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The development of factory templates for the integrated virtual factory framework

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Summary

Nowadays, companies are facing an intense global competition and increasing demand from stakeholders. Thus, the capability to introduce into the market new and innovative products, anticipating the competition, reducing productions costs and improving quality has become a priority for managers. Indeed, a new generation of factories is coming in order to provide more competitiveness to the industrial companies through innovative approaches, methods and tools that can compose efficiently a factory-planning framework.

The Virtual Factory Framework project, intends to be a key enabler for the future manufacturing: Virtual Factory. In fact, the implementation of a holistic, integrable, up-gradable and scalable Virtual Factory, carries high costs savings in the implementation and reconfiguration of new or existing facilities thanks to the effective representation of buildings, layouts, machines, workflows and Factory&Product life-cycle. The ability to simulate dynamic complex systems, covering all factory life-cycle, is one of the main advantages that allow the optimization of processes and resources, follow and evaluation of strategies and also design, manage and reconfiguration of facilities.

In line with this context, this dissertation work intends to develop a Knowledge Management system, called Factory Template, which will allow the simple and intuitive access to the Knowledge Repository of the factory. The developed templates will not only address the physical and operational form of the factory itself, but they will also incorporate product and process layouts and strategies. This way, compiling all the knowledge available, Factory Template module will support the planning and optimization of processes, ensuring the reuse of knowledge acquired and also storage of the corrective actions performed successfully.

Moreover, templates integrating the factory's response to internal and external disturbances will be developed as well. In order to achieve this, a performance estimator tool was developed. Thus, this innovative approach will enable the introduction of a new paradigm called anticipation performance control, within the Factory Management, which will support the reduction of the reaction time to external and internal changes or disturbances.

Abstract

Nowadays the global industry faces a continuous increasing of the competitiveness that forces companies to adopt and develop new strategies and methods of production. In that context, the current challenge in the manufacturing engineering consists in the innovative integration of the Product and Factory worlds and of all corresponding data managements and tools, in order to give reality to the synchronization between the Product, Process and Factory Lifecycle.

The next generation of factories have to be modular, scalable, flexible, open, agile, and knowledge-based in order to be able to adapt in real time to the continuously changing market demands, technology options and regulations. Because of that, it's essential that each factory can be able to integrate models and strategies capable of adapt their production system to the market demands and fluctuations including capacity planning methods, demand profiles and forecasts, provide internal and external influences *and more. Due to this flexibility and efficiency requirements, the ability to simulate all the production life cycle of a factory, takes an crucial role in order to decrease ramp-up and design times, increase performance in the evaluation and reconfiguration of new or existing facilities, support management decisions and provide tools to guaranty a real-time performance monitoring.*

Therefore, it is necessary to research and implement the underlying models and ideas at the foundation of a new conceptual framework designed to implement the next generation Virtual Factory, also meant to lay the basis for future applications in this research area. This new Virtual Factory Framework should promote major time and cost savings while increasing performance in the design, management, evaluation and reconfiguration of new or existing facilities, supporting the capability to simulate dynamic complex behaviour over the whole lifecycle of the Factory - based on the industrial paradigm "Factory as a Product".

In line with the context here presented and, in particular, in order to strongly enhance perception of the factory as a product notion, we purpose the development of factory templates addressing the design and operation practices throughout the whole lifecycle of the factory.

Acknowledgments

I am grateful to my supervisor, Prof. Américo Azevedo, whose encouragement, supervision and support from the preliminary to the concluding level enabled me to develop an understanding of the subject.

Lastly, I offer my regards to all of those who supported me in any respect during the completion of the Project, specially collegues from INESC-Porto and VFF consortium.

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Abbreviations and Symbols

List of abbreviations

BP	Back-Propagation
CIMOSA	CIM Open System Architecture
DDT	Delay of the Delivery Time
EKF	Extended Kalman Filter
FEUP	Faculdade de Engenharia da Universidade do Porto
FT	Factory Templates
GERA	Generic Enterprise Reference Architecture
GERAM	Generic Enterprise Reference Architecture and Methodology
GUI	Graphical User Interface
KMS	Knowledge Management System
KPI	Key Performance Indicators
KRS	Knowledge Repository System
MA	Moving Average
MLP	Multi Level Perceptron
NON	Number of Orders with Nonconformities
NN	Neural Networks
PERA	Purdue Enterprise Reference Architecture
PVE	Performance Value Estimator
RBFN	Radial Basis Function Network
VFF	Virtual Factory Framework

Chapter 1

Introduction

This chapter presents the context where this research work is involved. Furthermore explains the main goals and purpose to be achieved, not only of the Factory Templates but also of the European project where this work is integrated. Finally a description of the methodology adopted and the structure of the document are presented. Thus, it is intended to demonstrate and present the relevance of this research, the context and scope of this work as well as highlight the procedures used both for research as for the validation of the results.

1.1 - Context and Motivation

Nowadays European Companies are facing an extreme level of competitiveness, accompanied by a slow economy growth. Moreover, has been observed the transfer of power from companies to clients, what has been forcing the decreasing of product life cycles, a higher replacement of products and services and a significant change of processes, plant facilities and human and technical resources.

To survive in this cut-throat competition, the development of a new industrial paradigm becomes essential in order to guarantee the European industry competitiveness. From production perspective, it becomes clear that, more and more, the next generation of factories needs to be modular, scalable, flexible, open, agile, and knowledge-based in order to be able to adapt in real time to the continuously changing market demands, technology options and regulations. Moreover, this new generation of factories should be able to integrate models and strategies capable of adapting their production system to the market demands, accelerate the plant design and optimize production.

To achieve this, is essential develop and include in the processes of factory management, new methods of capacity planning, forecast and analysis tools, as well as develop techniques to anticipate and better react to internal and external disturbances. Moreover, in order to achieve the flexibility and efficiency requirements, the ability to simulate and study all the production life cycle of a factory takes a crucial role not only to decrease ramp-up and planning time but also increase performance in the evaluation and reconfiguration of new or existing facilities, supporting decision makers and provide tools that guaranty a real-time performance monitoring.

To be able to answer many of the requirements and functionality previously mentioned, it is proposed the study and development of Factory Templates component. This approach is aimed to support the process planning, integrating the industrial knowledge and best practices achieved, and also evaluate their performance, in order to improve them.

The Factory Template is a functional component developed within the framework of a large research European project called Virtual Factory Framework. This project, which will be presented in greater detail during the next chapter, intends to support and provide all the functionalities need for the next factories generation, as cited before.

The development of the Factory Templates architecture can be seen as a great challenge once it involve the integration not only of systems but also knowledge, experience, internal and external data and forecast information. Indeed, this unexplored thematic, if properly applied, can undoubtedly take a greatly influence on the performance and productivity of a factory.

1.2 - Objectives

In broad terms, the main goal of this research work is based on the necessity to explore and implement the underlying models and ideas at the foundation of a new conceptual Framework, designed to implement in Europe the next generation of Virtual Factories [6]. Thus, it is expected to establish, in this research area, the foundations for future applications, exploring new paradigms and importing methods and tools from other areas.

This innovative project called VFF should be able to promote major time and cost savings, while increasing performance in the design, management, evaluation and reconfiguration of new or existing facilities, supporting the ability to simulate a dynamic and complex behaviour over the entire lifecycle of the Factory, based on the new industrial paradigm “Factory as a Product”.

So, in order to contribute to the success of this project, a module called Factory Template (FT) need to be explored and developed. In fact, the main goal of this tool is to support the planning, design, follow and evaluation of the factory operations and processes as well as planning its dismantling or recycling. In other words, it is the purpose of this document present a methodology that should plan and follow all the life cycle of the factory in parallel with the product life cycle.

Moreover, FT aims to integrate the factory’s response to internal and external disturbances, decreasing their impact, as well as support the factory design and operational strategies efficiently, addressing fluctuating market demands. The FT will also incorporate flexibility measurements as attributes for the factory designs. The developed templates do not only address the physical and operational form of the factory itself, but also incorporate product and process strategies based on simulations and historical data. Another purpose is provide a tool that support the management performance system, management decisions and Knowledge Management.

Inserted on this context, is proposed the development of a tool which provides estimates with small errors, that follow the system tendencies caused by oscillations and seasonality’s. Thus, it is expected to explore a new theory that supports the performance management analysis taking into account the future behaviour of the factory, and not the present performance indicators measures. It is important to understand that companies need to anticipate their performance and find the origin of their problems in order to decrease the reaction time and increase their capability of anticipate in regard to competition. So, during this document is proposed to break with the approach of feedback control, and start studying a new paradigm of control by anticipation.

Known the requirements and main objectives of the Factory Templates module, three questions were proposed as the plumb line of the research work:

1. *How should be the vision and functionality about the Factory Templates issue?*
2. *How Factory Templates can support the planning process optimization, guaranteeing its reliability and quality?*
3. *How Factory Templates should be integrated within the Virtual Factory Framework Project?*

In sum, this work is intended to design the architecture of the factory templates, explore its concepts and architecture, as well as study its different components and main functionalities. Several concepts, methods and tools will be introduced in the work context in order to provide theoretical foundations that support the proposal here presented.

1.3 - Methodology

During the development of this research work, a series of steps have been taken in order to meet not only the VFF Project goals but also to respect the requirements of the industrial partners. Firstly, was essential clearly understand the purpose, scope and main goals of the project. After that, it was important integrate this information with the factory template subject, in order to understand the importance of this module as well as develop its vision and concepts. To achieve this, an exhaustive state-of-art about this subject was essential to instil the Factory Templates concepts and start define its architecture. So, a strong research about reference models, frameworks, generalized models and other related topics from other areas was done. Moreover, once the VFF Project has a lot of partners and covers a lot of thematic, it has been crucial, follow all the work packages of the project and support them with research, suggestions or tools in order to keep a comprehensive and updated view on the draft.

However, a lot of other tasks have been developed within the INESC Porto VFF Team, in order to be possible achieve with success all the objectives proposed before. In following it is enumerated a series of tasks that have been executed and can demonstrate the methodology adopted:

- Literature journal review
- Exploration of international journal, thesis and white paper in the domain;
- Project internal research, through questionnaires done to the industrial partners asking for necessities and functionalities;
- Requirements capture, based on fieldwork and through stakeholder meetings;
- Design of experiments cases to evaluate partial functionalities. In this context we have explorer G3, a real Brazilian supply chain.
- Weekly Skype meetings with work packages and Tasks leaders;
- Validation of methodologies and new paradigms through the publication of two papers (FAIM and MCPL conferences);

- Validation of factory template vision, architecture and functionalities with industrial partners, in order to respond to them necessities and expectative;
- Contacts with companies external to the project, in order to realize the real problems that these enterprises deal with. This work was done with the objective of become our proposal as robust as possible.

1.4 - Document Structure

After a brief introduction to the context of this document, and as a response to the critical situation describe before, the second chapter presents the state of art that support and serve as the pillar to the proposal presented. Here the concepts and main goals of VFF project will be introduced, as well as the components, modules, goals and main advantages of the Generalized Enterprise Reference Architecture and Methodologies (GERAM) and some examples of reference architectures and methodologies such as CIMOSA and PERA Model and Zachman Framework. It is also developed at this chapter the applicability, importance and advantages of Knowledge Management and Data Fusion. During this chapter it is also presented the Petri-net tool for workflow analysis as well as a series of forecast methods such as Kalman filter, Neural Networks, Weight Moving Average model, among others.

The third chapter presents the Factory Template design, where is developed its architecture, modules, components and functionalities. Moreover, the proposal is tested and validated in the chapter number four, where the scenarios and use-cases are described and the results are presented. Finally, conclusions are presented in fifth section, being explained the main results and the future work that will be done during the VFF project.

Chapter 2

State of Art

Due to the complexity and wide scope of the project presented before, it becomes relevant to present an overview of main subjects and concepts in scope of the VFF project domain and namely aligned with development of the Factory Templates methodology. This state-of-art chapter has this purpose.

Therefore, firstly an overview about the Virtual Factory Framework Project, with its architecture and key benefits will be presented. Moreover it will be explored briefly important concepts such as Factory Ramp-up, Performance Management, Knowledge Management and Concurrent Engineering. Furthermore we intends to underline the importance of this concepts for the success of companies, and namely, some of existing approaches and the main activities that should be performed and improved in order to apply this concepts.

This chapter presents also a survey on Reference Architectures and methodologies. Finally, it will be presented some techniques seeking to solve significant challenges with regard to topics such as workflow, Data Fusion and Forecast.

2.1 - Virtual Factory Framework - Overview

The primary objective of the VFF project [6] is the research and development of tools which support the next generation Virtual Factory that interact with the Real Factory in order to achieve time and cost savings, while increasing performance in the design, ramp-up, management, evaluation and evolution of new or existing facilities. To achieve these goals, techniques and methods that support the ability to simulate the different dynamic complex behaviours over the entire cycle of life of a factory must be developed. To simplify the idea explored before, we can use an analogy with the complete life cycle of a Product “Factory as a Product” [7].

Factories can be seen as long life products that have to be flexible enough to adapt their production methods and process to the needs and requirements of markets and economic efficiency. But all this influencing factors are continuously changing and have to be seen as noise or turbulence. Factories operate as large networks of information and are part of logistics networks that support supply-chains from customer’s orders, for consumable materials and waste, factory machines, equipment and tools. Therefore, a factory as a whole is structured in basic components that support factory transformability or changeability. This vision can benefit from the advantage of applying the life cycle paradigm to the factory as a product. In line with this context it's possible to look at a factory as a complex product, and take some new and innovative features, for example:

- Being digital in a static state and virtual in a dynamic state. Digital manufacturing uses a wide range of engineering and planning tools and applications to integrate new efficient and effective information and communication technologies into manufacturing processes;
- Support the full life-cycle through a Knowledge Management approach;
- Being subject to permanent adaptation and transformability;
- Transferring the life cycle paradigm, optimization and value creation, from products, process and technology to the factory.

Considerable benefits can be achieved if these entities are taken into consideration, such as faster time-to-market, lower costs, reduction of rework and rejection dates and increasing component and technology reuse.

The Virtual Factory Framework is based on four main pillars namely: Reference model for factory planning, Virtual Factory manager, Virtual Factory Modules and Knowledge [6]. The first one is based on two key concepts which have been explored before, the "factory as a product" and the "non-linear, non-deterministic planning methodology". The reference model establishes a coherent standard extensible data-model at the base of the common Factory Objects. The VF Manager handles the common space of abstract objects, representing the factory. The VF modules are the decoupled functional modules that implement the various tools that work for the Factory design, evaluation, evolution, management, etc. The last one, the Knowledge pillar is seen as the engine of the VFF concept to model a wider range of complex systems and to promote a greater comprehension of the methods adapted at the factory. The research work proposal in the context of this dissertation involves manly this last pillar.

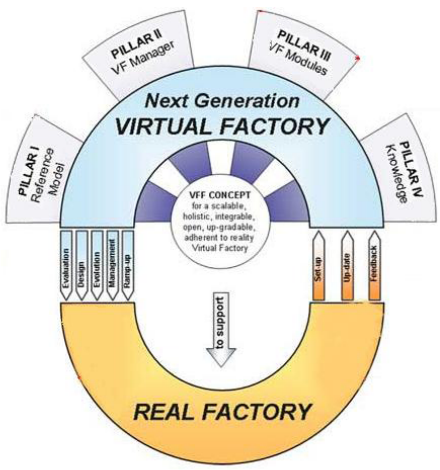


Figure 2.1 – Virtual Factory Framework Concept

In the VFF perspective, the development of a framework and a reference model for a holistic view of the factory will enable a wider perspective, compared with the methods and techniques used nowadays, capable of describing a factory as a whole, as far as for processes, dependencies and interrelations, factory modules and data flows are concerned.

Plenty of tools and software have been developed aiming to optimize the production processes and factory planning and design. However, there are still large amounts of issues that need to be worked on, such as methods and tools to create a configurable plant, enhance process management and manage the efforts of moving towards Mass Customization Products.

The implementation of a holistic, modular, open and scalable Virtual Factory is meant to achieve clear, well-identified and measurable goals for real production systems. In fact, the development of a framework which primary goal is to integrate the Real Factory with the Virtual Factory, where data, information and knowledge are easily accessible, make it possible to achieve a lot of advantages and benefits which, at the moment, are not available even to some of the more technological innovative companies. So this project, more than a digital tool for industrial support, should be seen as a framework designed to implement the next generation of factories. This tool needs to strongly intervene on the technological and data resources of the factory, supporting data exchange, systems integration, simulation models and other capabilities. Furthermore, the VF Framework will improve not only the way as companies project and design factories' facilities and resources, but also how they should manage their processes, during all factory life cycle, explicit the knowledge and good practices acquired with the experience and the continuous improvement conducted by the company and guaranty reliable monitoring and performance management using innovative methods, techniques and tools.

Thereby the most relevant key benefits are:

<u>Product and Process Life-cycle integration</u>: As was referred before, flexibility, agility and adaptability should be the more important characteristics of the virtual factory framework. In fact, nowadays-industrial companies are facing volatile changes of the market needs and demands derived from the transfer of power from the companies to the consumers. This situation force companies to decrease stocks, life and setup times of products as well as increase their variety, quality, innovation and services. Keeping these factors in mind, VFF will provide tools, methods and techniques such as factory templates, which will enable companies to improve their capability of: manage the factory planning, evaluate factory life cycle phases and continuously improve its performance, formalize and explicit processes and forecast markets changes for decision support. All this will be done during the entire factory life cycle, from its design and conception, until it's dismantling or recycling in order to achieve the goals described. Moreover it will be possible not only to achieve the good communication between different teams and sectors, but also maintain an up-to-date digital model over the complete life cycle.

<u>Reduction of global response time</u>: VFF will be able to improve factories flexibility and adaptability to the market needs throughout effectiveness and efficiency design, re-configuration and re-engineering of the factory resources and facilities. This strongly reflects in the reduction of the ramp-up.

In fact, nowadays, ramp-up can be seen as a very important competitive factor, figure 2.2. Companies are confronted with stagnating or even shrinking markets shares. So this leads to a tough competitive situation what requires companies to be innovative and put their products in the market as soon as possible (Time-To-Market). The ability of a company to create, develop and leak the product to the market as quickly as possible, should be seen of pivotal importance for the success and survive of the product series in question or even the brand. Aware of this, the ability to respond to changes or recommendations from outside should be taken at account too. In fact because of what was said before, recommended modification and refinement through optimization processes may have significant beneficial impact on the product success, only if there are processes which allow good ramp-up times. In summary, it is possible to say that the slow product development lead to a bad vicious cycle which can lead to high and undue costs.

In conclusion it is possible to say that successful companies distinguish themselves by their capability to perform ramp-up management against the background of Time-To-Market, Time-To-Volume and strict management of cost, quality and product complexity. In fact VFF will support and enable companies to achieve all this benefits and competitive advantages.

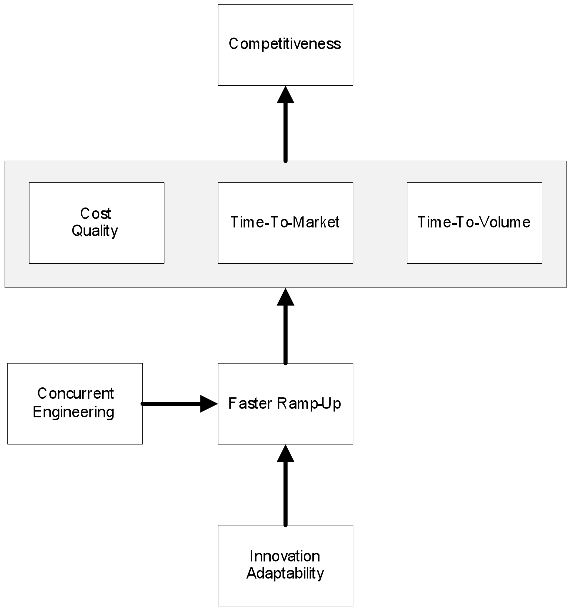


Figure 2.2 – Business competitiveness factors

<u>Re-use of useful Knowledge and Good Practices</u>: The knowledge is embedded and carried through multiple entities including organizational culture and identity, routines, policies, systems, and documents, as well as individual employees. So it becomes clear that the development of methods and techniques of formalization of the knowledge takes an increased importance nowadays. In fact the possibility to a company generate, absorb and capture the intellectual assets, knowledge and good practices, at the same time that share and diffuse it, make it possible to achieve high performance levels by itself. Therefore employees are able to increase their productivity, reduce processes times and re-work and improve product quality but also optimize the industrial resources, improve communication between teams with different trainings, better/faster the innovation inside the company, improve customer service and finally guaranty the performance levels independently of the turnover of the employees working in the company.

Real Time Decision Support: Not only knowledge and good practices are developed by the VFF. In fact, the support given, by the mechanisms developed, such as simulation modes, to the decision makers, managers and stakeholders, who have responsibilities at the processes, should be taken in consideration. This will be important to increase the confidence of employees and decision makers at the decisions, predict and anticipate any problems arising from the choices made and finally lower margin of error. For example, companies could use simulation tools as a sales aid to support proposals to clients, simulating various options. Therefore both supplier and client can evaluate alternatives in a short time, and both will then have confidence that the agreed solution will work.

Cost savings: The effective virtual representations of the entire production systems, fostering multi-loop evaluation procedures, multi-dimensional target systems, knowledge-driven decision support and quickened problem-solving sub-processes, allows a cost and time saving evaluation of existing and designed processes, resulting in radically enhanced production quality. The effectual virtual representation of all the production phases and of their mutual interrelation enables the intelligent selection of parameters affecting critical product characteristics and the improvement of production parameters, resulting in a reduction of process normal variation and of the overall amount of defective products answering to increasingly stringent design specification requirements.

Overall Continuous Improvement: Due to highly competitiveness that firms face nowadays, it is essential that companies design or re-design costumer-oriented processes in order to meet client's necessities. And, as it is known, customer expectations are normally defined in terms of product quality, on-time delivery and competitive pricing. So, it becomes clear that manufacturing performance requirements should be associated with quality product, customer service, availability, operating costs, safety and environmental integrity, time response, and so on.

So in this context, in order to achieve performance outcomes, some inputs might be taken in account, for instance, design, operating, maintenance and improvement practices. In fact for defined, primary functions, processes, inputs and outputs should be identified and related with critical Key Performance Indicators, as figure 2.3.

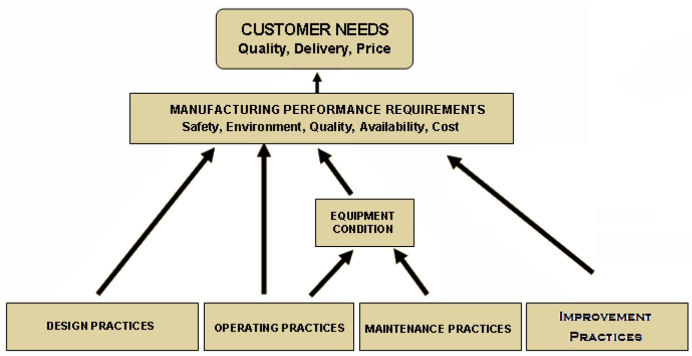


Figure 2.3 – Customer needs integration with factory design

The KPI's results would make it possible not only to analyze and evaluate the processes and methods applied in each of the inputs defined in the previous figure, but also enable the desired harmonization and performance comparison between the Virtual Factory and Real

Factory, which would be very useful to the factory planning. So, with this it is possible to achieve a reliable comparison between the two worlds in order to match their performance (“as-is” and “to-be” performances).

Finally it is possible to conclude that the use of a performance management system can support the decision-makers, beyond that could anticipate possible problems, optimize processes already implemented, meet market needs, and also to improve the relationship with the actors of the supply chain.

The key benefits itemized should be quantified in order to study the real impact of the VF Framework in the industrial environment. Furthermore the Key Performance Indicators to be defined should be associated and might support the overall phases for the product and processes life-cycle. Two sets of KPI’s should be defined in concordance with the different perspective: Customer perspective (internal and external) and Provider perspective.

With the customer perspective, the aim is to evaluate the effectiveness of the products and services. In other words, KPI’s related with the customer address product quality, service quality, availability, price, etc. On the other hand, the provider perspective addresses the efficiency related KPI’s, namely resource usage and process costs.

2.2 - Factory Ramp-up

Ramp-up can be defined as the time since a new series product or major product change is to be produced until that full production capacity is reached. In other words it is possible to say that the ramp-up starts when the first unit is produced and ends when the planned production volume is reached. However, to accomplish with success this stage of the factory life cycle it is important to perform a fairly long preparation period, starting near or after finalization of the engineering design of the product. In this stage factors like new factory facilities, new layout production, new or changed production equipment, logistics, staff, technologies and other processes, are normally taken in account. Moreover, to deal with this novelties or changes is important to have in mind flexibilities needs, human factors, and administrative and legal requirements.

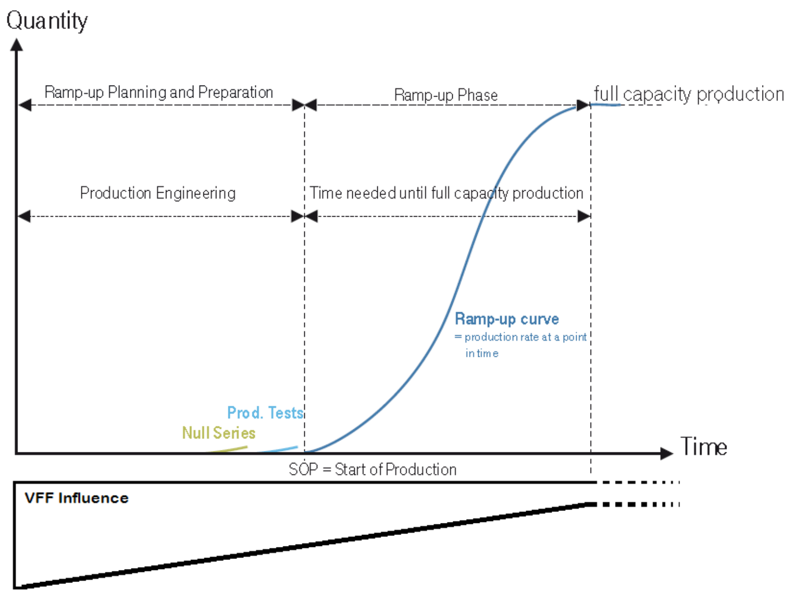


Figure 2.4 - Ramp-up phases specification (Source [20])

The essential factors that influence the product Ramp-up can be grouped at four main clusters [16], [17]. First it is important to understand which is the manufacturing capability of the factory in study (ability to make things rapidly and efficiently). A high manufacturing capability results in rapid prototype cycles, fast tool development times and effective ramp-up volume production. It is important to monitoring the ramp-up curve too. This factor takes into account how the old product is ramped down and the new product is ramped-up. The longer this transition period is the less steep and hence risky is the ramp-up. The operation pattern is another factor that affects the product ramp-up. This factor is seen as the rate of production and mainly affects the ramp-up due to its impact on the line speed, the number of products in the line and the overall operation time per day.

Finally depending on the ramp-up curve there are different policies that should be decided and taken in order to align the work force with the production rate. In order to decide which strategy should be use, there are some factors that can strongly influence the ramp-up characteristic. The main variable that should be taken in account is the volume of production that is intended to be produced. However there are several other related parameters such as variety, decoupling level and ramp-up time desired.

Different strategies and frameworks have been developed in order to decrease Ramp-up times and increase its understanding [22]. Examples of what was said before are the “Dedication strategy”, “Slow-Motion strategy”, “Step-by-Step strategy”, Frizelle framework and SPOT framework. The Frizelle framework supports itself at three main dimensions, which are novelty, learning and performance. In other hand, the SPOT framework’s [15] main pillars are strategy, process, organization, tools and culture.

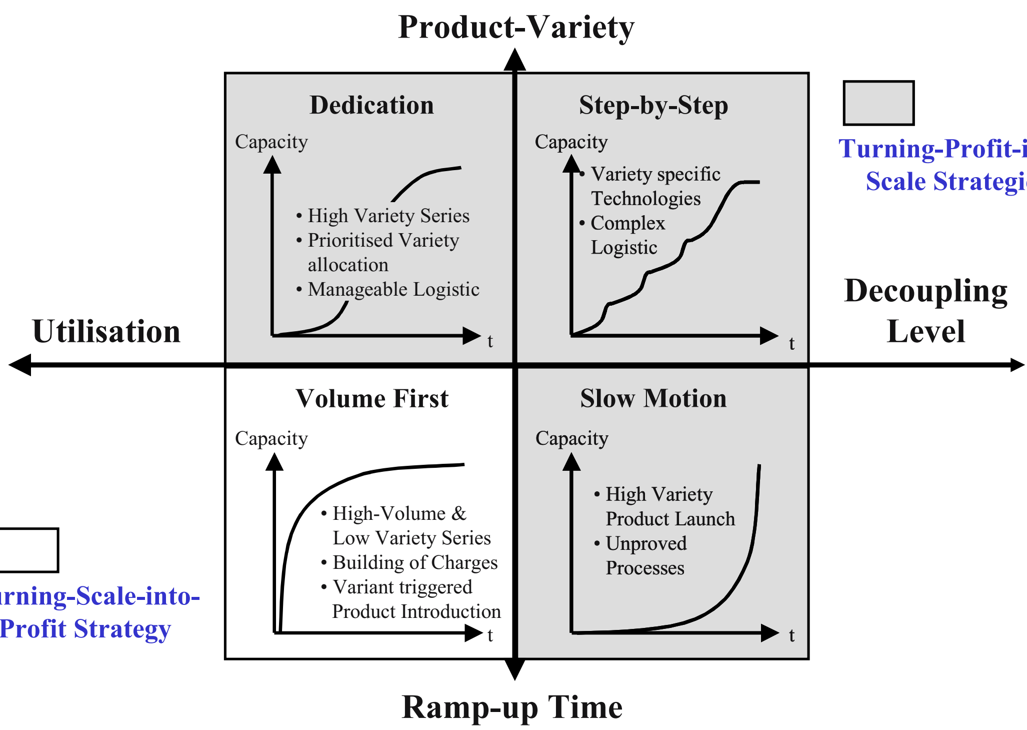


Figure 2.5 – Ramp-up phases specification (Source [22])

Independently of the strategies and frameworks adopted by the decisions makers and company leaders, concurrent and simultaneous engineering should be considered a critical technique for the product development success [18]. In fact it enable engineers teams to work in different domains simultaneously while facilitating collaboration across disciplines, allowing multiple interactions and improved communications. This leads to reduced rework, shorter product development cycles and more robust and higher quality manufactured products. In fact Ramp-ups are a joint effort of many disciplines and departments in the company.

In the follow table is shown different perspectives from different studies, which help us to understand how to improve Ramp-up Management [19].

Tabela 2.1 — Ramp-up perspectives.

Authors	Conclusions
Langowitz (1987)	Developed and tested a conceptual framework to explore the impact of the development process, the product design and the manufacturing capability on the initial commercial manufacturing period.
Clark and Fujimoto (1991)	Present evidence that product development is closely linked with successful ramp-up management
Terwiesch and Bohn (1998)	Analyzed the effect of learning on ramp-up performance, described as capacity utilization and yield. The results of their simulation highlight the importance of learning during ramp-up in order to achieve fast time-to-volume compared with the still dominant paradigm of time-to-market.
Terwiesch et al. (1999)	Using a longitudinal case study approach, their finding revealed several organizational patterns that seem to shorten a product ramp-up period. (Soft handover from pilot production to volume production; clear organizational responsibilities, high commitment, cross functional interaction and finally introduction of product platforms)
Almgren (2000)	He argued that the number and frequency of disturbances during the start-up period overload the organization and result in a loss of production capacity or increased production load. (Disturbance sources: product concept, material flow, production technologies and work organization)
Kuhn et al. (2002)	They identified the factors that affect ramp-up performance: product development, production process, organization and personnel, logistics, network and cooperation and methods and tools
Fleischer et al. (2003)	Developed a simulation tool that generates ramp-up curves as result of the interaction between several elementary processes.
Van der Merwe (2004)	Developed a conceptual framework that extends the concept of learning as a driver of ramp-up performance with the concept of novelty

In summary, although the various authors developed their studies at different industries and with different methods, they all agree about the main factors that affect the Ramp-up stage: product architecture, the manufacturing capability, human resource setup, product development process, material logistics, the cooperation model and the applied tools.

Presented the reasons that may influence the Ramp-up stage performance and the various strategies that can be adopted, it will be demonstrated during this document, how the Factory Templates can be important to the success of this stage of the factory life-cycle. Moreover, the Factory Template module will be applied on a ramp-up scenario, in order to be tested and validated. This chosen was done due to the importance of the Ramp-up phase to the introduction of new products into the market and therefore to the success of the brand.

2.3 - Performance Management

According to Peter Drucker [60], it is not possible to manage a process if we cannot measure its performance. In other words, performance management should be seen as an essential principle of management because it not only enables the detection of gaps in the processes (matching between current performances and desired performance) but also indicates where processes should be improved, in order to fulfil these gaps and increase the overall performance of the factory. Because of that, it is so important to determinate and choose the key performance indicators, which, delivered to the right person, can provide the crucial information to assure the factory processes improvement.

In fact, as Hronec argues [57], traditional measurement of the system output should not be seen as adequate or efficient. Indeed, this raw data do not focus on processes behaviour or at the organizational strategy, neither explains to decision makers how to do better or even which are the roots causes of poor performance. So, this kind of measures simply does not add more value to the manufacturing management.

In fact, to achieve a useful performance management, it is required to perform an exercise of balance between the interests of the supply-chain participants, the knowledge about costumer's requirements, and the business processes knowledge. Indeed, the choice of performance measures not only must integrate strategies, resources and processes but also should allow the continuous improvement processes. In fact, this is a factory capability that should be assured, in order to make the company more flexible and capable to adapt, in real time, to the continuously changing market demands.

Introduced the importance of the performance management, it becomes crucial to differentiate performance measurement from performance management. Performance measurement, as was defined by Lardenoij, Raaij & Weele [55], should be seen as the activity of quantitatively evaluate efficiency and effectiveness of processes. On the other hand, Amaratunga & Baldry [58] define performance management as the capability of, using performance measurement information, improve processes in order to achieve the proposed goals and optimize resources. In fact, these two performance aspects complement each other in order to support the manufacturing management.

During this document, it will be presented a methodology that will mainly support the performance management once, within the VFF project, the performance measurement will be performed by another module called "KPI module".

2.4 - Knowledge Management

Knowledge, in the contemporary economy, represents a fundamental matter. Increasingly, the information is distributed across individuals' workers, work teams and organizations. So, the ability to create, acquire, integrate and deploy knowledge has become a fundamental organizational capability.

But, what is the knowledge? In fact, Thomas Davenport [25] defined knowledge as "*a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knower's. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices and norms.*"

So what is immediately understood is that, knowledge is not neat or simple. It exists within people, is part and parcel of human complexity and unpredictability, and because of that Knowledge Management [26] is not a simple and elementary matter.

As referred before [23], knowledge is embedded and carried through multiple entities including organizational culture and identity, routines, policies, systems, and documents, as well as individual employees. Because knowledge-based resources need time to be achieved, are usually difficult to reproduce and are socially complex, these resources represent a long-term sustainable competitive advantage. However, this resource only reflects on industrial advantages if it is possible to capture, store and exploit the company's intellectual assets, helping employees better perform their work for the benefit of the organization. Moreover companies should continually invest in the exploration of new knowledge, and look at this as a part of the company internal strategy.

Because of what was said before, Knowledge Repository Systems should be developed. For example, Chrysler stores the knowledge for new car development in a series of repositories called "Engineering Books of Knowledge". The goal of these files is to be an "electronic memory" for the knowledge acquired by automobile platform teams.

So, the role of Knowledge Repository Systems (KRSs) [23], [26] is to facilitate the exchange of knowledge among those who have the knowledge and those who have interest in their application within a manufacturing environment. KRSs allow the sharing of experiences and methods of work among employees of an organization and allow the normalization of their view on the company's positioning in the market. All this can be accomplished by publishing documents in a database, managing all the information and make it accessible to all members of an organization. In fact, knowledge repository systems can be described as special instances of knowledge management systems, which enable an easily access to the knowledge channels.

The knowledge management systems (KMS) [23], [26], [60] refer to a class of information systems applied to the organizational knowledge management. Moreover, KMS should support the creation of expert's databases, decision aids and expert systems development as well as hardwiring of social networks to aid access to resources of non-collocated individuals [ref].

Normally IT-based systems are developed to support and enhance the organizational processes of knowledge management. In fact functionalities of information technologies play a critical role in shaping organizational efforts for knowledge creation, acquisition, integration, valuation and use. Information systems have been crucial to enable business processes, flows of information, and sources of knowledge to be integrated as well as assure synergies from such combinations.

Another common application of KMS is the creation of knowledge networks. For example [23], when Chrysler reorganized from functional to platform-based organizational units, they quickly realized that unless suspension specialists could easily communicate with each other, across plat-form types, expertise would deteriorate. In this case the KM effort was focused on bringing the experts together so that important knowledge was shared and amplified.

As it is easily possible to understand, the content of knowledge management may vary based on different views of knowledge. For example, if knowledge is an object, then KM should focus on building a managing knowledge stock, on the other hand if knowledge is a process, then KM should emphasize the knowledge flow and the processes of creating, sharing, and distributing knowledge, and so on.

Centring the study on process-based view, Ruggles [20] proposed eight major categories of knowledge-focused activities for KM, which included how knowledge should be generated, accessed, presented, embedded, facilitated, transferred and measured, as well as how knowledge should be used for decision making. Similarly, Alavi and Leidner [3] define KM involving various activities in four basic processes including creating, storing/retrieving, transferring, and applying knowledge which will be explained at the table 2.2 [23].

Tabela 2.2 — Knowledge Activities

Knowledge Activities	**Description**
Creation	Organizational knowledge creation involves developing new content or replacing existing content within the organization's tacit and explicit knowledge. Through social and collaborative processes as well as an individual cognitive process (e.g. reflection). Knowledge is created, shared, amplified, enlarged and justified in organizational settings.
Storage/Retrieval	While organizations create knowledge and learn, they also forget. Thus, the storage, organization and retrieval of organizational knowledge, constitute an important aspect of effective organizational knowledge management. Organizational memory includes knowledge residing in various components forms, including written documentation, structured information stored in electronic database, codified human knowledge stored in expert systems, documented organizational procedures and processes and tacit knowledge acquired by individuals and network of individuals.
Transfer	Transfer occurs at various levels: transfer of knowledge between individuals, from individuals to explicit sources, from individuals to groups, between groups, across groups, and from the group to the organization. Considering the distributed nature of organizational cognition, an important process of knowledge management in organizational settings is the transfer of knowledge to locations where it is needed and can be used.
Application	An important aspect of the knowledge-based theory of the firm is that the source of competitive advantage resides in the application of the knowledge rather than in the knowledge itself.

Accordingly to [24], there are three main types of knowledge problems that should be addressed at knowledge management researches: knowledge coordination, knowledge transfer and knowledge reuse. These problems arise from the complexities faces by individuals, groups and organizations in recognizing the nature of knowledge needed to solve problems or make decisions, the difficulties in assembly the necessary dispersed components of this knowledge, and difficulties rooted in the ambiguity of adjudicating knowledge ownership as well as encouraging reuse of knowledge.

2.5 - Concurrent Engineer

The concept of Concurrent Engineer [31] was initially proposed as a means to minimize product development time through the simultaneous development of product and processes. Since then, many definitions of CE have emerged in literature:

- "Systematic approach to the integrated, concurrent design of products and their related processes" [27];
- "Goal directed effort, where ownership is assigned mutually among the entire group on the total job to be completed, not just pieces of it, with the understanding that the team is empowered to make major design decisions along the way".

In fact, after a small reflection and understanding of the definitions given before, it is possible to infer that most of the basic principles of CE revolve around the notions of teamwork affinity and shared knowledge leveraging. In fact, this matter presents a very complex thematic since today systems that are currently developed contain large numbers of components and encompass the knowledge of thousands of person-years. Clearly, this is much more than one individual can retain in their limited mental storage capacity. Because of that it becomes crucial, at the modern engineering, the engagement of several individuals in the realization of an artefact or product. In fact, the essence of CE is not only the concurrency of the activities but also the cooperative effort from all the involved teams, which leads to improving profitability and competitiveness.

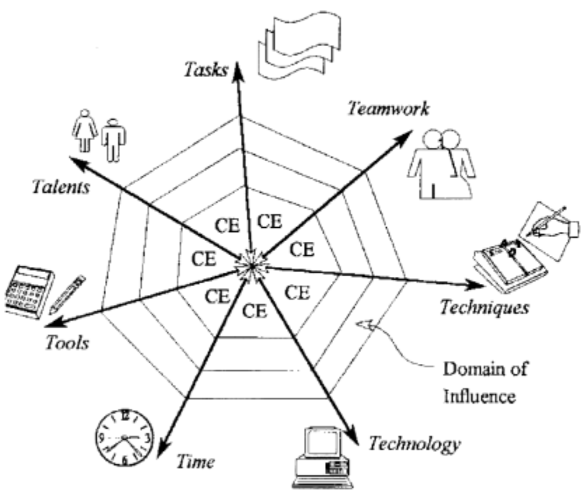


Figure 2.6 – Seven influencing agents of concurrent engineering

As shown at the following picture, Prasad [53] identified seven main agents that can influence the CE application: talents, tasks, teams, techniques, technology, time and tool. However, in a succinct way concurrent engineering can be comprised of three key elements: collaboration among team members, implementation of information technology and the establishment of formal concurrent processes involving engineering, marketing and manufacturing.

The Concurrent Engineer define that, during a product conception it is vital simultaneously consider all design goals and constraints for the products and systems that will be produced [27], [31]. In fact, in many industries where the competition between companies is higher, this methodology has become an essential concept to guaranty their survival. Indeed, design can be seen as the essence of engineering once it is possible to be described as “the creative process by which our understanding of logic and science is joined with our understanding of human needs”.

The CE philosophy [27], [28], [31] advocates that early considerations of manufacturing issues, in the design phase, is very important to reach substantial benefits. Similarly, taking into account the design processes as early as possible during the product life cycle development, might expose alternative solutions that could provide remarkable quality improvement for an insignificant cost increase. These will enable savings in setup and production costs, reduction of lead times required to bring a new product to market, reduction of part inventories and associated overhead, and improvements in overall product quality and reliability.

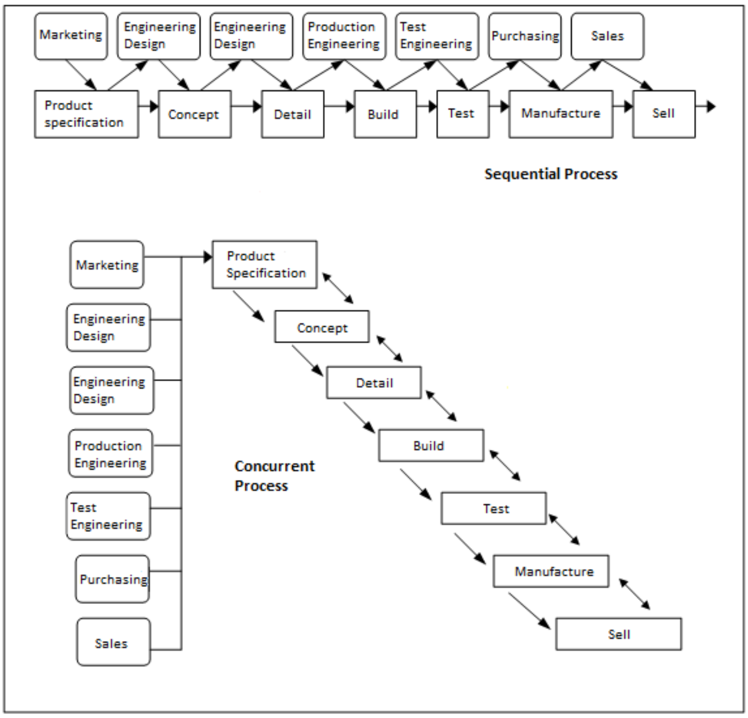


Figure 2.7 – Sequential and concurrent development of new products (Source [30])

On the other hand, this philosophy supports the idea that the delivery of a product to market typically requires complex interactions between several activities. These activities, individually and in combination, determine the quality, ramp-up and cost of new or improved products. As examples of these activities, only for the product design phase [28], it is possible to refer: market analysis and product selection, product and component design, material selection, component and material purchasing and inventory, fabrication technology and tool selection, material handling and process control, assembly, test and rework, service, support, and retirement. However, the interactions between these different activities need to be managed and structured, in order to optimize the product development and the production and delivery processes as a whole [31].

As shown at the figure 2.7, taking the product design as example, concurrent engineering intend to couple activities between market analysis, product design, production system design, manufacturing, and sales and distribution. Clearly, this concurrent approach is much more complex, sophisticated, and demanding than the sequential process. However, with this it is possible to get and overall project optimization, avoiding sub-optimization of the parts.

Salomone [29] and Books [30] also define some key organizational issues that can be essential and prevalent in order to implement concurrent engineering:

Tabela 2.3 — Concurrent Engineering factors

Author	Concepts
Salomone [29]	• Collaboration among team members (teamwork), • Virtual Teams, • Implementation of information technology • Establishment of formal concurrent processes • Minimize total number of parts • Develop a modular design • Use standard components • Design parts to be multifunctional, multiuse and for ease of fabrication • Minimize assembly directions, handling and compliance • Maximize compliance
John Hartley and John Mortimer [30]	• Multidisciplinary task-forces • Product defined in customer terms and then translated into engineering requirements • Design of process parameters • Design for manufacture and assembly • Concurrent development of product, manufacturing process, quality control and marketing

As a summary it is possible to say that the fundamental thought of the process of concurrent engineering is a process of convergence, where large scale collaborative thinking and an effective cross-functional teams leads to innovative ideas, market understanding, increasing market share, customer satisfaction and reduce of product lead-time [27], [31]. This key issue, of ideas convergence is well illustrated at figure 2.8.

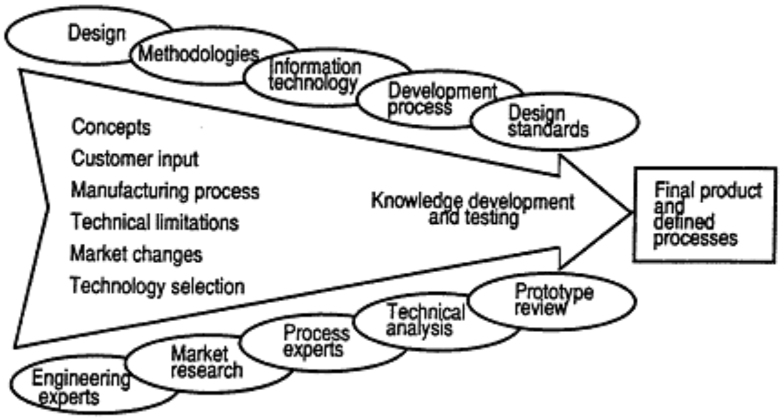


Figure 2.8 – Concurrent engineering as the convergence of ideas

2.6 - Reference Architecture and Methodologies

2.6.1. Generalised Enterprise Reference Architecture and Methodology

The IFAC/IFIP Task Force on Architectures for Enterprise Integration was formed, at the 11th Triennial Congress of IFAC, as a group of manufacturing engineers, computer scientists and information technology managers to study, compare and evaluate the different available architectures for enterprise integration for enterprise integration.

However, after study some of the existing reference architecture such as PERA, CIMOSA GRAI-GIM, and others, this entity early understood that none of them subsumed the others; each of them had something unique to offer. So it was developed an overall definition of a generalised architecture called GERAM (Generalised Enterprise Reference Architecture and Methodology). GERAM [34], [33], [35] is about those methods, models and tools that are needed to build and maintain the enterprises for their entire life-history. However GERAM cannot be seen as another proposal for and enterprise reference architecture, but is meant to organise existing enterprise integration knowledge, being applicable to all types of enterprises.

In conclusion, [33] the scope of GERAM encompasses all knowledge needed for enterprise engineering/integration. Thus GERAM is defined through a pragmatic approach providing a generalised framework for describing the components needed in all types of enterprise engineering/integration processes. GERAM was proposed in order to allow the integration of methods of several disciplines used in the change process, such as methods of industrial engineering, management science, control engineering, communication and information technology, i.e. to allow their combined use, as opposed to segregated application. One aspect of the GERAM framework is that it unifies the two distinct approaches of enterprise integration, those based on product models and those based on business process design. It also offers new insights into the project management of enterprise integration and the relationship of integration with other strategic activities in an enterprise.

GERAM provides a description and enumeration of all the elements recommended in enterprise engineering and integration and sets the standard for the collection of tools and methods from which any enterprise would benefit to more successfully tackle initial integration design, and the change processes which may occur during the enterprise operational lifetime. At the following picture it is identified and related the set of components identified in GERAM.

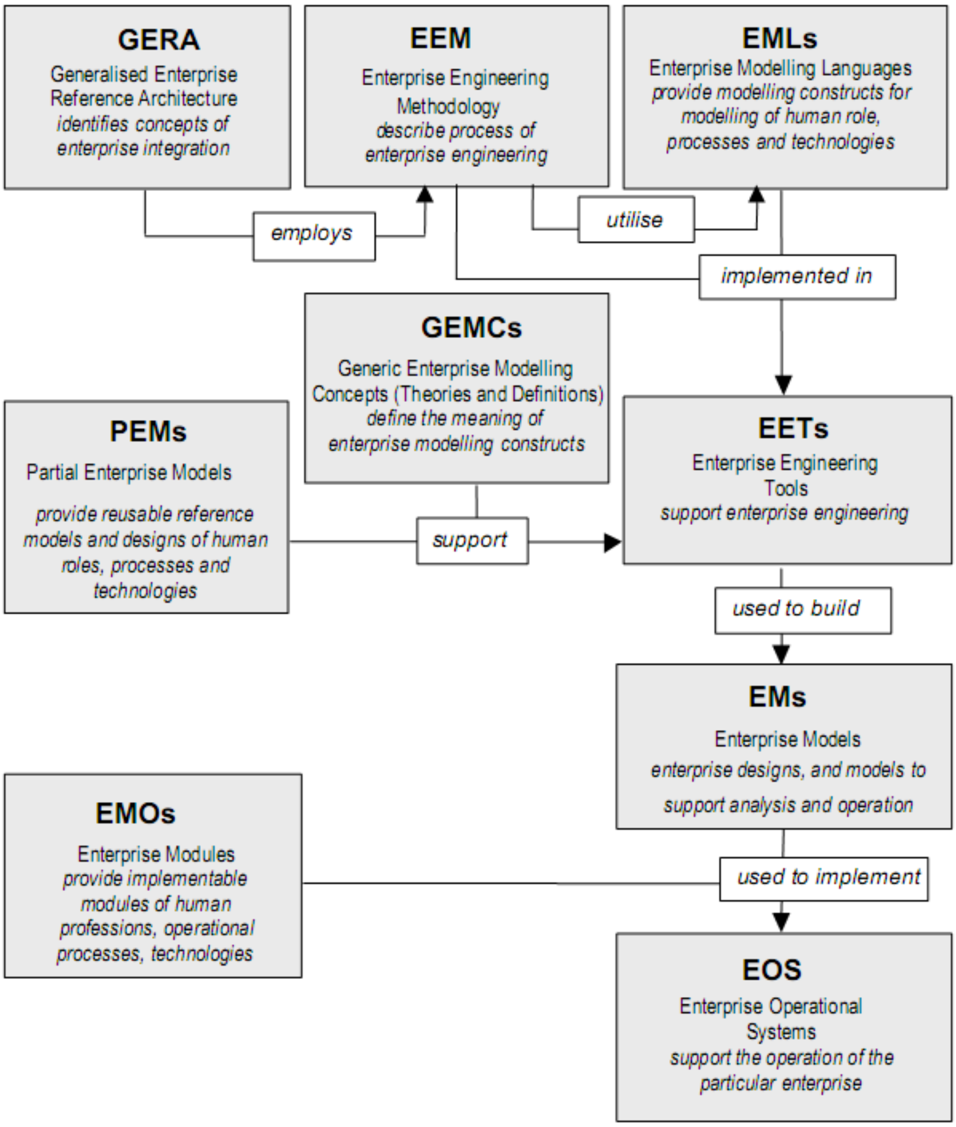


Figure 2.9 – GERAM framework components (Source [33])

Generic Enterprise Reference Architecture (GERA)

This component defines the generic concepts recommended for use in enterprise engineering and integration projects. These concepts can be classified as human oriented concepts, process oriented concepts and technology oriented concepts.

The first one covers all human aspects such as capabilities, skills, know-how and competencies as well as roles of humans in the enterprise organisation and operation. Here, modelling constructs are required, in order to facilitate the description of the human roles as an integral part of the organisation and operation of an enterprise and to promote the retention and reuse of models that encapsulate knowledge (Knowledge Repositories). These constructs should facilitate the capture of enterprise models that describe the human roles, the way in which human roles are organised and the capabilities and qualities of humans as enterprise resource elements.

On the other hand, the Business Process Oriented Concepts deals with enterprise operations and cover enterprise entity life-cycle and activities in various life-cycle phases. It aims to describe the processes in the enterprise capturing both their functionality and their behaviour. The process-oriented concepts defined in GERA are:

- Enterprise life-cycle phases: the different life-cycle phases define types of activities that are pertinent during the life of the entity.

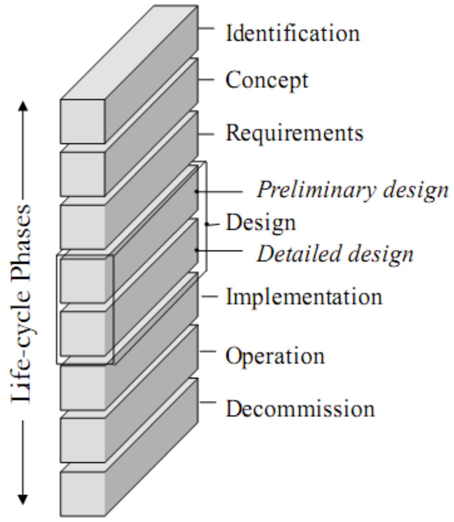


Figure 2.10 – GERAM Enterprise life-cycle (Source [33])

- Life history: the life history of a business entity is the representation in time of tasks carried out on the particular entity during its entire life span. Relating to the life-cycle concept described above, the concept of life history allows identifying the tasks pertaining to these different phases as activity types. Typically multiple change processes are in effect at any one time, and all of these may run parallel with the operation of the entity. Within one process, such as continuous improvement project, multiple life-cycle activities would be active at any one time.

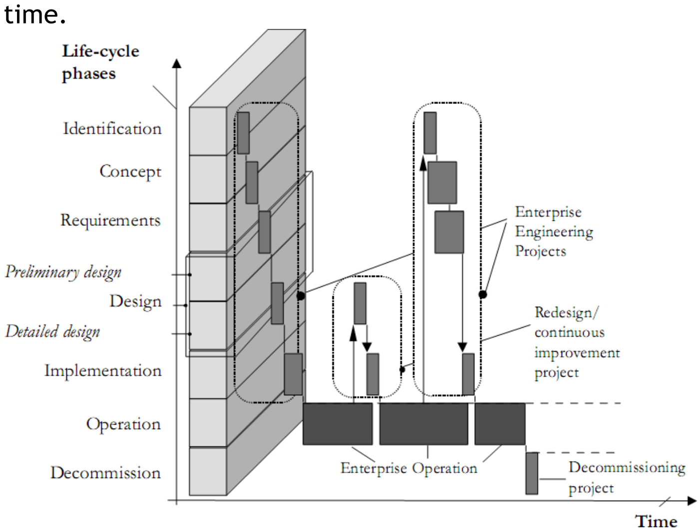


Figure 2.11 – Parallel processes in the entity's life history (Source [33])

- Enterprise entity types: in the following picture it is possible to understand how the life-cycle activities of two entities may relate to each other. The operation of entity A supports the life-cycle activities for design and implementation of entity B. Conversely the life-cycle activities of entity A need to be supported with information about the life-cycle details of entity B. That is, to identify a plant, to define its concepts and requirements, and to design it one must use information about which life-cycle activities of the plant's need to be covered in the operation of this plant.

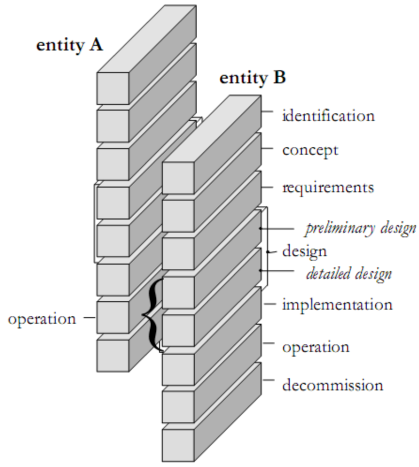


Figure 2.12 – Example for the relationship between life-cycles of two entities (Source [33])

- Enterprise modelling: this is the activity that results in various models of the management and control as well as the service and production processes, and their relationships to the resources, organisational, products etc. of the enterprise. Process modelling allows representing the operation of enterprise entity types in all their aspects: functional, behaviour, information, resources and organisational.

The Technology Oriented Concepts deal with the different infrastructures used to support processes and include for instances resource models, facility layout models, information system models, communication system models and logistics models.

GERA provides an analysis and modelling framework that is based on the life-cycle concept and identifies three dimensions for defining the scope and content of enterprise modelling:

- Life-cycle Dimension: providing for the controlled modelling process of enterprise entities according to the life-cycle activities.
- Genericity Dimension: providing for the controlled particularisation (instantiation) process from generic and partial to particular.
- View Dimension: providing for the controlled visualisation of specific views of the enterprise entity.

The following picture shows the dimensional described above.

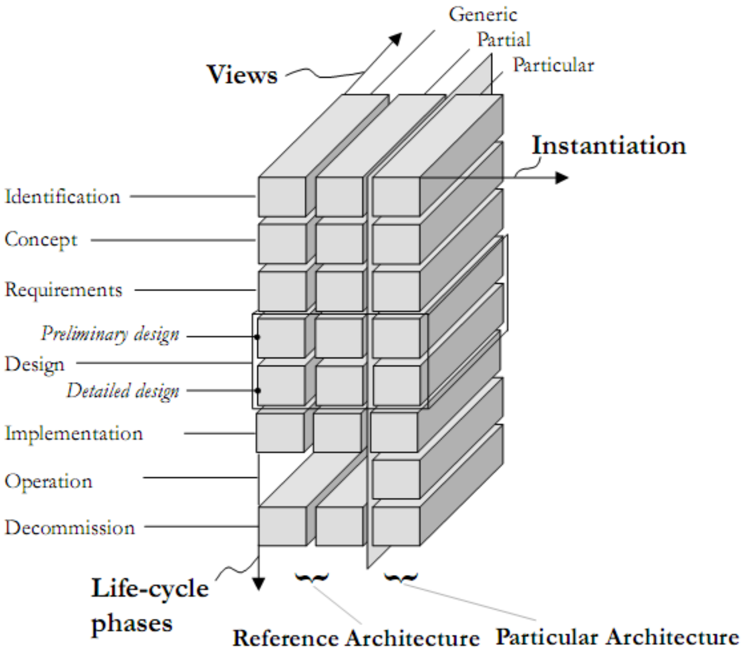


Figure 2.13 – GERA Modelling Framework (Source [33])

Generic Enterprise Engineering Integration Methodology (GEEM)

The GEEM has as primary goal the description of the processes of enterprise integration. This component will support users in the process of the enterprise engineering integration projects whether the overall integration of a new or revitalised enterprise or in management of on-going change. It provides methods of progression for every type of life-cycle activity. GEEM also intends to describe the process of enterprise integration and guide the user in the engineering tasks of enterprise modelling

Enterprise engineer methodology should contain exhaustive and detailed process descriptions and instructions. This will allow not only better understand the methodologies, but also will enable the identification of information to be used and produced, resources needed and relevant responsibilities to be assigned for the enterprise engineering process.

Generic Enterprise Modelling Languages (GEML)

The GEML describes the generic modelling constructs for enterprise modelling. All this, adapted to the needs of people creating and using enterprise models. In particular, this component will provide tools to describe and model human roles, operational processes and their functional contents.

In fact, the engineering of an enterprise can be highly sophisticated, multidisciplinary and volatile. Because of that, to develop generic enterprise models potentially more than one modelling language is needed. The set of languages must be capable of express and represent the enterprise operations from various modelling viewpoints. For each area of the GERA modelling framework, there may be a modelling language selected according to the enterprise engineer methodology.

Generic Enterprise Engineering Tools (GEET)

The Enterprise Engineering Tools support the processes of enterprise engineering and integration by implementing an enterprise engineering methodology and supporting modelling languages.

Enterprise tools should provide user guidelines for the modelling process and provide useful analysis and evaluation capabilities for the use of the models in the enterprise engineering process as well as enable users to connect models with the real business process in order to keep the models up-to-date. Furthermore, it is important that there are available a great variety of engineering tools for all the enterprises entities.

For example, if the enterprise entity in question is a product, the chosen tools should support the design of the product such as functionality, geometry, control system and so forth.

Some examples of engineering tools based on modelling languages are: ARIS Toolset (ARIS), FirstSTEP (CIMOSA), MOGO (IEM), KBSI Tools, METIS, Processwise, etc.

Generic Enterprise Modelling Concepts (GEMC)

GEMC define and formalise the most generic concepts of enterprise modelling. This component may be defined in various ways, such as:

- Glossaries: Natural language explanation of the meaning of modelling concepts;
- Meta-Models: describe the relationship among modelling concepts available in enterprise modelling languages;
- Ontological Theories: define the meaning of enterprise modelling languages, to improve the analytic capability of engineering tools, and through them the usefulness of enterprise models.

Generic Enterprise Models (GEM)

The Enterprise Models has as primary goal the creation and continuously maintenance of a model of a particular enterprise entity. This model should represent the reality of the enterprise operation according to the requirements of the user and his application.

However, there are others applications where GEM can be very useful, such as decision support, communication between internal/external stakeholders, model driven operation control and monitoring and new personnel training.

Enterprise models are expressed in enterprise-modelling languages and are maintained using enterprise engineering tools.

Generic Enterprise Modules (GEMO)

Enterprise Modules are implemented building blocks or systems that can be utilised as common resources in enterprise engineering and integration. Generally enterprise modules are implementations of partial models identified in the field, as the basis of commonly required products for which there is a market. Enterprise modules may be offered as a set, such that if the design of the enterprise is following the partial models that form the basis of this set, then the resulting particular enterprise's business system can be implemented using some or all modules of this set of modules.

Generic Partial Enterprise Models (GPEM)

Partial Enterprise Models are models that capture concepts common to many enterprises. This component not only increases the modelling process efficiency but can also be used as tested components for building particular enterprise models (Ems). Following is presented a list with some partial models:

- Partial Human Role Models
- Partial Process Models
- Partial Technology Models
- Partial Models of IT systems

Generic Enterprise Operational Systems (GEOS)

The GEOS support the operation of a particular enterprise. They consist of all the hardware and software needed to fulfil the enterprise objective and goals.

2.6.2. CIMOSA

Also known as Open System Architecture for CIM [8], CIMOSA aims primarily at the development of an open architecture of reference for the implementation, definition and specification of CIM systems (Manufacture integration by computer). CIMOSA consists of an Enterprise Modelling Framework and an Integrating Infrastructure. This method gives its own perspective on the architecture of reference, specifying procedures and guide operators, system managers and users throw the life cycle pre-defined.

CIMOSA enterprise models may be used not only in decision support for engineering and evaluating enterprise operation alternatives, but also in model-driven operation monitoring and control.

The CIMOSA modelling framework shown at the following figure structures the CIMOSA Reference Architecture into a generic and a partial modelling level, each one of them support different views on the particular enterprise model.

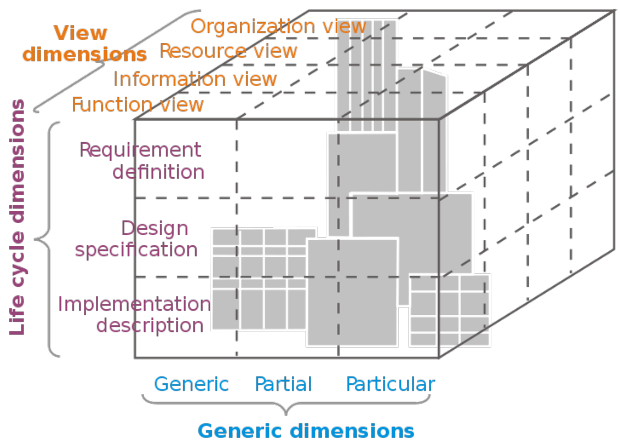


Figure 2.14 – CIMOSA Cube

CIMOSA has defined four different modelling views: function, information, resource and organizational views. Moreover CIMOSA Reference Architecture supports modelling of the complete life cycle of enterprise operations, from the requirement definition to the Design specification and Implementation description. With a set of common modelling buildings blocks/languages, CIMOSA Reference Architecture provides the base for evolutionary enterprise modelling, as was showed at the GERAM chapter. In fact, the common modelling language enables different people to model different areas of the enterprise, ensuring the integrity of the overall model. At the following image it is presented the basic set of CIMOSA building blocks for business modelling.

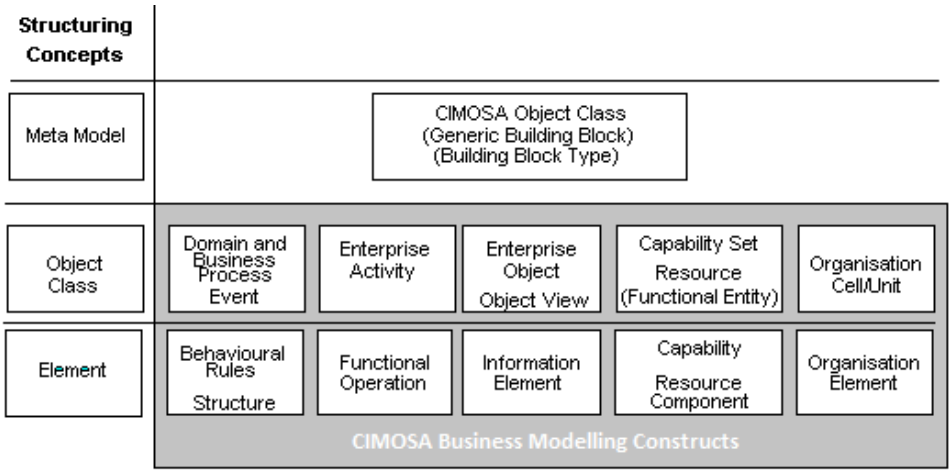


Figure 2.15 – Basic Set of CIMOSA Methodology

Processes, Events and Enterprise Activities are the object classes that describe the functionality and behaviour of the enterprise operation. Inputs and outputs of Enterprise Activities define the information and resources needed. Organisational aspects are defined in terms of responsibilities and authorisation for processes, functionalities, information, resources and organization, and are structured in Organizational Units or Cells.

CIMOSA explicitly differentiates enterprise engineering from enterprise operation. On the figure 2.16 it is clearly demonstrated the use of CIMOSA in model engineering as well as in operation control and monitoring.

Using the CIMOSA Reference Architecture, Particular Enterprise Models are engineered under the control of the Enterprise Engineering Implementation Model. To do this, it is normally used a CAE Tool which guides the user through the engineering phases of the CIMOSA System life cycle. The released Particular Implementation Model is then used to directly drive the operation through monitoring and controlling the relevant product life cycle phases or parts of it and their business process implementations.

In fact, the CIMOSA concept has been validated and verified in numerous case studies and pilot implementations. It was verified that CIMOSA models provide for a high flexibility in enterprise engineering, thought fast modelling and evaluation, via simulation of operation alternatives and direct implementation of the final solution. CIMOSA also present other important benefits such as analysis capability, lower time to model the particular domain and significantly improved re-usability of models parts.

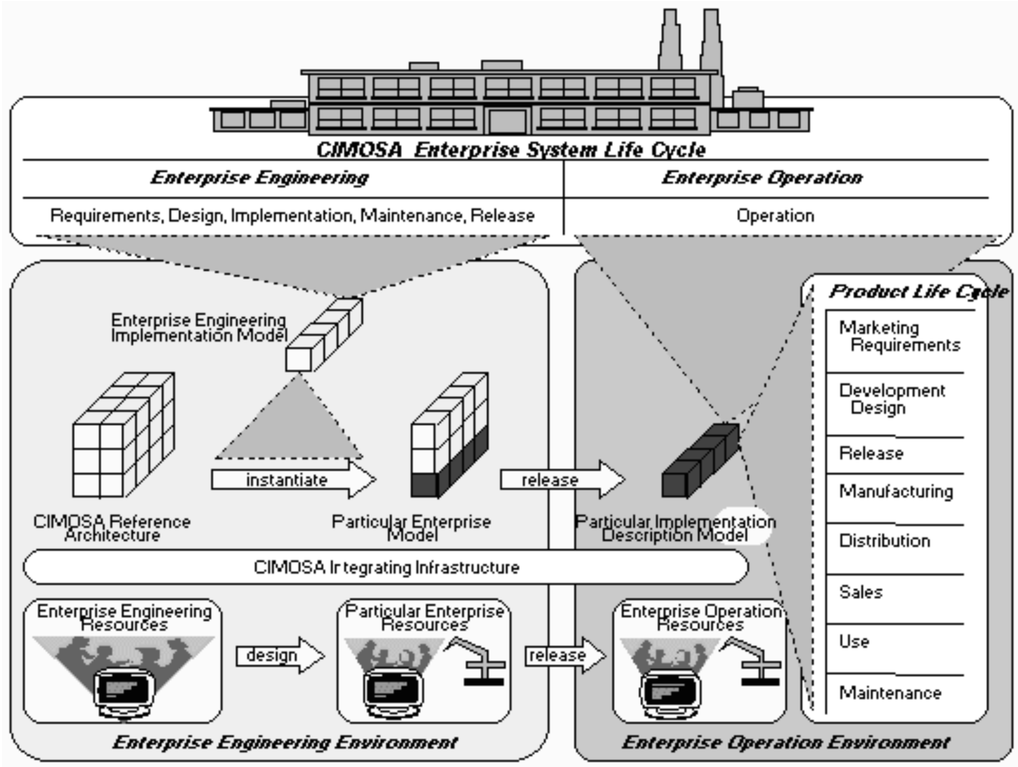


Figure 2.16 – Example of CIMOSA in model engineering and operation control and monitoring

2.6.3. PERA

The Purdue Enterprise Reference Architecture [5] has been developed at the University of Purdue since 1989. Based on a structure of layers, its aim is to create a model of all company life cycles, targeting the manufacturing environment, and simply apply that model to other enterprises. This Architecture satisfies all currently known requirements of GERAM [9].

The generic model PERA includes three basic components: Human as Organizational Architecture; Manufacturing Equipments Architecture and Information System Architecture.

These components are described as the three columns that start with the creation and definition of a company, and come to an end with the dissolution of the company. Each one of these columns has interfaces with the others, and thus it is possible for them to relate to each other.

The PERA architecture defines that the next level to structure the company's model should be made through "phases". So, PERA breaks the life cycle into phases, as shown in the previous image. During each phase of the company life cycle, different diagrams are used to reflect the development details at the moment, and to monitor the way the enterprise goes from the initial definition step to the dissolution, passing by the operation layer. At each step or phase of the PERA model, it is possible to define and discriminate documents and tools, explaining the precedence between them and their utility.

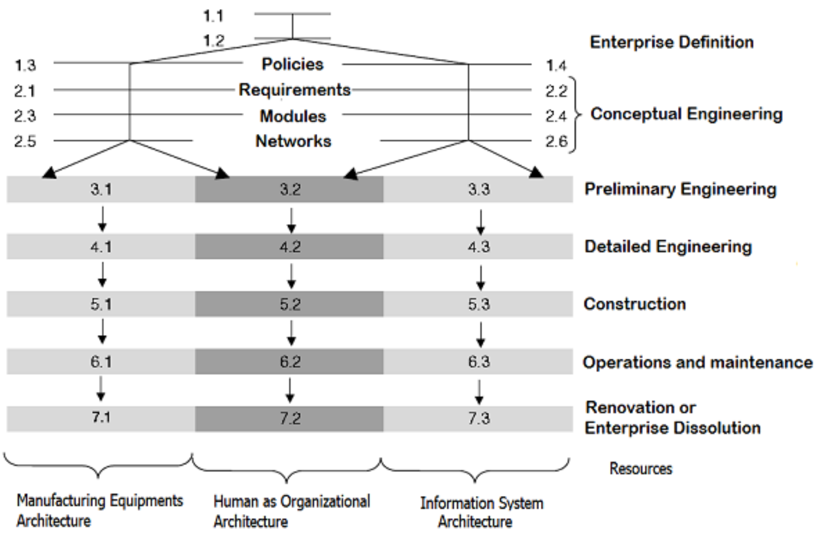


Figure 2.17 – PERA model

It is essential that the interfaces between the different groups that develop the enterprise are always well coordinated and in touch. For example, during the phase of preliminary engineering, when the industrial processes are being defined, it's necessary for the information and control system, as well as the human and organizational system, to be developed too in parallel.

The Purdue Enterprise Reference Architecture includes as main advantages: the possibility to provide a full life cycle for the facilities that are being developed within the company's project; to provide a means to handle human and organizational factors inherent to these projects and to the company's approach to these projects; to present a "phase" approach to reduce repeated work while carrying out projects; to provide an understanding of the dynamic interfaces between the different disciplines of engineering and management, working on a particular project; to provide informal models and templates of each phase in order to improve understanding and to monitor the work in progress; lastly, perhaps the best of all advantages is the fact that PERA diagrams look intuitively correct and present the life history in a way that follows the design that most engineers and managers in the industries have of their plants and companies.

2.6.4. Zachman Framework

The Zachman framework [3] was created in 1987 and instead of dividing the process into a series of processes, it organizes it from the point of view of the various players in the process, see figure 2.18.

This framework uses an original approach towards life cycle, resenting the life cycle phases as perspectives of the various stakeholders involved in the enterprise engineering effort. However the different levels of abstraction used by the various stakeholders, to consider the enterprise entity in question, match the GERAM life cycle. In fact GERA contains types of activities, while Zachman describes deliverables that given stakeholders produce.

The players described before include people who have undertaken to do business in a particular industry, business people who run the organization, the system analyst who wants to represent the business in a particular industry, the designer who applies specific technologies to solve the problems of the business, the builder of the system and finally the system itself. Each of these actors is represented in the Zachman matrix as a row. On the other hand, the Zachman framework presents in the columns the data manipulated by an organization (what), its functions and processes (how), locations where business is conducted (where), events that trigger business activities (when), the people and organizations involved (who), and the motivations and constraints which determine how the business behaves (why).

However, the Zachman framework cannot be seen as a practical framework for enterprise architecture. In fact, this tool offers a static overview of all elements involved in information systems. It does not define the processes to go from an existing (as-is) situation to a future (to-be) state neither. Moreover, despite this framework identify the exhaustive list of possible documentation standards it does not define their content or gives examples.

Accordingly to John A. Zachman [14], [13] his Framework is not a methodology for creating the implementation (an instantiation) of the object. For John Zachman this framework "is the ontology for describing the Enterprise and implies nothing about how one might do architecture work". A process (methodology) based on ontological structure will be predictable and produce repeatable results, that is, an ontology is the basis for a science. John Zachman also compares his framework to the Periodic Table, because "it defines the elemental components that exist".

In conclusion, after using the Zachman Framework, Loretta Mahon Smith from Modern Analyst [11] explained that, although at first she thought that Zachman framework seemed really academic, she has found in practice that this framework aligns closely to the project life-cycle and best practices in developing a data design from a top-down perspective for new systems. The value that she had found in using the framework is it provided her a tool that helped her perform gap analysis and risk assessment while she was developing a data design. Moreover she noted that the questions, presented at the Zachman matrix, can be asked at any level in an organization, from single application system to the entire enterprise.

Figure 2.18 - Zachman Framework

2.7 - Workflow Modelling

The classical Petri net [1] is a directed bipartite graph with two node types called places and transitions. The nodes are connected via directed arcs. Connections between two nodes of the same type are not allowed. Places are represented by circles and transitions by rectangles. At any time, a place can contain zero or a non-limited number of tokens, drawn as black dots.

The number of tokens may change during the execution of the net. Transitions are the active components in a Petri net, and change the state of the net according to the following firing rule:

- A transition t is said to be enabled only if each input place p of t contains at least one token.
- An enabled transition may fire. If transition t fires, then t consumes one token from each input place p of t and produces one token in each output place p of t.

The classical Petri net makes it possible to model states, events, conditions, synchronizations, parallelisms, choices and iterations. However, the classical Petri net does not model data and time. To solve these problems, many extensions have been proposed. Three well-known extensions of the basic Petri net model are:

- Extension with colour to model data,
- Extension with time,
- Extension with hierarchy to structure large models.

A Petri net extended with colour, time and hierarchy is called a high-level Petri net. This tool can be seen as an important vehicle to model and implement any kind of workflow, since it adds value to development process, giving important advantages if necessary to manage workflow system.

As it is known, business logic can and should be represented by a graphical language. In the process dimension, the tasks that need to be executed and in what order are specified. In fact, there are some tools that play important roles in modelling and characterizing processes, such as swimlanes and matrix models. However, modelling a workflow process using Petri net, not only becomes quite direct (tasks are represented as transitions, conditions are modelled by places, and cases are modelled by tokens), but also brings plenty of other advantages [2]. Petri Nets, as a graphical and mathematical tool, provide a uniform environment for modelling, formal analysis and design of discrete event systems, fault detection and monitoring systems. In fact, simple analysis tools, such as reach ability trees and the matrix equation representation of a net, can be very useful to guarantee good system responses and performance.

In a simplified way, a task can be associated as a piece of work whose execution contributes to the completion of a business process. Task instances are executed by resources, such as a human, an application or a combination of a human and one or more applications. The capabilities of a resource are given by a set of roles. Each task requires a specific role that is used to map task instances for resources. A workflow procedure defines a partial ordering of tasks to handle specific cases. The definition of a workflow process comprises a workflow procedure, a set of resources and a strategy to map task instances for resources.

As an example of what was said before, figure 2.19 describes an example of the workflow procedure used for process complaints.

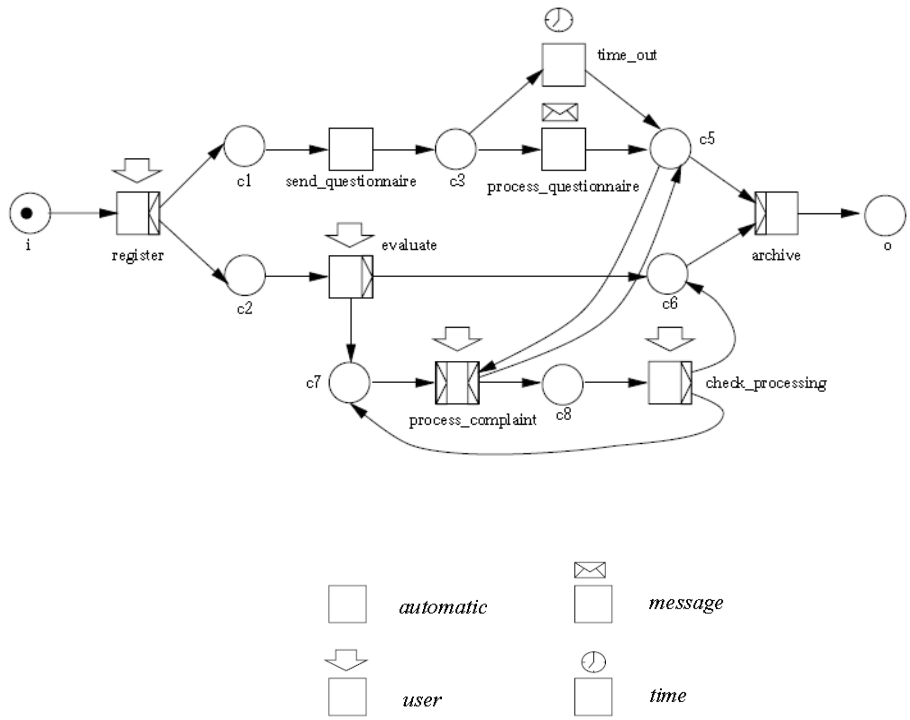


Figure 2.19 – Petri Net (process complaints example)

A Petri net that models a workflow process definition (i.e. the life-cycle of one case in isolation) is called a WorkFlow net (WF-net) [1]. With this, it is possible to draw a representation of the workflow that is close to the business process at hand. Another asset that this tool presents is the availability of many analysis techniques. In fact, this representation can be used as a starting point for various kinds of analyses. So, it is possible to say that the Petri net representation can be used as an interface between the business process at hand and the analysis method(s). In order to support the Petri-Nets analyses, there are some techniques that can be used to prove various types of properties, such as safety and invariance properties, deadlock, livens, etc. This tool gives us the possibility to calculate performance measures, such as response times, waiting times, occupation rates, etc. This way, it is possible to evaluate alternative workflows.

2.8 - Data Fusion

Usually, in organizations, the process data are vast and disperse. Due to this it becomes increasingly complicated to combine, manage and integrate a great amount and variety of available data. So, it is crucial to develop and integrate, on the company working methods, tools for data fusion approaches. Fusion [45] is the integration of information from multiple sources to produce specific and comprehensive unified data about an entity.

Accordingly [45], Data Fusion is “group of techniques that combine data from multiple sensors, and related information from associated databases, to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone”. The term sensor, in a management subject, can be represented by a specific source with some intelligence, for instance the performance databases.

In fact, the processes of data fusion stimulate the use of modern techniques such as Kalman Filter, clustering algorithms, neural networks or decision-based methods like the Bayesian method in order to identify targets or patterns [45] Moreover, this methodology enable to gather data in a useful way within a support decision system, what represent an important advantage on the current business environment.

One of the most influent data fusion model, is the JDL functional model, developed at 1988 [44]. The JDL process model is a functionally oriented model of data fusion and is intended to be general and useful across diverse areas and applications. This is a very useful tool for visualization of data fusion process and also to facilitate its discussion and comprehension.

The JDL is divided into five main levels:

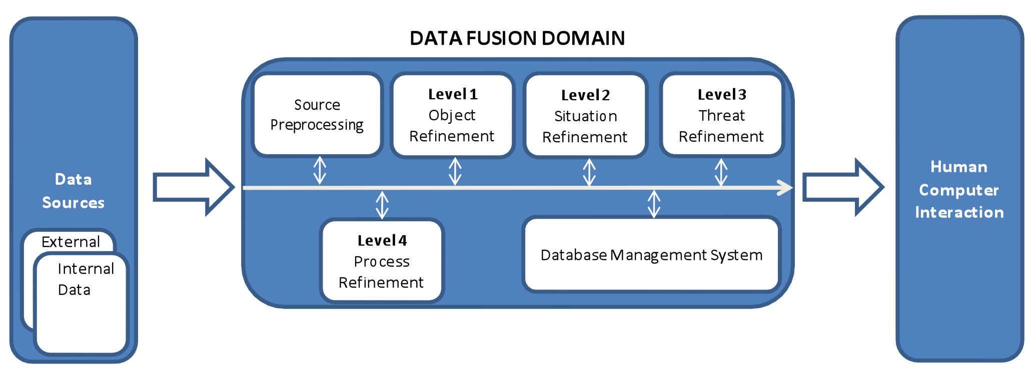


Figure 2.20 – JDL Functional Model

- Source Pre-processing (level 0) involves processing of individual sensor data to extract information, improve signal-to-noise ratio, and preparation of data such as spatiotemporal alignment for subsequent fusion processing;
- Object Refinement level (level 1) combine all the raw data to obtain the most reliable and accurate estimates of an entity’s attribute and identity;
- Situation Refinement (level 2) develops a description of current relationships among entities and events in the context of their environment;

- Impact Assessment (level 3) project the current situation into the future in order to increase processes and look for opportunities;
- Process Refinement (level 4) monitors the overall data fusion process to assess and improve real-time system performance;

The JDL data fusion model, also refers to the sources such as human inputs, database, local or external sensors accessible to the data fusion system. This can be seen on the left side of the figure 2.20. On the opposite side is possible to see the Human Computer Interface block, which allows operators to interact with the system. Finally, the Data Management System provides management of data for fusion such as measured data, environmental information, market data, models, estimators, among others factors.

In fact, data fusion is an increasing technology, with strongly application and development onto military matters, robotics and automation areas, medical diagnostics and smart buildings. However, is being also deeply used for the environment monitoring and representation of behaviour and performance of industries [45]. In this context, the Performance Value Estimator tool, which will be explored during the next chapter, intends to apply these principles and methods in order to extract performance values, and also define targets, guaranteeing data reliability and accuracy.

So, during this document it is expected prove that a data fusion approach can be a crucial tool not only to integrate business information but also to predict future performances and support decision makers.

2.9 - Forecast and Estimation

Because of the increasingly competitiveness and market changes, is becomes more and more crucial anticipate and identify potential opportunities as well as dangers in the business environment and appreciating the extent and impact of future uncertainty.

Available forecasting and estimation tools can provide the referred anticipation. However, there are some differences between estimation and forecasting. Estimation deals with past, present and future actions. On the other hand, forecasting tools are used to predict the future. In order to better understand these concepts it can be consider a robot that has to follow a specified trajectory. Thus, if the robot is equipped with a forecasting tool, then it will only be able to predict its location at a future time. However, using an estimator as a tool for its location, the robot will be able to calculate, with some uncertainty, its position across all the temporal scale (at a passed, present or future moment).

Historically, forecasting techniques have been of great scientific and industrial interest. Basically, there are three main methods of forecasting, completely different, as can be observable in figure 2.21 [46].

In a simple way, the explanation of the different methods can be done in the following way. The deterministic methods are supported by credible sources, knowing before hand future values. Indeed, this type of methods is very interesting for quantitative planning. On the other hand, stochastic and heuristic methods are characterized by being based on past data. Heuristic methods require a high knowledge about the system under study and are usually associated with large uncertainties. However, it has the advantage of being of simple application and low computational cost. Stochastic methods, in turn, using mathematical methods based on regression analysis, moving averages or exponential smoothing, enabling the mathematical extrapolation of known data. If correctly applied, this type of methods can generate predictions with low error, despite the need for a greater effort to implement it.

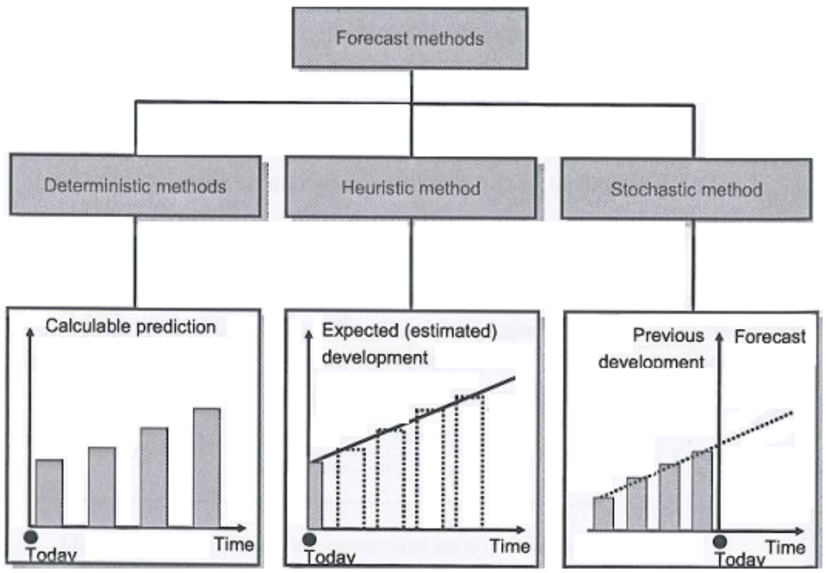


Figure 2.21 – Basic procedures for prediction (Source [46])

On normal environments, the performance is affected by three major factors: seasonality, trends and statistical irregular fluctuations, figure 2.22.

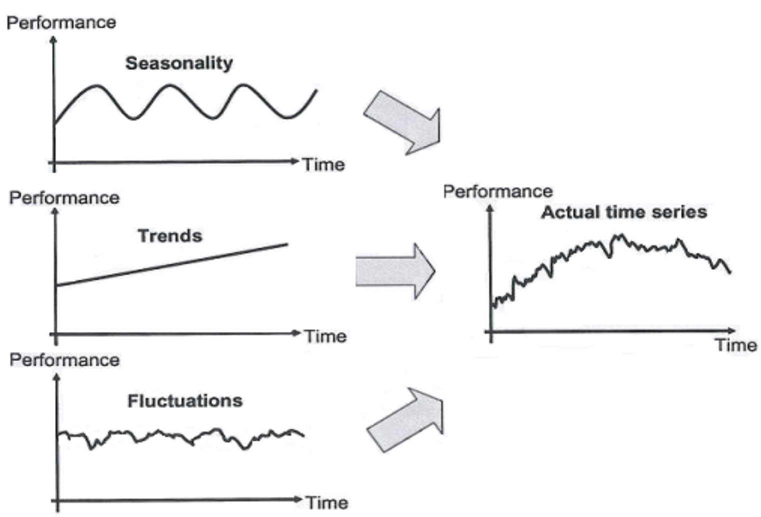


Figure 2.22 – Performance Forecast factors

The seasonality and trends translate the long-term system behaviour and can be captured mathematically, while the data consists on fluctuations affect the tasks of forecasting and estimation, making them more difficult and less reliable at short-term.

Following it is presented some estimators and forecast tools that are currently used not only on management areas but also on robotics and automotive subjects.

Moving Average Models

A moving average forecast model is based on an artificially constructed time series in which the value for a given time period is replaced by the mean of that value and the values for some number of preceding and succeeding time periods. On the other hand, a weighted moving average forecast model is also based on an artificially constructed time series however in this method the value for a given time period is replaced by the weighted mean of that value and the values for some number of preceding time periods. In fact, moving average (MA) models are used in time series analysis to describe stationary time series, i.e. data that changes over time.

$$MovingAverage = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2.1}$$

Since the forecast value for any given period is an average of the previous periods, then the forecast will always appear to "lag" behind either increases or decreases in the observed (dependent) values. For example, if a data series has a noticeable upward trend then a moving average forecast will generally provide an underestimate of the values of the dependent variable.

The moving average and weight average models have as advantage over other forecasting models in that they do smooth out peaks and troughs (or valleys) in a set of observations. However, they also have several disadvantages. In particular these models do not produce an actual equation. Therefore, they are not all that useful as a medium-long range forecasting tool. They can only reliably be used to forecast one or two periods into the future.

The moving average model is a special case of the more general weighted moving average. In the simple moving average, all weights are equal.

Kalman Filter

Rudolf Emil Kalman developed the Kalman Filter, as a mathematical tool, at 1930. Kalman is known as the creator of modern control and system theories because his research reshaped the field of the control engineering and also projected future researches and innovations in several sciences.

The Kalman Filter is a tool for optimizing the estimation of state models. This filter is known to be able to support estimations for past, present and future states even when the accuracy of modelling of the system is not known.

In a mathematical higher layer of abstraction, the Kalman Filter can be seen as a tool used for estimating the instantaneous “state” of a linear dynamic system perturbed by white noise. This goal is achieved using measurements linearly related to the state but corrupted by white noise.

Kalman Filter is certainly one of the major's discoveries in the history of statistical estimation theory because it has permitted to achieve results that, without this tool would be very complicated to reach. This finding has been applied in several areas such as automatics, robotics subjects, economics, manufacturing management, stock markets prevision, among others. Historically, the Kalman's algorithm found crucial practical applications in the Ranger and Mariner missions as well as in the NASA space shuttle programs. Nowadays, Kalman Filter has been currently used to support navigational and guidance systems, radar tracking algorithms for anti-ballistic missile applications, sonar ranging and satellite orbit determination, seismic data processing, nuclear power-plant instrumentation, Global Positioning System (GPS) and a lot of other applications which require a strong control capability.

At the table 2.4 is presented a series of important scientific publications since 1990 to 2010 where the Kalman Filter takes an important and crucial role.

Tabela 2.4 — Kalman Filter citations (extracted from Science Direct, 2010)

Journals/Subjects	Number of Articles
Automatica	922
Control Engineering Practice	664
Signal Processing	441
Journal of Process Control	236
Robotics and Autonomous Systems	230
Nuclear Instruments and Methods in Physics Research	197
International Journal of Forecasting	196
Computers & Chemical Engineering	192
Image and Vision Computing	176
Analytica Chimica Acta	164
Systems & Control Letters	164
Journal of Hydrology	154
Chemical Engineering Science	145
Journal of Econometrics	141
Pattern Recognition	136
Journal of Economic Dynamics and Control	122
Journal of the Franklin Institute	115
Mathematics in Science and Engineering	109
Neurocomputing	108
Electric Power Systems Research	106

To control a dynamic system, it is crucial to observe and follow what the system is doing. However, it is not always possible or desirable to measure all the variables that it is aimed to control. So, in order to overcome this problem, Kalman filter may, from indirect measurements, function as a means to infer the missing information.

On the other hand, the Kalman filter is usually used to predict the likely future courses of dynamic systems that are not likely to be controlled, such as the prices of traded commodities, stock markets values, and other variables that are strongly influenced by stochastic factors. So, in order to deal with the proposed study, the Kalman Filter is used in order to estimate possible errors in modelling, by the neural networks, and consequently improves the final results.

Prior initiate a deeper research about the Kalman Filter, it is important to underline some factors that characterize this tool.

- The Kalman filter is only a mathematical tool, made from mathematical models that should be used as a complement, and not as general solution. Because of that, it is required a deeper study about its uses and functionalities;
- The Kalman Filter uses a model of the estimation problem that distinguishes between phenomena (what one is able to observe), noumena (what is really going on), and the state of knowledge about the noumena that can be deduce from the phenomena. That state of knowledge is represented by a probabilistic distribution.
- Moreover, because it uses a finite representation of the estimation problem by a finite number of variables, Kalman filter is an ideally suited tool to digital computer implementation.
- Finally, the Kalman Filter does not require that the deterministic dynamics or the random processes should have stationary properties and is also compatible with the state-space formulation of optimal controllers for dynamic systems, providing useful properties of estimation and control.

As has been pointed out, the Kalman filter is strongly used to estimate states of dynamic systems. However, if we study carefully all the existing systems around us, we can easily conclude that almost everything at the universe is not constant. So, if it is necessary to estimate precisely the system's characteristics over the time, then it is crucial to have a clear vision about their dynamics. However, there are few times that it is possible to express accurately the mathematical model that describes the systems dynamics. So, given this state of partial ignorance, it becomes essential to express our knowledge gaps more precisely, and use it to estimate the state of the dynamics systems.

This filter also uses an entire description of the probability distribution of its estimation errors in determining the optimal filtering gains. This probability distribution may be used to assess its performance depending on the "design parameters" of an estimation system. So, with this, it is possible to better analyse and determine the types of sensors to use, the allowable noise characteristics of the sensors, the data sampling rates, and also the level of model simplification. The analytical capacity of the formalism of the Kalman filter also determines the error of the estimate to improve the level of accuracy needed.

In summary, the Kalman Filter can be seen as a tool used to estimate the state of a linear dynamic system perturbed by Gaussian white noise, using measurements that are linear functions of the system state but corrupted by additive Gaussian white noise. This mathematical model is a reasonable representation for many problems of practical interest, including control problems as well as the analysis of measurement and estimation problems.

Kalman filter model and mathematical explanation.

Firstly, it is important to understand what a state space representation is [47]. In a simplified way, it is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations.

In order to get a high level of abstraction, with respect to the number of inputs, outputs and states, the variables are expressed as vectors and the differential and algebraic equations are written in a matrix form. Thus, it is possible to provide a convenient and compact way to model and analyze systems with multiple inputs and outputs, equation 2.2.

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned}, \tag{2.2}$$

The internal state variables are the smallest subset of system variables, which can represent the entire state of the system at any time. So, as it can be understood, the minimum number of state variables required to model the system, n, is usually equal to the order of the system that is being modelled. It is also important to refer that the state space model can be represents not only as a state space, but also as a transfer function. In this case, the minimum number of the state variables is equal to the order of the transfer function's denominator. It is also possible to change from one representation to the other, as is showed at the following equations.

$$G(s) = \frac{n_1 s^3 + n_2 s^2 + n_3 s + n_4}{s^4 + d_1 s^3 + d_2 s^2 + d_3 s + d_4}, \tag{2.3}$$

$$\dot{x}(t) = \begin{bmatrix} -d_1 & -d_2 & -d_3 & -d_4 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} u(t), \tag{2.4}$$

$$y(t) = \begin{bmatrix} n_1 & n_2 & n_3 & n_4 \end{bmatrix} x(t), \tag{2.5}$$

This state space realization is called to be canonical form because the resulting is guaranteed to be controllable.

Explored the concept of state space modelling, is now important to understand the mathematical fundamentals around the Kalman filter tool [50]. The primary goal of the Kalman filter is to calculate the optimal filtered state of the system $\hat{x}(t \mid t)$, which is the estimation of $x(t)$ at the instant t. This occurs when the covariance of the error $x(t \mid t) = x(t) - x(t \mid t)$ is minimal.

The update equation of $\hat{x}(t \mid t)$ is the following:

$$\hat{x}(t \mid t) = \hat{x}(t) + K_f \tilde{y}(t) = \hat{x}(t) + K_f(t)\left[y_s(t) - C\hat{x}(t)\right], \tag{2.6}$$

Where:

$\hat{x}(t)$ - Estimation of $x(t)$ at instant t-1

$\hat{x}(t \mid t)$ - Estimation of state $x(t)$ at the instant t

$K_f(t)$ - Kalman filter gain

$y_s(t)$ - System output

How it is easily to conclude, $\tilde{y}(t) = \left[y_s(t) - C\hat{x}(t)\right]$ represents the modulation error. This occurs because, as was referred before, in complex dynamic systems, it is never possible to determine exactly the state model of the systems in analysis. Hence, minimize this error is the challenge.

As pointed out, the Kalman Filter is a recursive computation approach that calculates, at each iteration, the best K_f that minimize the covariance of the modulation error. Thus, the equations that enable the determination of the Kalman filter gain are:

$$K_f(t) = \tilde{P}(t)C^T\left[C\tilde{P}(t)C^T + R\right]^{-1}, \tag{2.7}$$

$$\tilde{P}(t \mid t) = \tilde{P}(t) - \tilde{P}(t)C^T\left[C\tilde{P}(t)C^T + R\right]^{-1}C\tilde{P}(t), \tag{2.8}$$

Where:

$\tilde{P}(t \mid t)$ - Covariance of the Kalman Filter error

Extended Kalman Filter

The Kalman filter as represented in equations 2.6-2.8 is not useful when analyzing complex nonlinear systems that are not gaussian. So, an Extended Kalman Filter (EKF) [48] should be used and developed. This filter, gives an approximation of the optimal estimate, becoming the non-linearities of the system into a linearized version around the last state estimate. For this approximation being considered credible, it is necessary that this linearization should be an efficient approximation in the entire uncertainty domain associated with the state estimate. Contrary to the Kalman filter, the EKF may diverge if the consecutive linearizations are not efficient within the associated uncertain domain.

Each iteration of the extended Kalman filter should be composed by its dynamics concept stages, prediction and filtering updates steps. On the prediction cycle it is expected to linearize the system dynamics, $\hat{x}_{k+1} = f(x_k) + w_k$ around $\hat{x}(k \mid k)$, and then apply the prediction step of the Kalman filter to the linearized system dynamic just obtained, yielding $\hat{x}(k+1|k)$ and $P(k+1|k)$. Following, on the filtering cycle, the filtering or update cycle of the Kalman filter is applied to the linearized observation dynamics, yielding $\hat{x}(k+1|k+1)$ and $P(k+1|k+1)$.

Extended Kalman Filter Algorithm

Predict Cycle

$$\hat{x}(k+1|k) = f_k(\hat{x}(k|k)), \tag{2.9}$$

$$P(k+1|k) = F(k)P(k|k)F^T(k) + Q(k), \tag{2.10}$$

Update Cycle

$$\hat{x}(k+1|k+1) = \hat{x}(k+1|k) + K(k+1)\left[y_{k+1} - h_{k+1}(\hat{x}(k+1|k))\right], \tag{2.11}$$

$$K(k+1) = P(k+1|k)H^T(k+1)\left[H(k+1)P(k+1|k)H(k+1) + R(k+1)\right]^{-1}, \tag{2.12}$$

$$P(k+1|k+1) = \left[I - K(k+1)H(k+1)\right]P(k+1|k), \tag{2.13}$$

Neuronal Networks

The first neuron model was proposed by W. McCulloch and W. Pitts [43], at 1943, based on the nervous system. McCulloch was a brain research scientist at Yale, professor of psychiatry and later a scientist at the MIT Research Laboratory of Electronics. Along with other contemporary scientists, he is seen as one of the great thinkers of the previous century. He researched the experimental theory of the origin, nature, and limits of knowledge going from psychology to neurophysiology, reaching a superior skill on an array of mathematical and logical.

The Neural Networks (NN) are finding increasing use as an alternative computational method for solving complex problems from distinct areas, such as [38], [39] economy, forecasting of electrical load, engineering systems, robotics, pattern recognition, signal processing, sports, medicine, and weather forecasting, among others areas.

So, NN presents a strong importance at a wide range of applications. This is only possible because this tool stands out by its characteristics of continuous learning capability, what enable:

- Continuous adaptation to different conditions;
- Response to new situations;
- Modelling of more common and complex systems with non linear behaviour;
- Fitting the tolerance to structural and parametric changes;
- Rejects input noise;
- Provide a faster processing capacity.

Indeed, one of the major applications of the NN is forecasting [37], [38], [40]. In fact there are a series of characteristics which make the neural networks an attractive and valuable tool for forecasting tasks [37], [38] and [40]. Neural Networks are a data-driven self-adaptive method and universal functional approximate with the ability to generalize. These characteristics makes the systems modelling a task greatly simplified because it allow approximate any continuous function to any desired accuracy, enabling predict the future using past examples. Moreover, NNs are nonlinear, what is a crucial advantage because in the real world, almost all systems are nonlinear. So, this tool enables the performance of nonlinear modelling without a priori knowledge about the relationship between input and output variables, in opposition to the traditional methods such as Box-Jenkins and ARIMA.

Accordingly Pitts and McCulloch [43], "*Numerous nets, embodied in special nervous structures, serve to classify information according to useful common characters. In vision they detect the equivalence of apparitions related by similarity and congruence, like those of a single physical thing seen from various places. In audition, they recognize timbre and chord, regardless of pitch.*" Thus, all these features can classify neural networks as general and flexible modelling tool, well guided for forecasting tasks.

Before starts the study on the Neuronal Networks, it is important to understand how a human brain works once the NN tool was inspired by biological systems, particularly by research into the human brain [39], [40] and [41].

"*Because of the "all-or-none" character of nervous activity, neural events and the relationships among them can be treated by means of propositional logic. It is found that the behaviour of every net can be described in these terms, with the addition of more complicated logical means for nets containing circles; and that for any logical expression satisfying certain conditions, one can find a net behaving in the fashion it describes. Many particular choices among possible neurophysiological assumptions are equivalent, in the sense that for every net behaving under one assumption. There exists another net which behaves under the other and gives the same results.*" Warren S. McCulloch and Walter H. Pitts.

This human organ, which consists [41] of an estimated 10^{11} nerve cells or neurons, is a high complex structure, with non linear behaviour, parallel operation and is really fast. Neurons communicate with each other's throw electrical signals, which are short-lived impulses. The interneuron connections are mediated by electrochemical junctions called synapses, which are located on branches of the cell referred to as dendrites. Each neuron typically received seamlessly many thousands of connections from others neurons. All this information is integrated, and if the signal exceeds some threshold value then the neuron generates a voltage impulse in response that is then transmitted to other neurons via a branching fibre known as the axon.

In fact, although this is the description of the biological human brain, this is also the architecture that is used at the neural networks. The artificial equivalents of biological neurons are the nodes, while the synapses are modelled by a single number called weight. Each input is multiplied and summed with the other weighted inputs before being sent to the node activation. Following, the activation is compared with a threshold. If the activation exceeds the threshold, the unit produces a high-value output, otherwise it outputs zero. In summary, the output value of each neuron Y_i depends on the potential of the neuron, the threshold (or bias) and the activation function σ.

Following it is presented a prototypical example about neurons/nodes behaviour, which was presented by [39] and [41].

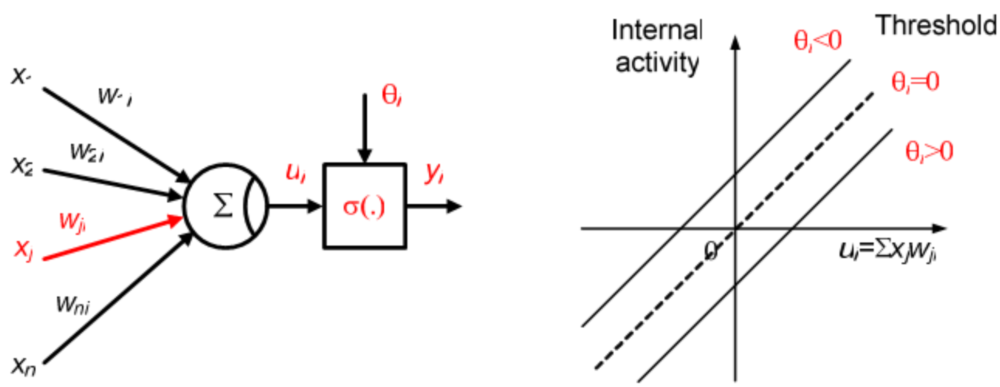


Figure 2.23 – Basic diagram of an artificial neuron and neuron internal activity

Where:

X_j is the input stimulation (0 or 1) and represents the state of neuron j;

W_{ji} is the sinaptic weight between neuron j and I;

Θ is a bias values (or threshold);

Y_i is the neuron I output;

σ is the activation function.

The term “network” refers to any system of artificial neurons. This may range from a single node to a large collection of nodes in which each one is connected to every other node in the net.

How is possible to see on figure 2.24, each node is shown by only a circle, being the weights implicit on all connections. The nodes are distributed in a layered structure where signals flow from an input to an output passing by a series of hidden layers.

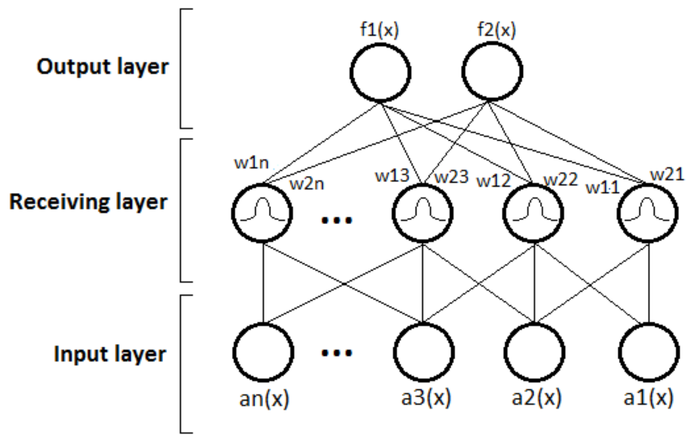


Figure 2.24 – Simple example of neural network (RBFN)

According [37], among the various NNs architectures available, the back propagation (BP) and radial basis function network (RBFN) are the most currently used and which present better results regarding the forecast of demands, performance values, risk, cost and others manufacturing factors. The RBFN is known to be more accurate and less time consuming. As the input variables pass direct to hidden layers without weights, the RBFN models are simpler compared to BP architecture. In fact, the main problem of the back propagation architecture in forecasting domain is its slow convergence and generalization difficulties as well as arbitrariness in network design. However, the RBFN has been found to overcome these limitations and provide better results.

Radial basis function (RBF) networks are nonlinear hybrid networks typically containing a single hidden layer. This layer uses Gaussian transfer functions, rather than the standard sigmoidal functions employed by Multi-Layer Perceptron (MLPs).

The RBFN consists of three layers of neurons. The first one is an input layer where converge the input data. The second layer, also called the receiving layer, is the unit that receives $x = \left[x_1, x_2, \ldots, x_n\right]$ and puts at its output $R_i(x)$. The receiving units can be determined from different formulas, such as:

$$R_i(x) = \exp\left(-\frac{|x - c_i|^2}{\sigma_i^2}\right) \qquad\qquad R_i(x) = \frac{1}{1 + \exp\left(-\frac{|x - c_i|^2}{\sigma_i^2}\right)}, \tag{2.14}$$

Where σ_i is a scalar, and $c_i = \begin{bmatrix} c_1^i & c_2^i & \ldots & c_n^i \end{bmatrix}$

Finally the output layer supplies the response of the network to the activation pattern applied to the input layer using the following equation: $y = f(x) = \sum_{i=0}^{M} w_i R_i(x)$

Let's now understand and notice the emphasis on learning from experience. In real neurons the synaptic strengths may be modified so that the behaviour of each neuron can change or adapt to its particular stimulus input [39], [41]. In fact, on the artificial neurons it is expected to introduce the same technique in order to modify the weight values.

In a simplified way, training is the process of determining the arc weights that are the key elements of an NN. In fact, the knowledge acquired is stored in the arcs and nodes, in the form of arc weights and nodes biases. As was referred before, one of the main importances of the NNs comes from the fact that it has the capability of learning and generalization. So, after a good process training, it is possible to get excellent results when a new condition is presented to the Neural Network.

Among the different training/learning methods the most important ones are:

- Supervised learning: adaptation of the connection weights, from the comparison between the NN output and a defined target;
- Non-supervised learning: in this case there is no reference for the output, data sets are classified;
- Reinforcement learning: an external critic evaluates the response given by the network (reward or penalty).

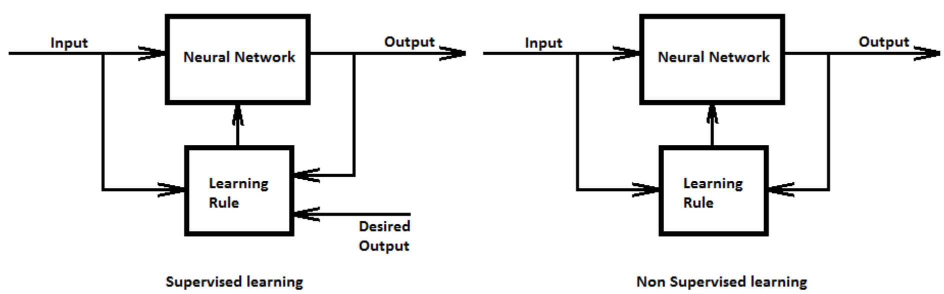


Figure 2.25 – Learning paradigms

On the RBFN the centres and widths of the Gaussians are set by unsupervised learning rules, while supervised learning is applied to the output layer. These networks tend to learn much faster than MLPs.

To carry out the training process, is common dived the total data available into a training-set (in-sample data) and a test set (out-of-sample). In fact, the training stage will enable the estimation of the arc weights while the test set is used to measure the NN's ability to generalize. During this, examples of the training sets are entered into the input nodes, and follow a well-defined methodology. Fist, the activation values of the input nodes are weighted and accumulated at each node of the first hidden layer. After that, the sum is transformed by an activation function into the node's activation value and this value is transferred to the next layer, until eventually the output activation values are found. The training algorithm used has the responsible for minimize some overall error measure such as sum of squared errors (SSE) or mean squared errors (MSE).

The two main learning algorithms are the Delta and Hebb rules. The first one adjusts the weight in function of the "distance" between the output and the reference, as $e_k(n) = d_k(n) - y_k(n)$. In other words, the main goal of the Delta rule is to minimize a cost function based on error, typically $J = E\left[\frac{1}{2}\sum_k e_k^2(n)\right]$. The cost function minimization in relation the network parameters lead to the use of the gradient descent algorithm.

The Hebb rule, in turn, is based on two fundamentals statements:

- If two neurons in the two sides of a synapse are simultaneously active, then the strength of that synapse should increase;
- If two neurons in the two sides of a synapse are active asynchronously, then the strength of that synapse should be reduced or eliminated;

However this technique present some disadvantages. In fact, the known rule of product activity, when it repeat the same input signal, it leads to an exponential increasing of the connection weights and consequently to its saturation. However, this fact can be managed introducing a forgetting factor α, as is presented in the following equation.

$$\Delta w_{kj}(n) = \eta y_k(n) x_j(n) - \alpha y_k(n) w_{kj}(n), \tag{2.15}$$

Despite all the advantages and satisfactory characteristics of NNs, building and neural network forecaster is not a trivial or consensual task. In fact, one critical decision is to determine the appropriate architecture (number of layers, number of nodes in each layer and the number of arcs which interconnect with nodes). Moreover, it is important to study and select some aspects such as the activation functions of hidden and output layers, the training algorithm, normalization methods, training and test sets and also the performance measures.

In conclusion, a Neural Network can be considered as a strongly tool with a wide range of potential. In fact, the NN allow the realization of arbitrary non-linear mappings which characteristic will be explored during this document in the following topics. Also, NNs presents a continuous learning capability, thereby allowing the response to new situations (generalization). It is tolerant to parametric and/or structural changes what makes this tool a very robust tool. In conclusion, because of all the features already listed and due to faster processing of this tool, it is possible to apply it not only on forecast tasks but also in a lot of situations, even when real-time is requested.

2.10 - Brief Summary

The factory Template is an ongoing research developed within a European project called Virtual Factory Framework. The primary objective of this project is the research and implementation of the underlying models and ideas at the foundation of a new conceptual framework, designed to implement the next generation of factories. Thus, this a complex project which is divided into four main pillars: VF Module, VF Manager, Reference Model and Knowledge.

In line with this context, this research work is mainly linked with the Knowledge pillar and concepts and methodologies that enable its creation, reuse and storage. Thus, along this chapter were explored important concepts such as Knowledge Management, Knowledge Repository, Performance Management and Concurrent Engineering.

In sum, the objective of Knowledge Management systems is to support creation, transfer and application of knowledge in organizations. On the other hand, to ensure that the plant achieves the desired performance, factory managers need a good track of performance on all kind of processes (Performance Management). In fact, it is only possible manage and control a system if we are not able to read its performance. Finally, concurrent engineering is a methodology that enables the formation of cross-functional teams, which allows engineers and managers of different disciplines to work together and simultaneously since the developing product and process design.

Once the factory planning is another subject that is related with the Factory Template, it was essential study generalized architectures and methodologies that support this innovative approach. Thus, during this chapter were studied not only different types of reference models such as PERA, CIMOSA and Zachman framework but also tools that support data fusion and performance estimation.

Grasped the bases of this dissertation work, it will be presented in the next chapter the vision, architecture and main functionalities of the Factory Templates.

Chapter 3

Factory Templates Design

During this chapter, a Factory Template architecture, methodology and tool will be introduced based on subjects and concepts covered in the chapter of the state-of-art. In fact, concepts as Concurrent Engineering, Knowledge Management, Workflow analysis, Virtual Factory Framework fundamentals, among others topics, will be the pillars of this chapter.

Moreover, it will be explored the context where the Factory Template module will be integrated within the Virtual Factory Framework project as well as the FT vision that has been under research during this work.

3.1 - Concepts and Requirements

Factories [51] should be seen as enormous and complex products that require exhaustive planning processes during the entire life-cycle, from its idealization to it's dismantling. Current research addresses these issues by developing new design methods for the Factory of the Future and by integrating new technologies and tools, which may be used to manage factories, products, processes and technologies over their life cycle from engineering up to decommissioning.

The factory planning process includes several concepts and elements present in almost all phases of the factory life-cycle. These concepts point to the development of methodologies necessary to plan and execute all engineering tasks associated to successful production and operations.

Thus, Factory Template (FT) can be viewed as a meta-reference model that embodies the VFF factory concept (Fig. 3.1), [52].

In a succinct way, Factory Templates can be compared with software patterns with its advantages and final purposes. From software engineering, software patterns are designed patterns fit to provide reusable solutions to a commonly occurring problem. So, as in software science, where the use of templates makes it possible to reduce the development time and to increase programming agility, in the manufacturing management science, it is crucial to use models and standards which allow faster and efficient systems development. These systems present characteristics such as modularity and standardization of industrial processes. Therefore, it is crucial to explore the advantages occurring from the similarity between the Factory Life-cycle Model and Pattern Life-cycle Model [52].

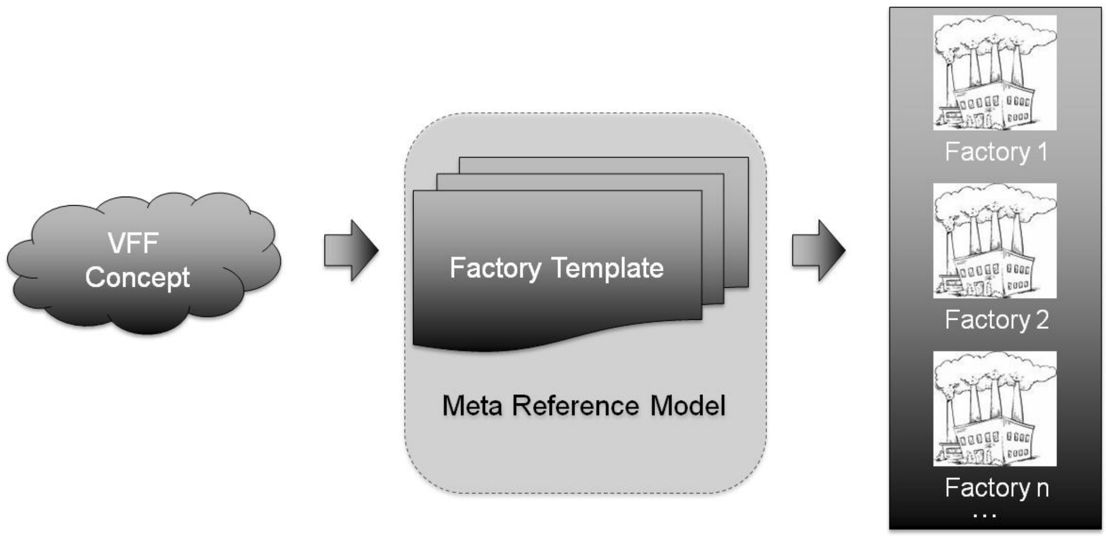


Figure 3.1 – VFF meta-reference model

In order to strongly enhance the perception of the factory as a product, Factory Templates have been developed in the VFF project. In fact, these templates will: support the operation and evaluation of all factory design phases; show how processes operate; compile perspectives of all the stakeholders involved; structure the information that must be shared and how it should be meaningfully analyzed and reported. Moreover FT will support decision makers in the planning and design of factory life-cycles. So, in order to achieve this purpose, Factory Templates will be divided into two main modelling components: Static and Dynamic strands.

In the first one, factory templates [51] should structure and manage documents, best practices, methods, techniques, processes and knowledge, as well as constraints, goals, requirements and concurrent engineer processes. On the other hand, the dynamic strand will incorporate forecast exercises, internal and external disturbances analysis and performance evaluation of the real factory in comparison with the virtual factory instances.

In fact, all this should be done taking into account different factors and issues, such as production facilities, human roles, information and control systems, energy efficiency, environmental and social issues, among others.

This modelling and standardization concerns are well depicted in the FT. In addition, these templates are capable of facilitating communication aspects among the different manufacturing actors and of contributing to solve problems between people from different departments and origins. Another expected benefit occurs when Factory Templates are capable of providing higher performance through the ability to detect malfunctions in the systems before they affect the processes, thus preventing lower performance, increasing costs and higher rework.

Also, it will contribute to develop, in each factory, a multidisciplinary knowledge repository to support the continuous improvement of the factory design throughout each of the Factory Life-Cycle projects.

3.2 - Functional View and Architecture

Factory Templates supports itself on the Knowledge Management systems and Simultaneous Engineering concepts. So, becomes important, at this stage, make a brief summary about some issues, requirements and characteristics that were explained during the state-of-art chapter.

In order to focus the study on Knowledge Management processes, within the Factory Template module, were proposed eight major categories of activities that require a major detail analysis and exploration. From this list are encompassed the way how knowledge should be generated, accessed, presented, embedded, facilitated, transferred and measured, as well as how knowledge should be used for decision making. In fact, during the fieldwork performed, it was possible to infer the importance of the continuous improvement of knowledge storage and broadcast techniques, in order to guarantee the company success. For example, EMBRAER, one of the largest aircraft manufacturers in the world, due to the fact that handle with a huge amount of knowledge and technological advances, has been developing and exploring innovative methodologies of knowledge management. These developments, according EMBRAER employees, have been behind of the company success.

Moreover, the Concurrent Engineering philosophy and advantages were also studied. This concept advocates that early considerations of manufacturing issues, in the design phase, is crucial to expose alternative solutions that could provide remarkable quality improvement. This approach will enable savings in setup and production costs, anticipate and forecast bad functions, reduction of lead times required to bring a new product to market, reduction of part inventories and associated overhead, and improvements in overall product quality and reliability.

Based on the subjects mentioned before, it becomes clear that FT should be seen as an excellent platform to integrate design practices, knowledge and information systems. Once, this is not a simple question, it is crucial design and develop a good and well structured architecture that not only should take advantage of all the potential of the VFF project, but also enable its success and application.

The Factory Template is a component that, within the VFF Project, is inserted at the Knowledge Management pillar. However, in order to achieve all the potentials and goals proposed, the FT should not be linked only with the components of the Knowledge Management pillar, such as Knowledge Repository, Ontology, Best Practices and Knowledge Engine, but also with the VF Manager, in order to receive internal and external data to the system. Just to remember, the VF Manager is the module that defines and determines the features of abstract objects that represent the factory, its processes and equipment, orchestrating this according to the factory data model definition – Reference Model. Thus all the modules of the project are linked with the VF Manager, and so all information is accessible through this component.

In fact, working with Knowledge Management Systems make it essential manage the way how information is acquired, stored and exposed to the final user, as well as manage what information should be handled. This is an essential point, once this module is intended to be used by people with different levels of knowledge, preparation and technical training.

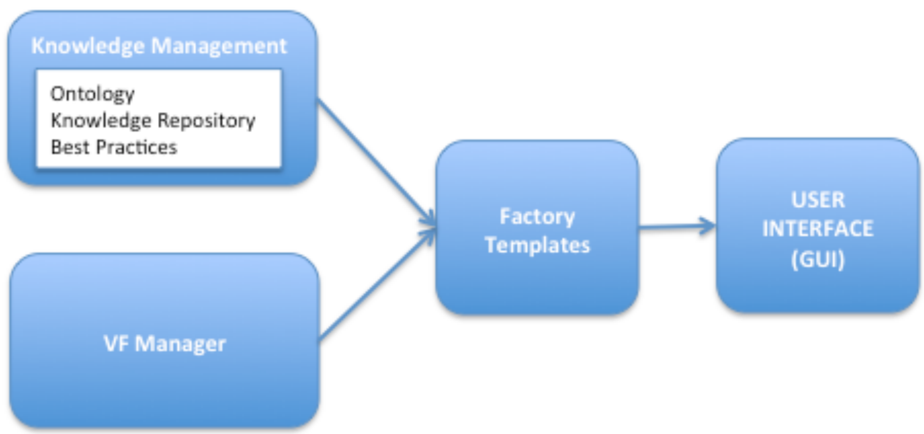


Figure 3.2 – Factory Template Module relationship

Defined the context, it is firstly important define the inputs that should feed the FT and the outputs that should result, as well as understand which should be the sources of the information and how this data should be handled.

In order to better express the author vision about how data should be handled by the Factory Template, in the figure 3.3, a context diagram is showed. Here the input data and respectively sources, the inputs of control, the methods/tools used and the output of FTs are presented.

Input information is divided into two main clusters, information from the module where the FT is inserted, also known as Knowledge Management pillar, and information from the Virtual Factory Manager (VF Manager) module, which has an extended knowledge about the whole factory and manages all the information system. The first one sends all the rules that make up the company's knowledge. In other words, this component can be seen as the expert of the company. Furthermore, the FT receives from this, the good practices, customs, documents references and business processes, which over time have showed good results and have been worked on and improved. In order to achieve optimal responses the VFF project will be supported by a Knowledge Engine. This module will capture all the data stored and will cluster this information in order to deliver to the FT module only the important and relevant information for a determined situation.

On the other hand, the VF Manager should transmit to the FT module not only the market information, such as economic situation, costumer needs, positioning of the company in the market and its competition, patents, technologies and regulations, among other factors, but also the internal information which characterize the factory behaviour and express its performance. Indeed, information about performance can be supplied thanks to a KPIs monitoring module. However other information like layout, workflow and processes data can also represent important and strategically advantages.

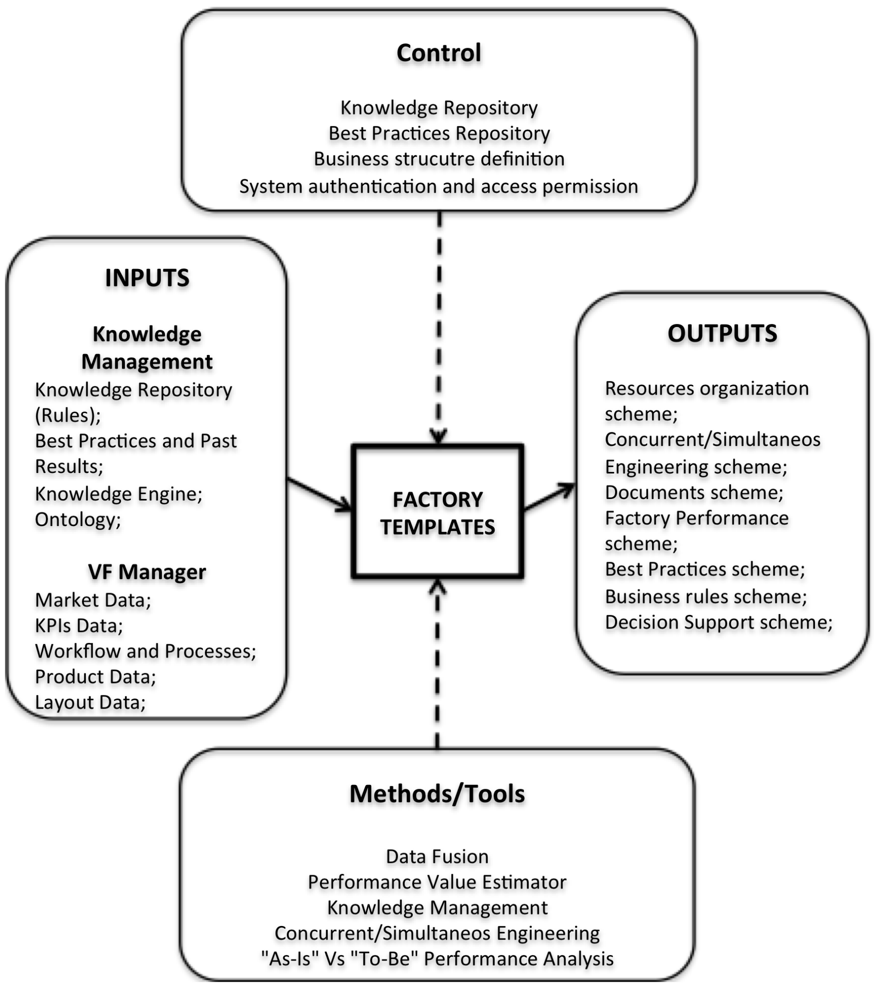


Figure 3.3 – Inputs and outputs of Factory Template Module

After data acquisition process, information must be treated and manipulated so that it is possible to meet all requirements and features mentioned above. Finally, the FT output, should be presented in an intuitive, fast and user friendly GUI, figure 3.2. This interface will be used by all the stakeholders with responsibilities on the processes in analysis. This GUI should enable employees to align themselves with the main goals and present objectives of the company, access company Knowledge and Best practices in an easily and intuitively way, analyze the global factory performance and allow decision support. Finally this interface should support the visualization of the factory planning and evaluation through its life-cycle phases, using a simultaneous engineering approach.

As it is possible to observe at picture 3.3, there are also two other data types that would support the factory templates module, which are the control inputs and the tools/methods. The control inputs allow shaping the Factory Template module to the system in study. So it is possible to define users and permissions, define the tree hierarchy of the company, deposit new business list of rules or new best practices that should be adopted within certain processes, among other activities. The second component intends to provide tools explored and studied during the state-of-art in order to solve and support the requirements and main goals described.

On figure 3.4 it is possible to observe, as summary, the functional components of the Factory Template module. In fact, these are the main functionalities that should be available to the user, in a simple and user-friendly way. FT will, above all, be able to support users to find answers to their problems, looking for the reasons that are affecting the system, and also supporting it correction and improvement (decision support). At the same time, FT will able to plan the processes of the factory at short, medium and long term in order to expose to all the stakeholders involved, **which** are the goals to be achieved, **How** it is supposed to be done, **Who** are involved, **What** are the dates of initiation and end of each process and finally the reasons **why** it should be done like planned and stipulated (Factory Planning support).

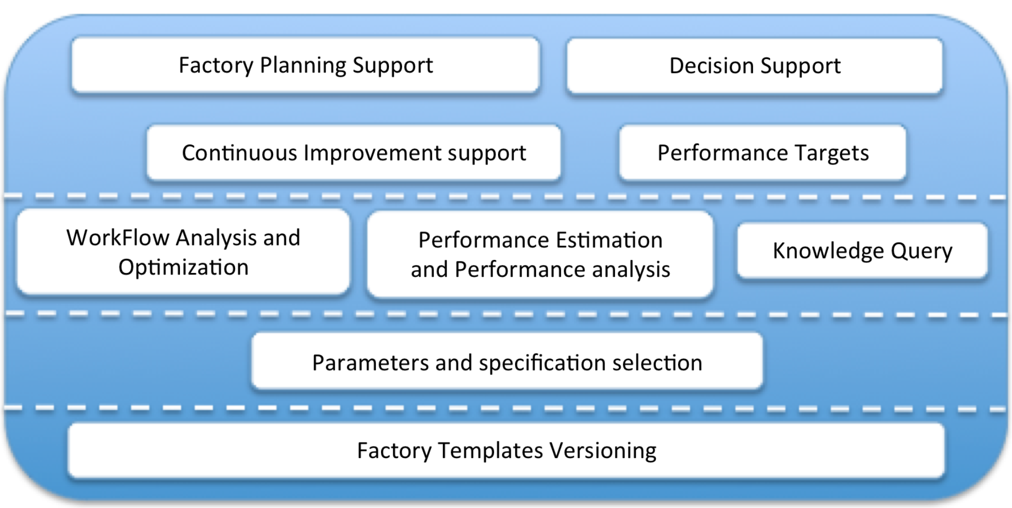


Figure 3.4 - Factory Template Functional view

In fact, these two functionalities will be supported by another two important concepts that should be also taken into account within the FT, which are the continuous improvement support and the performance targets definition. Within a company context, it is essential continuously define new targets and goals. This task will not only motivate employees to improve the factory productivity but also set a course that will characterize all the activities performed, in a clearly way for all the persons involved. However, to achieve this is essential that managers look for the improvement of processes, methods and technologies, which support employees. Moreover, it is crucial endow factories with tools that allow managers define reachable and possible targets, taking into account the capabilities of the factory. This subject will be deeply studied during this chapter, within the Dynamic Perspective subject.

Indeed, it is not only important evaluate and follow processes, but also study its performance, looking for new paths to achieve better results inspired by experts from the company, expertise's and past results. Finally, new process parameters and specifications should be defined and a new factory template version should be saved, in order to guarantee a versioning and historical template.

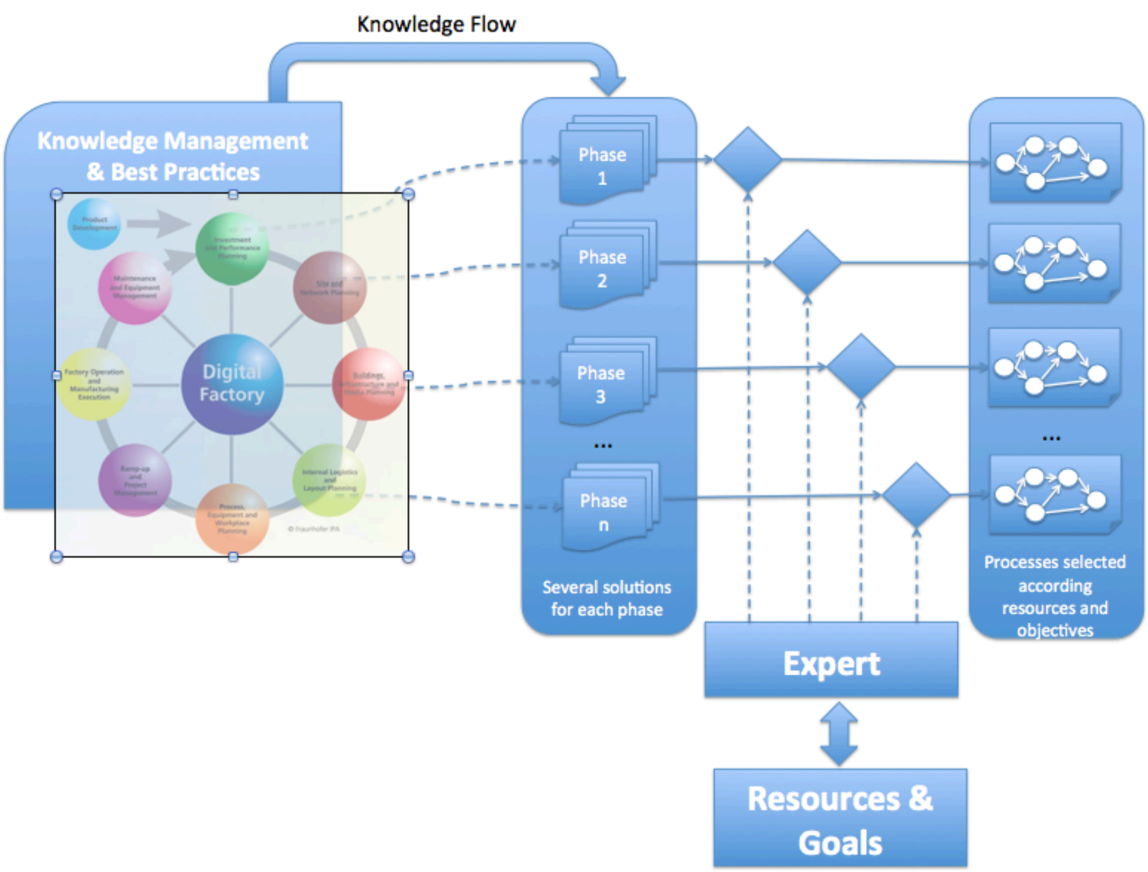


Figure 3.5 – Factory Template concept overview

Presented the functionalities and main advantages of the Factory Template module, it is now important understand how a KMS, like the FT, could behave within this context.

During the planning phase of a product there are some preliminary information that should be presented and discussed. Thus, after being introduced the main specifications and requirements of the product that is intended to be produced, the FT module should be able to review all the knowledge and best practices stored and already used. This may specify the different options of processes that can be implemented, as well as specify the main differences between them, performing simulations that will enable its comparison. With this information, the factory designer/expert must choose those processes that must fit his requirements and goals. Thus, are well defined the main processes and activities that should be follow at each stage of the life cycle of the factory.

Moreover, it is essential to close the circuit, using a feedback approach. In fact, once the FT module will be capable to question the Virtual Factory Manager about the Factory Performance, this module will allow the analyze and study of the actual processes and activities. Thus the factory manager will be able to detect and visualize bottlenecks that affect negatively the system, and after that, perform corrective actions in order to improve the global performance, figure 3.6. Done the corrective actions, it is essential that these new changes should be evaluated and the results confirmed, so they can be stored at Knowledge Repository and Best Practices databases.

All this should be done following a defined methodology and within the same tool. Because of that, static and dynamic perspectives were defined.

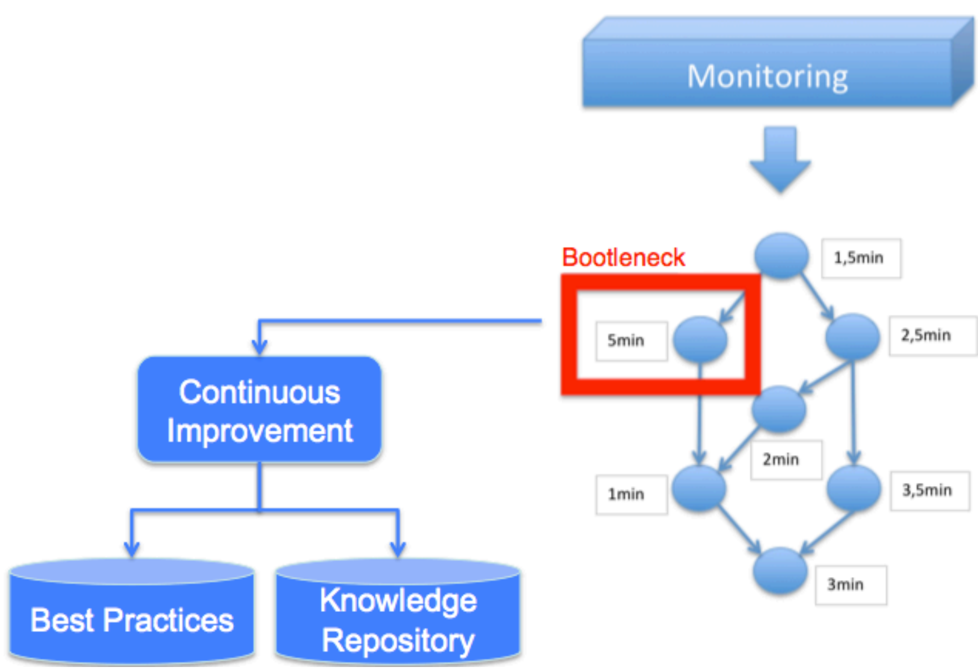


Figure 3.6 – Knowledge Repository and Best Practices databases improvement

With this approach it is possible not only faster the activities of factory design, which normally are crucial and time expensive, but also improve their quality. In fact, if the design activities of the factory are not well performed, it may limit the performance and quality of processes and products, what will affect consequently the quality and time response to client's requirements and demands, as well as increase the production cost. Consequently, this will affect negatively the company position on the market and its competitiveness in relation to the other companies.

Introduced the vision, architecture and the concept of the Factory Template purposes, as well as the main goals and functionalities that support this document, it will be explored more concretely the organization of the templates.

3.3 - Factory Template Organization

3.3.1. Static Modelling

A new concept for integration of product design, factory and process planning should be developed in order to combine data from product development with process data and thus simplify, optimize and improve processes quality as well as decreasing costs. In fact, nowadays the industrial paradigm of factories based on the fact that factories and their facilities have a longer durability than the products that are being produced. So, it becomes crucial to continuously adapt the infrastructures to the necessities of the market, making data available in different planning fields, phases and planning processes, thus keeping it consistent.

Each factory follows a life cycle from its initial concept stage to the ecological dismantling, through a series of stages or phases. During the planning and optimization phase, in great interdependence with the life cycle of products, the factory processes and its production facilities are planned. In fact, at this stage a lot of challenges are imposed in order to guarantee the concurrent engineering. These challenges arise from the migration of the rapid prototyping concepts, related methodologies and tools to the factory as a whole. This is achieved by the new paradigm as a new and complex type of product. For the manufacturing community "rapid design and virtual prototyping of factories" appeared as a new challenge.

For satisfying customer's orders, delivering the required products and/or services, facing turbulences, several planning functionalities should be performed. The steps presented below, include product design, factory and process planning. These do not only tend to promote and enable the factory to be ramped-up, monitored and maintained but also to guarantee the holistic planning, evaluation and permanent improvement of all factory structures, processes and resources of the factory in connection with the product.

- Seizing information of the product development;
- Investment and performance planning stages;
- Site and network planning;
- Building, infrastructure and media planning;
- Internal logistics and layout planning;
- Process, equipment and workplace planning;
- The ramp-up and management phase;
- Factory operation and manufacturing execution;
- Maintenance and equipment management.

In fact, the development and implementation of a life cycle perspective and, its integration with the product & factory life cycle, should support Factory Template to shorter time to market, achieve significant cost savings, reduce the number of reworks, resources usage, improving the technical and social performance, in various stages of a factory and product's life.

Based on the factory as a product paradigm, it is proposed to integrate this life cycle paradigm to products, into the factory as a whole, envisioning a better orchestration or harmonization of the specific life phases of products, production systems and corresponding design methodologies. This approach is called Unified and Sustainable Life Cycle Management and can be seen in the following picture.

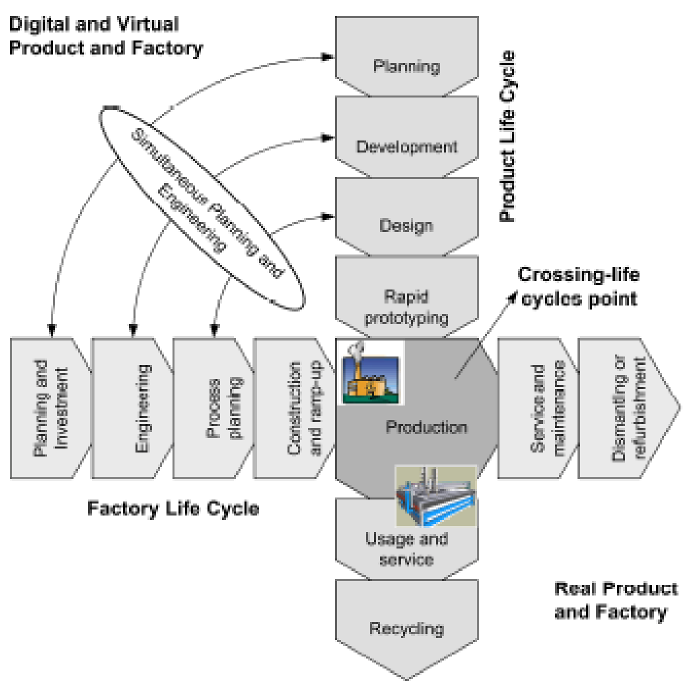


Figure 3.7 – The sustainable Product and Factory Life Cycle

A sustainable factory life cycle picks up the paradigm of Factories as a Product, by intending a harmonization of the Factory Life Cycle-Phases with the phases of the product life cycle. The migration of established life cycle thinking from products to the factory as a product generates/affects new methods and approaches. Synchronizing these two Life Cycles can be achieved with the approach already developed and studied at the state-of-art chapter, called Simultaneous Engineering. Within this approach, the different phases of the factory's life cycle are adapted to the corresponding phases of the product's life cycle. Furthermore, synergetic effects between Product-Planning and Investment Planning are pushed by a partitioning strategically planning and technological development.

Based on such a sustainable Life Cycle Management, and in order to allow the factory, not only to better adapt to the conditions and requirements of the environment, but also to improve its reaction on occurring changes and turbulences, it is proposed the addition of a dependent axe from the product and factory life-cycle. With this new variable it becomes possible make reference to the management, optimization and knowledge about the factory resources, as well as analyse the environmental characteristics and variables. Examples of these are the manufacturing equipments, human resources, Information systems, environmental issues, and local laws, among other factors.

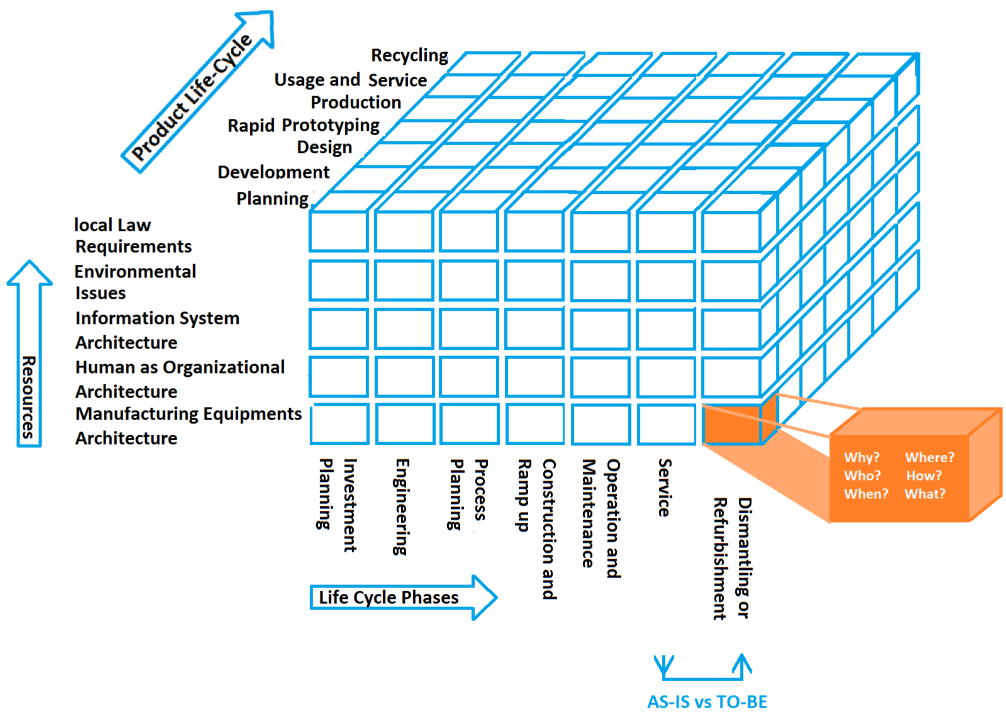


Figure 3.8 – Factory Template Static Perspective Cube

This new perspective and approach can be seen in the following picture, with the Factory Template Static Perspective Cube. In each cell of the cube there are questions that need to be answered, such as: **what** will be done, **how** will it be done, **where** will it be executed and developed, **who** will be responsible for it, **why** is it important and **why** should it be done. So, with this information, during the execution of each phases of the factory life, it is possible to guarantee that all the process is being done as stipulated, and work as a guide for those who will implement and participate in the process. These concepts can be classified as human oriented concepts, process oriented concepts and technology oriented. Thus, this tool can be compared to a Knowledge Management system, once it enables not only the creation and transmission of knowledge between stakeholders but also its storage and renewal

3.3.2. Dynamic Modelling

Presented the Static Perspective, it becomes now important understand how the factory templates module can follow and evaluate not only the factory behaviour but also the environmental situation. One of the main achievements of this module is the capability of study the factory performance and understand where improvements should be done using an “As-Is Vs To-Be Performance” methodology.

Once the factory template module is intended to work within the VFF Project, there will be a module called “KPI monitoring” which will support the performance measurement, “As-Is performance”. So, during this topic we will concentrate on the “To-Be Performance” study, using an estimation method called Performance Values Estimator.

The Performance Value Estimator (PVE) is a mathematical tool, which was developed to be applied in the performance management scope. The PVE main goal is provide estimation values and support targets definition, although this tool has the potential to be used in a number of others applications. It is also a tool that enables to fuse all the essential process information regarding activities, tasks, internal and external disturbances, and functional requirements that can positively or negatively affect the system.

Thus, the main purpose of this section is developing the PVE tool, which is supported by Neural Networks and Kalman Filter [42], [49]. The NN will enable the complex system modelling in a simple and intuitive manner. On the other hand, the Kalman filter will improve this approach. In fact, this component is a modelling error filter, which becomes this proposed tool immune to noises due to internal and external disturbances. This filter is very important when we are working with complex environments, such as factories, hospitals and other systems where the number of input factors affect the organizational system and make its modulation more difficult. In fact, when the amounts of factors are vast, and the way how these variables interact with the system is complex and nonlinear, it is not feasible to be controlled and managed by an operator without any technical support. So, the utilisation of the PVE tool in such situations can be very useful in order to support decision-makers stipulating targets to be achieved. At the same time, this estimation values contribute to manage operations, detecting bottlenecks and improve processes, define strategies, evaluate and select partners or suppliers among other management concerns.

This approach allows the complex manufacturing systems modelling, through data fusion, using an estimation tool, which is not concerned only with statistical data, but mainly with the factors that might influence the future. Moreover, once the success and effectiveness of performance measurement depends on the reaction time of the company, becomes crucial not only reduce these reaction time but also anticipate it, as is shown in figure 3.9.

So, with this approach, it is intended to break with the feedback control as it is known nowadays, and create a new paradigm, where companies can improve their processes, methodologies and technologies and, on real-time, understand and visualize which will be the impact of this changes at long, medium and short term. Indeed, this new paradigm intends to stimulate companies to brake with the normal performance management, where processes and strategies are evaluated using the present performance values, and start managing their processes taking into account the future performance caused by present actions.

In fact, this is a new concept which should be developed and studied because this way it is possible to reduce the reaction time of the company to external disturbances, caused by the market, and also optimize process in a faster and efficient way once companies become capable to anticipate the factory response to the applied changes, and thus be more competitive.

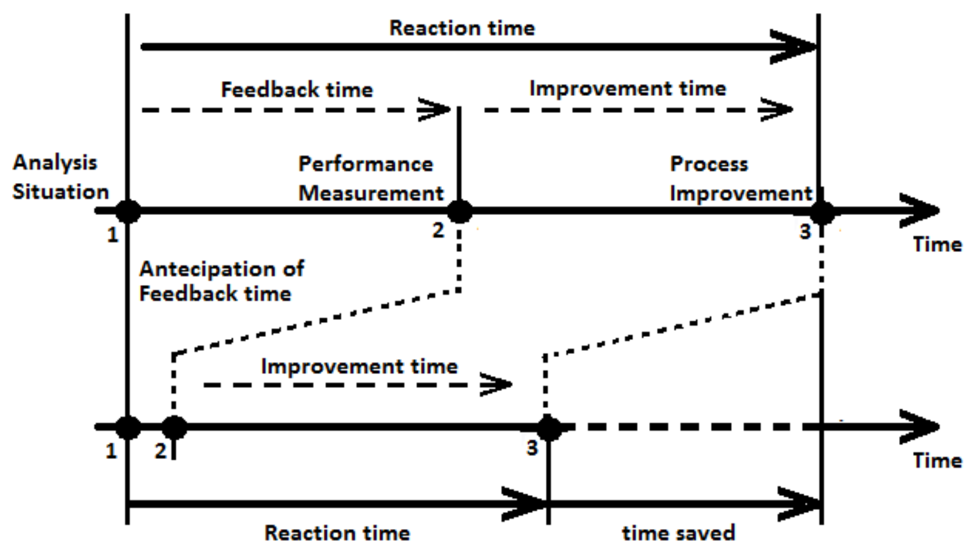


Figure 3.9 – Reaction time optimization

The PVE core is a component that operates in parallel with the system to be emulated, figure 3.11. This receives on real-time the measures (leading measures) in a proactive performance management approach [59], and the predictable information about the factors that influence and disturb positively or negatively the system. Then, with this information the PVE is able to produce targets estimates to the performance indicators chosen and taught to the tool. Estimates of these indicators can be monitored also in real-time, being possible to estimate and predict the system reaction to improvement processes, over time, using charts as figure 3.10.

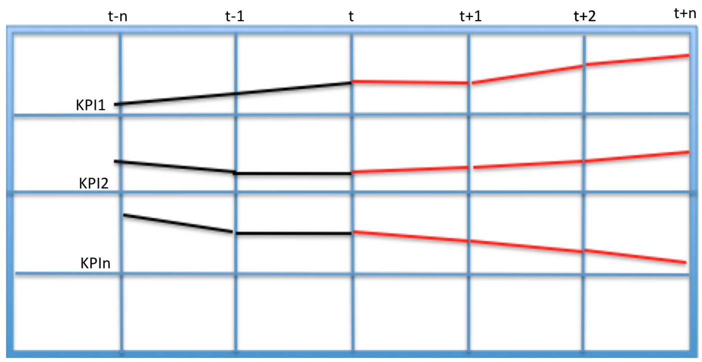


Figure 3.10 – System Performance Analysis chart

However, when the performance of complex systems is being analyzed and studied, it is essential divide the system into sub-systems in order to shape the PVE algorithm to the situation in study. For example, if we are implementing the PVE tool on an automotive production line, we can model each area of the referred line and analyse it as a network. In order to make this process more intuitive, it was developed a component called "System Emulator Core", figure 3.12. With this module, it is possible to apply this approach not to the entire system but to a network of different sub-systems, which interact with each other, representing the whole system. This component can be very interesting when we are dealing, for example, with Collaborative Networks, as will be explored and demonstrated on the following chapter.

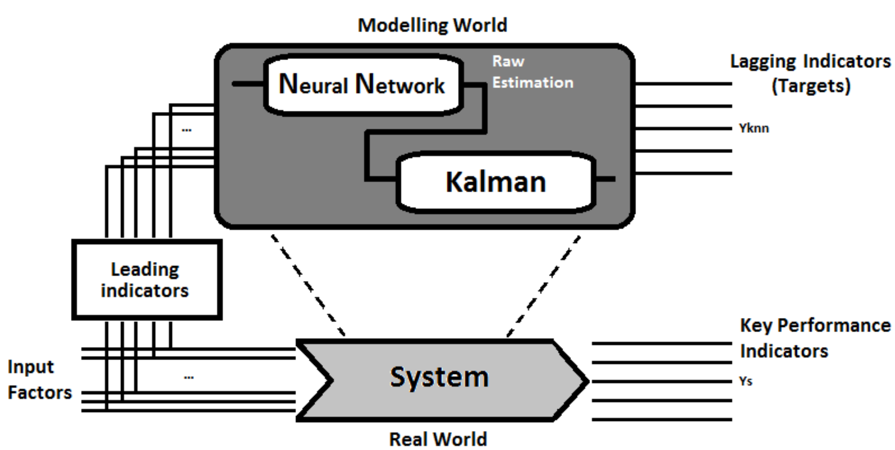


Figure 3.11 – Performance Value Estimator Concept

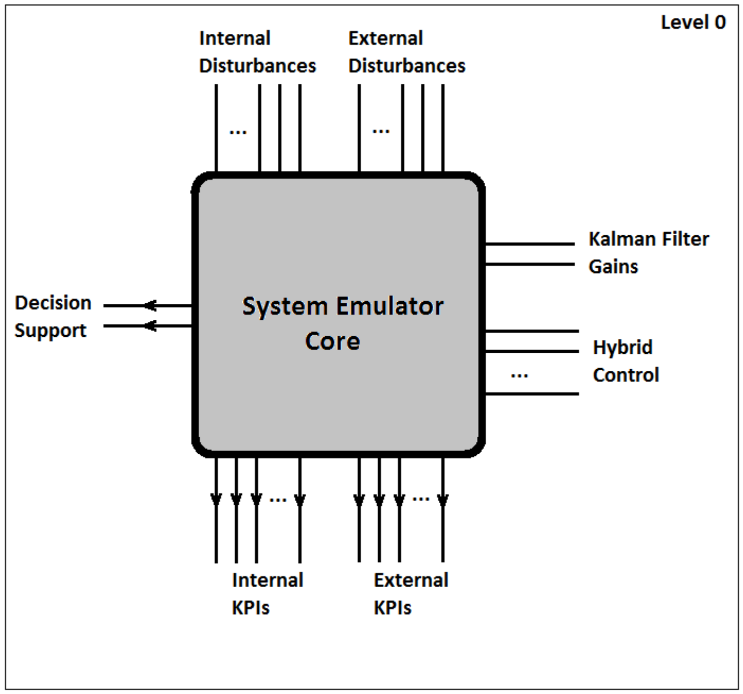


Figure 3.12 – System Emulator Core

This component deals with four types of data: disturbances, control, performance and decision data. The first one represents the information that disturbs and influences the performance and behaviour of the system. This information can also be divided into two main categories, which are the internal and external disturbances. Internal disturbances are the factors caused within the system in study. From here is studied the variables which reflect the sub-systems interactions behaviour. Furthermore, external disturbances can be seen as the non-controlled factors that are not derived from the system behaviour, but influence the system that is being analyzed.

Control data allows users not only to define the best filter gains, in order to tune and improve the estimation quality, but also to choose the behaviour desired at each moment. These two types represent the input data. On the other hand, the decision and performance data represent the response and the output of the PVE. In fact, the decision support data can be seen as an enabler to decision makers, presenting information that can guide and facilitate the design of the company's strategy. An example of this could be an expert system of evaluation, which could classify the sub-systems performance. Thus, a fuzzy logic technology would be very interesting once it would allow the classification of performance, according the necessities and requirements of the area where the sub-system was performing (Fuzzy Expert System).

Finally, performance data is the value of the KPIs targets, which is the best performance value that can be achieved by the system in a given context.

Performance Value Estimator Architecture

Presented the vision about the PVE tool, is now important explain its concept. Normally, in real-life scenarios, there are factors and variables which cannot be controlled nor predictable, that make the state model definition difficult to be achieved. Otherwise, estimation and forecast problems would be very simple to solve with deterministic observers already existing, such as Luenberger observer. So, it is possible to establish a difference between deterministic and stochastic processes. According Origlio [36] stochastic is synonymous with random. It is used to indicate that a particular subject is seen from point of view of randomness. On the other hand, deterministic means that random phenomena are not involved. So, it is possible to conclude that, stochastic models are based on random trials, while deterministic models always produce the same output for a given starting condition.

In fact, the PVE tool intends to solve problems not only with dynamic and complex environments but also where stochastic and deterministic factors are taken into account.

This tool comprises three specific moments that allow the achievement of the purposed goals. It begins with the collection of the specified data from data repository systems. From this stage, results are not only the leading factors that affect the system, but also the measures of the system performance. This last cluster of variables will support Kalman filter optimization.

In fact, the required information is mainly originated from two kinds of sources, figure 3.14:

- Internal to the system, being the source of this information the factory itself
- External to the system, being the source of this information the market where the factory is performing.

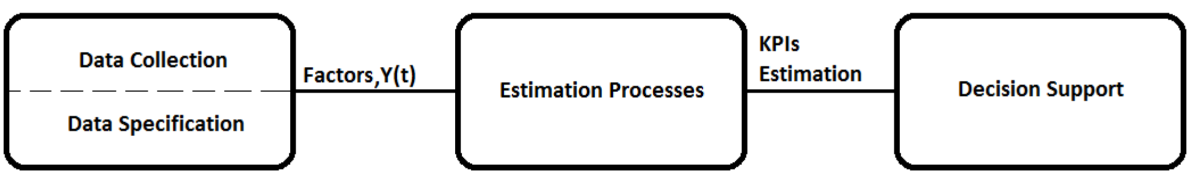


Figure 3.13 - Performance Estimator Data Flow

Indeed, these readings are subject to disturbances originated from measurements and process errors. In order to be able to predict and estimate future performance variables, these disturbances should be anticipated and considered in the estimation process. Thus, the Kalman filter is able to play an important role in order to overcome not only the modulation errors, but also anticipate the measurements disturbances.

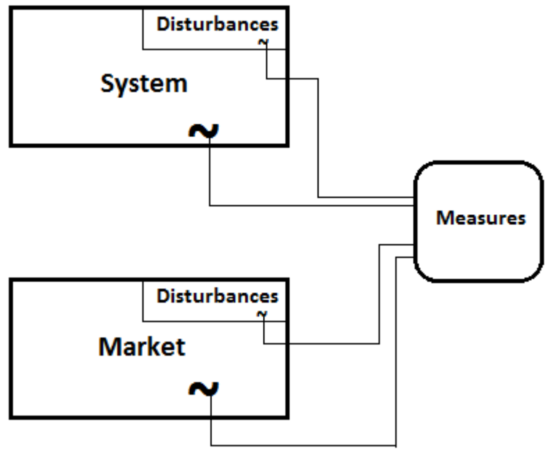


Figure 3.14 – Performance Estimator Measurement Processes and Disturbances

In sum, it is possible to guarantee that during the estimation processes one of the main stages is the data measurement and system modelling. Indeed, these two moments resulting in errors whose cancellation will be impossible to be achieved. Once known this stage of uncertainty, it becomes crucial understand how these errors should be handled and circumvented.

Intending to deal with these approaches becomes useful to represent this mathematical issue. To do this, the Deterministic-Stochastic System was chosen in order to represent a model with disturbances.

$$\begin{aligned} x(t+1) &= Ax(t) + Bu(t) + q(t) \\ y(t) &= Cx(t) + r(t) \end{aligned}, \tag{3.1}$$

Where:

A,B,C,D – state-modelling variables;

x(t+1) – estimation of x(t) at the instance t+1

x(t) – system state-space variables at instance t

u(t) – system inputs at instance t

y(t) – system outputs at instance t

q(t) and r(t) are process and measurement disturbances, respectively.

Indeed, q(t) and r(t) unpredictable factors are unknown signals, which strongly affect the observer's performance. It is normal to consider these disturbances as random and being modelled as ergodic stochastic processes.

Thus, the equation before result from the sum of the deterministic and stochastic models:

$$x_d(t+1) = Ax_d(t) + Bu(t) \qquad x_s(t+1) = Ax_s(t) + q(t)$$
$$y_d(t) = Cx_d(t) + Du(t) \qquad y_s(t) = Cx_s(t) + r(t) \quad , \tag{3.2}$$

Assuming that is used yd(t) and ys(t) without errors, it comes possible estimate the deterministic state space, xd(t) and the stochastic state space, xs(t), respectively, by a stable observer:

$$x_d(t+1) = Ax_d(t) + Bu(t) + K\left[y_d(t) - C\hat{x}_d(t) - Du(t)\right],$$
$$\hat{y}(t) = C\hat{x}_d(t) + Du(t) \tag{3.3}$$

$$\hat{x}_s(t+1) = A\hat{x}_s(t) + K\left[y_s(t) - C\hat{x}_s(t)\right],$$
$$\hat{y}_s(t) = C\hat{x}_s(t) \tag{3.4}$$

The observer's dynamics errors described above are respectively the following:

$$\tilde{x}_d(t) = (A-KC)\tilde{x}_d(t)$$
$$\tilde{x}_s(t) = (A-KC)\tilde{x}_s(t) + q(t) - Kr(t) \quad , \tag{3.5}$$

Assuming that observers are stable, (A-KC)<1, then the error of the deterministic observer is null at permanent regime, $\lim_{t\to\infty} \tilde{x}_d(t) = 0_n$. However, at the stochastic observer the same don't happen because disturbance effects occur. Thus, the Kalman filter provides a solution to counterbalance the components q(t) and Kr(t) existent at the stochastic observer dynamic error, which becomes forecasting a difficult task.

Analyzed the equations about Extended Kalman Filter (Equation 2.9-2.13) it makes possible to notice that the component $f_k(\hat{x}(k \mid k))$ can be a function of a specific tool which has the capability of emulate the system taking into account the state variables at the moment t and the inputs u(t). To do this, the Neuronal Networks has been studied to respond the requirements cited $f_k(\hat{x}(k \mid k)) = f_{NN}(x(t), u(t))$. In fact, there are others approaches that would be also capable to emulate the system such as the Least Square approach. However, this method is more "limited" than the Neural Networks, and it is less capable to shape nonlinear system.

Presented the reasons why the NN and Kalman filter are used together in the PVE, it becomes important explain how this two tools can interact in order to improve the last result.

Firstly, a rough estimation of the state variables is achieved, by the NN, through treatment of factors input data. In this block it is possible define the behaviour of the system, accessing the variables of the behaviour control. After that, the estimated state variables are translated to performance indicators estimation. This result is then compared with the output measures of the real system in order to approximate the gain of the filter to an optimal value. The behaviour of this gain can also be defined in order to become the filter able to react more or less quickly to the error variations, thus avoiding oscillations and overshoots. Finally, it is added to the rough estimate a variable tuning in order to bring the estimate to the real value, bridging the modelling, process and measurement errors.

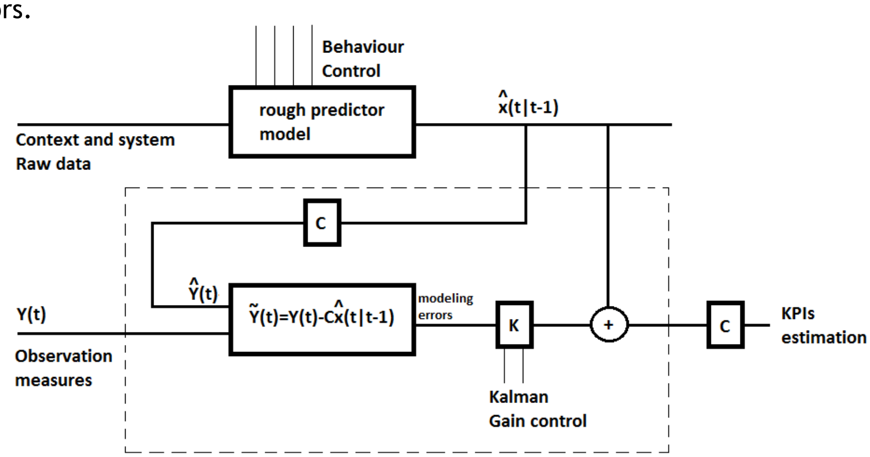


Figure 3.15 – PVE architecture

Following it is presented a mathematical representation of the performance value estimator tool.

$$\hat{x}(t \mid t-1) = f_{NN}(x(t-1), u(t)), \tag{3.6}$$

$$\hat{x}(t \mid t) = \hat{x}(t \mid t-1) + K\left[(y(t) - C\,\hat{x}(t \mid t-1)\right], \tag{3.7}$$

$$\hat{y}(t) = C\,\hat{x}(t \mid t-1), \tag{3.8}$$

In fact, the performance of the neural network within or not the extended Kalman filter remains the same if used under normal systems behaviours. However, the same cannot be verified when we are dealing with nonlinear system and with complex behaviours, where there are huge measures and process errors, factors with complex iterations and missing data. In these cases, it becomes essential to use a tool, like Kalman filter, which allows the development of a “stable neural network”.

3.4 - Factory Template Process Diagram

Finally it is presented the functional diagram of the Factory Templates, as a summary of what was said before. The scheme is divided into the different life-cycle phases. For each stage of the factory life-cycle it is intended to plan, follow and evaluate the business and industrial processes. In fact, all this is only achieved assuming the continuous improvement taking into account not only the internal data and information, but also, the market data, such as competitors, costumers, economics, politician and all the environmental information.

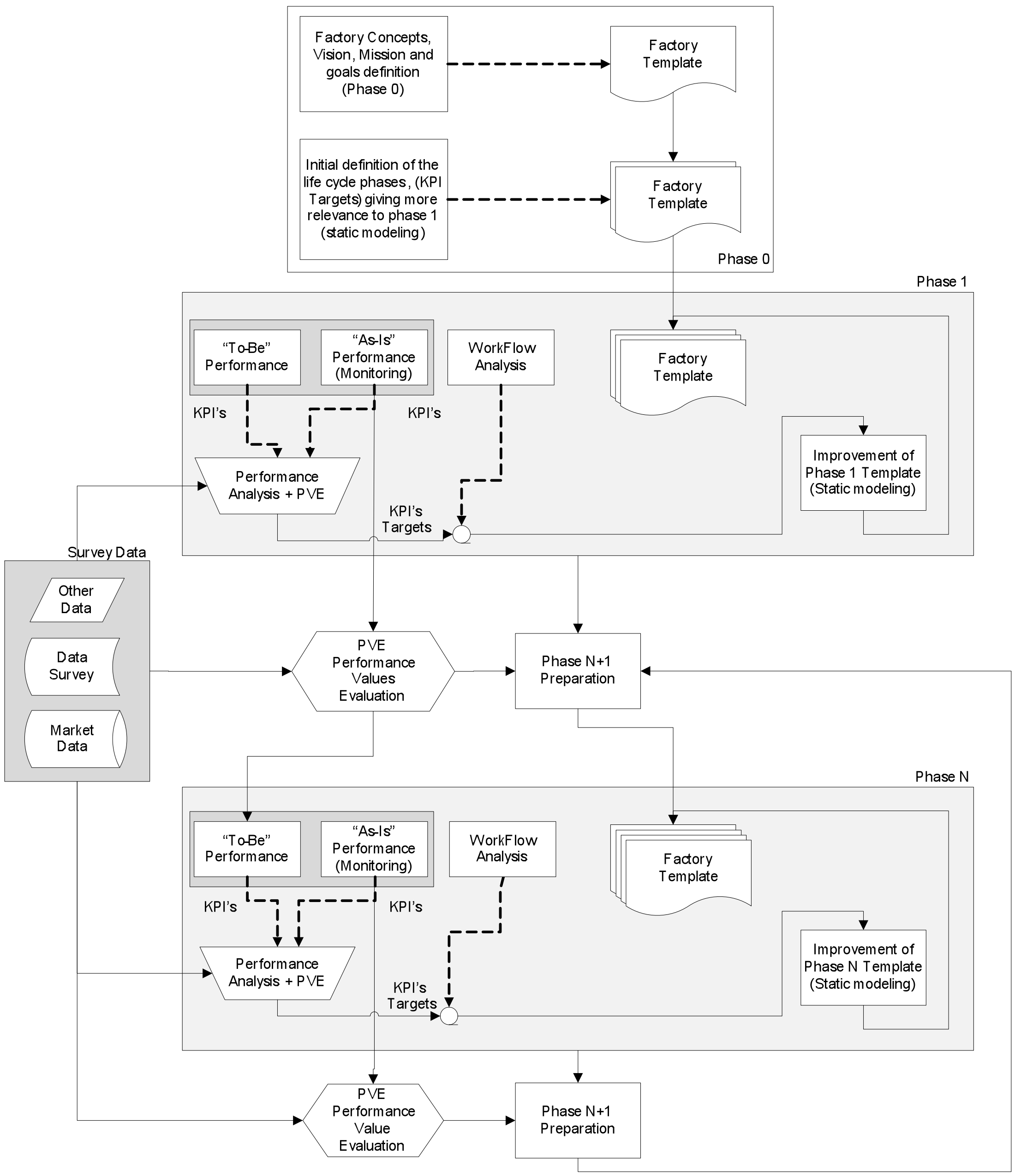


Figure 3.16 – Factory Templates Diagram

Firstly, a stage zero of factory concept, vision and core business definition should be performed as well as a rough definition of the factory life-cycle phases. This information's should be available to all employees and stakeholders. After this initial phase, the ramp-up activity (phase 1) should be designed and planned, taking into account not only the requirements and objectives for these phase but also the Knowledge and Best Practices stored and the estimations performed by the PVE tool. These estimations will take into account, not only the past behaviours of the factory but also the information about the present&future factory capability and the present&future market behaviour. During the activity, continuous improvement processes should be performed, through Workflow analysis, in order to detect bottlenecks and reduce its importance within the process performance. This methodology should be applied to all the following factory phases, being important to performe an initial planning activity before their beginning.

3.5 - Brief Summary

In sum, the Factory Template module is a meta-reference model that embodies the VFF factory concept. This has as main goal lead the factory planning, following all the stages of the factory life-cycle. Thus, it was detailed the importance of the exchange of information between this module and all the components which own the knowledge, such as Knowledge Repository, Best practices, Knowledge Engine, Ontology and also the Virtual Factory Manager. In order to achieve this, it was proposed a Factory Template Architecture. This structure is divided into two main modelling stages: Static Modelling and Dynamic Modelling.

The Static Modelling, underline the fact that there are several elements and concepts that are common to all companies and factories, that support and show the relation between the different aspects of the factory life cycle. Thus, this concepts support the development of a framework necessary to plan and execute all engineering tasks of a company integration that are fundamental for a successful production and operation. Moreover, this approach gives a general overview of the factory, taking into account not only the different stages of the factory and product life cycle ("Factory as a Product approach"), but also the perspectives of the different stakeholders and players who have responsibilities on the processes.

On the other hand, the Dynamic modelling has as main goal the evaluation and follow of the process performance. Thus, performance estimation becomes indispensable not only to establish targets of performance, but also to identify potential opportunities as well as dangers in the business environment and understand the extent and impact of future uncertainty – PVE (Performance Value Evaluation).

Chapter 4

Evaluation Scenarios and Validation

In order to evaluate and validate the purpose described on chapter two, a set of real scenarios and design experiments were developed and are presented during this chapter. In fact, within the VFF project, different scenarios were developed and will be used at the end to test and validate all the methodologies and technologies developed. On the other hand, it was used a real case of a collaborative network to validate the Performance Value Estimator which was also developed on chapter number two.

4.1 - Presentation of Scenarios Validation

The validation scenarios are meant as a proof of principle and prototypic implementation. The specific validation of the scenarios will take place through the realization of various industrial test cases that will directly derive from end-users real scenarios. This topic is intended to specify the scenarios that will be used to evaluate and test not only the Factory Template module but also all the VFF components.

In line with this context, four different scenarios were created in order to include all the industrial partners and the main life cycle phases of a factory. Thus, the four scenarios designed and created are:

- Design and optimization;
- Ramp-up and monitoring;
- Reconfiguration and logistics and,
- Next Factory.

By the time of writing, had not yet been made the validation tests of the static component of the FT tool. However it will be presented the objectives and purposes of each scenario, and also the industrial partner involved, indicating their concerns and requirements, figure 4.1.

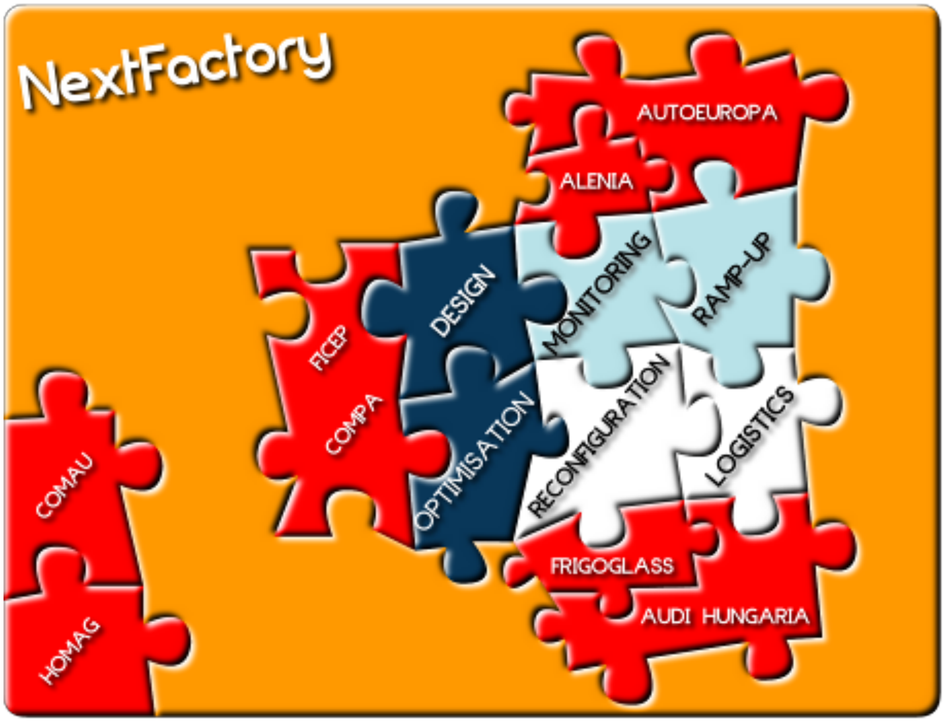


Figure 4.1 - Virtual Factory Framework - Validation scenarios

4.1.1. Purpose and scope of Design and Optimization scenario

Especially in the design stage, is very useful be able to explore different variants of the technology, technology flows and to detect any problems that may occur. Simulation of these possible variants in this new approach of the Virtual Factory will help to get in shorter time, with lower costs and trouble free, a new implementation version, based on an advanced decision support.

Based on the factors and goals described before, this scenario will explore the design and optimization factors of a factory. Firstly the scenario intends to demonstrate the capability to deliver a collaborative environment for a new efficient and time-effective factory set-up. Moreover, concerning the optimisation subject, it will be important to cover production line configuration and balancing.

So that it is possible to prove all the design and optimization potential, this scenario will be applied in two industrial use cases from the automotive part plant and steel manufacturing companies, more specifically at COMPA and FICEP processes respectively.

4.1.2. Purpose and scope of Ramp-up and Monitoring Scenario

Within the framework, the KPI are applied to both stages, although the Ramp Up stage is considered only from SOP (Start of Production) to SOP+1 (one year after start of production and maximum volume of production is reached). The monitoring stage provides feedback on system behaviour during steady state operation; this stage begins at SOP+1. The stage before the Ramp-up is considered the Preparation Process. All products produced during these phases of process are not for sell to clients and it includes four main phases:

- Phase 0: without in line production made for Board approval and some general quality issues.
- Phase 1: without in line production, prepped for some minor changes in product.
- Phase 2 and 3 are produced in line and are oriented to quality and process improvement.

In this second scenario, it is expected to demonstrate the advantages of the VFF tool at the ramp-up and monitoring activities. Along Ramp-up, the VFF tool will be tested in order to express an efficient setting up, verification and commissioning of software and procedures. Furthermore, with this scenario will be explored the capability to monitor the real factory, as well the connection between the real and the digital factory.

So that it is possible to prove the Ramp-up and monitoring potential, were defined two industrial uses-cases from the aerospace and automotive sectors, thanks to the industrial partners ALENIA and AUTOEUROPA, respectively.

AUTOEUROPA intends to test and evaluate their KPIs during the Ramp-up of a new product. On the other hand, ALENIA aims to improve their monitoring capabilities, developing the collection processes, manage and analyse of the information coming from the real Factory.

4.1.3. Purpose and scope of Reconfiguration and Logistics Scenario

In the reconfiguration scenario the effect of logistical related changes on the production process will be analysed and optimized with simulation-based solution of VFF. In spite of the fact that already exist several simulation models for analysis, none of them are capable to be easily adapted to conceptual changes, new set-ups and reconfiguration needs of the factory. Moreover, the legacy models are slow and they do not provide the right information.

In order to overcome the challenge proposed before, this scenario was created to explore the reconfiguration and logistics aspects of a factory. Firstly, the scenario intends to demonstrate the performance of VFF simulation and optimization in order to support decision makers. Moreover, concerning the logistic subject, it is expected to demonstrate in this scenario that the VFF tools, such as the Factory Template module, are able to ameliorate logistics, aiming to produce results such as variable demand accommodation, efficient and flexible networked operations and maintain product quality. It is also intended to prove the reconfiguration and logistics potential applying this approach in two industrial use cases, which are the reconfiguration of engine handling system of the Audi Hungary Company, and also the reconfiguration of a plant due the introduction of a new product, at Frigoglass Company.

Audi Hungary has as main goal integrate different simulation models in the overall planning, execution as well as factory infrastructure monitoring. Moreover, Frigoglass intends to improve their reconfiguration processes when are introduced new models for production.

4.1.4. Purpose and scope of Next Factory Scenario

The purpose of the next factory scenario is to demonstrate the possibilities, limitations and benefits of an integrated holistic planning and engineering process for a new factory.

This can be considered a summary scenario because it will enable the demonstration of the applicability of the VFF on the entire factory life-cycle. Furthermore, as an integrated scenario, will validate the interaction between the largest possible numbers of modules. In order to achieve this challenge, two industrial use-cases from the woodworking and automotive domains were defined, HOMAG and COMAU respectively.

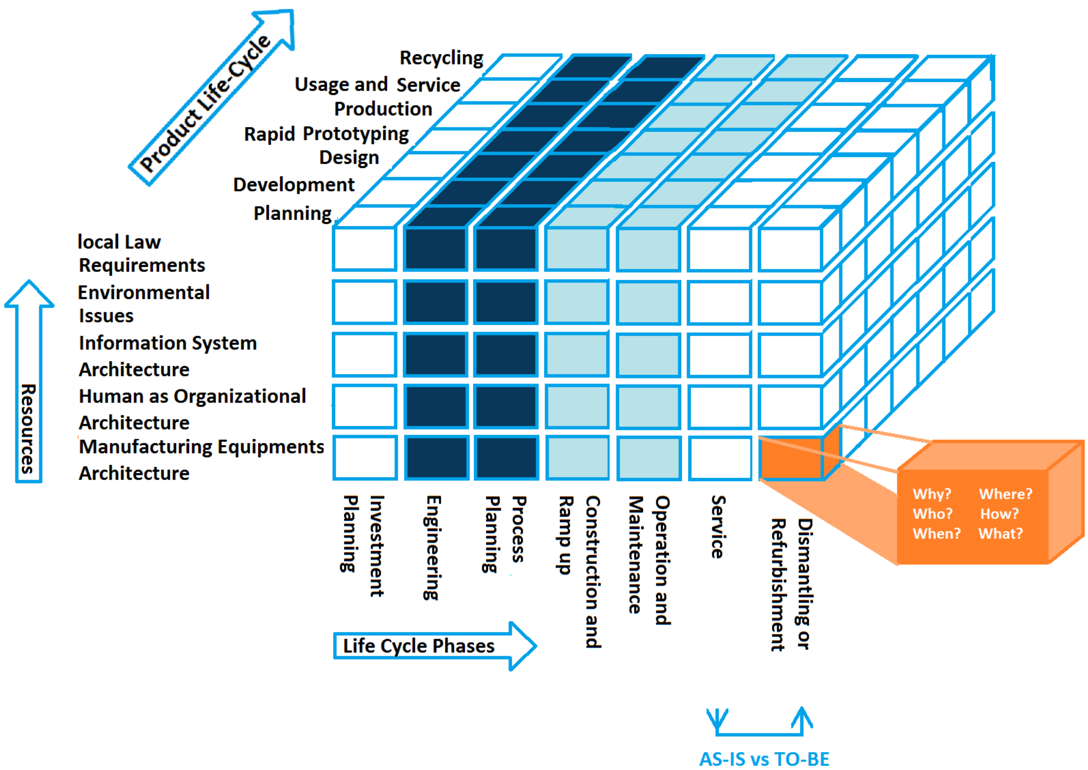
COMAU intends to test and evaluate the VFF tools capability in order to improve their production system regarding design, implementation and ramp-up. The machining line(s) and/or an assembly line(s) will comprise the production system. Similarly, HOMAG will evaluate the VFF tool through the different project phases defined by this company (Pre-Project, Project Implementation, Project Realization and Commissioning).

4.1.5. Life-cycle Phases Allocation

Once explored the Factory Template module, it was crucial re-analyze in detail all the requirements for each scenario and make a deeply reflection with this information in order to verify if the needs and requirements presented by industrial partners were respected. As result of this internal research resulted a clustering of functionalities that can be observed in the tables attached (Annex II).

In order to validate and test the Factory Template module within the scenarios previously defined, it was essential distribute and allocate each scenario by different life-cycle phases. Indeed, the VFF project was still at an early stage, when this document was writing, so it was not possible to test and validate the functionality of the static view, proposed for this tool. However, it is presented in the following figure the distribution of scenarios / industrial partners for the different stages of the life cycle of the factory. Here it is possible to associate the colours of each scenario, defined on picture

4.1, with the colours of each life-cycle phases. How it is possible to see on the figure bellow, not all industrial partners were associated with the Factory Template task. Thus it was essential allocate the scenarios in order to include on the validation tasks the main industrial life-cycles phases. This was a very important stage once, as further work, the Factory Template will be able to test all the Knowledge Management Module functionalities. Thus, it is intended to apply and test the FT module on partners' facilities, in order to prove the Factory Template module capabilities on a real scenario.



Company	Scenario	Life-cycle stage
Frigoglass	Reconfiguration	Engineering
Ficep	Design	Process Planning
Compa	Optimization	Construction and ramp-up & Operation and Maintenance

Figure 4.2 - Factory Template Static Perspective Cube with scenarios allocation

4.2 - Factory Template Validation within a Ramp-Up Scenario

In order to validate the static perspective of the presented proposal, on chapter two, a Ramp-up scenario was chosen. This stage of the factory life-cycle was selected, due to its importance and its crucial impact on the future performance of the Factory and products, as was described on the chapter of state-of-art.

Indeed, even before the start of production of a product, a series of planning activities, monitoring and validation must be performed in order to able the achievement of a high degree of optimization and quality during the continuous production phase.

So, the question here proposed is, how a company can faster the ramp-up phase, keeping high levels of performance and quality?

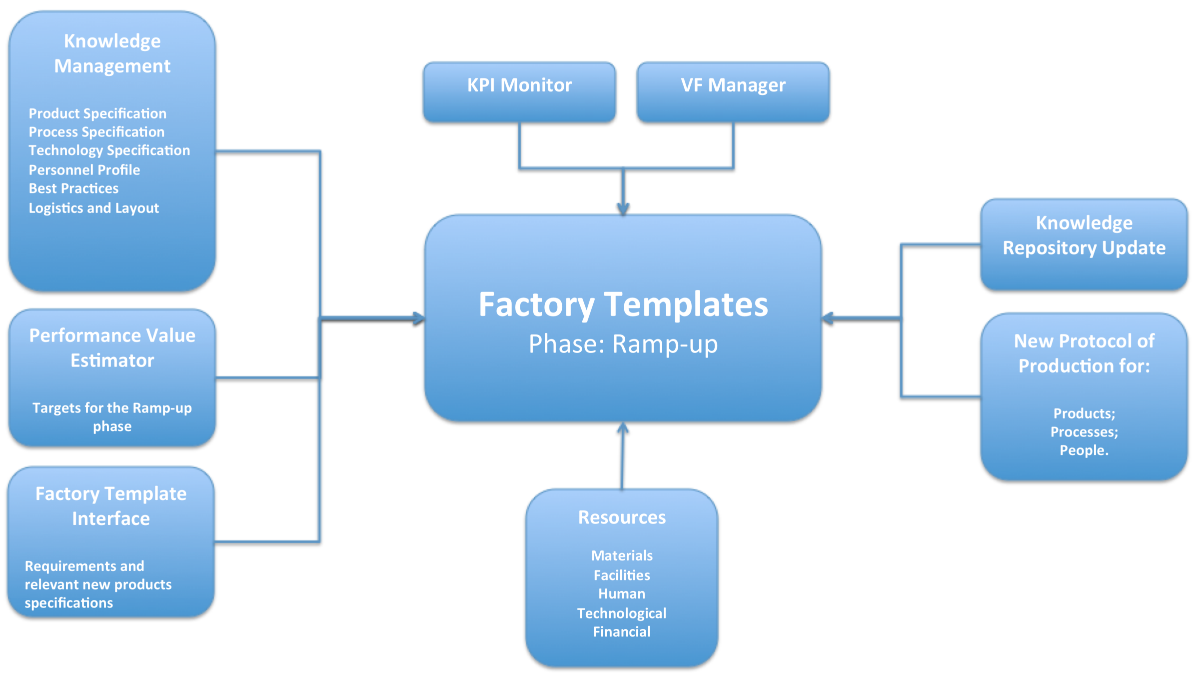


Figure 4.3 - Analysis of the Ramp-up phase by the Factory Template methodology within the VFF Project

Once the main goal of the Factory Template is the definition of processes, for all the life-cycle phases by a simple, quickly and effective way, becomes crucial endow the designed system with knowledge and best practices learned from the experience, and stored on proper databases. Thus, is demonstrated in the previous image which are the interactions necessaries for the Factory Template module be able to suggest users a set of processes that will optimize and streamline the entire ramp-up phase.

Firstly, the Factory Template module receives from Knowledge Management the information related with the product that will be produced, the best processes and practices usually used, the technology that support the production and the logistics&layouts proper to the situation proposed. From here, is received information similar to the data exposed on table 4.1, and a scheme of the ramp-up process is designed in order to better explain the process to the final user, figure 4.5. This is an important task, once one of the main goals of the Factory Template is facilitate the transmission of Knowledge.

Moreover, once this module is supported by a Performance value estimator tool, which was described and explained during the chapter number two, the Factory Template module will be able to draw a curve with the expected production volume growth and with other expected KPIs values over time, figure 4.4. Thus, the system will be able to match the expected values with the performance obtained during the ramp-up phase. This way, it will be possible to analyze and examine the processes, assist in decision-making and support the factory strategy improvement, comparing the real factory performance during the ramp-up with the forecast performance. It is important to remember that this expected variables corresponds to the best performance achievable, in a given context, by the factory.

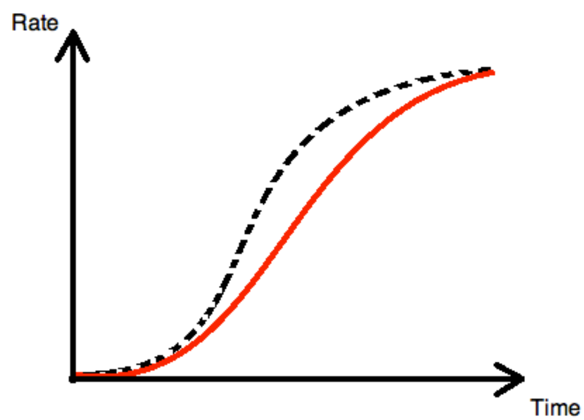


Figure 4.4 – Analysis of the Ramp-up phase Performance (Expected in dashed Vs Obtained in red)

From this moment, the targets of production volume to be achieved over time are defined, and also is predicted the end of the ramp-up phase. Indeed, this estimation is considered, taking into account the resources and capacity of the factory.

For example, in figure 4.4 it is possible to see that the overall factory performance is lower than it would be expected, taking into account the partners involved, resources available, employees' knowledge and skills, between other characteristics available. In fact, if it is possible to discriminate the main KPIs that allow the system behaviour monitoring, than managers would be able to understand which are the factors and causes that affect the factory performance, and improve them.

Tabela 4.1 — Ramp-up phases and activities

RAMP-UP			
Phases	Planning and Preparation	Operation and Monitoring	Series Production
Activities	• Data Gathering • Identification of needs • Preliminary new project feasibility analysis and submission • Ramp-Up Identification • Product, Processes and plant conceptual Design • Planning and schedule	• Processes and products test run • Pre-Production • Pilot run series • Production Ramp-up • Product and process engineering o Product, Processes and People skills validation o Effectiveness and efficiency analysis o Performance Testing o Safety Certification o Ramp-up time and cost analysis • Performance evaluation and corrective actions	• Cost Control • Product and Process design approval • Mass production

As can be seen on figure 4.5, the ramp-up phase, with the support of the Factory Template, can be seen as an iterative process, because it is intended to be improved with the increasing of the number of iterations. Thus, it becomes important, not only define new protocols for process, products and people, but also store this new upgrade information at the knowledge repositories, in order to be used on following opportunities. Through the Factory Template GUI, this interaction becomes simple and intuitive.

Indeed, it is possible to see as a complex and important stage of the Factory life-cycle, which required a strong and complex planning and design activities, can be easily achieved, using a component that can inform process designer which are the activities that should be performed, evaluate the system performance and support the continuous improvement, guaranteeing the storage of the new information. Moreover, through the use of the estimator, it is possible to anticipate internal and external disturbances, in order to keep the planning of manufacturing the most realistic and reliable as possible.

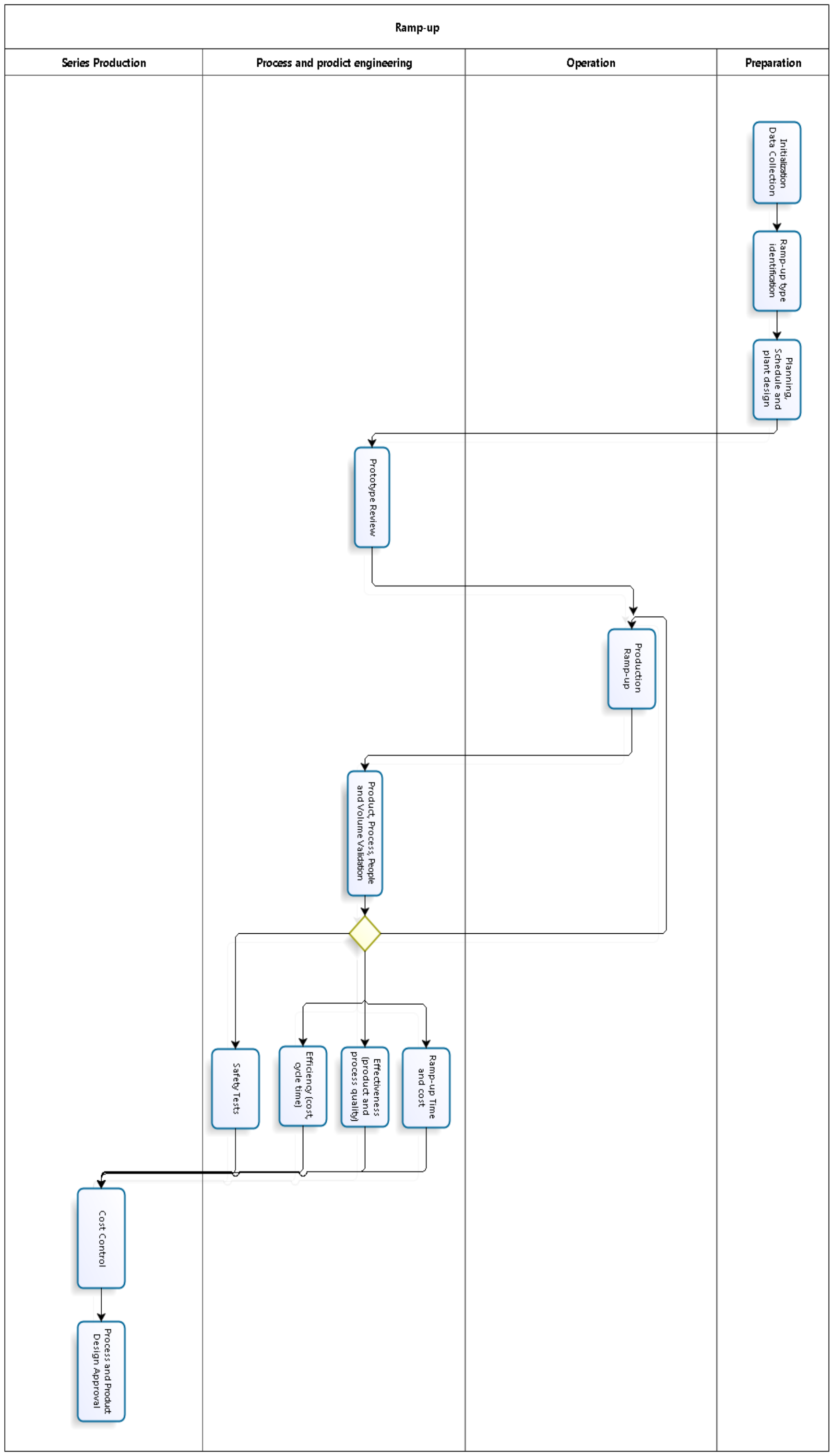


Figure 4.5 – Ramp-up phase BPMN model

4.3 - Dynamic Perspective

A model of performance estimation once built was evaluated through iterative testings and then applied to a concrete use cases. To do that, it was defined a set of key performance indicators (KPIs), which make it possible describes the specific operational performance as well as the factors that influence the systems behaviour. As a test environment was chosen a real supply chain network consisting of three manufacturing companies that operate in a collaboration context, called G3. In order to complete and validate with success this use-case, this task was done under the supervision of a G3 collaborative-network expert, who validated and provided some historical data.

4.3.1. Performance Management in Collaborative Networks

Nowadays, markets are increasingly volatile and uncertain, what forces organizations to formulate effective strategies to survive and prosper. Driven by the need to achieve higher levels of productivity and quality in their products and processes, companies have been recognizing that a strong interaction and coordination among partners, in its business chain, is a key strategy for achieving competitiveness and reduce uncertainty, and so this motivates them to act within a collaborative networks (CN) context.

The CN's decision-makers must consider the organisational structure, allocation and coordination of resources and activities among participants, as well as the interoperability in order to achieve their objectives within the required time, cost and quality frame, otherwise it can lead organizations into wrong directions. They must use systems of performance management and measurement derived from its strategies and capabilities [54]. The main principle is to integrate the goals with strategies and thus reach better definition of the processes, improve performance and their relationship with the internal and external clients. In this context, Amaratunga & Baldry [58] states that performance management uses information from performance measurement to trigger positive changes in the systems and processes of the organization, defining objectives and targets, allocating and prioritizing features.

4.3.2. Presentation of the Use Case

A collaborative network composed by the companies Cepalgo Films, Cepalgo Conversion, and GSA, which is called in this work as G3, manifested interest in monitoring the inter-organizational processes that directly impact on the overall network performance. This CN is controlled by the same stakeholders, the Mabel Group, a Brazilian industrial corporation. This corporation is one of the greatest cookies, and similar food products, companies in Latin America.

The Cepalgo Films produces plastic films co-extruded providing about 50% of its own production to the Cepalgo Conversion. The intention is to supply this partner offering low prices and, mainly, better delivery time and costs. However, permanently there is a possibility to purchase the films co-extruded by other suppliers in the Brazilian and global markets. Hence the Cepalgo Films must refine their processes and products to remain as a partner, and also continuously develop new products and customers in order to not be too dependent on others participants of the CN. On the other hand, the Cepalgo Conversion produces plastic films printed for food packaging and then supplies to GSA about 40% of their own internal production.

The G3 supply-chain has the following behaviour. Cepalgo Films receive an order from Cepalgo Conversion. After that, the first one sends the goods to the second factory. This process is managed with a feedback loop, which will enable Cepalgo Films to improve their performance in order to meet Cepalgo Conversion necessities and requirements. This process is repeated between the Cepalgo Conversion and GSA factories. As it is possible to see, in figure 4.6 GSA becomes very dependent of the two suppliers of the G3 chain. So it becomes crucial establish a method and technique, which enable GSA to prevent and compensate possible nonconformities and delays of the rest of the supply-chain. The tool and methodology that is proposed at this document for this use case, has the following stages. In picture 4.6 it is possible to see the G3 supply-chain, which will be used to evaluate and test the PVE tool.

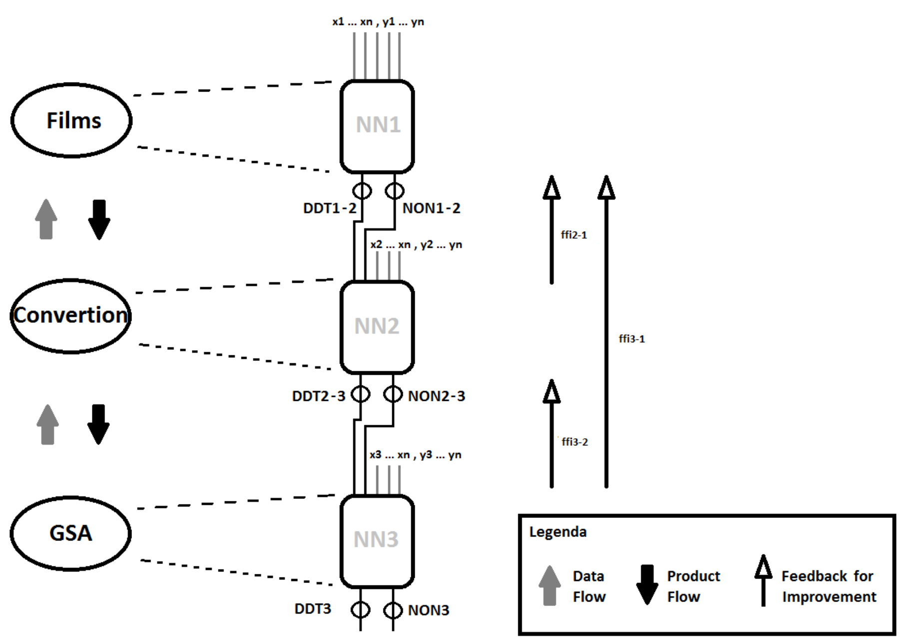


Figure 4.6 - G3 emulator system

At the beginning it is essential train the three Neural Networks (NN1, NN2 and NN3) in order to give them the capability to emulate the different factories of the supply-chain (Films, Conversion and GSA).

To do that, it was defined two key performance indicators, Delay of the Delivery Time per Order (DDT) and Number of Orders with Nonconformities (NON) which are the output of the Neural Network tool and will be following described. Also, it was defined a series of factors which are the inputs that influence and disturb the KPI chosen (DDT and NON). With this type of data, measured during a series of months, it is possible to train and model the NN tool to the factory dynamic.

At this stage, each Neural Network is capable of receive in its input the different predictable factors, and estimate which should be the factory reaction and the respective KPIs. However, it is important to understand that a supply-chain like this has behaviour like a “snowball”. In fact, all the nonconformities and delays verified at the previous factories will have a crucial impact at the bottom of the supply-chain. This is the reason why, not only exist a constant feedback between the different factories (ffi2-1, ffi3-1, ffi3-2), but also the output of the previous factories (DDT1-2, NON1-2; DDT2-3, NON2-3) should be used as input (factors) of the ensuing factory (NN2 and NN3 respectively) on the estimation process. So, it becomes possible to compile more easily (data fusion) all the information at the supply-chain and support decision makers to offer better services to the final costumer.

As mentioned before, two different KPIs were defined, in order to allow the G3 performance analysis possible. The key performance indicators (KPI) that are used in this case are defined as:

- DDT is the number of orders with delay on the delivery time by the total numbers of orders;
- NON is number of orders with nonconformities by the total numbers of orders.

The DDT is concerning on the quantity of orders that had delays in this delivery time. So, it intends instantiate how many orders were delayed in certain periods, which factors can cause more or less delay, and then estimate values for this situation in future periods. This can support decision markers decreasing delay's downstream propagation within the collaborative network because decision-makers can anticipate possible delays and then implement actions to improve the processes, especially those that affect more decisively. It gives a crucial indicator for improving the agility of the supplier and impels each participant in the chain to reduce the delivery time in order to meet the due date stipulated in the orders. In a CN with more than two participants, the propagation of delays can significantly compromise the level of agility to the end customer. It impacts on the level of service expected by the end consumer that leads to reducing the competitiveness of participants, namely those of front-line.

Nonconformity (NC) is a term arising from the ISO quality standards (ISO, 2008) that means refusal or failure to conform to accepted standards, conventions, rules, or laws. Deliver products and services with a higher degree of quality is an imperious challenge in order to reach competitiveness. In this context, by identifying non-conformities makes possible act to improve products, processes and people, and establish appropriate policies to manage the quality and productivity of internal and inter-organizational processes. So, the NON is concerning on the quantity of orders that presented nonconformities of product. So, it intends to obtain instances of many orders that were nonconformities in certain periods, which factors can cause more or less nonconformities, and then estimate values for this situation in future periods. This can contribute to decrease the nonconformity's number as well as the effects on delay and costs because the decision-makers can foresee the number of nonconformities in the next period, and then also implement actions to improve the processes, especially those that affect more decisively the appearance of nonconformities.

In this case, the number of orders requested by customers is not constant. This happens in most companies and it usually implies a dependency of the month of the year by reasons underlying the type of product, such as seasonality, climate, etc.

Regarding to the factors that affect the estimation results of the KPIs DDT and NON, these are illustrated in the following Table 4.2. Such values are effectively dependent on system factors (U) and process factors (Q). In other words, there are variables that are known beforehand, as is the case of the number of the requested orders, as well as the overbooking possibility and the scheduled actions for preventive maintenance. On the other hand, variables such as the production performance and the supply and transportation reliabilities, although though restrained within a range known or proposed, affect the system in an unpredictably way.

Presented the context of the use-case, the key performance indicators and the factors that affect each KPI (Annexe I), is now possible apply the PVE tool to this situation in order to understand its potential and applicability.

Tabela 4.2 — KPI Input Factors

KPIs	SOURCES	INPUT FACTORS		DESCRIPTION	DATA TYPE
		Factor	factor type[1]		
DDT	*Internal Factors*	**Preventive Maintenance**	U	This factor affects the available time to schedule production because it reduces the number of production days hampering the recovery of delays which accumulate daily. When there is orders overbooking this effect may increase.	Binary
		Production Performance	Q	This factor takes into account speed loss and affects the overall equipment effectiveness (OEE)[2]. It is impacted by all factors that cause the process to operate at a speed less than the maximum speed possible during operation. For instance, these factors include machine wear, nonconforming materials, failure to supply row materials properly, and operator inefficiency.	Decimal
	External Factors	**Overbooking 1** **Overbooking 2**	U	When there are more orders than the planned production capacity, is required that the production cycle it be shorter. If this is not possible this factor will affect the delivery delays. However, other solutions may be implemented such as extending the production time schedule, or outsource the product (if possible), etc. Overbooking can arise due to inefficiency in the planning or due to seasonality.	Binary
		Supply Reliability	Q	This factor shows just how reliable are the deliveries on time by suppliers. It can affect the delivery time because obviously causes delays due to production's stoppage.	Decimal
		Transportation Reliability	Q	This factor affects the delivery time due to problems or inefficiencies of transporting the products to the customer.	Decimal
NON	*Internal Factors*	**Personnel Skills and Capabilities**	U	Whether the production's personnel are not able to operate efficiently the processes, this can affect more or less the nonconformities occurrences since many people are committed in many operations within the factory environment. A matrix representing the human resources competency levels provide a percentage of current compliance with the planned global human resources competency level.	Decimal
		Absenteeism	Q	Absent of employees that affect directly the product quality requirements.	Decimal
		Equipment Reliability	Q	The capability of the production and utility equipments to accomplish with the product quality requirements.	Decimal
		Storage & Handling Reliability	Q	The capability to store and handle the product packages with adequate protection rules and appropriate equipments and facilities.	Decimal
	External Factors	**Environmental**	U	This factor affects the nonconformities appearance due facility inefficiencies regarding climate protection.	Decimal
		Row Material Quality Reliability	Q	This factor affects the nonconformities appearance due more or less quality requirements compliance of the row materials.	Decimal

4.3.3. Analysis of Results

After applied the PVE tool for this use case was possible to draw some interesting conclusions about the accuracy, reliability and its flexibility. As described before, a scenario was created for each relationship between companies. Here was also included the interaction with the external environment in order to improve the simulation reliability. In Annexe I is presented an example of factors data that was used in simulation module.

After established the scenarios the PVE tool was applied, being the results presented for each relationship as follow. In order to facilitate understanding of the following graphs we consider the following caption: blue corresponds to the values associated with reality, green corresponds to the values associated with neural network; red corresponds to the values associated with PVE tool.

Indeed, the expert and GSA planner, in order to test and validate this estimator tool, placed two questions:

1. The planner intends to forecast KPI's values for the next six months in order to support him to define KPI targets for a medium- and long-term. It intends to support the commitment of the production team in order to manage the factors that negatively affect the KPIs, and then improve the performance, or at least keep them within these predicted values. The following Figure 4.7 shows the results to this question.

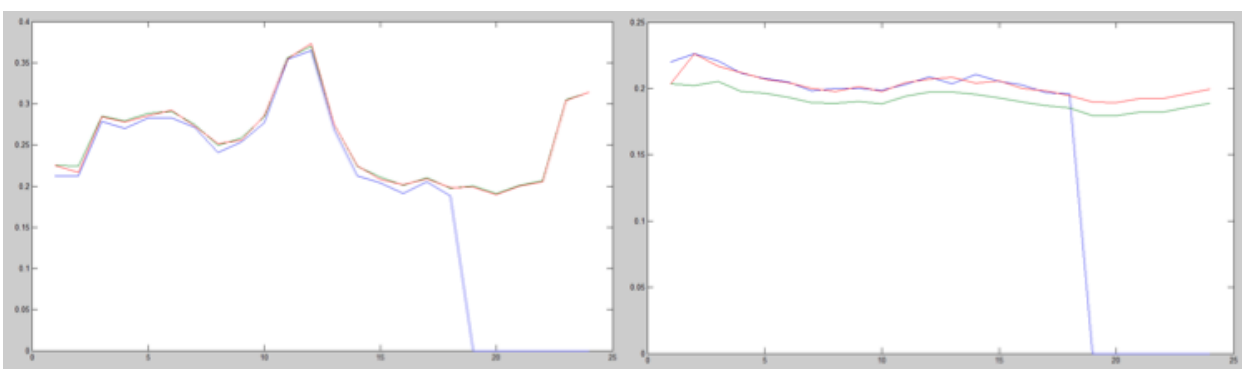


Figure 4.7 – Six Month Estimation for DDR and NON respectively

As it is possible to observe on the figure bellow, after eighteen months of filter training, the PVE tool was launched for forecast the next six months. As can be seen in the NON graphic above, a smooth offset error of modelling exists by the neural network (difference between green and blue lines). However, the Kalman Filter fulfils its function that was to nullify this error, as proposed in the architecture of the PVE tool.

Also, it is demonstrated that the PVE tool does not just follows the trend in the past but takes a proactive behaviour taking into consideration the factors that influence each month. Thus, it is possible to say that the PVE is a consistent tool because the admissible error is low and the degree of confidence is high (97%).

Tabela 4.3 — Different methods errors comparison

Tool	Films		Conversion		GSA	
	Delay	NC	Delay	NC	Delay	NC
MM	0.1386	0.1351	0.2924	0.1790	0.3190	0.1512
MEM	0.1063	0.0197	0.1273	0.0266	0.1147	0.0145
PVE	0.0055	0.0035	0.0135	0.0073	0.022	0.0090

In order to validate the described PVE characteristics on Table 4.3 can be seen a comparison with another methods currently used for predicting performance values. In this case, the PVE tool achieve about 2,2% of error for DDT, and 0,9% for NON, less than another ones.

The modelling error is different in each KPI because was used as a neural network to emulate both simultaneously. In this case, DDT is introduced first and so presents minor error. For multiple KPIs should be used neural networks in parallel that emulate each KPI in order to reduce the error with the increasing number of KPIs.

2. The planner also intends just to forecast KPI values for the next month. It is possible that the leading factors involved cannot happen as previously expected, or changes in patterns of each factor may occur. For example, improve or worsen the production performance, as well as the supply reliability, occurs or not occurs overbooking, upgrade of processes, eliminate bottlenecks, and so on.

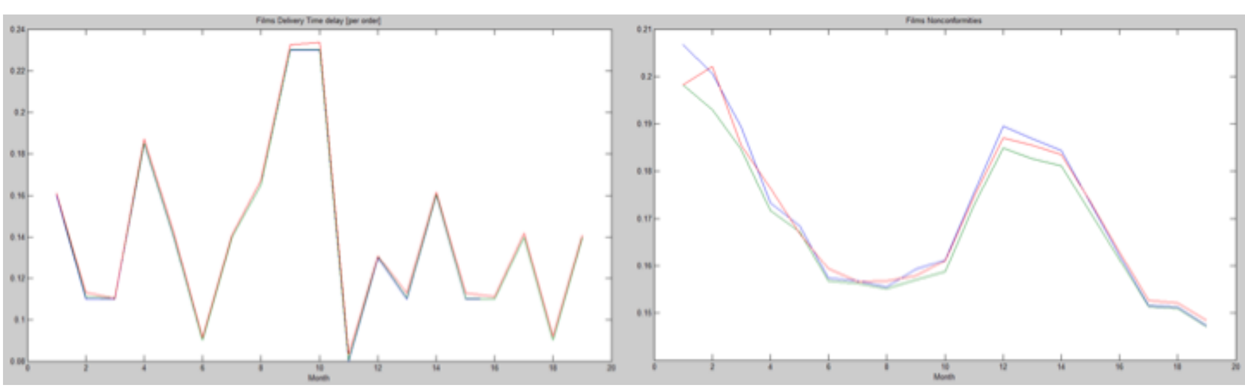


Figure 4.8 - Estimation Results for DDR and NON respectively (Relationship 1)

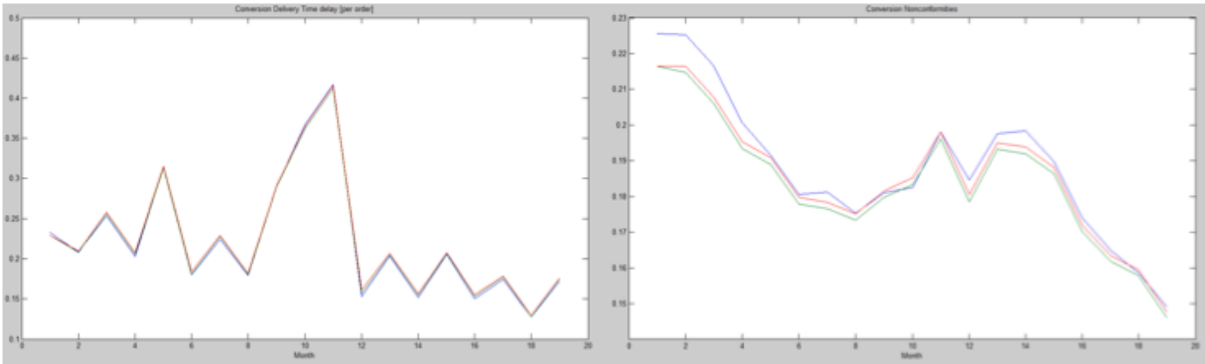


Figure 4.9 – Estimation Results for DDR and NON respectively (Relationship 2)

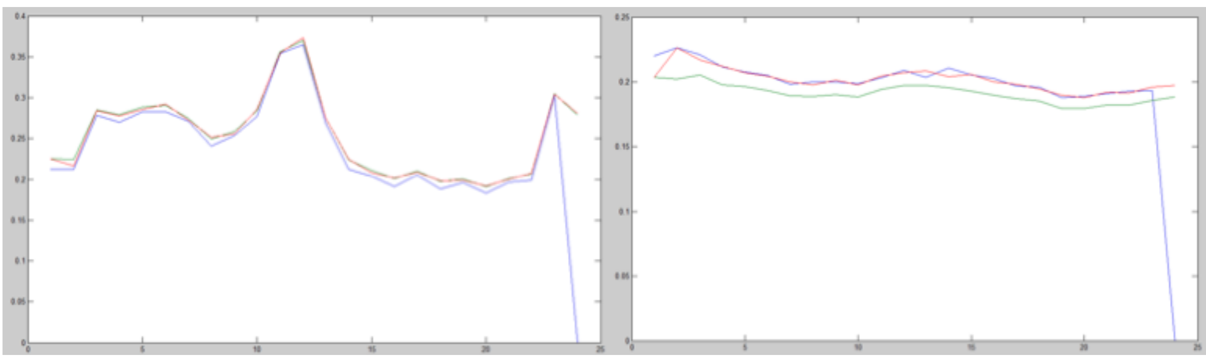


Figure 4.10 – Estimation Results for DDR and NON respectively (Relationship 3)

This strategy can guarantee that is obtained a more update values regarding the leading factors changes when it is necessary and requested by the planner. So, are presented the graphics of the three relationships. It can be seen that the interrelation between them always affects the subsequent one. In the buyer-supplier relationships, in a supply chain, there are effects that occur consequently just in the following month. Because this it is visualized a mismatch in each relationships.

In fact, if the DDT charts of the six-month forecast, and next month forecast are carefully analyzed, it is possible to see that the forecasts in last month (month number 24) don't match. Indeed, the forecast done to the next month presents more optimistic than the six-month forecast. This happens because, when was done the six month forecast, the estimation was done taking into account the preliminary scheduling of the preventive maintenance. However, when the next month estimation was done, the planner stipulated that it was better cancel the preventive maintenance in order to decrease the number of delays. This test was done, in order to demonstrate that, the PVE tool could be flexible enough to follow the factors changes, not being just a historical data estimator. This is the reason why this tool can be so useful and powerful in a competitive and volatile market.

4.4 - Brief Summary

Presented the purpose for the Factory Template concept, during this chapter it was important describe the scenarios defined for the project validation. Thus, eight use-cases were presented, being distributed two companies by four different scenarios: design and optimization, ramp-up and monitoring, reconfiguration and logistics and next Factory.

Moreover, it was demonstrated the importance of the static modelling within a crucial factory life-cycle stage as is the Ramp-up phase, as well as the impact of the dynamic modelling, more concretely the PVE tool, for the decision support into complex systems. Thus was chosen the alignment of a real collaborative network to evaluate this last functionality.

Chapter 5

Conclusion

5.1 - Main Conclusions

In the context of the research work done, it was explored the virtual factory framework as a new and innovative paradigm. Aware of this, it was also studied the concept of “Factory as a product” which strongly support the static perspective of the Factory Template. These two concepts together were able to not only enable the product and process life-cycle integration but also the reduction of global response time, improve re-use of knowledge and good practices, decrease cost and time-to-market improving ramp-up, support real time decision and finally improve the overall continuous improvement.

Within the VFF project, knowledge structure and management represent a basis of the Virtual Factory Templates in the generic factory design and planning. This tool can be seen as an intuitive Knowledge Management system, which allows not only seeking information, consistent with the context in study, but also reusing this information. Moreover, it supports the improvement of the activities that are considered the bottlenecks of the processes and finally stores the changes made in Knowledge Repositories Systems oriented to factory life-cycle structuring, in order to make it available to all workers and partners of the company.

Due to the capability of continuously understand the behaviour of the factory and project the future performance of the system in study, the Factory Template module make it possible to analyse if the factory performance is in the desired direction. If not, it enables managers to understand the reasons why it is not, and the corrective actions that should be done. Thus, Factory Template module makes it possible to break with the normal feedback performance control and support the introduction of the anticipation performance control paradigm. With this change of paradigm, companies will be able to reduce their reaction time, becoming more competitive and flexible.

To allow the achievement of this significant advantage, Factory Templates architecture is divided into two main modelling perspectives, static and dynamic. The static perspective enables the application of the “Factory as a Product” paradigm. Here, the factory life-cycle follows the product life-cycle, using as pillar the simultaneous/concurrent engineering. On the other hand, the dynamic perspective has as main advantage the continuous factory life-cycle evaluation. With this component, the Factory Templates make it possible to follow and improve processes, detecting bottlenecks. This can be achieved using as pillar the “As-Is vs. To-Be Performance”.

The application of a successful knowledge structuring initiative, just like the Factory Templates, within a industry or service areas, can reduce agent training time, speed up new employee integration during ramp up process, improve communication between departments and decrease time of planning and design increasing its quality. Knowledge-powered problem resolution enables agents to become more confident and competent sooner than they otherwise would without a KM practice. By having access to a knowledge base, new employees can get answers to common questions without having to constantly ask other more experienced agents.

Factory Templates, as a knowledge structure system, should be seen as an evolving discipline that can be affected by new technologies and Human resources skills. Moreover, there are some Factory Templates concepts that will guarantee the company competition and the achievement of certain goals and good practices such as concurrent/simultaneous engineering, performance management and knowledge creation, sharing and storage.

Finally, it becomes important underline the importance of the application of the Factory Template not only inbounds of a factory, but also as a collaborative network tool for companies alignment. In fact, as was showed during the chapter number four, more and more companies need to work together in order to become more competitive and have capacity to respond to the market demands. So, the dynamic perspective of the Factory Template can have a great importance regarding the selection and evaluation of partners, as well as anticipate delays and malfunctions of the network.

In conclusion, it is possible to ensure that were achieved all the objectives purposed for this research work. In fact, all the questions presented on chapter one were deeply studied, being presented solutions for them. The first question was defined as: “*How should be the vision and functionality about the Factory Templates issue?*” To answer this question, firstly it was essential understand and build a clear vision about the scope, context and importance of this methodology, not only within the VFF project but also in the actual industrial market and economic context. To do this, was done a survey on reference architectures and its methodologies, in order to build a generalized and robust model. This structure and architecture can be studied on the Concepts and Requirements topic. A more practical proposal can be seen on the Factory Template Process Diagram.

Question number two, “*How Factory Templates can support the planning process optimization, guaranteeing its reliability and quality?*” is the pillar of this work. Indeed, one of the main requirements for this methodology, was develop something that allow industrial process designers to perform their work not only in a intuitive and faster way, but also with the possibility of evaluate their decisions as soon as possible. With these goals in mind, was developed a methodology that allow the simple access to the company Knowledge Repository, and a estimator tool called Performance Values Estimator that support the performance anticipation control paradigm. These concepts are well structured during topics 3.2 and 3.3.

Finally, last formulated question defined as, "*How Factory Templates should be integrated within the Virtual Factory Framework project?*" was the compulsory question that required a clear and effective answer. In fact, all this work was done taking into account the advantages and potentialities of the VFF project. Indeed, this is a very complex project that deals with a significant number of subjects and industrials areas, since the factory planning and logistic until the factory maintenance and dismantling. In line with this, was essential develop the interactions of the FT module, not only within the Knowledge Management but also with the other VFF pillars. This question is deeply studied on Functional View and Architecture topic.

5.2 - Contributions of this research work within the VFF Project

Along this dissertation work, the efforts taken not only were targeted on the development of the Factory Template methodology, but also on others subjects were offered a significant contribution. Thus, during this research work it was supported the definition of the conceptual framework of the VFF, addressing the basic foundations, interactions and development requirements of the four pillars at the base of the VFF concept. In line with this context, a great contribution was done, not only defining the global vision about the Knowledge pillar but also its architecture, inter-relationships and synergies between Knowledge modules.

Moreover, considering the difficulties of realising an integrated multi-technology, multi-level collaborative VF Tools framework the definition and requirements of the validation scenarios were also developed in partnership with ATEC.

Finally, it was performed a relevant contribution for the development of the ramp-up reference model and into the development of the "KPI Monitoring" module that will be applied within Autoeuropa facilities.

5.3 - Future Development

The Factory Template concept, as explained throughout this document, will be integrated with more tools in a complex platform able to full support either the virtual and real factory design, planning and operation.

With this research work has been successfully developed the vision, functionalities and architecture of this innovative knowledge structure system. In order to achieve this stage of knowledge about the Factory Templates it was crucial analyze and study very carefully all the requirements and needs of the industrial partners.

However, there are still several tasks that are important to be done. Thus, it becomes crucial guarantee not only the integration of the FT module with the VF Manager but also with the other modules of the Knowledge Management pillar. Examples of these modules are the Knowledge Repository, Best Practices, Ontology and Knowledge Engine. For this, it will be essential develop strong protocols which will enable a good understanding between the modules. This integration is expected to feed the Factory Templates with all the requested knowledge and guarantee its storage when new improvements were achieved.

Furthermore, it is necessary to develop a user-friendly and intuitive interface. This GUI should be customized to users types. For example, users who belong to viewer's type just should have access to Factory life-cycle phases and its information. On the other hand, people with special authorizations will be able not only to access special information, but also edit factory life-cycle specifications.

In order to implement this, we identified the Google Web Toolkit (GWT) as an adequate technology. This is a development toolkit for building and optimizing complex browser-based applications using AJAX language. A good example of the AJAX application is Google Maps. In fact, this approach presents important advantages such as: avoid incompatibilities between browsers and platforms; is a Google open-source project; it is possible use any Java "debugger" with GWT and this framework presents a lot of components and development tools.

After developed the interfaces and explored the integration between the VFF modules, it will be essential execute validation testes within the VFF Validation scenarios, that were explored before. This stage will be essential to prove and demonstrate the importance of this knowledge management and structure system regarding the VFF main goals and purposes.

Annexe I

Factory	Factors	Months											
		Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
Films	Nº ORDERS	15	20	25	31	19	21	22	32	36	40	25	18
	Preventive Maintenance	1	0	0	0	1	0	1	0	0	0	0	1
	Production Performance	0.2	0.2	0.2	0.2	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.1
	Supply reliability	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Transportation reliability	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.15	0.15	0.15	0.15
	Overbooking	0	0	0	1	0	0	0	1	1	1	0	0
	Overbooking	0	0	0	0	0	0	0	0	1	1	0	0
	Personnel skill	0.35	0.35	0.35	0.35	0.32	0.32	0.3	0.3	0.3	0.28	0.28	0.28
	Absenteeism	0.015	0.012	0.008	0.005	0.009	0.007	0.014	0.009	0.005	0.005	0.007	0.01
	Equipment reliability	0.2	0.20	0.20	0.19	0.2	0.20	0.2	0.20	0.20	0.19	0.19	0.2
	storage handling reliability	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Environmental Factors	0.9	0.8	0.6	0.3	0.2	0	0	0	0.1	0.2	0.5	0.7
	Row material quality reliability	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Annexe II

ID	Potential functionality	Description or gaps to fill
1	Classification of past solutions	The main objective is to utilise past knowledge on the basis of the aforementioned criteria (decision attributes) used for making decisions in manufacturing: cost, quality, flexibility and time. The development of a set of relevant models could lead to the support in the overall decision making process for selecting the best template from the list of the ones available, when a new process has to be elaborated
2	Forecasting	Estimation of future key performance indicators Targets
3	Workflow Analysis & Optimization	Follows and evaluate processes, enabling their continuous improvement. Allow simulations, and enable that all processes are related to the respective requirements.

4	Performance Analysis	
5	Data analysis	Allow the internal and external data analysis. With this it is possible to reduce mistakes and redundant manual data entering or input files manipulation; Factory data repository management, also allow a choice of data that can contribute to each project;
6	Scheduling	The scheduling tool should be seamless integrated with the simulation model in order to optimize the scheduling plan. The main goal of the optimization process should be the minimization of the lead time to produce a job;
7	Knowledge Management GUI module	A Knowledge repository with best/good practice should be linked to the scheduling tool in order to support the definition of a good scheduling plan; cover the refinement of the KPIs.
8	“As-Is” vs. “To-Be” Analysis	
9	Continuous Improvement support	Factory improvement data reworks, recycling process, evolutions, suggest corrective actions;

10	Decision Support system	Enabling faster decisions and support them; select from the alternatives proposed by the VFF modules;
11	Data Fusion	
12	Versioning management	All planning and engineering data should be versioned so the ongoing progress of the process is documented;
13	Quality Inspection and Control	Defining standards, monitor product compliance, nonconformities resolution, and procedure recycling.
14	ICT module (information and communication technologies)	Allow communication between modules and systems
ID	Potential functionality	Description or gaps to fill
15	Facilities maintenance and utilities management	Planning and scheduling maintenance actions for machines, equipment and utility structures
16	Process Layout	

17	Work places layout
18	Internal Logistics
19	External logistics
20	Physical flow control
21	Storage and handling

Annexe III

```
% Author: António Almeida
% Computes PVE tool (Kalman filter + Neural Networks)

function [xfilt, Vfilt, Vmfilt, loglik] = kalmanFilterNN3( Z, A, W, F, S, x0,
V0, a,U,net)

% parse input

T = size(Z,1);
n = size(Z,2);
k = size(F,1);
xfilt = zeros( T, k);
Vfilt = zeros( k, k, T);
Vmfilt = zeros( k, k, T);
erro=[0;0;0];
xMPesada=0;
somaerro=0;
somaerro2=0;
x=x0;
meses=1;
KME=2/(meses+1);

if n~=size(A,1)
    error('Dimension error - A & Z must agree.');
end

if (n~=size(W,1) || n~=size(W,2))
    error('Dimension error - W is not valid covariance matrix.');
end

if (k~=size(F,2))
    error('Dimension error - F not square.');
end

if (k~=size(A,2))
```

```
        error('Dimension error - F & A do not agree.');
    end

    if (k~=size(S,1) || k~=size(S,2))
        error('Dimension error - S is not valid.');
    end

    if nargin < 8, a=0; end

    if nargin < 9, B=0; end

    if nargin < 10
        U = zeros( size(Z,1), 1 );
    else

        if size(U, 1) ~= T
                error('Dimension error - U & Z must have same number of
observations');
        end
    end


    % Initialize log-likelihood
    loglik = 0;

    for i=1:T
        % Time update

        if i==1
          nn = sim(net,U(i,:)');
          xhatm = nn;
          Vm = F*V0*F' + S;
          x=x;
       else

          nn = sim(net,U(i,:)');
          xhatm = F*xhat+  nn;
          Vm = Vm-Vm*A'/(A*Vm*A'+S)*A*Vm;
```

```
    x=x+KME*(( Z(i-1,:) )' - x);
 end

 % Correction

 H = A*Vm*A' + W
 K = Vm * A' / H;

if i>1
    xhat = xhatm + K*(( Z(i-1,:) )' - A*(xfilt(i-1,:))');
    erro=(( Z(i-1,:) )' - A*(xfilt(i-1,:))');
else
    xhat = xhatm;
end;

if (i==14) || (i==23)
    xMPesada=Z(i-12,:)'*0.5+Z(i-11)'*0.25+Z(i-13)'*0.25;
end;

if (i>14) && (i<23)
    xMPesada=Z(i-12,:)'*0.5+Z(i-11)'*0.2+Z(i-13)'*0.2+Z(i-10)'*0.2+Z(i-
14)'*0.2;
end;

if (i==13)
    xMPesada=Z(i-12,:)'*0.5+Z(i-11)'*0.5;
end;

if (i==24)
    xMPesada=Z(i-12,:)'*0.5+Z(i-13)'*0.5;
end;

V = ( eye(k) - K*A) * Vm;

nnGraph(i,:) = nn;
erros2(i,:)=Z(i,:)-nnGraph(i,:);
xfilt(i,:) = xhat';
```

```
        Vfilt(:,:,i) = V;
        Vmfilt(:,:,i) = Vm;

         % Update log likelihood
         loglik = loglik - (n/2)*log(2*pi) - .5 * log( abs(det(H)) ) -.5*(( Z(i,:)' - a -
A*xhatm )' / H)*( Z(i,:)' - a - A*xhatm );
    end;


        grafo(:,1)=Z(:,1);
        grafo(:,2)=nnGraph(:,1);
        grafo(:,3)=xfilt(:,1);
        plot(grafo);

        figure;
        grafo2(:,1)=Z(:,2);
        grafo2(:,2)=nnGraph(:,2);
        grafo2(:,3)=xfilt(:,2);
        plot(grafo2);
```

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