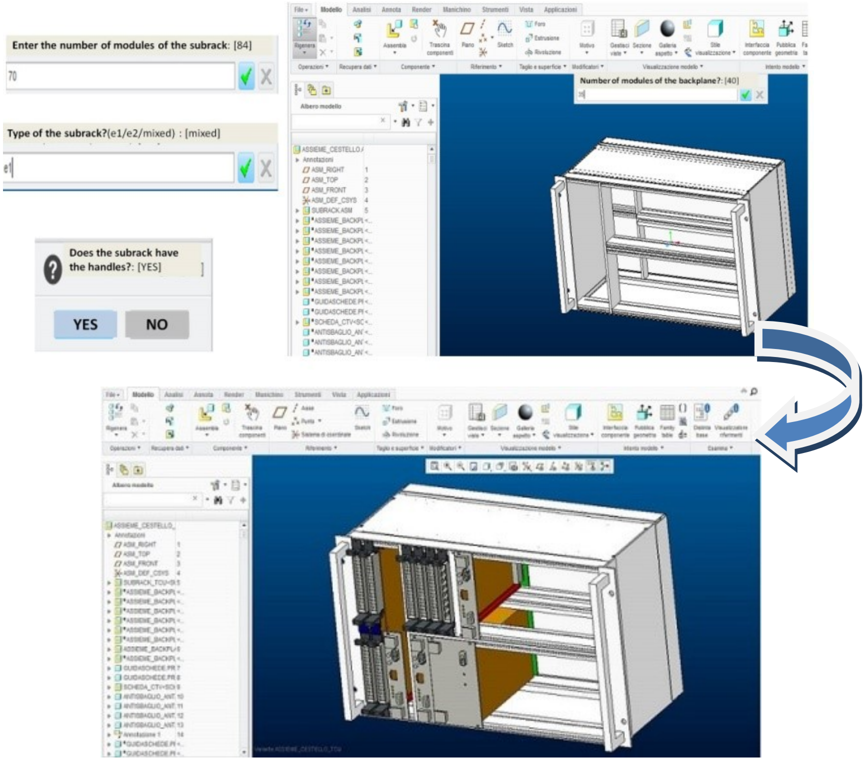

Figure 3.12: Examples of questions for the data-entering phase. After this phase, the desired rack is automatically created.

3.5 Conclusions, results and future works

The aim of the research has been studying on a methodology and implementing a system that supports a company acting in the railway market in the evaluation of its existing products that best suit the requirements of new bids. The proposed approach and system allow the company to carry out technical and economic evaluations in order to assess the use of its technical know-how within new projects. The use of the product catalog and the AAI analysis dramatically reduce the duration of the bidding process: before the use of the new methodology, the time from the tender notice to the tender offer was about 60 days; on the contrary, as a result of some simulation made, it can be said that with the use of the product catalog and the AAI the time has been halved. In addition, the use of this objective and rational system reduces at the minimum the risk of participating in a not economically convenient competitive tendering.

The other strand of the research has been the introduction of the template. The study conducted on the rack of the TCU has demonstrated that the time required for the designing phase can be, for components of average complexity, more than halved, bringing obvious economic and time benefits. Certainly, the creation of a template CAD file takes time and the entry phase of the inputs can be heavy when the input values are numerous; on the other hand, the model composes by itself at the end of the parameter-entering phase. Future objectives are researching on more powerful template CAD files, testing the tool on more complex products, implementing techniques which may make the tool more interactive.

3.6 References

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CHAPTER 4

A DIGITAL PATTERN METHODOLOGY SUPPORTING RAILWAY INDUSTRIES IN PORTFOLIO MANAGEMENT

4.1 Introduction

The object of this chapter is the development of a decision support system involved in the bidding for invitations to tender in the railway field. The proposed methodology is based on the characterization of the whole train and its components, through several attributes according to a digital pattern approach. In particular some key components were chosen such as the traction motor, the bogie and the auxiliary equipment converter. The system measures the extent to which the products offered by the company fit the one required by the customer, comparing the homologous attributes. Such analysis is called 'adopt/adapt/innovate' (AAI). In this way it is possible to identify products already designed that fully or partly fit what required, obtaining huge benefits in terms of effectiveness and efficiency.

In the railway field the success of a project is strictly linked to the right decision about whether to bid to an invitation to tender (BID/NO BID). Companies operating in this sector mostly make to order. Consequently they need to evaluate appropriately the technical and economic feasibility of the required vehicle [1].

The process involved in bidding to an invitation to tender is very complex. It involves several business functions with different priorities and goals. Mistakes and unfounded choices would be unavoidable if decisions were taken on the basis of mere intuition or subjective analysis. Therefore the process of preparing the bid is expensive in time and money. To use the knowledge heritage of the Company is mandatory to evaluate in a short timeframe whether to bid or not [2], [3].

This paper proposes a tool to improve the company products portfolio management using a methodology based on Digital Pattern (DP). In particular, times and costs are reduced by using all the process or product patterns existing within the Company, according to Knowledge Based Engineering (KBE) approach [4], [5], [6]. A digital pattern represents a series of predefined and parametrical data structures, both geometrical and numerical; such data structures adapt to specific different contexts. Designers reduce the concept phase time and improve the reliability of choices using simulations, specific models and reference rules and standards as decision support tools [7], [8], [9].

In particular, the Decision Support System (DSS) object of this paper allows:

- To catalogue and visualise Company products. It is possible to interrogate the system in order to extrapolate information about standard products (e.g. vehicles, subsystems and components);
- to compare catalogued products to those required in the invitation to tender. The system provides the list of the products best fitting the required one with a percentage affinity index. This index is calculated on the basis of the comparison between homologues features

of the products using a specific research algorithm.

The opportunity represented by the systematic visualization of the company portfolio and its confrontation with the required product supports the whole bidding decision making process. Activities were carried out in collaboration with AnsaldoBreda Spa, a Finmeccanica Company.

4.2 Methodology

The proposed methodology is based on the development of a DSS and the characterization of the whole train and its components through several attributes. This methodology has been implemented through CD.

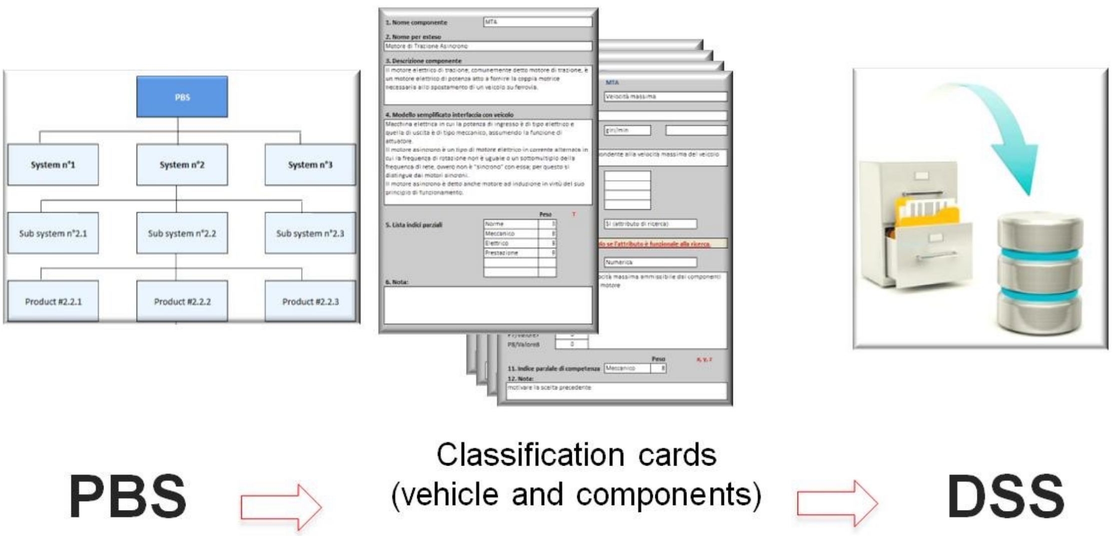

Figure 4.1: From the PBS to the DSS

The Database is created from the elements of the Company Product Breakdown Structure (PBS) [10]. Each element is described by a series of characteristic attributes [8]. Every attribute is associated with a comparing function, a weight and a class. These objects are used by the search algorithm described in paragraph 3.
In this way a pattern of a specific element of the PBS is created. To complete the database (DB) creation, assigning a value to pattern attributes is needed.
This procedure allows to populate the DB. Therefore this process is reiterated as many times as the number of products in the digital portfolio. For example the PBS element "Traction Motor" was reiterated 18 times, which is the number of different traction motors chosen for the digital portfolio.
The pattern containing the attributes with a value of a specific company product represents the Characteristics Matrix. All the Characteristics Matrices of the different PBS elements form the digital portfolio.
Similarly the pattern containing the attributes with a value of a product required by an invitation to tender is called Requirements Matrix.

The second phase concerns the database query, with the purpose of finding the product that best suits what required. The system compares the Requirements and Characteristics Matrices by a search algorithm. Such algorithm outputs the affinity indexes of the digital portfolio products. In particular the offset from 100% represents the effort needed to make the digital portfolio products fit to what required.

Starting from the affinity index the results analysis is performed with the paradigm Adopt/Adapt/Innovate (AAI). This paradigm consists in “adopting” a product if the affinity index is 100%; in this case no effort is required to satisfy client requests. The algorithm output is “adapting” if the offset requires an acceptable effort. Finally, if the offset is bigger than a certain amount, the output is “innovating” the product, since designing from scratch a new product involves less money and time than modifying what is already available [1].

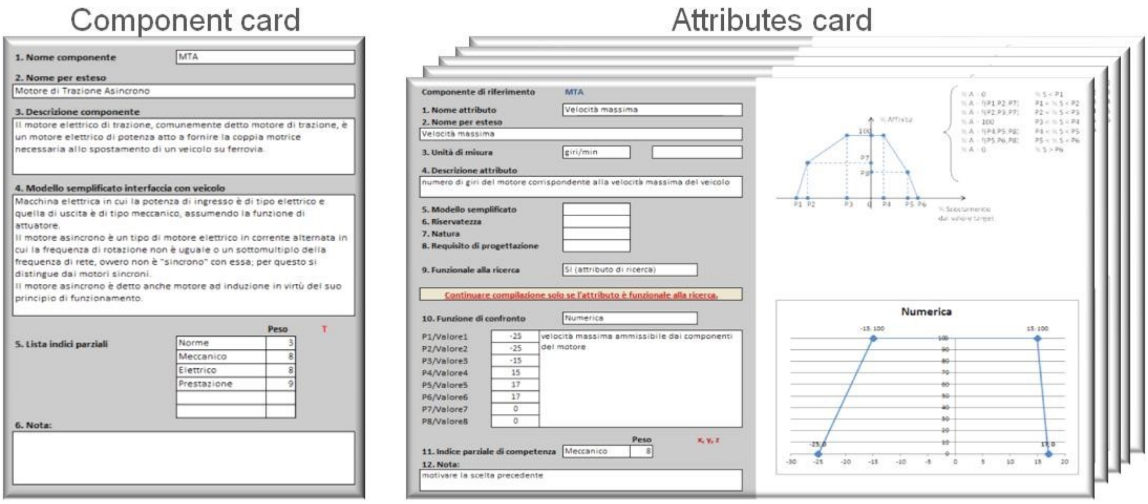

Figure 4.2: Classification cards: components and attributes forms

4.3 Search Algorithm

A key element of the methodology above described is the search algorithm which, receiving requirements in input, provides in output the affinity index between the requested element and those available in the Digital Portfolio.

It consists in three steps represented in the diagram below (Figure 4.3). It is suitable to search for any type of product, be it a whole vehicle or a component.

Each stage is characterized by input, output and functions. For each output corresponds a different level of view.

The inputs that characterize the step 1 of the algorithm are represented by the requirements of the tender notice and by the characteristics of the products in the Digital Portfolio. They are contained in the Requirements and Characteristics Matrices. The two matrices are compared by specific “Comparison Functions” (Ct). The matrices attributes can be of different type (numeric, range and string); for each type of attribute a different type of function is used.

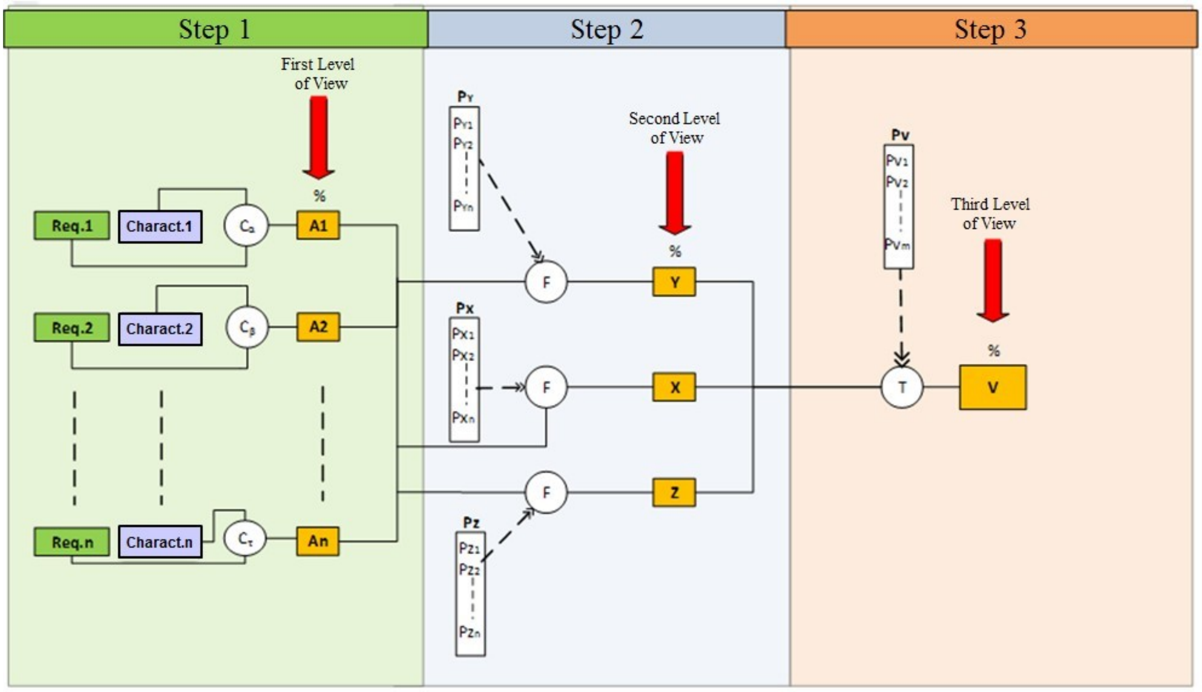

Figure 4.3: Search algorithm

The comparison functions provide the outputs of Step 1, the affinity index of each attribute (Ai). They indicate the percentage of affinity of each attribute with the requirements of the customer in the tender notice.

The Ai represent the input of Step 2. To generate the synthetic indicators of affinity is the objective of this stage. For this purpose, the attributes with similar characteristics are grouped in the same class. Furthermore, for each attribute a weight between 1 and 10 (Px, Py, Pz) is assigned. The step 2 outputs the affinity indexes divided into different classes (X, Y, Z) by appropriate functions (F).

In this way it's possible to monitor the percentage of affinity of a subset of attributes that have in common a same functionality.

In the last step as well, a weight from 1 to 10 (Pv) is attributed to the affinity indexes X, Y, Z. Merging these inputs by the function T, we obtain as output the percentage of total affinity (V).

In conclusion, it is important to highlight that the comparison functions and the weights are defined with the aim to obtain the affinity index whose deviation from the 100% represents the effort to achieve the target value. In particular, the function used for attributes of numeric type is based on the Digital Pattern approach. Indeed, thanks to the flexibility guaranteed by its 8 parameters, it is adaptable to a multitude of specific cases (Figure 4.4).

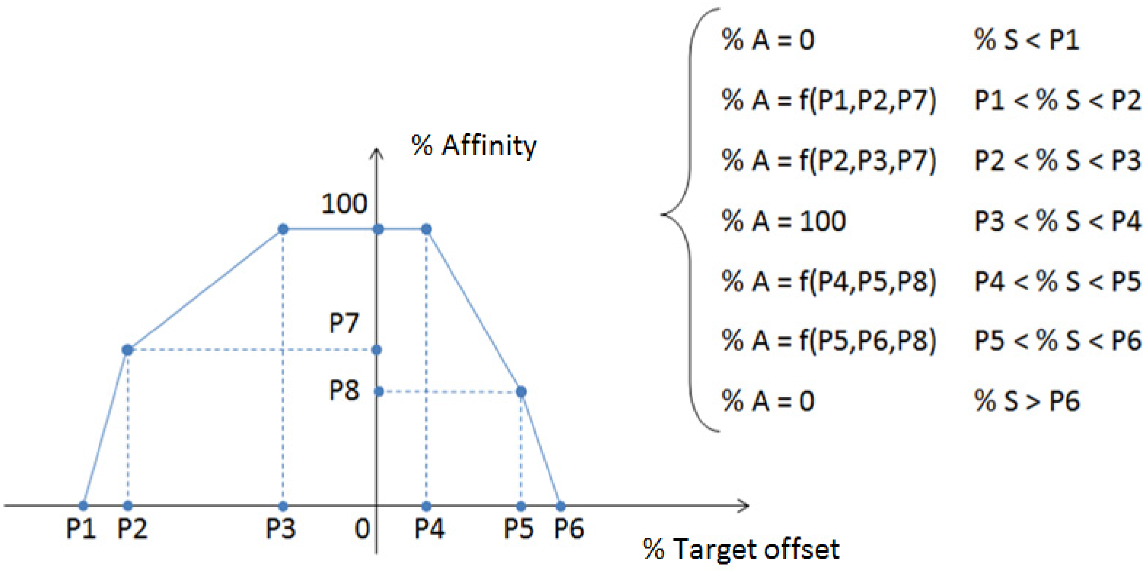

Figure 4.4: Comparing function

4.4 Case Study: "Asynchronous Traction Motor"

During the work carried out at AnsaldoBreda, the methodology described above has been successfully applied both to the whole vehicle and to different components [Figure 4.5]. In this section the case study for the component "Asynchronous Traction Motor" is shown as example.

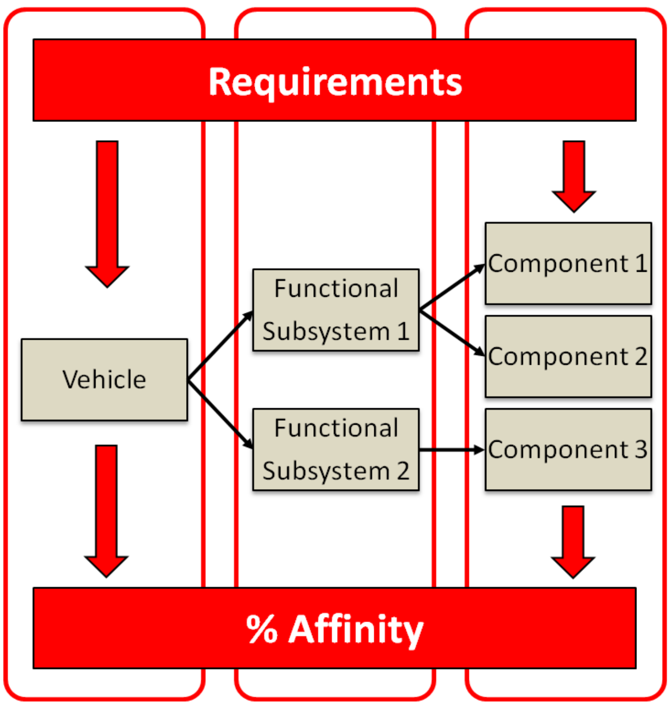

Figure 4.5: DSS architecture

First of all, the characterizing attributes and classes were selected and to each one of them a weight was assigned (Table 4.1).

Component	Class	Weight	Attribute	Weight
Traction Motor	Normative	7	EN603492	8
			EN613771	8
	Mechanical characteristics	8	Max speed	8
			Transverse dimension	9
			Longitudinal dimension	9
	Electrical characteristics	10	Voltage (braking)	9
			Voltage (traction)	9
	Performance	10	Synchronous speed	7
			Voltage	9
			Power	7

Table 4.1: Traction Motor weights and classes

Data needed to describe the traction motor and its associated attributes were collected through the format shown in figure 4.6.

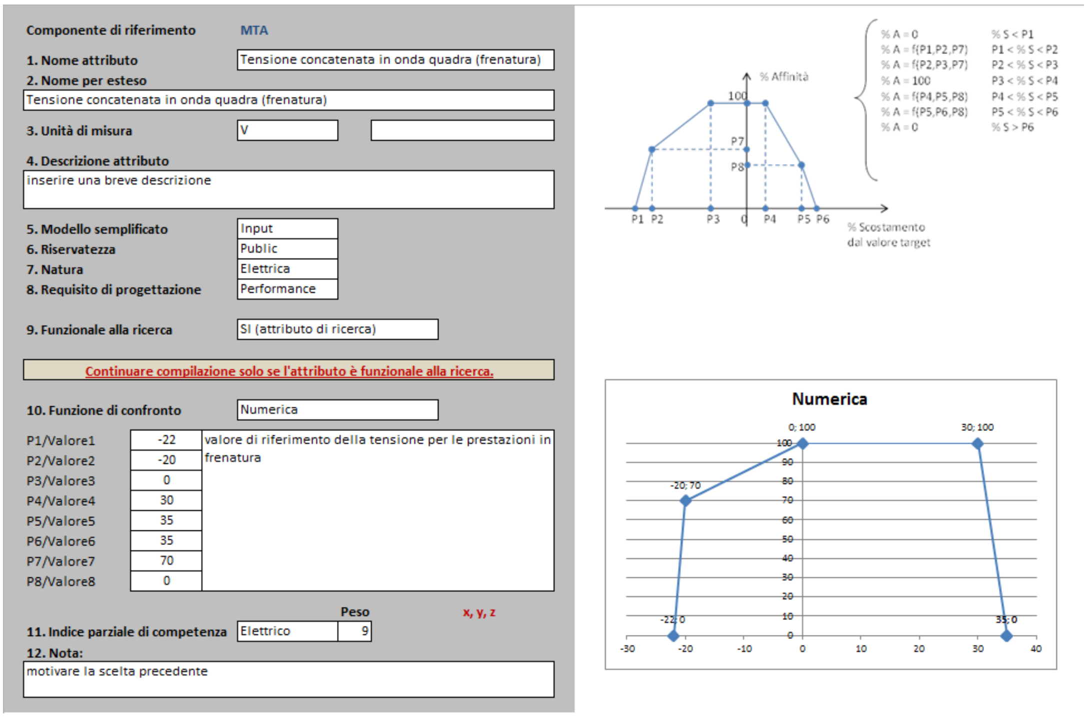

Figure 4.6: Attribute format

As can be seen, the format for the collection of attributes also shows the comparison function with its parameters and classes. At the end of the data collection, the information was saved into the PLM Collaboration Desktop software.

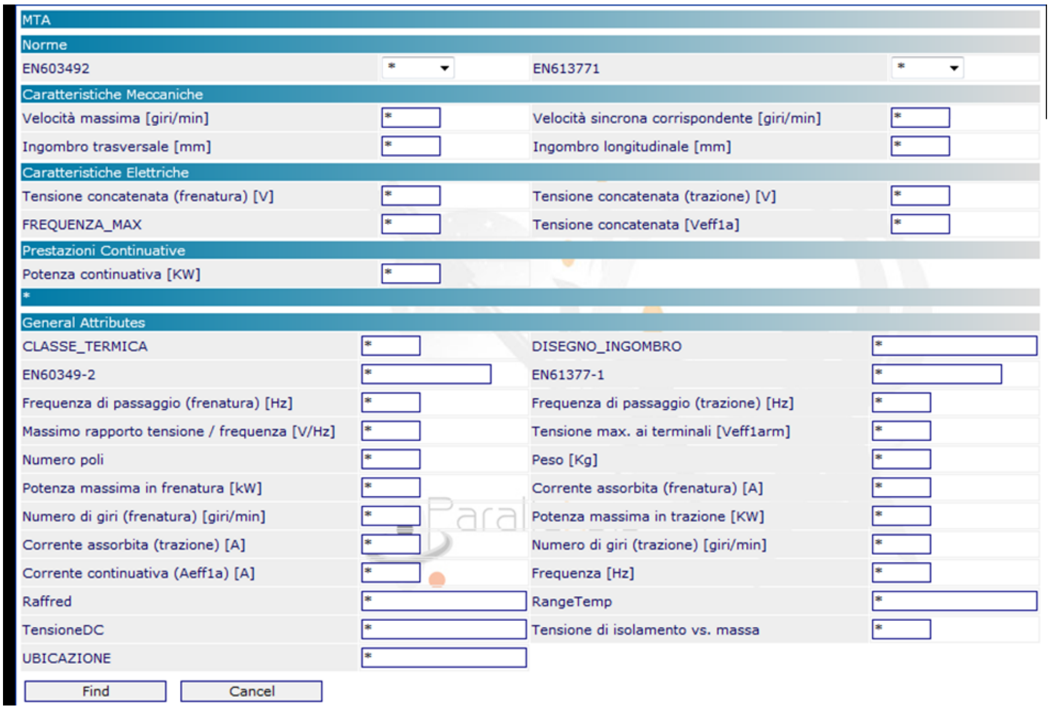

Figure 4.7: New product input data window

Data needed to describe the traction motor and its associated attributes were collected through the format shown in figure 4.6. As can be seen, the format for the collection of attributes also shows the comparison function with its parameters and classes. Data were inserted into CD and a query was launched to test the affinity indexes carried out by the system (figure 4.7). The achieved result is shown in the figure 4.8, in the form of various diagrams, automatically generated by the DSS in an EXCEL format.

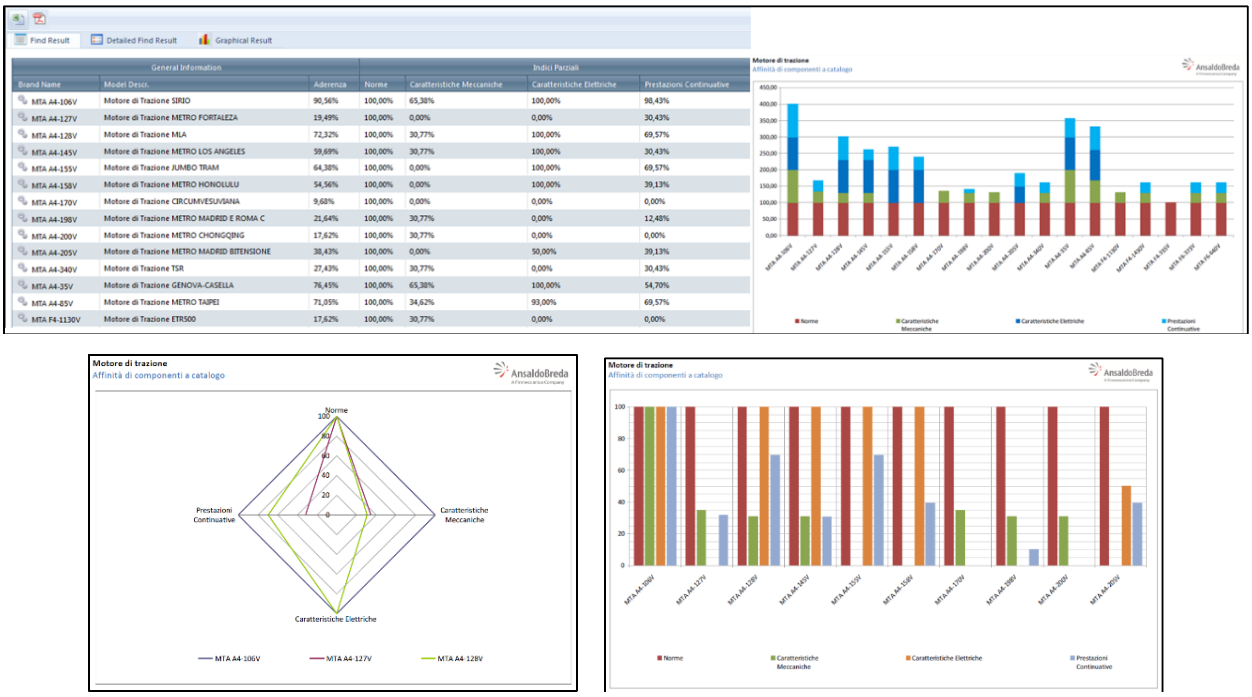

Figure 4.8: Output reports

4.5 Windchill – Collaboration Desktop integration

As said above, CD already has its native integrations functions with PTC solutions (both WINDCHILL and CREO) that permit the user to open the EBOM of the CAD file and CAD file itself directly into CD. Besides, the attribute mapping integration functionality have allowed the definition of a link between the attributes of the CAD model in CD with the attributes of the CAD model in WINDCHILL. Using these capabilities, CD has been strongly integrated with WINDCHILL and through it the link with SAP R/3 has also been obtained. CD-WINDCHILL link works via the item part number and allows to view in CD all the parameters and attributes associated with it in WINDCHILL.

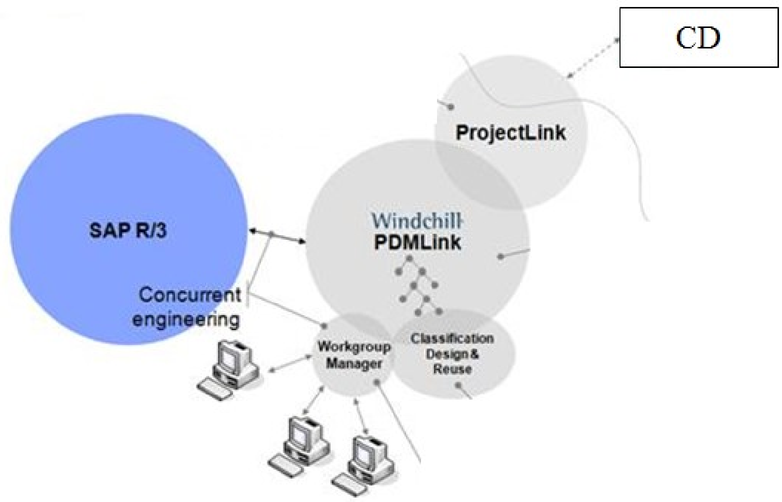

Figure 4.9: Windchill - CD integration

4.6 Digital-Pattern applications

Other activities were carried out in collaboration with AnsaldoBreda, all confirming the possibility to implement the proposed methodology. The purpose of these activities is to achieve a quality improvement and to collect data for Portfolio Management in order reduce times and costs of product development.

This goal was fulfilled by using, integrating and, whenever possible, unifying all the process or product patterns within the Company, including numerical simulation and virtual reality tools.

In the following sections the most meaningful activities are presented. With regards to the Decision Support System proposed, the results of these activities are used to improve the “adapt” phase.

4.6.1 Digital Pattern Methodology in structural mechanics

As for electric motors, Digital Pattern methodology has been applied to structural simulations. These simulations are performed using Finite Element Method (FEM). To Generate a finite element model (preprocessing phase) can be very time consuming, especially for complex systems, therefore the methodology has been applied to this phase. The goal is to generate a parameterized FEM model for each structural analysis performed on motors.

Each model handles the variability of the analysis (e.g., geometric dimensions, loads, material). In this way it is possible to get the required FEM model simply typing the input data; so the preprocessing phase is reduced to the choice of the input parameters. In this way the Company know-how is used to optimize the process.

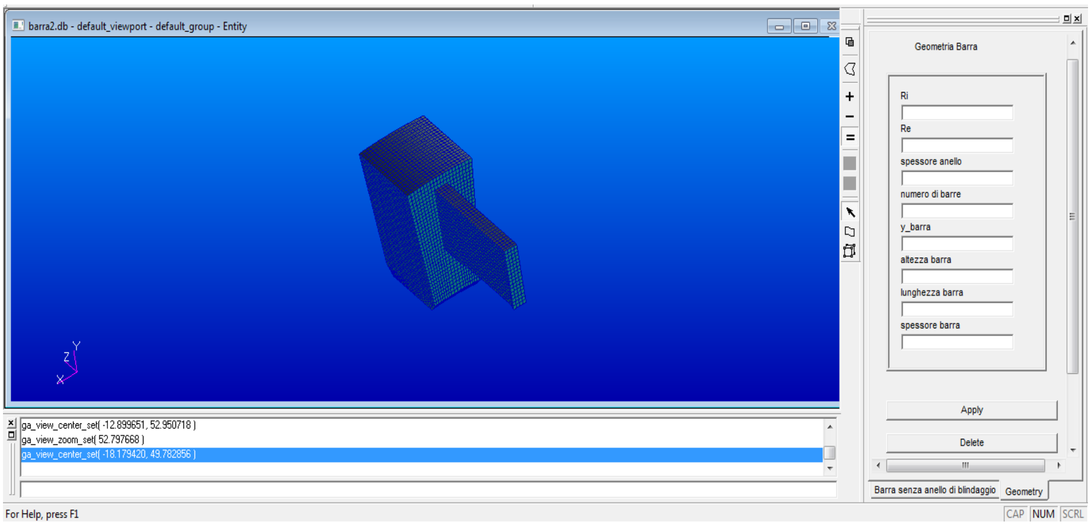

Figure 4.9: GUI that allows the user to enter dimensions.

The first case study is the rotor cage. This is a yield analysis; the load is the centrifugal force caused by the rotation of the rotor. Patran by MSC is the preprocessor software used to generate the model; Nastran is the Finite Element Analysis program chosen. In detail, a tool of the Patran suite has been used, the Patran Command Language (PCL). This is a programming language that can be used to write application, perform variational modeling, and build GUI (Graphical User Interface). A tool has been developed in Patran using PCL; it allows the user to automatically generate the finite element cage model, to enter dimensions (Figure 4.9), load values, and material through an interface.

After performing the analysis in Nastran, the tool developed allows the user to post-process the results, for example plotting element stresses and strains.

The described methodology drastically reduces the duration of the design phase of electric motors, as a result of reduced time spent performing structural analysis.

4.6.2 Digital Pattern Methodology in converter thermo-fluid dynamic modelling

Digital Pattern methodology can be applied to the design of aeraulic ducts for cooling electronic components. Although each vehicle has its own specifications, every auxiliary converter can be thermo-fluid dynamic modeled as a system composed of heat generating components, heat transferring components (heat exchangers), and cooling fluid moving components (cooling fans), figure 4.10. Particular attention must be paid in heat exchanger sizing and in the choice of the cooling fan.

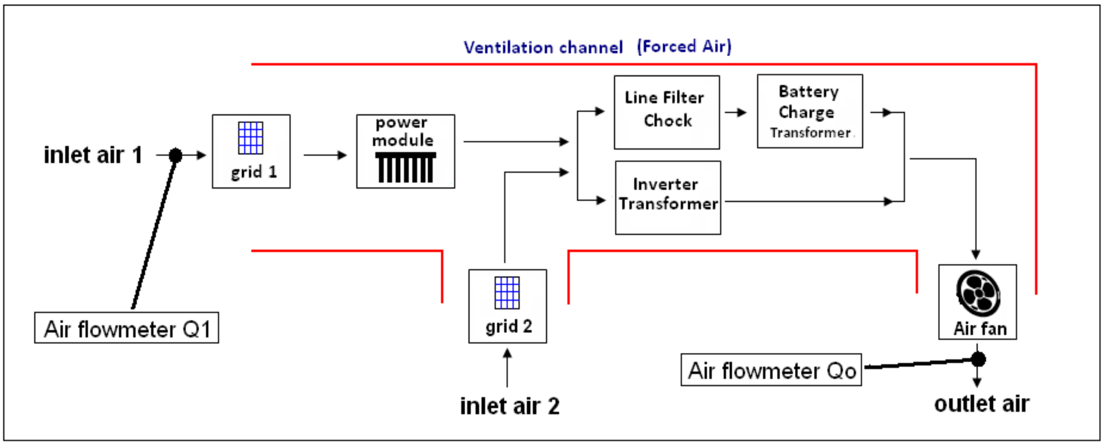

Figure 4.10: Air flow pattern of an auxiliary converter

The traditional approach is to build the aeraulic duct, to experimentally measure the pressure loss, and to choose the fan. The use of CAD and CFD systems allows to evaluate the duct fluid dynamic characteristics and to perform changes in the design phase reducing costs and time. The goal is to create a parametric geometric model; such model has to be *simplified given the complexity of components' real geometry.*

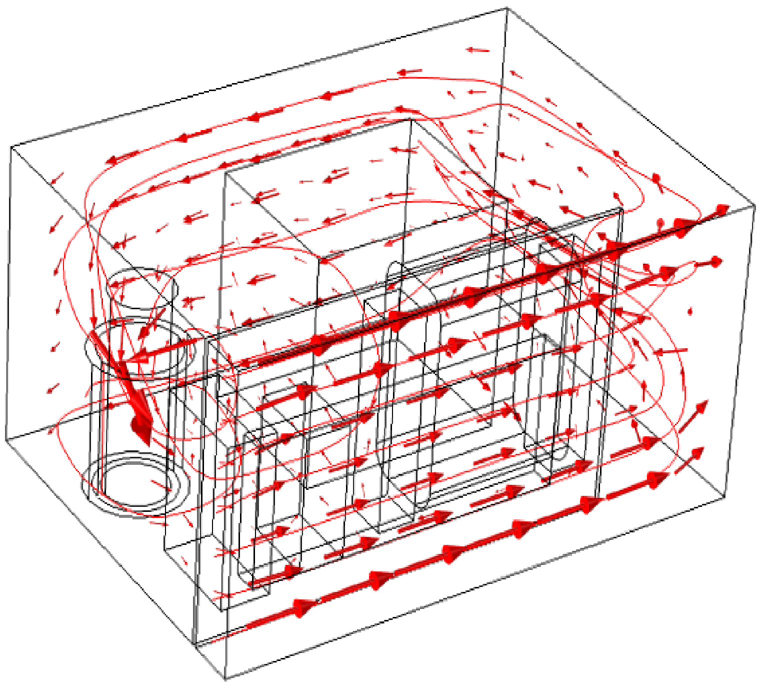

Figure 4.11: Mean value of the velocity field

The simplified geometric model is imported in Comsol Multyphysics through the LiveLink feature; the analysis can start after applying thermal and fluid dynamic boundary conditions. As example figure 4.11 shows the mean value of the velocity field obtained after the run.

Sometimes geometric variability, components' number and position, heat exchanger's possible presence do not allow to generate such model. Therefore a Matlab script has been developed; such script calculates the duct characteristic curve, requiring as input physical and geometric parameters. The user interacts with the script through a GUI. The script allows the user to calculate a stable operating point, intersecting the duct characteristic curve with the available fans' ones. Though this method is less accurate than a CFD analysis, it quickly provides approximate results and it is more flexible.

4.6.3 Equipment design and process simulation

One of the main activities related to bogie manufacturing planning is to produce the equipment necessary for the manufacture and to set up the bogie manufacturing plant. Generally the aim is to design equipment that can be adapted to different types of products in order to reuse them in more areas; however, this is not always possible so it is necessary to design special equipment depending on the need. An analysis of the process was necessary to increase the productivity of the painting department because it is a production bottleneck which is currently a bogie frame at a time. So, after a well-defined design requirements the equipment was designed (Figure 4.12).

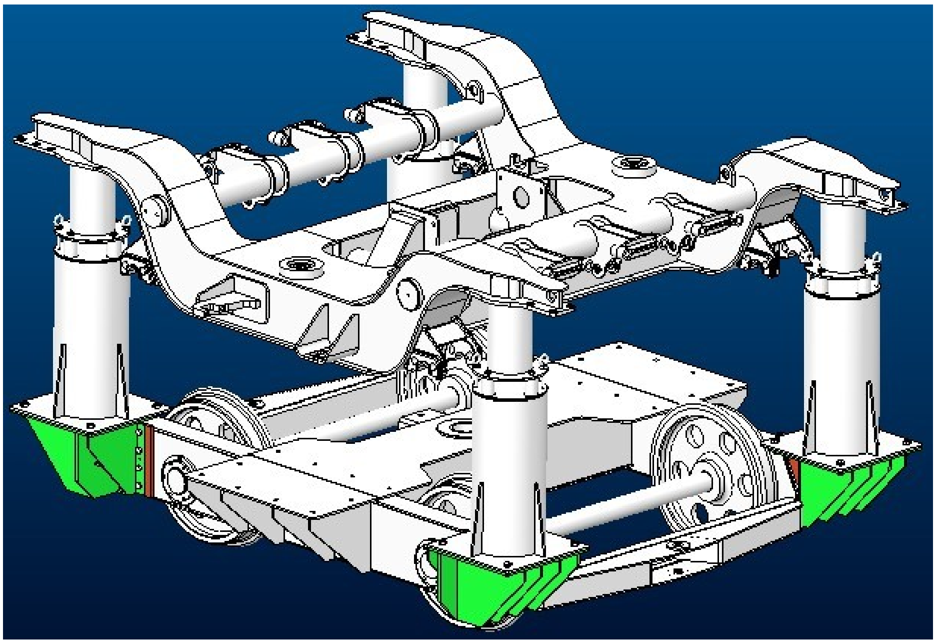

Figure 4.12: Equipment built with 3D modeling software Creo Parametric.

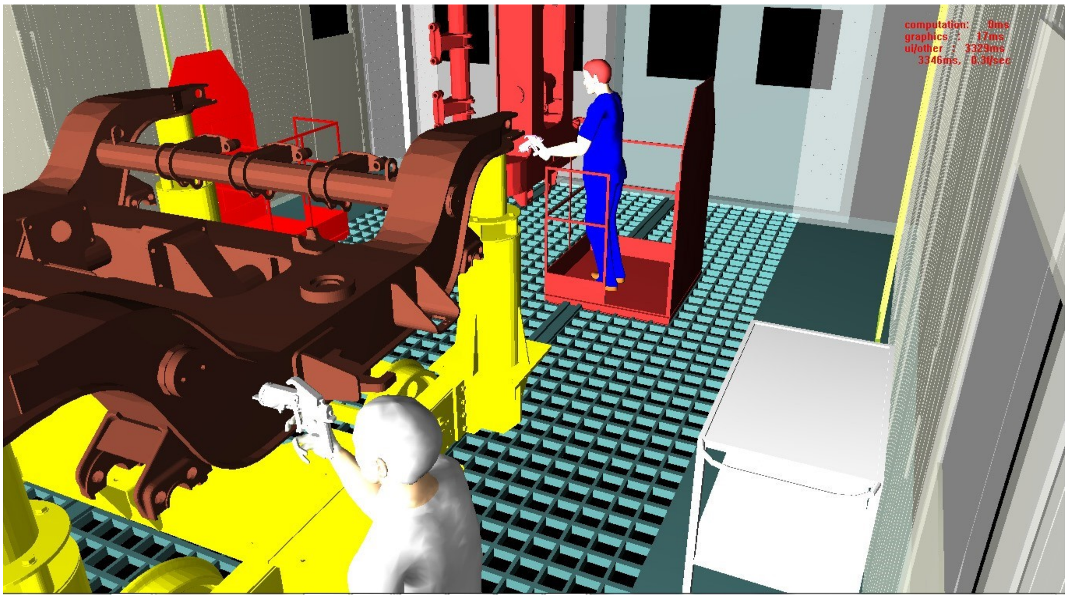

Figure 4.13: Simulation of the painting process in the cabin by Jack Siemens software.

Such equipment allows to paint a bogie frame disposed in a horizontal position in addition to the pre-existing vertical one. By using 3D and digital human modeling software, according to the Digital Pattern paradigm, the equipment was designed and the effectiveness in a virtual environment was verified (figure 4.13). The ability to simulate the process and to verify the interaction between operators, equipment and surrounding environment has allowed to anticipate and ensure a more consistent assessment of the adequacy of the design process. The simulations have allowed to identify possible ergonomics, accessibility and workability issues at an early stage of the project and before the production of physical parts expensive to change.

4.6.4 Industrial Engineering tools design

Digital pattern concepts can be successfully applied also in the Industrial Engineering field. Though every commission has its own peculiarities, there are nonetheless some operations which are conceptually the same no matter what kind of train is being assembled (i. e., positioning of door drivers, traction converter assembly, motion of specific big parts in space-constrained contexts…); for many of these operations, production cycles often require custom-made tools. The traditional approach requires the Company to design these tools from scratch for every new commission, or to buy this project from third Companies. The above mentioned analogies however imply that the tools themselves are analogous each other: dimensions, shape of some features or other minor aspects can differ, hence the use of parametric functions allowed by the modern CAD systems, coupled with the knowledge heritage preservation and valorization allowed by PDM/PLM systems give the Company the possibility to reduce the costs and time required to design the above mentioned tools (figure 4.14). Moreover, the tools can be tested in a virtual reality environment, so a subset of mistakes can be corrected in the design phase, when the economic damage is minimized.

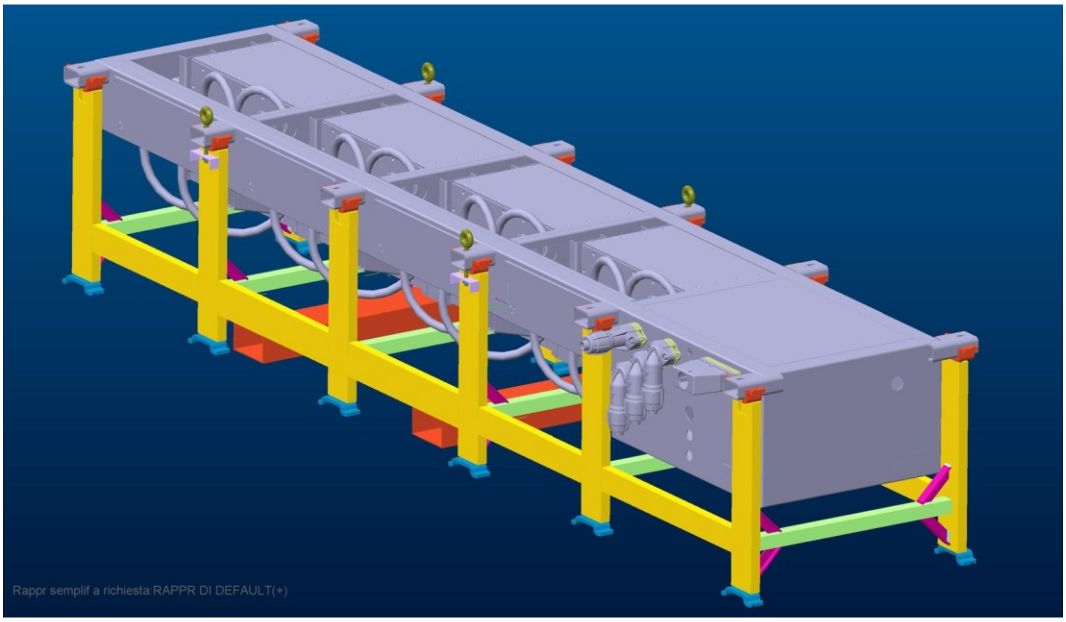

Figure 4.14: A tool for moving and storing traction converters. The design can be easily adapted to every other traction converter.

Finally, virtual manikins can be used in all the circumstances where ergonomics is a concern, or where the health and safety of the workers is at stake. For these reasons Digital Pattern philosophy can be a valuable asset even in the Industrial Engineering field, since it allows the Company not to waste precious time and resources, to avoid mistakes and to anticipate them in a production phase where the damage is minimized.

4.7 Conclusions and Future Developments

The prosed digital portfolio not only is an archive of standard products but a database of the whole company knowledge. It is also integrated with PLM by the direct link between products and CIs. The DSS was validated with the critical analysis of the results obtained for the "Asynchronous Traction Motor", using as inputs a set of requirements whose results were known in advance.

A perfect match was found comparing the search outputs with the expected results. In conclusion though DSS does not provide a deterministic result about whether bidding or not to an invitation to tender, gives the bidding team in a brief time a series of parameters supporting their decisional process.

In this way decisions are less impulsive and do not depend only on subjective opinion of one individual. This methodology offers good development possibilities if applied to a specific component. In fact an automatic modeling of the single component it is currently object of study. Such modeling is based on the correct definition of the key attributes and on the parametric modeling principles. In other words, the goal is to generate automatically the 3D model of the component starting from the client requirements.

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CHAPTER 5

VIRTUAL REALITY ENVIRONMENTS AND VIRTUAL DESIGN REVIEWS ON NEW AUTOMOTIVE PROJECTS

5.1 Introduction

Collaborative design has defined the need to develop and to use an immersive virtual reality environment aimed at deploying critical reviews of the project by design and manufacturing teams with interdisciplinary skills. A manufacturing company can design the entire production process in the digital and virtual environment while designers work in parallel on the products. In this way, manufacturing engineers can identify design and mounting constraints, transmitting real-time information to the designers. The collaboration between the production and design teams creates a complete vision for the development and optimization of products and processes. Born from these considerations, downstream of a thorough benchmark among the products available on the market, it was decided to develop appropriate procedures to make effective Design Review session through the use of the Virtual Reality software IC.IDO by ESI Group. Part of this activity was developed thanks to the collaboration with an big automotive enterprise which provided some case studies.

Nowadays, Digital mock-up (DMU) and numerical methods, such as FEM or CFD analyses, have become very common in the industrial design field. However, the full integration of these analyses with other aspects mainly related to the context of use of the product and its life cycle (e.g. ergonomics, maintainability, usability, etc.) is still quite a challenge for designers [1]. Besides, complex industrial products like trains or cars, need very specialized skills that may not belong to a single individual. Virtual Reality (VR) allows designers to interact each other and in real-time inside a single virtual environment (VE), working together on the DMU, making possible an objective and measurable analysis of the human factor in the context of use of the future product.

Nowadays, 3d modeling and virtual simulation are valuable tools to achieve excellent results in the design of industrial products. Engineering design is the activity that requires the highest improvement because today, for the completion of the entire process, times are becoming shorter and shorter. These are the reasons that justify the use of hardware and software tools sophisticated, complex, costly and constantly evolving, which also require the work of technicians with adequate level of preparation and continuous update.

Concurrent engineering is the methodological choice to be undertaken, already implemented in the most competitive industries (automotive, aeronautics, space); it is based on the development of the digital model of the product or DMU, supported by solid modeling CAD systems of the latest generation, which finds in Virtual Reality the most advanced environment of its application.

Since simulation techniques tend to become more and more effective, reliable and accurate, the use of DMU product allows all kinds of verification, testing and benchmarking between multiple alternatives. Required times are much shorter than those required for the construction of as many physical prototypes. The advantages of employing digital models, greatly reducing or abandoning the use of physical models, are achieved with the construction of virtual environments in which the designer and manufacturing engineers can immerse themselves in order to simulate and evaluate, to every detail, all the functional characteristics of the product.

Working on digital models in a virtual environment, it is possible to conceive, develop, compare to each other and finally decide the best solutions. Using such a methodology, in fact, technicians experience functional characteristics and requirements of maintainability; these last are very important, because their proper fulfillment affects the entire useful life of the product, which, as it happens for airplanes, for ships or trains, may also cover the span of some tens of years. In this case it is necessary to analyze the morphological characteristics of the components, the functional relationships of interdependence that exist between them for the demands of assembly and disassembly and to consider whether the operations are possible, and if operators are able to perform all the necessary tasks without making excessive efforts and taking ergonomically correct. The simulation in virtual environment also allows to better define the characteristics of tools and resources.

Finally, it is necessary to design, as well as the product, the technological process for its manufacture. Using appropriate simulation tools is easy to define the most convenient solution for the layout, accessibility and studying the ergonomics of workstations, checking all space problems and the functionality of the handling systems.

Automotive manufacturing companies operate in a market where more and more innovation is required. Innovation is needed in the production system and in the manufacturing process, in terms of flexibility, life cycle cost, customization and lean approach. This paper deals with a Digital Manufacturing approach aimed at proposing a methodology of use of a Virtual Environment (VE) for a collaborative Virtual Design (VD) approach which integrates a set of concurrent design activities. A VD review system is presented in which product designers and production engineers can cooperate, together with the factory workers, in order to share their expertise and identify critical situations in an assembly line many months before the start of the production [1].

5.2 Virtual manufacturing

In recent years, simulation modeling and analysis have been enhanced significantly. This growth has been made possible by the increasingly powerful computational platforms. But the simulation activities must be supported by a structured approach aimed at modeling the factory operations and simulating the manufacturing related tasks in a Virtual Environment (VE) [2]. In [3] a structured approach, with the term Virtual Manufacturing (VM), is described.

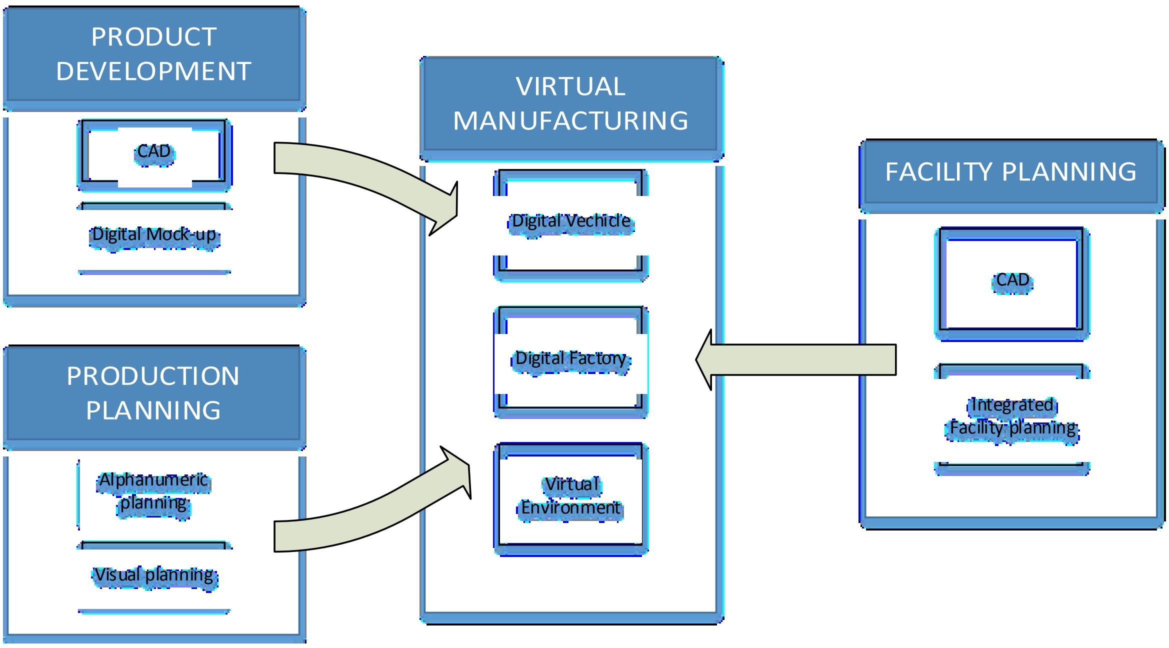


Figure 5.1: Virtual Manufacturing elements and input.

VM permits to perform technical analyses on the basis of virtual data at any time in the product development process, to address particular spatial issues of manufacturability or accessibility by humans and tools from the engineering and production perspectives, to have a fast and intuitive way of visualizing and analyzing product data and of reaching or validating decisions, to analyze the overall product in its completeness in a 1:1 representation, with the most intuitive interaction possibilities.

Other advantages of using a VE and to have a structured approach aimed at modeling the entire factory and simulating the manufacturing activities are:

- the possibility to have an early communication and coordination between the groups participating in digital engineering and production verification processes;
- virtual validation in early phases of production development, verifying suitable tools and assembly processes and initiating considerable savings in production and manufacturing development;
- virtual Try-Out of an assembly process based on a digital model in an early production development phase, ensuring a reduction in development cycles;
- enhancement of the validation depth and quality;
- continuous optimization of product development times with enhanced product diversity;
- virtual validation of manual assembly helping to create the production processes planning certainty without using hardware prototypes

Engineers and technicians can realize, in first person, assembly and disassembly analyses many months before the first hardware models are available; they can test the accessibility and the ergonomics of each workstation and each operation by a direct and realistic interaction with the virtual reality environment.

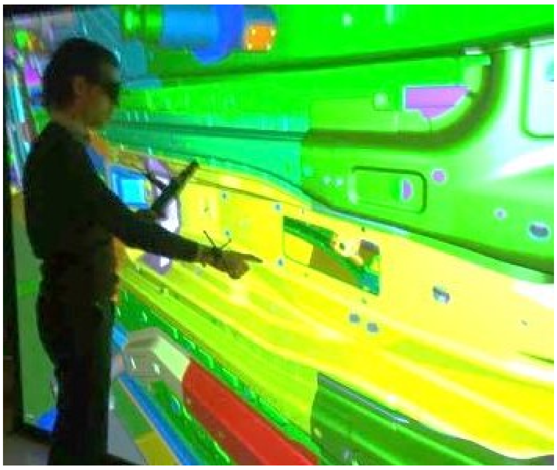


Figure 5.2: The display of the Virtual Design Review system developed at the virtual laboratory.

Since the design phase of a process or a product, all the manufacturing team can be involved, with the advantage that all the members of the team can share their experience during Design Review sessions aimed at the evaluation of the process and/or the product characteristics that could affect the manufacturing and the assembly process [4].

5.3 The VR system

The software chosen as simulation manager for this research activity is IC.IDO by ESI Group. This software is an wide-ranging tool containing many functions for product development, from the creation of the VE to the assembly simulation or ergonomic analyses; IC.IDO can be used to perform collaborative and immersive design reviews, to evaluate and optimize assembly and disassembly sequences, to verify resources and tooling for both manufacture and maintenance, to support documentation and workflow animation/ training. It also detects contact and obstruction during assembly and maintenance procedures, and enables instant evaluation of flexible components such as pipes and cables.
The Virtual Lab has been equipped with typical specific hardware components: a retroprojector, a cluster of PCs, a projection wall, a tracking system, and various input devices.

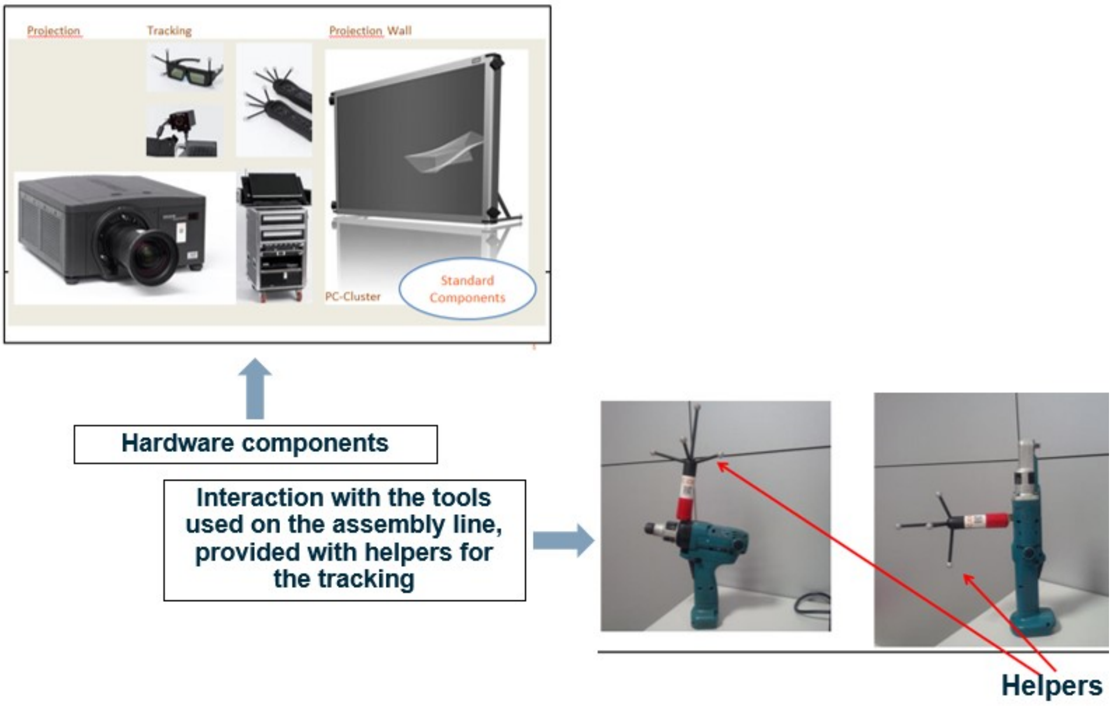


Figure 5.3: Hardware components and special tool for virtual manufacturing

The Virtual Design Review (VDR) system provides a complete set of tools for the user entry into the world of visual decision-making, an immersive system for true-size displays; products can be viewed, edited and analyzed from all sides letting users obtaining a highly efficient and informative means of analysis that far exceeds conventional techniques; it is possible to highlight every element of the scene, pointing virtual markers, taking high resolution snapshots.

Possibility to integrate flexible components in digital product development in real time, useful wherever hoses, cables and cable harnesses are planned, laid and checked.

An ergonomic module that offers a manikin with which ergonomic questions can already be answered at an early stage; with the aid of the virtual human being, operator controls can be examined in relation to their reachability and how well they handle, positioning and comfort analyses can be conducted and visual areas can be meaningfully assessed

A kinematic environment allows to define the constrained degrees of freedom, giving the opportunity to enter the allowable limits of translations and rotations. Father-son kinematical links can be defined to allow interaction between the various kinematic parts and define the kinematics of the entire system.

LINK	Translations [mm]			Rotation			Father-Link
	X	Y	Z	X	Y	Z	
0	*0*	*0*	*0*	*0*	*0*	*0*	*FIXED*
1	*-800÷800*	*0*	*0*	*0*	*0*	*0*	*0*
2	*0*	*0*	*0*	*0*	*0*	*360°*	*1*
3	*0*	*0*	*0*	*0*	*30°÷90°*	*0*	*2*
4	*0*	*0*	*0*	*0*	*10°÷10°*	*0*	*3*
5	*0*	*0*	*0*	*0*	*0*	*360°*	*4*
End effector	*0*	*0*	*0*	*0*	*0*	*360°*	*5*

Table 5.1: Admissible values and degrees of freedom for a manipulator

A specific behavioural module provides all the functionality to define component behavior quickly and easily. Components can be moved in defined constraints and it is possible to set conditions for the triggering of animations and events.

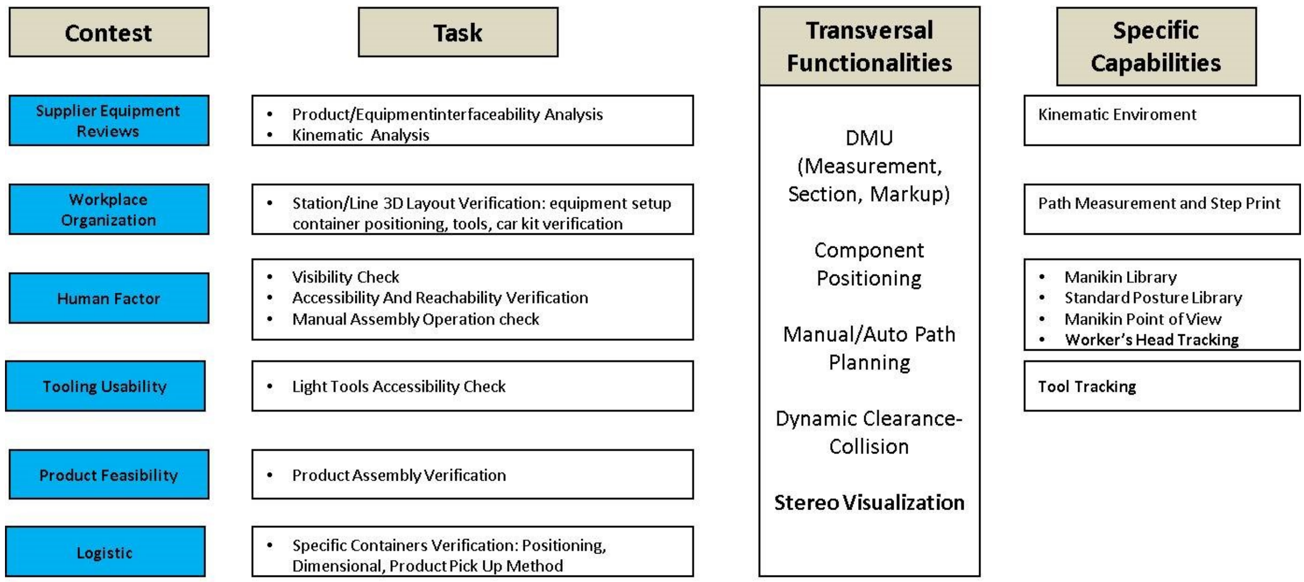


Figure 5.4: Task and capabilities of a VR system

5.4 Methodology and use-cases

The proposed methodology has born considering that VR can be extremely effective in the setup phase of the project, during which technicians and experts belonging to different business units must interact to define and later deliberate the ultimate solution. VR, in fact, provides the ability to analyze and critically review the project to more people at the same time, giving the necessary tools to detect errors and make changes in real time. In this way, it is possible to involve in the analysis not only the designers, but also the manufacturing staff or other corporate sectors, with the aim of Concurrent Engineering. The virtual simulation environment allows, for example, to evaluate the best workplace layout configuration which minimizes the lead time in the line production, or to carry out kinematic simulations of robots and manipulators, or making ergonomic evaluations taking in account safety requirements, too. Product, process, equipment, lineside can integrated for the definition and optimization of the process; all the NPD (new product design) stakeholders – e.g. R&D, ME, EHS, Quality, Logistics, Plants, Purchasing, Suppliers - are involved. Design review sessions involve internal staff and suppliers to manage and improve layout and equipment solutions. The approach is based on an intensive use of 3D modeling: starting from the 2D plant layout, passing by standard 3D equipment models and 3D specific models from suppliers, the entire 3D models can be used by VR team for process definition and workstation optimization.

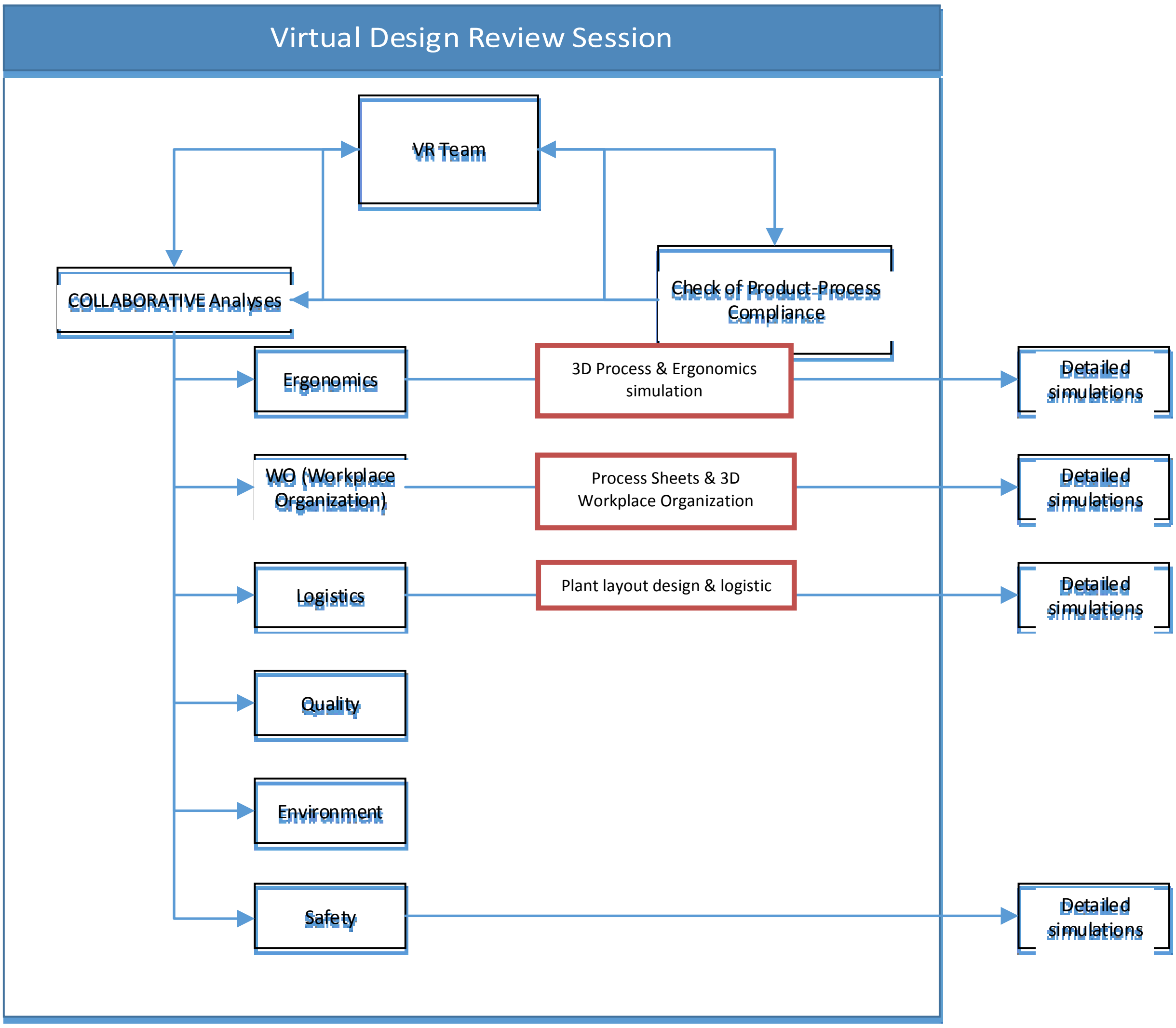
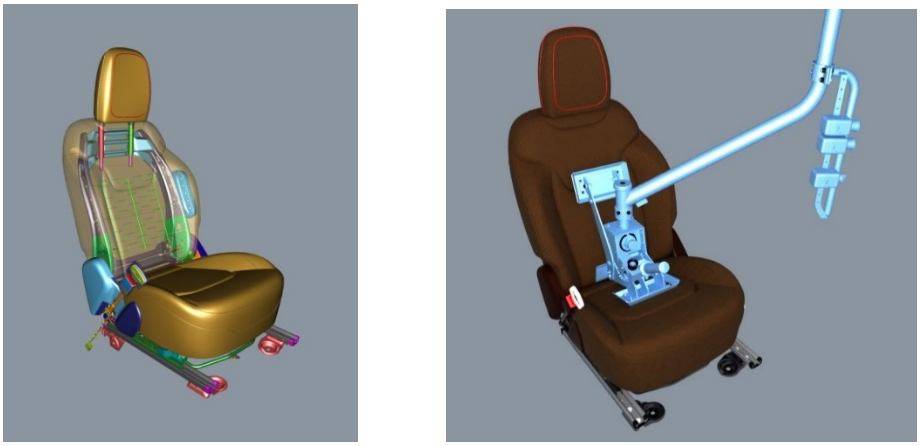


Figure 5.5: Virtual Design Review sessions organization

In figure 5.5, the scheme of the VDR process is reported. Thanks to a VE, critical themes, points, operations or tasks can be highlighted and analyzed. VR can be applied as an important support in the analyses of the whole design and manufacturing system. With the aid of the virtual tools, in fact, it is possible to carry on preliminary verification of the various workplaces, entire sections of lines and of the whole plant, already in early design phase. During the sessions, the analyses can concentrate on the critical points highlighted and, if necessary, plan successive and more in-depth analyses with detailed simulations.

5.4.1 Use cases

It is a common practice in automotive industry that the manufacturer tries to reuse its existing equipment. Virtual design sessions can test the adaptability of supplier existing equipment and/or the reuse of past workplace organizations to new products and projects. As an illustrative example, the use of a pre-existing manipulator for assembling a new car front seat can be tested in the VE.

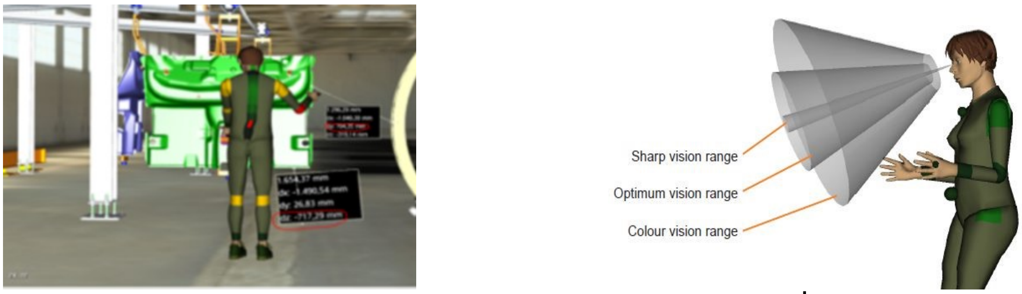


a b

Figure 5.6: The seat (a) and the manipulator moving the seat (b)

In the assembly line, the worker has to pick up the seat from a container with the aid of a manipulator for nullifying the weight. The seat must be inserted into the car e must be assembled. In order to achieve a simulation as realistic as possible, it is possible to take into account all the structures and objects that may interfere with the movements of the seat, with the manipulator and with the operator. The objective of a simulation of such type is to assess some typical problems in industrial engineering, like verification and analysis of:

- worker's posture, movements and visibility;



a b

Figure 5.7: Posture analysis (a) and manikin's vision ranges (b)

- workplace environment and spaces;
- interaction between the manipulator and the surrounding objects;
- sub-operation sequence;
- time.

Furthermore, it is possible to realize explanatory videos.
The VR team can validate in a digital and virtual environment the operations performed in each station, highlighting critical issues related with it. These simulations allow the analysis of different activities, such as the definition of correct working postures, DMU and interfaceability analyses or verification of the layout in order to properly perform the front seat assembly operation.

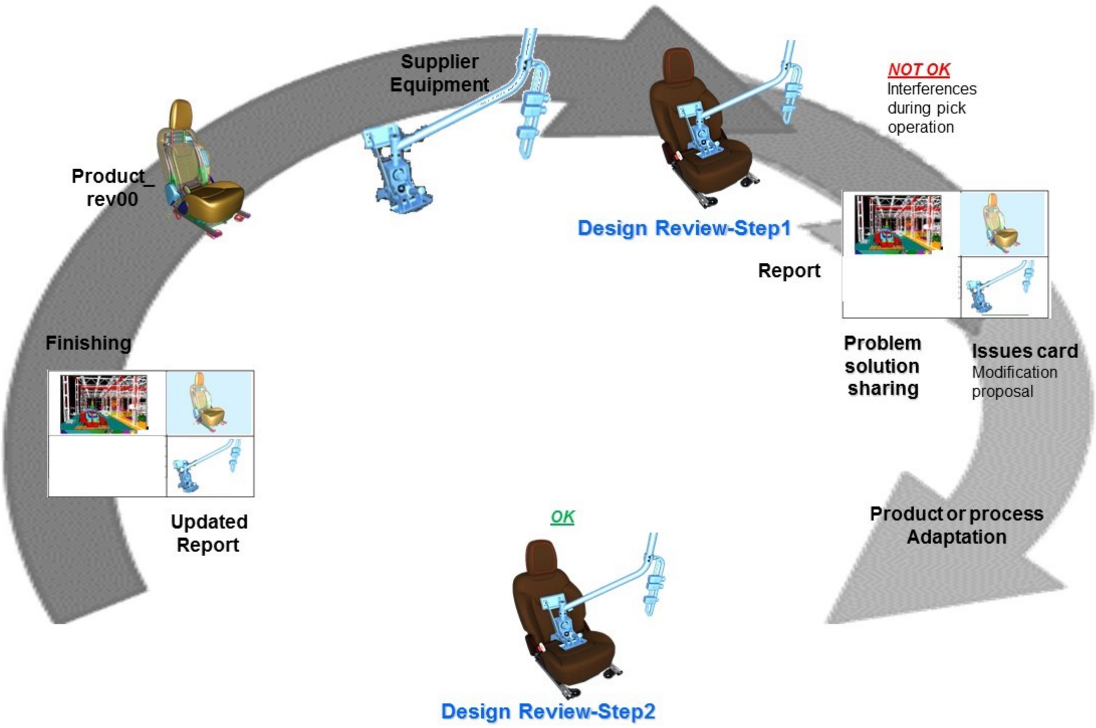


Figure 5.8: Product/Equipment/Human interfaceability analysis workflow

As said above, a VE gives the ability to simulate in immersive realistic way an operation so to evaluate different solutions. Thus, it is also possible to simulate manufacturing activities in virtual environment and evaluate ergonomics, accessibility and visibility in first person and find the best solution (figure 5.9).

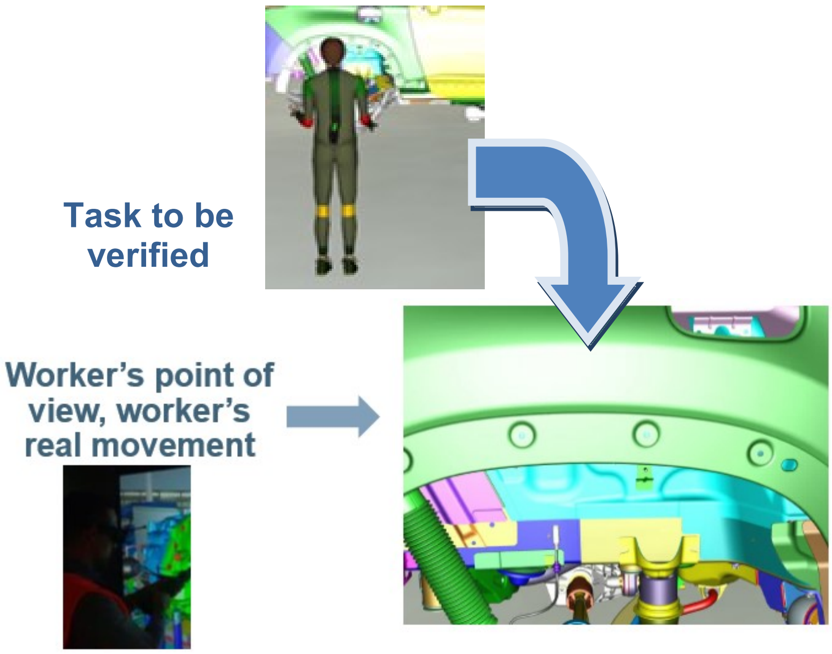


Figure 5.9: Immersive simulation of an assembly operation

5.5 References

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CHAPTER 6

VIRTUAL PRODUCTION PLANNING OF A HIGH-SPEED TRAIN USING A DISCRETE EVENT SIMULATION BASED APPROACH

6.1 Introduction

This research activity deals with an application of Discrete Event Simulation (DES) within the manufacturing process of a high-speed train. Today, the use of a DES tool is common for supporting engineers in designing the production lines and planning the production, representing a valid help in what-if analyses and in the measurement or validation of a solution. In this research activity, differently from the common use, it has been developed a DES model whose function is not to measure and/or validate a solution of a problem, but to quickly generate a solution that will be nearly to the optimum one.

This chapter describes DES tools, the methodology used, the model built, the case-study and the obtained results. The scope of the project has been implementing a tool for the optimization of the production planning of complex products, in terms of time and/or human resource. The methodology chosen has been to use a Discrete Event Simulation (DES) approach, strongly customizing a commercial software tool. A case study has been implemented, regarding the improvement of the assembly process of a high speed train. As illustrated in figure 6.1, there are several ways to study a system.

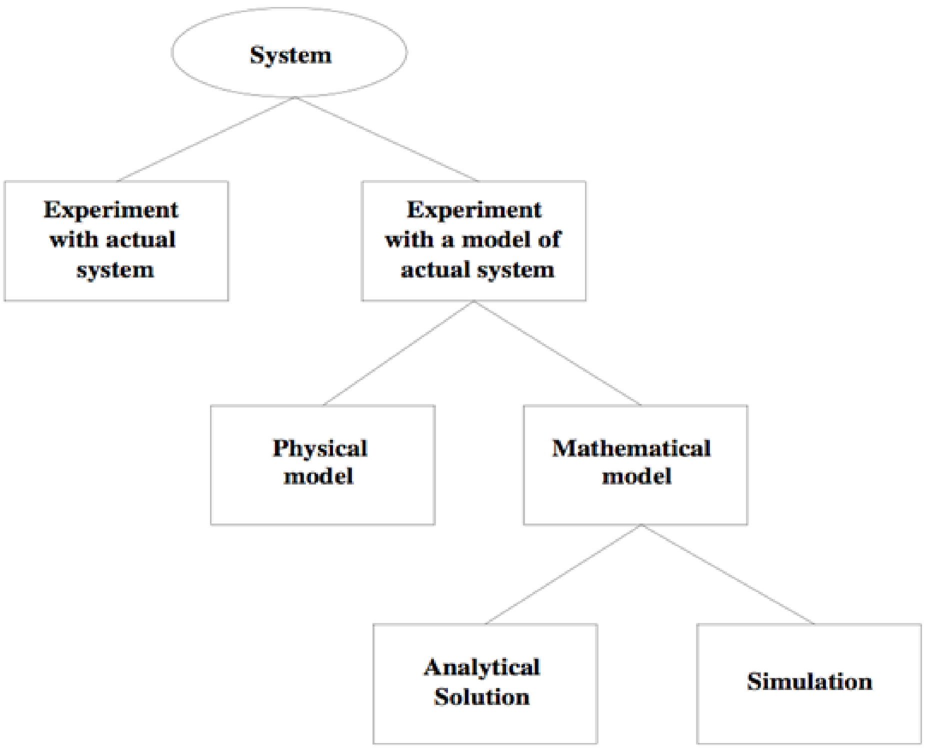

Figure 6.1: Process modeling techniques [1].

According to [2], process modeling techniques are generally used to collect and evaluate knowledge on processes, to gain an understanding of the static and dynamic behaviours of systems. Following the scheme proposed in figure 1, a physical model is a simplified or scaled-down physical object, for example a scale model of a train; a mathematical analytical model is a set of equations or relations among mathematical variables; simulation is the imitation of the operations of the real-world system over time thanks to a computer model, that is a program description of the system [3]. Through this model, it is possible to simulate the actual system and when the studied system is characterized by complexity, dynamic and stochastic behaviour, simulation appears to be the appropriate technique for modeling and analyzing it [4].
Simulation is traditionally used to evaluate a given set of decisions and to provide the user with some key performance indicators. According to this principle, the common job and use of DES software tools is to measure and/or validate a solution of a problem. Hence, they are not powerful if they are used for the construction of a solution, and of a good solution of a problem. Instead in this work, aiming to obtain a tool that generates a suboptimal solution of complex manufacturing scheduling problems, a DES software tool has been heavily customized.
In this chapter it is described the development of this tool and an application of it, with the intention of providing useful information for the development of similar projects.

6.2 DES software tools

Throughout the years, simulation it is becoming a valid problem solving methodology for the solution of many real-world problems. A detailed comparison between simulation and other modeling approaches is done in [5]. All the advantages in using DES have been discussed in [6] and [7]. In accordance with [8], DES software tools available in the market can be classified as simulation languages and simulators. The former (e.g. SIMULA, SIMSCRIPT II.5) are high-level languages that offer the programmer more flexibility and a more powerful language than the simulation packages can give. On the other hand, using languages is much more time consuming than using simulators. The latter (e.g. WITNESS, PROMODEL) are data driven systems with little or no programming required. They reduce coding considerably by providing graphical model construction environments. When this approach is used the modeling time can be notably reduced, but only if the system under consideration fits the domain of the simulator. But there is a third approach, too: as it can be found in [9], in the market exist also hybrid systems which combine the flexibility of a simulation language with the user-friendliness of a data driven system. These systems combine the speed of a simulator package and the flexibility of a simulation language. In this research activity, this third approach has been followed. Several tools exist in this category, Delmia-QUEST is the one chosen in this work.

TOOL	SOFTWARE HOUSE	AREA
ARENA	ROCKWELL	**DISCRETE EVENT PLANT SIMULATION**
AUTOMOD	BROOKS AUT.	
DELMIA - QUEST	DASSAULT SYSTEMES	
FACTORY CAD	SIEMENS	

Table 6.1: Main DES software products adopted in thef manufacturing field [10].

A DES model, as reported in [5], can be defined as one in which the state variables change only at discrete points in time at which events occur. Events occur as a consequence of activity times and delays. The model is populated by the entities. An entity represents an object that requires explicit definition. An entity can be dynamic in that it "moves" through the system, or it can be static in that it serves other entities [7]. Static entities are named resource, too. The actions of the entities is controlled by the logics. Logics are the mechanism that control the entities' behaviour and each entity has its own logic.
In a Delmia-QUEST model, inter alia, there are:

- parts, the entities that move through the system, occupying resources and undergoing processing. They may represents goods, customers, orders, tasks or messages between resources.
- sources, the entities that create parts and release them into the simulation;
- sinks, the entities that remove parts from the model.
- buffers, entities used to represent the locations where parts are stored or where they queue to get access to other resources such as machines;
- machines, the entities that process parts.

6.3 Phases of a simulation study

In table 2, the necessary steps in a generic simulation study are listed, as well explained in [6]. Similar tables or diagrams, with their interpretation, can be found in [7] [11] and [12].
The process going from the problem formulation to the implementation is typically iterative. Every step is important and no phase can be skipped or taken lightly.

STEP	TYPE	DESCRIPTION
1. Problem fomulation	Interpretative	Define the problem to be studied, including a written statement of the problem-solving objective
2. Model conceptualization	Analytical	Abstract the system into a model described by the elements of the system, their characteristics, their interactions, all according to the problem formulation
3. Data collection	Developmental	Identify, specify and gather data in support of the model
4. Model building	Developmental	Capture the conceptualization model using the constructs of a simulation language or system
5. Verification and validation	Analytical	Establish that the model executes as intended and that the desired accuracy or correspondence exists between the model and the system
6. Analysis	Analytical	Analyze the simulation outputs to draw inferences and make recommendations for problem resolutions
7. Documentation	Interpretative	Supply supportive or evidential information for a specific purpose
8. Implementation	Developmental	Fulfill the decision resulting from the simulation

Table 6.2: Simulation projects steps.

Every simulation study begins with a statement of the problem. If the statement is provided by those that have the problem, the simulation analyst must take extreme care to insure that the problem is clearly understood. It is fundamental to clearly define what are the scope, the start and the arrival points, as well as the available tools. Even with all of these precautions, it is possible that the problem will need to be reformulated as the simulation study progresses.

The real-world system under investigation is subsequently abstracted by a conceptual model, a series of mathematical and logical relationships concerning the components and the structure of the system.

Most simulation models, as a matter of fact, require a significant amount of data that are not always immediately available. Besides, where it is, many analyses may be required to put it in a form suitable for the simulation.

In the model building phase, the conceptual model constructed in Step 2 is coded into a computer recognizable form. This step requires the most amount of time. If the work done previously was not good, this step could last much more of the necessary, doing number of revisions and redesigns increase exponentially.

Verification concerns the operational model, if it is performing properly. Validation defines if the conceptual model is an accurate representation of the real system, that is the model can be substituted for the real system for the purposes of experimentation.

At the end of validation there are the simulation runs and the appropriate analyses to evaluate the performance for the simulated scenarios.
In the final step, there is the implementation in the real world of the results deriving from the simulations.

6.4 Brief notices on railway vehicles

The case-study focused on the optimization of the assembly process of a high-speed train. As illustrated in [13], a railway vehicle is essentially composed by two principal systems: the case and the bogies.
As written in chapter 3, the case consists of a metallic structure of steel or aluminium alloy. The jobs to do concern the montage of the electrical equipment (illumination, signaling, power), the pneumatic system (brake and other services), the furnishing (seats, baggage racks, doors, dividing walls, lining), the auxiliary equipments (conditioning, hygienic services, fire-fighting) and, finally, the connection parts of the vehicles (hook-ups, repelling, electric and pneumatic couplers). The tasks are largely manual.
In production field, a case is often divided into different working zones. In this activity, six zones have been identified: the cab, the body side, the underbody, the imperial, the hallway, the compartment. Figure 6.2 illustrates this division.

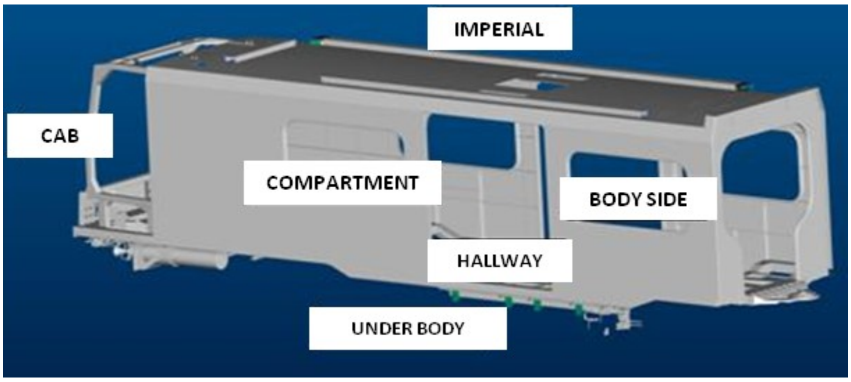

Figure 6.2: A 3D mock up of a case and its division in zones

6.5 The case study: virtual production planning of a high-speed train

The use of DES tools today touches many different areas, going from health care [14] to shipbuilding [15] [16] and, latterly, to heavy construction [17] [18], with innovative applications arising from Research. Nevertheless, researches in manufacturing contexts are not so many and research activities seem to be in pause in such fields, especially in production and process planning.
The project of the virtual production planning of the high speed train was born starting from these considerations above and from a need of the collaborating company to optimize this train's assembly process.
The studied system is a line composed by six stations, in which is assembled an eight-car train. As a consequence, the model built is composed by six groups of 15 machines, where each group represents a station. As said before, in the conceptual model, each case has been divided into six

modules/zones: cab, body side, underbody, imperial, hallway, compartment. In the model, this situation has been translated associating a typology of machine to each zone.

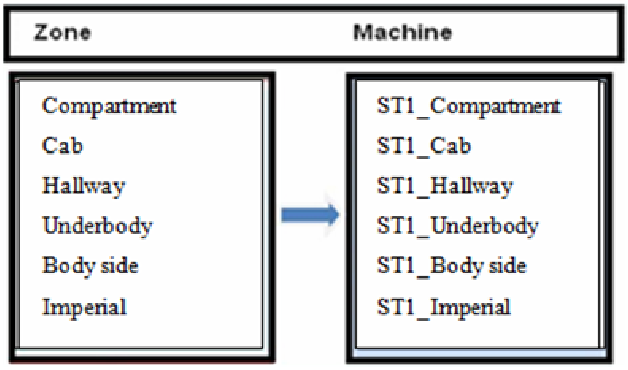

Figure 6.3: Zone-machine correspondence for station ST-1.

In details, have been created:

- 2 machines for the cab zone;
- 2 machines for the hallway zone;
- 2 machines for the compartment zone;
- 3 machines for the underbody zone;
- 3 machines for the imperial zone;
- 3 machines for the body side zone.

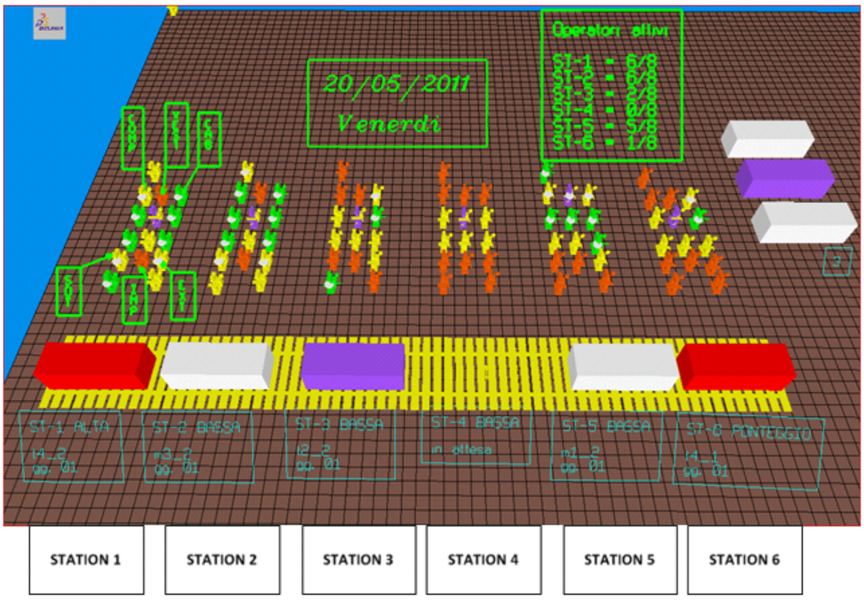

Figure 6.4: The line modeled in QUEST.

The inputs for the machines are the parts representing the activities to do. In QUEST, each real task has its own corresponding part. Every machine can process a part at a time, so two or three machines have been created depending on the number of tasks together processable in the zone (this number is a parameter given by the company collaborating in the research activity).

As said above, the logics are the entities' soul. They have been written in order to obtain a specific behaviour of the entities, and as a consequence of the entire model, aiming to find a suboptimal solution of complex scheduling problems. Customization has been done with the SCL code, a programming language similar to the more famous PASCAL. Thanks to the written logics and procedures the model:

- builds a suboptimal solution through a new constructive heuristic algorithm designed and implemented;
- is easily usable by non-expert personnel;
- requires in input a unique and simple file: an Excel datasheet;
- gives in output Gantt charts ready to be used in the workshop.

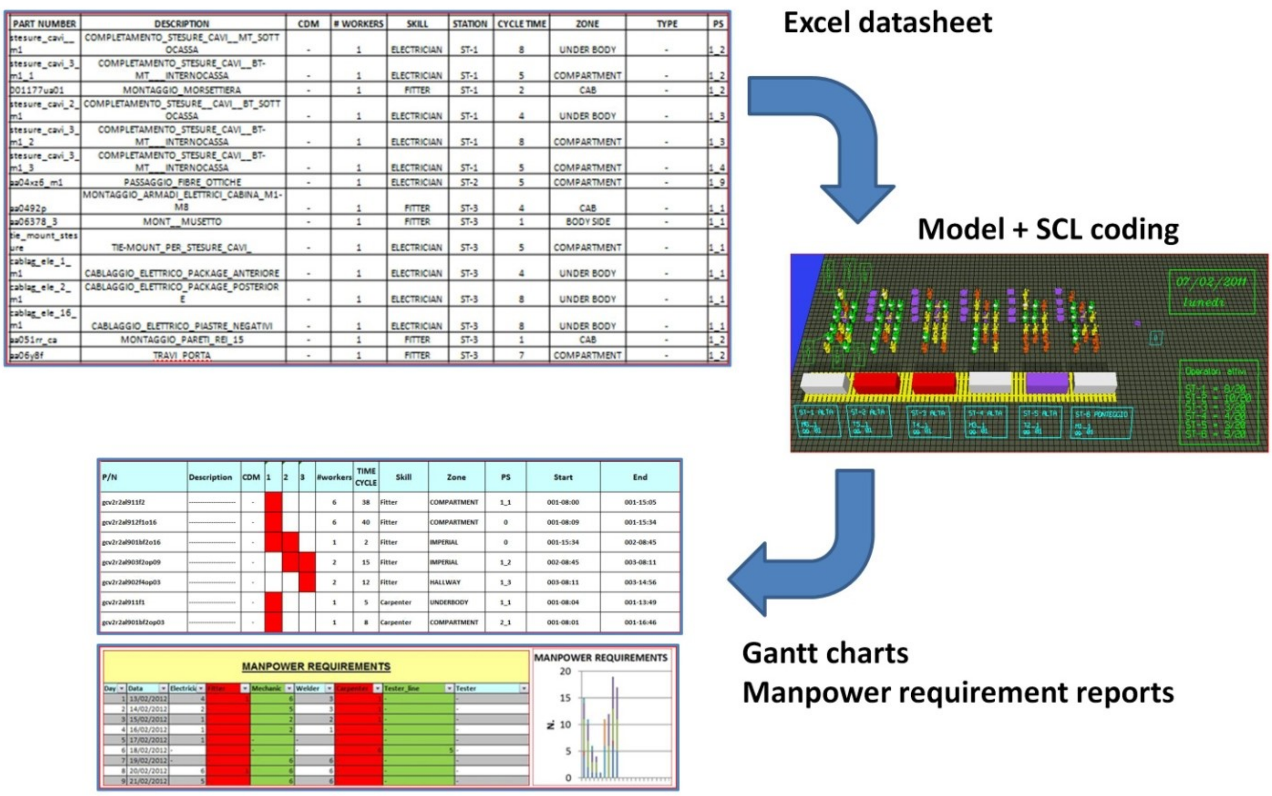

Figure 6.5: Input–model –output scheme.

The input file is in a .csv format, an excel file that stores tabular data in plain-text form.

6.5.1 Precedence constraints management

In complex scheduling problems there are, generally, a lot of activities. The difficult is that almost all of them are linked each other by precedence constraints and it is not easy to manage this situation. The proposed solution for giving precedence constraints information to the model and making it able to automatically manage them, is to assign each task an id. This id, named P_S (P stands for Pack, S for Sequence), identifies the subgroup of membership and the sequence position within the subgroup.

More precisely:

- every task is initially associated by production engineers to one of the six stations;
- in each station, subgroups of tasks (named 'Packs') linked each other by technological constraints are identified;
- within the subgroups, tasks are numbered according to precedence constraints.

At the end of this identification phase, each task has its own P_S id. Below there is a simplified example.

TASK	***P_S***	***TASK***	***P_S***
a	1_1	**h**	2_3
b	1_2	**i**	3_1
c	1_2	**l**	3_2
d	1_2	**m**	0
e	1_3	**n**	0
f	2_1	**o**	4_1
g	2_2	**p**	4_1

Table 6.3: Example of tasks with their P_S id.

In table 6.4, there are five lines. The first four lines represent the 4 packs. The last line, named 0, is for the tasks which do not belong to any pack, that is they are not linked in any way with any other activity.

PACK	**P_1**	**P_2**	**P_3**	**0**
1	**a**	**b,c,d**	**e**	
2	**f**	**g**	**h**	
3	**i**	**l**		
4	**o,p**			
0				**m,n**

Table 4.4: Links between tasks.

In consequence of this assignment, it derives a graph (figure 6.6). The graph is clearer than the table and well illustrates the links between activities. For example,
tasks **a**, **f**, **i**, **o** and **p** are not linked and they can start and process together. It will be the model to decide the starting order. Tasks **b, c, d** can start only at the end of task **a**. Task **e** can start at the end of tasks **b, c** and **d**. Tasks **m** and **n** do not belong to any pack and are not linked in any way with other activities.

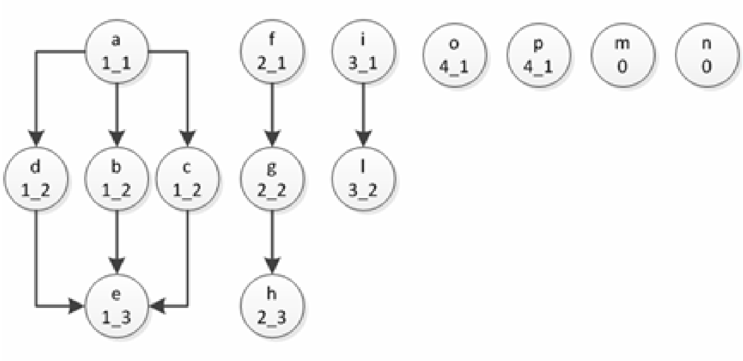

Figure 6.6: Graph showing the links between the tasks.

In complex scheduling problems there are several hundred of tasks and managing the links between them becomes hard. Using the model built assures that the planning is admitted, that is it respects all the existing constraints.

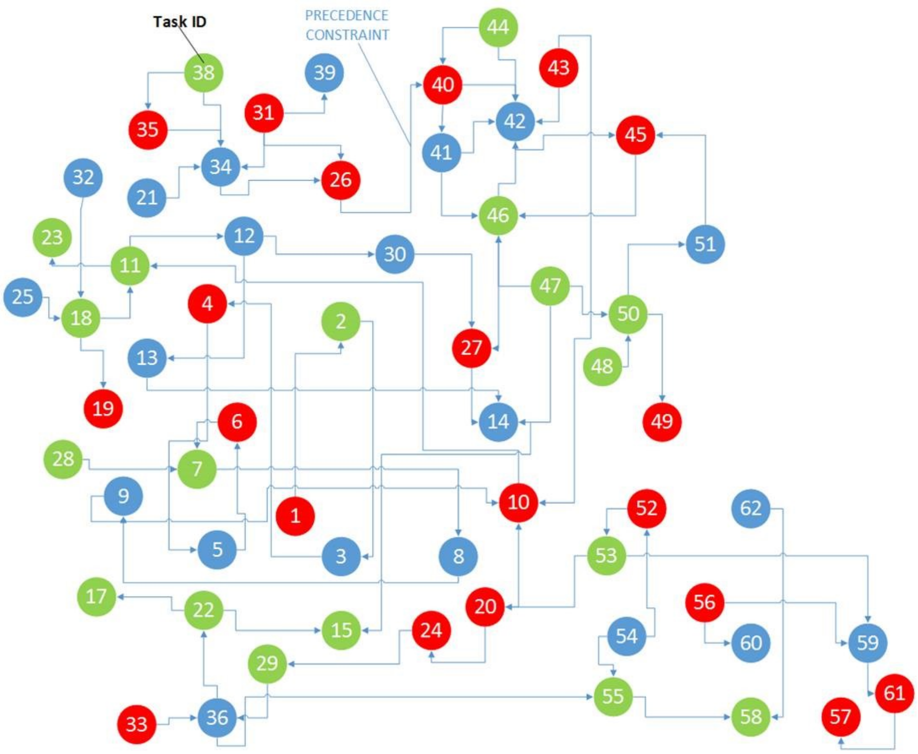

Figure 6.7: Sample graph of complex scheduling problems.

6.5.2 Objective function choice

When planning the production of a product, the choice can be between the minimization of the time, the minimization of manpower requirement or an intermediate objective. According to these considerations, the model has been built and customized so that, depending on the specific needs, it is possible to use it in order to minimize the time to complete all jobs (in situations of delay in delivery it is a useful mode of use) or to optimize the manpower requirement taking into account an upper bound limit of time. The behaviour of the model has to be set before the start of the run through a pop up window.

The problem of scheduling n jobs on m stations to minimize makespan (the time difference between the start and finish of a sequence of jobs) is known to be NP-hard [19] and hence too difficult to solve in polynomial time. Makespan is the time to complete all the n jobs and, if C_i is the time to complete the job i, makespan is C_{max}, where

$$C_{max}=\max\{C_i\} \qquad (6.1).$$

During the run, the model built allocates tasks respecting the constraints imposed and, if at a given moment two or more jobs could start, chooses the job with the longest processing time, that is following the LPT rule. The Longest Processing Time rule, implemented through SCL code, gives good results for the makespan problem [20]. But, the solution that optimizes the makespan uses, aiming to reduce the lead time, a lot of workers. This is an undesirable circumstance, unless there is an emergency situation. Instead, the second mode of using the model is more suitable to the needs of a company, minimizing the number of workers used while respecting an upper bound limit of time (the takt time).

To differentiate the behaviour of the model, has been thought to make available to the model a "bin" with a prefixed and precalculated availability of workers. With this trick the model can use, to process the tasks, only the workers in this bin. Such container of workers can have a finite or an infinite capacity and the choice about it can be done before starting the run. If an infinite capacity is set, the obtained solution is the optimum of the makespan. Otherwise, if the desired solution is that one which minimizes the number of workers used for finishing the assembly operations in a fixed time, it can let the model calculate the optimum number of workers to be made available to the line. An example scheme of how the model calculates the composition of the bin it is reported in table 6.5.

INPUT	Max Workers (no distinction between skills)	5	5	5	5	5	5	Σ	30,00		
									15%	% riduction	
	LT	5	5	5	5	5	5				
	Tot-hh	200	200	200	200	200	200				
	Case	C1	C2	C3	C4	C5	C6				
		ST-1	ST-2	ST-3	ST-4	ST-5	ST-6				
	Sum of necessary working hours								Σ		
	ELE h	90,00	60,00	90,00	55,00	65,00	45,00		405,00		
	FIT h	65,00	80,00	90,00	115,00	130,00	125,00		605,00		
	TOT h	155,00	140,00	180,00	170,00	195,00	170,00		1.010,0		
	Units of workers								UB	UBR	
	ELE	2,25	1,50	2,25	1,38	1,63	1,13		10,00	9,00	
	FIT	1,63	2,00	2,25	2,88	3,25	3,13		15,00	13,00	OUTPU
	TOT	3,88	3,50	4,50	4,25	4,88	4,25		25,00	22,00	
								Tot-hh=Max Workers * LT * 8hh			
								FIT=FIT h/Tot-hh*Max Workers			
								ELE=ELE h/Tot-hh*Max Workers			

Table 6.5: Sample scheme of the bin of worker sizing.

In this examples there are only 2 skills for simplicity: fitters and electricians. In the red square there are the inputs the model needs:

- the maximum number of contemporary workers working in a station
- the desired takt time;
- optionally, a reducing factor that permits to be cheaper in terms of workers in the bin.
- These inputs are given through a pop-up window at the beginning of a run of simulation.
- The output, in the blue square, is the composition of the bin in terms of unit of workers. This parameter, named UBR (Upper Bound Reduced), contains the number of workers, skill by skill, to put into the bin. This bin, it is important to underline, is unique for all the workplaces.
- In the green square there is mathematics, computation. Some simple operations are performed by the model and all the calculations are done station by station, considering each workplace by itself. The 6 stations are considered on their own, as if each station had its own team of workers. But later, as said before, a unique set is made of these workers: the bin of workers. And all the stations draw workers from the same bin. So, it can happen that a task cannot start because the workers it needs are engaged in another station. In this case, the start of the task is delayed and, in the extreme case, can happen that the task is moved to the next station. This bin of worker expedient forces the model to be cheap in using manpower and brings an efficient resource saturation.

6.5.3 Operating modes of the model

Consider the situation in which 6 cases have just entered the 6 stations: if "X days" is the takt time, after X days the 6 cases step forward to the next station. The takt time is settable before the start of a run through a pop-up window.

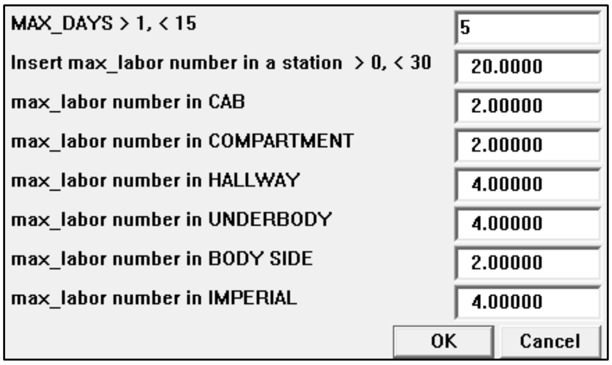

Figure 6.8: Takt time and max workers constraints setting.

Through the algorithm for sizing the bin, the model calculates the manpower requirement for the next X days. Workers made available for the line are put into the *bin of workers* that, now, has a specific composition. At this point the model has to choose, station by station, which task let begin. Respecting the precedence constraints imposed, the model makes this choice using the LPT rule. This rule has been implemented within the model through SCL code. Following LPT's logics, the model chooses the task with the longest processing time. After this choice, the model controls if in the bin are available the workers the chosen task needs. If yes, the current task starts. Otherwise it does not start and the model chooses another task, always with the LPT rule. Again, there is the manpower availability check and so on.

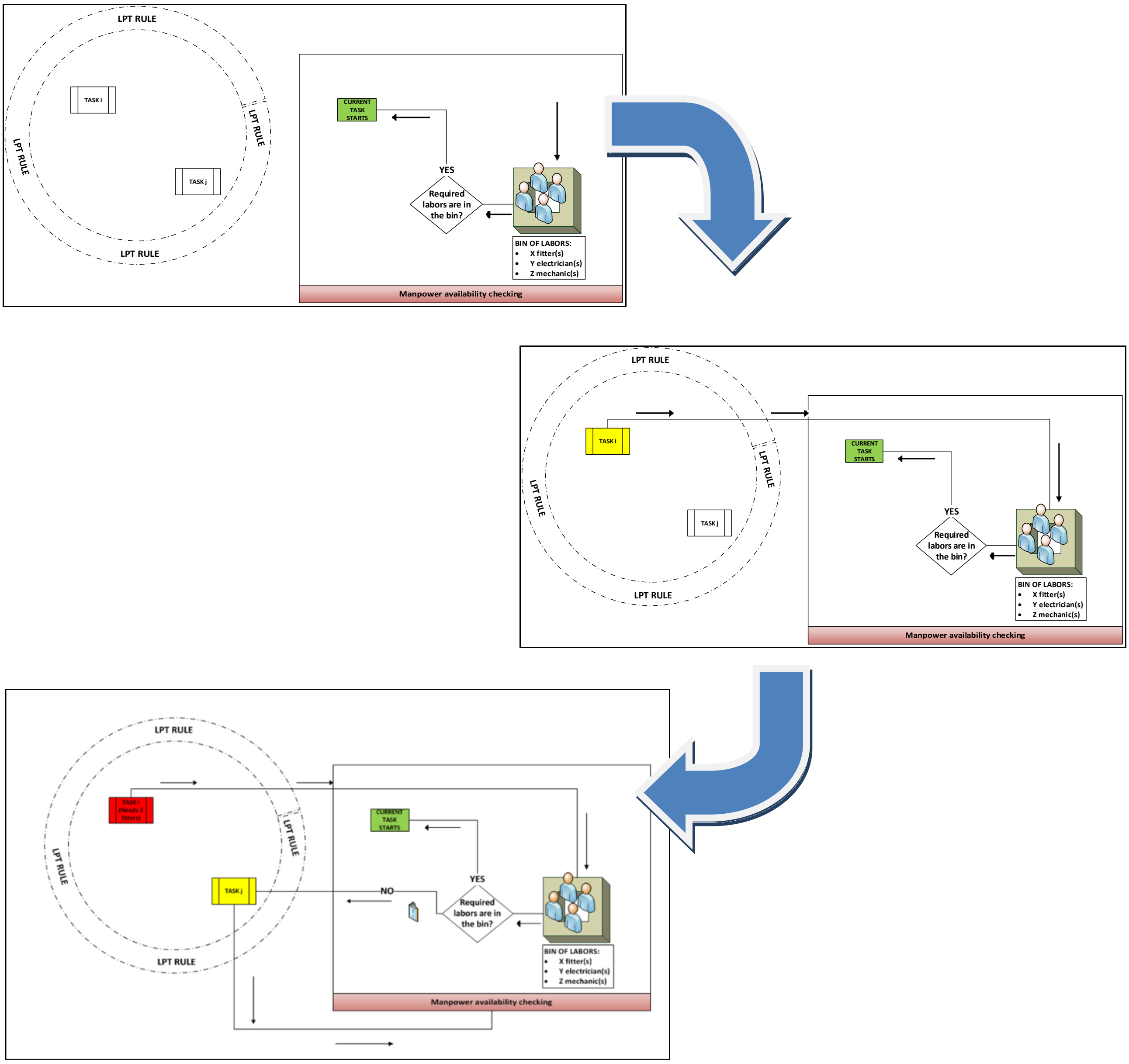

Figure 6.9: Flow diagram illustrating how the model works.

This is an heuristic procedure that, as shown in the concluding paragraph, produces good results.

6.5.4 Output documents

The model built, thanks to SCL coding, gives in output Gantt charts immediately usable into the workshop (figure 6.10). Information reported in these documents includes, for each task, the start time and the end time, the worker requirement and its duration.

P/N	Description	CDM	1	2	3	#workers	TIME CYCLE	Skill	Zone	PS	Start	End
gcv2r2al911f2	--------------------	-				6	38	Fitter	COMPARTMENT	1_1	001-08:00	001-15:05
gcv2r2al912f1o16	--------------------	-				6	40	Fitter	COMPARTMENT	0	001-08:09	001-15:34
gcv2r2al901bf2o16	--------------------	-				1	2	Fitter	IMPERIAL	0	001-15:34	002-08:45
gcv2r2al903f2op09	--------------------	-				2	15	Fitter	IMPERIAL	1_2	002-08:45	003-08:11
gcv2r2al902f4op03	--------------------	-				2	12	Fitter	HALLWAY	1_3	003-08:11	003-14:56
gcv2r2al911f1	--------------------	-				1	5	Carpenter	UNDERBODY	1_1	001-08:04	001-13:49

Figure 6.10: Example of a Gantt chart generated by the model.

Moreover, manpower requirements reports are generated in the form of excel files with detail reports of daily workers needs, for each station and for the entire line (Figure 6.11). Thanks to this information, production engineers know the exactly daily demand of manpower and can optimally plan the allocation of workers.

MANPOWER REQUIREMENTS

Day	Data	Electrician	Fitter	Welder	Carpenter	Line_Tester	Tester
1	12/02/2012	4	1	6	1	-	-
2	13/02/2012	2	-	5	1	-	-
3	14/02/2012	1	-	2	1	-	-
4	15/02/2012	1	-	2	-	-	-
5	16/02/2012	1	-	-	-	-	-
6	17/02/2012	-	-	-	6	5	-
7	18/02/2012	-	-	6	-	-	-
8	19/02/2012	6	1	6	-	-	-
9	20/02/2012	5	-	6	-	-	-

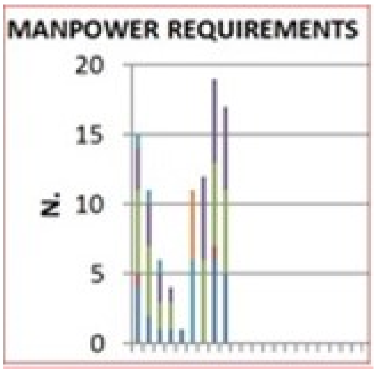

Figure 6.11: Workers requirements report.

6.5.5 3D environment

In figure 6.12 the model stopped it is shown. At the bottom of the model, there are several buffers. Buffers #1 and #2 “contain”, station by station, the tasks waiting for starting (in figure 6.13, white parts into the buffers represent these activities).

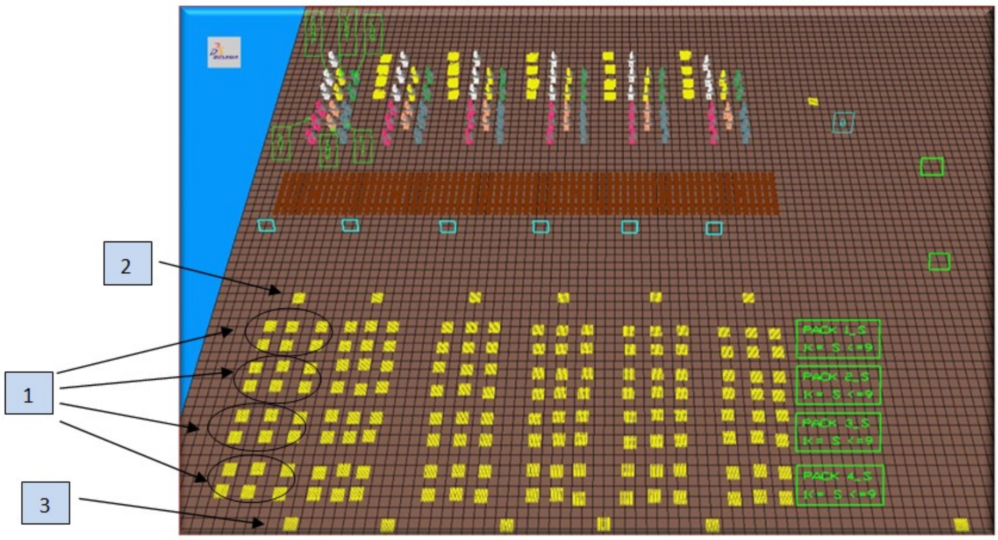

Figure 6.12: The model stopped.

Each working zone (figure 6.3) has its own buffers; each **Pack** (table 6.4) has its own buffers, too. Buffers #3, the ones between two adjacent stations, “contain” the tasks initially planned in a station but automatically moved to the next one in order to respect the takt time. These things give a useful visual feedback when performing a run.

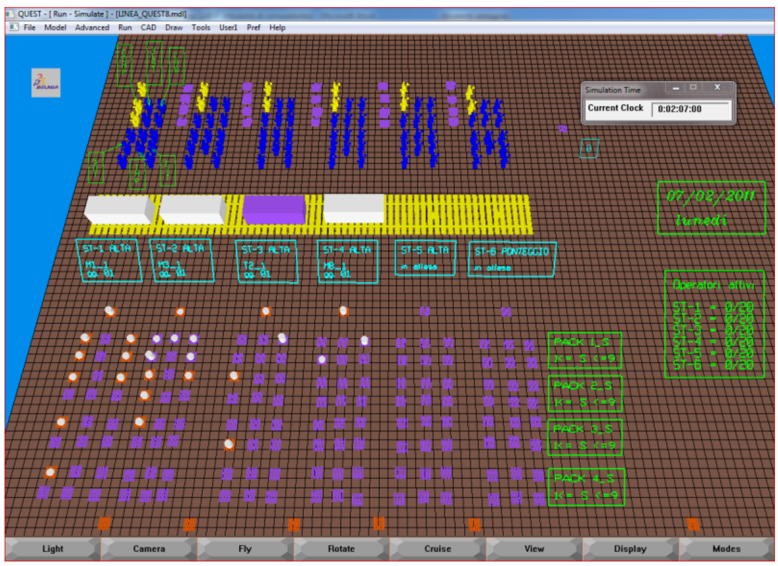

Figure 6.13: The model during a run.

6.5.6 Results, conclusions and future applications

The comparison between the plannings of a powered case before and after the project is reported in figure 6.14.

STATION	LEAD TIME		STATION	LEAD TIME
ST-1	7	BEFORE AFTER	ST-1	5
ST-2	6		ST-2	5
ST-3	7		ST-3	5
ST-4	5		ST-4	5
ST-5	6		ST-5	5
ST-6	5		ST-6	5

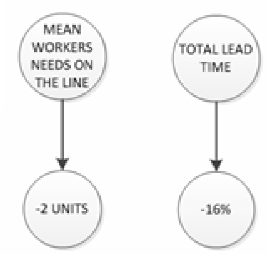

Figure 6.14: Comparison between the plannings before and after the project.

There has been a huge improvement of the planning in terms of time and workers utilization: before the project, the assembly process of a powered case was planned with a 36 days schedule; after the project, it is planned with a 30 days schedule. The mean workers need on the line has decreased, too.

Finding the optimal schedule for the production of a train is a hard thing to do because of the high number of tasks, the complexity of the existing constraints among them, the high number of workers involved on the line, the need to contain costs and time. Thanks to the model built, production engineers can find suboptimal solutions, compare design alternatives very quickly and, above all, with the assurance that the plans developed by the tool are admissible (in terms of technological and resource constraints respected).

The tool has been customized in a manner that it can be used, with very slight appropriate modifications, in any manufacturing context. It can be a valuable help for production engineering in any complex contests in which there are large number of operations, strong interaction between tasks, strong time and workers constraints.

In future, it will be an interesting objective researching a way to permit not to give in input the deterministic number of workers for processing the task, but a range of admissible values, so to give another degree of freedom to the model in its research of the optimum solution.

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Conclusions

This thesis is the result of a three years' work whose scope has been to investigate on the theme of knowledge and to propose software solutions, digital pattern approaches and KBE methodologies able to qualify themselves as a collaborative environment for companies acting in railway market and, generally, for manufacturing industries. A product catalog, based on a three-level classification of company's best practices and standards, shapes, together with a tailored three-steps search algorithm, a decision support system which can help the company to carry out engineering evaluations for assessing the reuse of its technical know-how within new projects. Thanks to the DSS, decisions can be less impulsive and not dependent on subjective opinion of one individual. The use of the implemented DSS in a big railway company, AnsaldoBreda Spa, has demonstrated the effectiveness of the proposed system: before it, the time from the tender notice to the tender offer was about 60 days; on the contrary, using the proposed tools and approach, the time has been halved. The proposed Adopt-Adapt-Innovate analysis, together with the CAD and CAE templates and the whole DSS, can be the base for future research activities for obtaining a KBE system that automatically models complex products starting from the customer requirements, drastically reducing time and cost, bringing high quality in terms of error reduction, consolidating the know-how and maximizing the reuse of best-practices.

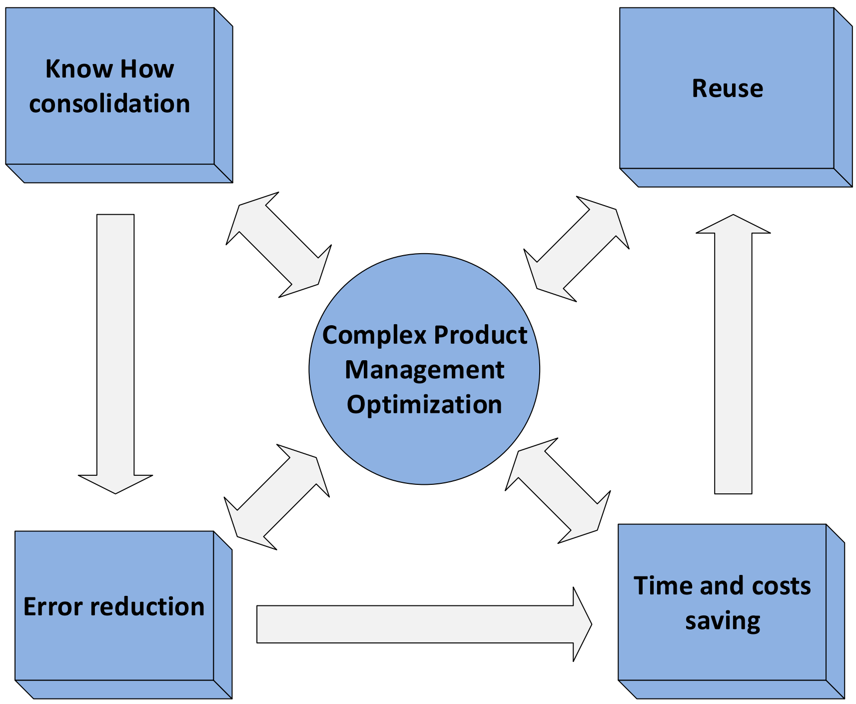

Figure A: Virtuos circle for complex products management

A discrete event simulation application has also shown the potential contribution that customized DES models can give in manufacturing domain, bringing time benefit and allowing a better allocation of human and machine resources.

The theme of virtual environments for concurrent and collaborative engineering has been examined, too. Several test-cases, developed in collaboration with an important automotive company, have shown that the use of a virtual reality software and of a virtual immersive environment can enhance the quality of decision-making and the collaboration within interdisciplinary teams, accelerating the design phase and anticipating manufacturing problems. On the other hand, a limit of VR tools and virtual environments is that it is difficult to integrate them into a KBE environment and, at least with current technologies, they risk to remain isolated “isles” in the digital knowledge processes of the company.