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THESIS SUMMARY

Contributions to the development of a model for improving product quality and streamlining engineering processes in a knowledge-based industrial organization in the field of aeronautics

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Note:

Thesis summary includes chapters, subchapters, figures, tables, mathematical relations etc. taken from the doctoral thesis.

They are numbered identically as in the doctoral thesis.

The annexes of the doctoral thesis are not presented in the summary of the thesis.

This material is an integral part of the thesis.

Author

List of abbreviations

CAA - Civil Aviation Authority

APQP - Advance Product Quality Planning

CAA - Civil Aviation Authority

CAD - Computer Aided Design

CAM - Computer Aided Manufacturing

CMM - Coordinate Measurement Machine

CNC – Computer Numerical Control

DMS - Document Management System

DPD - Digital Product Data Definition

EASA - European Aviation Safety Agency

ERP - Enterprise Resource Planning

FAA - Federal Aviation Administration

FAR - Federal Aviation Regulations

IAQG - International Aerospace Quality Group

MBD - Model Base Definition

NADCAP - Aerospace and Defense Contractors Accreditation Program

NC – Numerical Command

ICAO - International Civil Aviation Organization

PDM - Product Data Management

PLC - Product Life Cycle

PLM - Product Lifecycle Management

PPAP - Production Part Approval Process

SIPR - International standards and recommended practices

Foreword

The thesis entitled "*Contributions to the development of a model for improving the quality of products and streamlining engineering processes in an industrial organization based on knowledge in the aeronautical field*" is the subject of research on improving the quality of products made within industrial organizations in the aeronautical field. This topic has been and is of high importance both for the author and the industrial organizations in which he has been involved for about 11 years.

The research and elaboration of the doctoral thesis took place under the rigorous guidance of the scientific coordinator, Mr. Prof. Eng. & Ec. Aurel Mihail ȚÎȚU, Sc.D & Ph.D to whom I offer my full gratitude and sincere thanks for the competence of guidance, help, goodwill, and availability granted throughout the entire research period in the elaboration of this doctoral thesis.

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Author

Introduction

In the current context of the trend of increasing the products quality with minimal costs, the present thesis approaches this topic from the perspective of industrial organizations in the field of aeronautics. The main objective of this thesis is *to "implement within a knowledge-based industrial organization in the field of aeronautical industry a dedicated methodology, specially created, to improve the management of integrated systems to streamline the quality of production processes."* This goal is generated by the needs to improve processes within industrial organizations.

This thesis consists of two parts. First part presents the current state of knowledge in the field, and in the second part present the directions of research, the main objective, the specific objectives, the research methodology and the original contributions of this research.

The approach to the topic set out in the main objective required documentation on the current state of how today's organizations are structured, and how they operate. This topic is presented into the chapter 1. The study of the literature reveals a tendency in the development of organizations to give increasing importance to intellectual capital. Identifying the model of the type of organization and the way of organization helps to establish specific objectives for achieving the main objective.

Knowing the current state of the organizations in the field of industry approached it from a general perspective and considering the field of interest for the author, namely the aeronautical one, during chapter 2 a more specific study was carried out on the current state of the organizations in this area.

Given that the research area of this thesis overlaps the of product quality requirements management, it was considered appropriate that also in chapter 2 to be present such historical evolution of the products of this field, namely aircraft. This approach highlights the development of the degree of complexity of aircraft, respectively of each component of their structure. This development of complexity is directly proportionally linked to the volume and complexity of product quality requirements, topics addressed in the subsequent chapters of this thesis.

Management of product quality requirements in an organizational context can be achieved through a properly implemented quality management system. For this reason, chapter 3 presents the current state of how quality and quality principles are addressed in industrial organizations. Those aspects of quality management that are defined in quality management standards, but which within organizations are interpreted and partially implemented, are highlighted. At the same time, this implementation of the quality management system requirements and quality concepts enables the organizations to approach the improvement process on a continuous basis.

As well in the current state, in chapter 4 it was studied and presented the actual stage of the process management. Thus, the area approached in this research was brought closer to the subject of the main objective of the research, namely the improvement of processes.

In this research, the improvement and efficiency of production processes are approached through the perspective of the main inputs, namely the deliverables of engineering processes, which have a direct impact on the quality of products. Also, the quality level of their deliverables has significant impact on the efficiency of production processes. For these reasons, the analysis of the current state of engineering processes within the organization studied, is included into the first part of this thesis, being considered a reference point.

Chapter 5 of the thesis presents conclusions on the current state of knowledge in the field of this research and a critical analysis on it, highlighting areas that can be improved.

The second part of the thesis presents the original contributions as result of the research process. Thus, in the first chapter of this part (chapter 6 of the thesis) are defined the research directions, the main objective of the research, the specific objectives, and the research method. In addition to the six-step method, an original method of research development was also used. This method, called *the mind map method*, allows the researcher to start from the main objective and, using keywords, to simultaneously develop several directions of research, at the same time connecting them to achieve a common goal. This method was used throughout the research program for the development of intermediate research reports and finally the thesis structure.

In chapter 7 was approached the first step proposed in the research method, that of analyzing and hierarchically structure the requirements of product quality, with the aim of establishing a study area in the field of product requirements management. In this chapter, the global model for the analysis of metallic structural requirements in the field of aeronautics was presented, aiming that this model should include as many similar products as possible. Also, in this chapter was achieved the classification of the requirements of the structural and metallic products in the types of quality requirements, namely: expressed, unexpressed, measurable, and non-measurable.

The next chapter takes these analyses of the requirements and integrates them into the engineering processes. Thus, during chapter 8, various methods of analyzing the requirements of product quality are addressed, offering different perspectives on them and how they can be integrated. Among the topics addressed and developed in this chapter, analyze of the requirements importance and the interactions between them during the development of engineering processes was realized.

Through methods developed during this research, in chapter 9 are approached the knowledge within the engineering processes, starting from the basic mechanisms of these processes. The development of methods for evaluating the types of knowledge used in engineering processes has led to the identification of more than seventy types of knowledge, all being used repeatedly in the twenty-three sub-processes, respectively seventy different activities. All these combinations of knowledge, activities and subprocesses are presented in this chapter in matrix form.

Analyzing the knowledge within the engineering processes being carried out separately on each individual process, there was generated the needs of modeling all the engineering processes from a common perspective, namely that of the realization of the products. Thus, the flow of engineering processes in the industrial organization in which this research was carried out was called a *global engineering process*.

In chapter 10, the modeling of this global engineering process was carried out through the IDEF0 method. The use of this method allowed the realization of the functional models of all processes, ensuring the traceability from the global process to each individual activity and vice versa. The need to use such a method is given by the need to visualize processes in an integrated way, highlighting the mechanisms of engineering processes and related knowledge.

Having these functional models realized for each activity in the entire global process, and at the same time the matrices of interaction between requirements, respectively knowledge, in chapter 11 were applied statistical methods to conform the correlation between quality requirements and knowledge. Using the Umetrics-M® SDGE13® application, the direct correlation between product quality requirements and knowledge of engineering processes through the deliverables of these processes was graphically represented.

The mathematical modeling of the correlation between requirements and knowledge was achieved in chapter 12, the starting point of the mathematical model being the functional graphic model realized by the IDEF0 method. Thus, it was realized the mathematical relations for all the deliverables of engineering processes. The requirements-knowledge correlation is proposed to be calculated by the level of quality of the deliverable resulting from this correlation. Due to the variation in the level of quality requirements, product quality and knowledge in the production of deliverables, the weighted average method was applied for each factor of the equation. Thus, from this mathematical formulation we obtain the average level of quality.

The mathematical model being realized, also in this chapter was made its simulation for a specially chosen deliverable (the 3D model of the product), following the influence of consciousnesses and the impact they have, in the conditions in which the inputs have the maximum quality level.

In chapter 13 it was achieved the comparison of the results of simulation of the mathematical model with tangible results from the studied organization, thus validating the model. Also, in this chapter is presented the economic perspective that results from the correlation requirements-knowledge. A simulation of future cost reduction is also carried out, based on data calculated using the mathematical model and validated with real data.

In addition to this economic perspective, a methodology has also been developed to address the improvement and quality of products that can be used in any field, together with the analysis tools and methods addressed in this thesis.

PART I

CURRENT STATE OF KNOWLEDGE IN ADDRESSING PROCESS IMPROVEMENT IN AERONAUTICAL KNOWLEDGE-BASED INDUSTRIAL ORGANISATIONS

Chapter 1 CURRENT STATE OF INDUSTRIAL ORGANISATIONS

1.1 Organization as a system

Nowadays, any organization is considered a system consisting of inputs, conditions, and output. To be able to locate the study area of this thesis, namely that within the industrial organizations, a current state of industrial organization types was realized.

1.2 Industrial organizations

To be able to understand the diversity and complexity of the industrial field, it is appropriate to include a presentation of its evolution in the current state of this thesis.

The evolution and development of the industrial field has depended and depend on the knowledge accumulated over time, which is why the direction of the industrial field development is difficult to predict. At the same time, the time needed for development is also much shorter, due to the substantial volume of information available and the creativity of the human resource.

Following the evolution of the industrial environment, we can see an especially important aspect, namely that its development is based on the knowledge accumulated by the human resource within the organizations. That is why it was considered important, also in this part of the thesis, a review of organizations with learning capacity.

1.3 Learning organization

According to the generalized model of the system, learning organizations must have mechanisms that support the process within it, namely mechanisms that work based on knowledge. That is how we get to the area of knowledge-based organizations, which are presented in this part of thesis.

1.4 Knowledge-based organizations

New organizations are those that adapt their development strategies and adopt a new vision of how to conceive and practice a different point of view. The differences between the organization perceived as the "classical", based on control and authority, and the new model of organization, based on knowledge, are big and can create difficulties in terms of the long-term success of the organization.

In both, the current and future new contexts, understanding the significance of the resource or organizations is fundamental. This knowledge is beneficial to organizations and allows them to avoid the dangers arising from their forecasts or approach leading to improvements and efficiency. Through their specific culture, knowledge-based organizations are focused on promoting conceptual value in society as a source of influence and competitiveness.

Studying the literature, some trends have been identified regarding how organizations are viewed in the future. These ideas set up a type of organization called *the organization of the future*. For this type of organization, several perspectives were extracted from the literature, presented in the first part of the thesis.

1.5 The organization of the future

To be able to define this organization, we must first identify its main characteristics. Thus, the main feature of the XXI century is change, which leads to creativity, but at the same time also to risk-taking. Risk reduction can only be achieved by increasing knowledge. This is the explanation of the "explosion" of the publications of famous authors in the contemporary world, appeared especially after the year 2000, which have as object the change and its implications in the organization of the future and in its management.

The general opinion of specialists is that we should not prepare for the organization of the future: we are already in it, and we must adapt quickly, otherwise we are in danger of missing chances, opportunities. It is a chain reaction of history, which, if we disregard it, we take great risks and losses, which today cannot even be assessed, anticipated, or imagined.

Chapter 2 CURRENT STATE OF AERONAUTICAL INDUSTRIAL ORGANISATIONS

2.1 Aeronautical organizations

2.1.1 The evolution of the complexity of the aeronautical industrial field

History shows us that the great inventors approached the technique of flight from two perspectives. On the one hand, they tried to invent equipment lighter than air; on the other hand, they tried to design equipment heavier than air, but with an aerodynamic shape that would allow them to move into the air.

In this thesis, the evolution of the complexity of aircraft is progressively presented. Thus, starting from the idea of making flight equipment lighter than air, to the airplane made by Traian Vuia from pipes and wheels to complex metal structures and composites assembled with modern high-performance electronic equipment. This evolution highlights the complexity and large volume of product requirements that aeronautical industrial organizations must manage.

2.1.2 Current structure of aeronautical organizations

The current complexity of the aircraft leads to the involvement of several organizations with different fields of activity, but at the same time with a common goal, namely "the realization of an aircraft that flies safely at the lowest possible cost".

In this first part of the thesis, the presentation of the types of organizations specific to this field, directs the present research towards the target research area.

<u>Design organizations</u> are those organizations that develop products (aircraft) according to customer requirements - airlines - for commercial or military purposes.

The execution organizations are divided into fields of activity, so that the organization of the final product requires several organizations, connected by a supply chain well controlled by standard requirements in the field of aeronautics.

Certification organizations are those entities that, by their statutes, can grant to all organizations various certifications attesting to their capability to achieve a product, respectively services in aeronautics, in relation to the applicable standards.

Aircraft maintenance organizations are those organizations that maintain aircraft in accordance with applicable standards. These organizations are important in the life cycle of aircraft and are equally responsible for the safety of passengers by applying aircraft verification procedures at each time they are stationary.

This huge structure consisting of organizations with different fields leads to high aircraft costs. To highlight the importance of addressing this area, some current economic data are presented in the following subchapter demonstrating the direct link between product complexity (aircraft) and costs.

2.1.3 Economic aspects of the aeronautical industry

According to statistics related to the annual income of large aircraft manufacturers, Boeing organization holds the first position, closely followed by Airbus.

In recent years, the challenge facing these organizations is driven by the global trend of reducing fuel consumption, reducing the cost of flights, and increasing the number of passengers.

For aircraft manufacturers and their suppliers, a significant impact is held by the development and approach of production technologies. Also, design organizations work closely with execution and certification organizations to develop new materials and production technologies in the shortest possible time. In their help, various aeronautical associations provide support and develop various standards that facilitate collaboration between organizations with different fields of activity.

A big challenge for aircraft design organizations is the infrastructure used to transfer technical information to organizations that execute structures, assemblies, components, and materials. The technical documentations are aligned with international standards, but also with the standards of large organizations such as Airbus, Boeing and beyond. To ensure a good organization of technical information control, these organizations have developed standardized processes for the transfer of design data. Having a major impact on product compliance, these processes have also been introduced into international standards for the certification of management systems.

Product requirements management has been and is a challenge for industrial organizations. The quality management system, nowadays, is the key system that helps industrial organizations to control the quality requirements of products. For this reason, in this thesis are addressed and presented the principles of quality and the operation of the quality management system.

Chapter 3 CURRENT APPROACH TO QUALITY MANAGEMENT IN THE AEROSPACE INDUSTRY

3.1 Quality and associated concepts

Research involving the term *quality* requires rigorous documentation on how its concepts are defined. The field of quality is highly studied, which is why the presentation of a current state requires a large space in a thesis on the field of quality. However, the systematic approach to quality, in the present thesis, is aimed at gradually introducing the objective of the thesis, in close connection with this subject. The starting point for this approach is when the transcending to the production and mass consumption of products, as well their huge diversification, has had a major impact on the broadening of the concept of product quality. When obtaining quality in this new context, it mattered the way of constructive and technological design, the development and maintenance of technological processes and the way of assembly and delivery of products. The terminology and meanings of quality are now sized in relation to all these aspects. At the same time, it differentiates between a designed quality, a manufactured quality and a delivered one.

Having a quality management system, products made in organizations require verification to ensure compliance of. Quality control must be carried out with appropriate inspection methods and techniques. To ensure optimal control for the entire production flow, it is important to know the inputs and outputs of each phase of the product manufacturing process. The quality management system it is supported by quality assurance, which within an organization shows its level of involvement in giving confidence that the quality requirements of the products are met.

It was found lately a strong trend to associate the requirements of standards, guides, strategies principles, techniques and approaches aimed at streamlining activities, increasing the competitiveness of organizations, increasing added value, reducing cost, and more flexibility in relation to customer requirements *(Oprean & Țîțu, Quality Management in Knowledge Economy and Organization, 2008).*

In the design of the quality management system, the process-based approach involves identifying both the flow of processes/information in the organization and the interactions between them.

Total quality management provides organizations a system that allows them to make products and services, according to customer requirements, with minimal costs and through the involvement of the entire organization. The 'TQM culture' may be considered in relation to the following values shown in Figure 3.5.

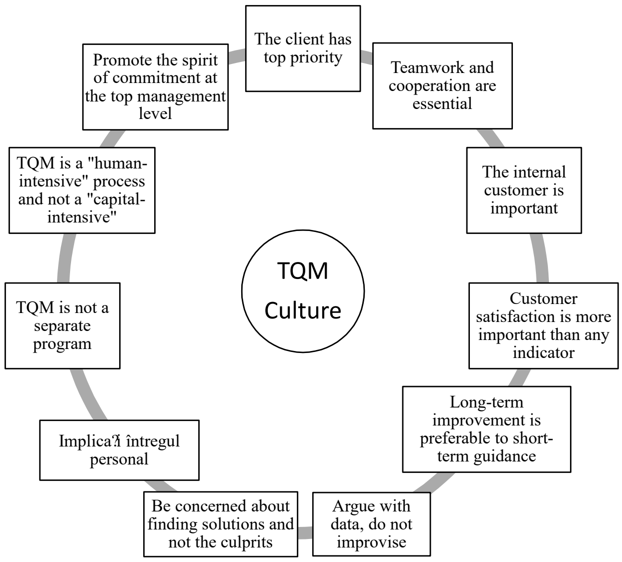


Fig. 3. 5 The values of organizational culture *(Oprean & Țîțu, Quality management in knowledge economy and organization, 2008)*

For, even a better understanding of total quality management, as found in the literature, the principles of the "zero defects" strategy and "obsession with the customer" bring different perspectives on quality, with the aim of preparing some answers that may arise.

Competition between organizations is an engine to motivate people to continuously seek the development of new products / services to satisfy customers.

3.2 Current perceptions of quality management systems in the aerospace industry

Quality in aeronautics

The aerospace industry is responsible for the quality of thousands of aircraft carrying millions of people around the world, every day. Aircraft components have a service life of more than 50 years, which means that quality practices must be incorporated into every stage of design, production, operation, and maintenance to ensure reliable processes that can withstand intensive use.

The International Quality Group has developed the *AS 9100 – Quality Management System* standard, to establish a global reference point for the aerospace industry. The AS 9100 standard applies to the entire aerospace supply chain, including aircraft design, manufacture, replacement, and maintenance.

The aerospace and defense industry encompasses civil and military needs for aircraft, helicopters, rockets, satellites, and other products that are maintained to the highest safety and quality standards. Aerospace and defense manufacturers and their suppliers build their products using expensive materials and high-precision processes and often operate in short-term and in high-complexity production environments.

The globalization of the aerospace industry requires an investment in the quality management system to satisfy the final customer of the products. The International Organization for Aerospace Quality (AIQG) has made huge effort to support this demand and has achieved a series of quality standards starting with EN AS 9100, based on the ISO 9001 standard.

Some of the concepts of qualities considered the most important in this thesis, were presented in this first part.

Process-based approach

Each produced product goes through a series of processes within each aeronautical industrial organization, either production processes, support processes or management processes. The approach of quality from the perspective of the process is the most logical approach, which ensures the shortest path towards the result of the quality improvement *(Cupșan, Țîțu, & Pop, 2019).* The process-based approach is achieved by defining systematically the processes and managing interactions between them, to achieve the results pursued according to the quality policy defined in the organization's strategy. For an organization to be efficient and effective in achieving its objectives, it is necessary that all processes are interconnected in a system, as a whole.

The continuous improvement

If an industrial organization wants to play a significant role in the competitive market, it must implement any actions necessary to meet the requirements and increase customer satisfaction, such as:

- Continuous improvement of products and services to meet the requirements, but also as a useful preventive measure in addressing future needs.
- Correction, prevention, or reduction of undesirable effects.
- Improving the performance and effectiveness of the Quality Management System.

Integration of legal requirements into the Quality Management System

The importance of implementing in the quality management system of the legal requirements started from the need to regulate some security requirements required by government organizations. The integration of the requirements is critical for industrial organizations if they want the products made to be used in functional aircraft.

The importance of the traceability of products in the aeronautical field

In the field of aeronautics, traceability is essential, which is why it is a mandatory requirement in the quality management system. From the point of view of production organizations, each part or part made must meet the minimum identification requirements. Thus, in the case of unwanted aeronautical events, respectively during maintenance checks, the process of identifying the causes of nonconformities is easy to achieve. Thus, the implementation of corrective actions can be extremely specific.

Aeronautical audit

Audits are not only undertaken to ensure regulatory compliance, but also to identify weaknesses in the management system. The audit process is designed to serve management needs, provide them with *feedback* on existing systems, on implementation and effectiveness, and to provide objective data to contribute to decision-making.

Complementary to the process audits are product audits, audits conducted especially by customers. Also, for EASA certified organizations, these audits are also over-verified by the Civil Aviation Authorities of the country where the organization operates.

Advanced Product Quality Planning (APQP)

The multitude of requirements of aeronautical-specific products, combined with the increasing demand for aircraft development, has led to the adoption of methods in the automotive field, namely Advanced Product Quality Planning (APQP) (*Țîțu & Pop, Advanced Product Quality Planning Management in a Knowledge Based Organization, 2021), (Pop, Pop, & Țîțu, 2022).*

APQP borrows certain risk analysis tools from the military industry. Now, APQP is a mandatory requirement for all suppliers of the three major American manufacturers when developing new products. AIAG now has as members, apart from Ford, GM and Chrysler, and Japanese manufacturers such as Toyota, Honda, Nissan, as well as most of their suppliers.

This methodology is in full development and adaptation to the field for which it was designed, leaving room for future research.

Chapter 4 CURRENT STATE OF THE PROCESSES MANAGEMENT IN THE AERONAUTICAL INDUSTRY

4.1 Current perceptions on process management in aeronautical industrial organizations

People need to "know" how things are done and follow the usual paths. However, unless there are explicit descriptions of the processes, it is not possible to analyze these descriptions to establish their effectiveness or to improve them.

Many organizations have continued to perform unnecessary tasks for decades, without analyzing the purpose of certain things. The risks in such cases are, for example, to send a document to more people than necessary and therefore to wait for additional approvals. However, within organizations there are several types of processes, namely management processes, operational processes, and support processes.

Management processes

The functions of the management process are interrelated and cannot be ignored, especially since the management process designs and maintains an environment in which staff, working together in groups, meet selected objectives effectively.

Operational processes

In the management of business processes, the principles of value-based management have been introduced. Existing analyses of this issue operate at a high level, preventing the use of value-based business process management at the operational process level, both in research and in practice.

Support processes

The support of business processes through methods, techniques and software applications is done with the aim of designing, adopting, controlling, and analyzing the operational processes involving people, organizations, applications, documents, and other sources of information *(Weske, van der Aalst, & Verbeek, 2004).*

Modeling of systems and processes

The functioning of systems and processes within industrial organizations depends on a large number of a range of factors and the dependencies between them.

International standardization organizations have developed quality management systems with the aim of facilitating organizations access to a reference structure on how to organize processes. The way of making the process map is a concrete example of a method that can be used to model the systems and processes of organizations. However, the process map is designed on a general level and does not highlight the factors that influence the processes and the interaction between them. The structure of the quality management system in industrial organizations, in the field of aeronautics, is based on the standard AS 9100:2016. However, the challenge that organizations must answer is to comply with the requirements of this standard and the requirements of the customers at the same time, within the production processes. The complexity of the requirements of aeronautical products requires in management processes an approach based on risk analysis. Thus, management decisions are influenced both by the knowledge of managers in the field in which they operate, as well as by the available information related to related processes, information that they can use.

It can be stated that, at this moment, in all organizations, the evaluation of the integration of processes in the quality management system is made by carrying out process audits, using as a criterion the standard of the quality management system.

The importance of the process map in system modeling

Usually, the process map is the starting point for the detailed modeling of each process. Any organization can improve its quality management system. The conformity of processes, products and the quality management system in the organization can be demonstrated, even if the standard does not expressly require it, by drawing up documents such as (*Mendes, 2013)*: process map (matrix); specifications for the product; production programs; list of approved suppliers; testing and inspection plans; installation, operation, and service manuals; rules and procedures.

In preparation of process map, equal importance is given to the performance of all component processes. This performance shall be determined based on process-specific objectives or performance indicators.

Once the research has reached this point, we can establish within the organizations the existing processes and their connections. In this research, due to the special interest in the processes with the greatest impact on the requirements of the product quality, the approach is directed towards the engineering processes.

4.1.1 Classical engineering processes in the industrial field

In an aeronautical industry organization, engineering processes are those processes that are responsible for transferring product quality requirements into production requirements. The production processes can be considered as complementary to the engineering processes, which is solely engaged in the manufacture of products and their control.

As can be seen in Figure 4.8, engineering processes can only be applied if there are production processes with technology and equipment capable of taking over the "engineering" generated by them. Engineering processes can be grouped according to the categories of deliverables they generate.

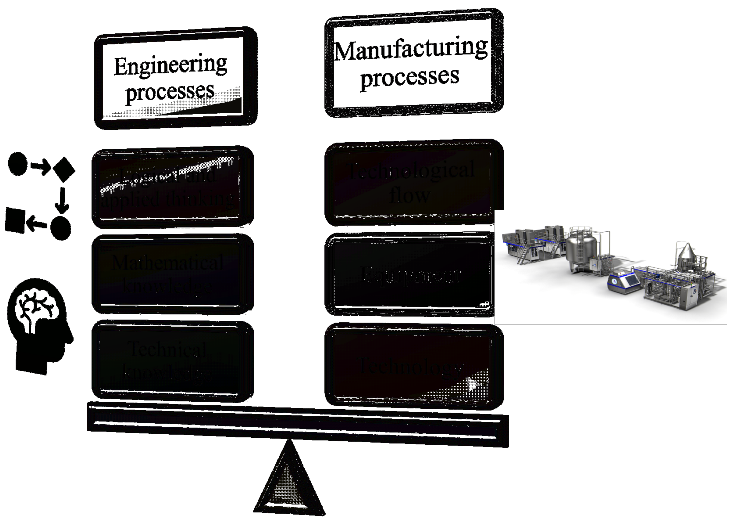


Fig. 4.8 Correlation of engineering processes with production processes (*Pop & Țîțu, Modeling the global engineering process in an aerospace organization, 2021)*

Design processes take the most major place within the engineering processes, due to their main purpose – to use the technical knowledge, and not only, for the development of products required by customers.

The processes of production documentation preparation are based on the conversion of product documentation, as designed, into documentation specific to production organizations.

Technical data management systems configuration processes are those processes that establish and control the flow of technical data of products within organizations, necessary for production processes.

Manufacturing process design processes are those processes that convert the design requirements, product, and process, into technological production flow.

Thus, for the studied organization and its field of activity, that of making metallic structural parts from the aircraft structure, it was found that, in addition to the design processes of cold and hot plastic processing and deformation of products, the design processes of technological processes also include the processes of surface treatments of products and those of assembly. Thus, we can establish the level of complexity of engineering processes. The more stages of the production process within an industrial organization comprises of the product production process, the more complex and difficult the process of designing the technological process.

Analyzing all the engineering processes within the organization studied, in this thesis was defined the concept **of a global engineering process** that can be defined as the ***assembly of engineering processes within an industrial organization, that have a common purpose and are structured in a logical sequence related to the technological process of product production.***

The method of product control in aeronautical production organizations is applied in quality control processes. This process must incorporate into the control plan, in addition to the process and product requirements, and a reaction plan where the measured values tend to go out of the control limits (tolerances). Some of the requirements that are incorporated into the control plans also appear from the production processes, after the first batches manufactured, as preventive actions of process control.

4.1.2 The global engineering process applied within an aeronautical industrial organization

As an integral part of the global engineering process, engineering processes have the role of transforming the technical requirements of product quality into production requirements and parameters and are key processes in the organization, due to the major impact they have in applying the requirements in the production process. These engineering processes are applied in any production organization and constitute the link between the design processes and the production processes or, in other words, the link between theory and practice.

In the aerospace industry, each product is identified by a set of documents containing the design data. Thus, in addition to the geometric shape and dimensional requirements of the products, this set of documents is completed by legal requirements for approving the products. The approval of products in the field of aeronautics is related to their safety in aircraft operation. The requirements to be complied with and verified for the approval of the products are given by the strict observance of the projected data and the requirements of the production and inspection process.

The challenge of the design organizations in the aeronautical field is that all structural products must be designed in such a way that they have a weight as low as possible and at the same time to ensure a high resistance to mechanical, chemical and fatigue stress.

For a proactive approach, it is necessary to study the current process and the deliverable results, and then to draw conclusions and make assumptions about the approach to this process.

From the perspective of the global engineering process, the use of an ERP application for the management of technical input data is necessary for any organization. The need is not necessarily given by the large volume of information or its large variety, but also by the need to manage changes that have occurred for various reasons in the shortest possible time frame.

4.2The current state of the processes in the industrial organization and their integration into the quality management system

Figure 4.16 shows both the distribution and connections of processes in an industrial organization in the aeronautical field, specifically on the manufacture of metal structural components.

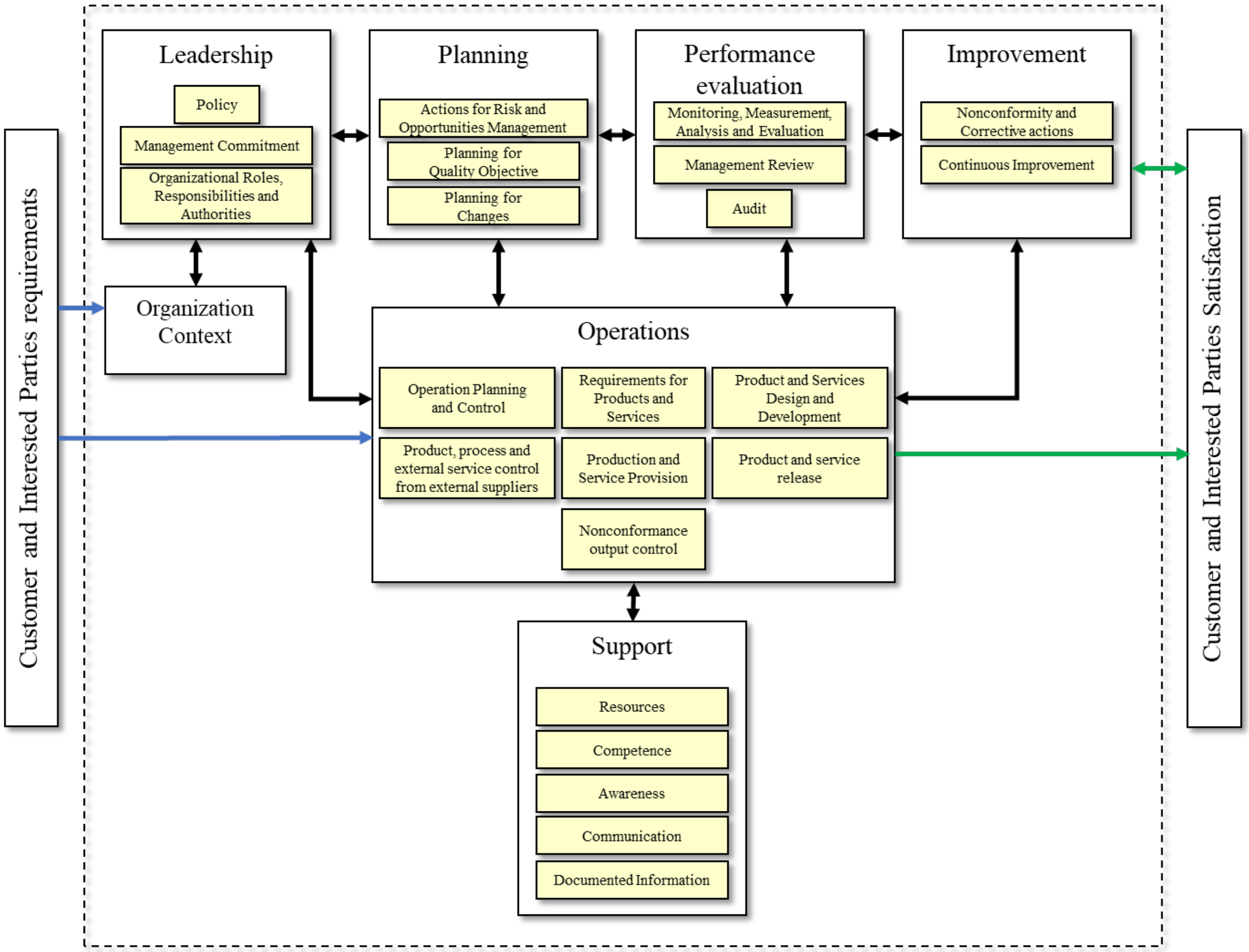


Fig. 4.16 Process map in an industrial organization in the aerospace industry

The leadership process (position five in Figure 4.16) is a management process with a major impact in the organization, which is why within these organizations the focus is on the commitment of senior management and its level of involvement in processes. The work of the leadership process is carried out in relation to the context of the organization.

The Planning process is the key to the success of any organization, regardless of the field of activity. Thus, the planning of the organization's objectives will be found at all hierarchical levels. Planning can be achieved by carrying out development projects, long-term or short-term production projects or improvement projects.

The control process by measuring and evaluating activities within the organization is represented by the processes in positions 9 and 10 in Figure 4.16. Evaluating the performance of the organization is carried out through management analysis and audits of all processes.

In addition, **the improvement process** helps to evaluate activities and at the same time becomes a major entry into the improvement planning process.

The support processes (position seven in Figure 4.16) are the processes that deal with the management of human resources, in particular:

- The process of hiring human resources.
- The process of assessing competences.
- The process of awareness of human resources at all hierarchical levels.
- The process of communication within and outside the organization.

Operational processes (position eight in Figure 4.16) represent the "engine" of the organization. Thus, the processes within this group of processes are important and they are given special attention.

In the field of aeronautics, certain production or production processes are of a more special nature, being considered processes with a major impact on products. Because of this, aircraft manufacturers are directly involved in the qualification of suppliers, carrying out qualification audits and process evaluation. Thus, the processes of materials/ semi-finished products, heat treatment and inspection processes of materials / semi-finished products, certain mechanical processing processes, surface treatment chemical processes, non-destructive inspections, assembly processes and inspection of assembly elements are special processes.

Within the studied organization, the global engineering process is functional and integrated into the quality management system, aiming to achieve the stages in relation to the inputs and outputs corresponding to each stage. In addition, the sequence of steps is carried out in such a way that each entry is available at the time when the stage requesting it must be applied to the process. The importance of some stages can be given not only by its complexity, but also by the impact that the outputs of that stage have on the entire process. For example, the realization of the 3D model at the stage of preparing the CAD documentation within the process, a stage that does not have a very high degree of complexity, has an impact on 60% of the sum of all other outputs from the later stages, being also the internally generated deliverable containing the most important characteristics of the products.

As a direction of research can be considered re-evaluation of the influence of the complexity of products on their stages and outputs, to develop alternative lanes for the process. The development of these alternative paths, as well as the introduction of process distribution nodes, can be even more beneficial as they are identified closer to the onset of the process. However, the development of multiple alternatives has a disadvantage, related to the fact that at the level of an organization there are multiple possibilities in carrying out a process, which can lead to decision-making bottlenecks. For this reason, all alternatives must be analyzed and experimented with, so that in the end the optimal variants are chosen.

Chapter 5 CONCLUSIONS ON THE CURRENT STATE OF RESEARCH IN ADDRESSING PROCESS IMPROVEMENT IN AERONAUTICAL KNOWLEDGE-BASED INDUSTRIAL ORGANISATIONS

The organization can be considered as a system that, through processes of transforming inputs process them and generates output. The evolution of industrial organizations has been and is generated both by the increase in the level of product quality on the part of customers and by the increasing volume of requirements. Also, a key factor in the evolution of industrial organizations is played by competition and technological development.

Nowadays, due to the huge volume of information and the way it can be accessed, industrial organizations have had to adapt and implement new systems of work and processes that can manage many more parameters and variables. This stage is called Industry 4.0, a term introduced in 2011 at the Hanover fair. This approach has taken up and developed by many authors in the field, such as Hermann, M., Pentek, T., & Otto, B., who in 2016 presented the basic principles of this concept.

As Drucker stated since the nineties, humanity irreversibly fits into the information society, also called the society of knowledge or organizations (*Drucker, The new society of organizations, 1992).* Today, about 30 years after this statement, it can be found that we are in this information society, and organizations depend on the amount of knowledge they possess to be able to lead a business to success. Therefore, organizations are obliged to learn, create, and update new technological skills, as well as to abandon outdated procedures to remain competitive in a world characterized by rapid technological progress.

The main feature of the XXI century is change, which leads to creativity, but at the same time also to risk-taking. Risk reduction can only be achieved by increasing knowledge. History shows us that the great inventors approached the technique of flight from two perspectives: an attempt to invent equipment lighter than air, or equipment heavier than air, but with an aerodynamic shape that would allow them to remain in the air.

In the last part of the XX century, the enthusiasm for the development of the aeronautical field was reduced, the organizations focusing more on the digitization of the equipment necessary for airplanes and on investments in the production technologies of the components. This direction was given by the desire of organizations to reduce fuel consumption and at the same time the cost of flights for passengers. Aircraft development involves organizations with different fields of activity, but with a common purpose, namely the realization of an aircraft that flies safely, at the lowest possible cost.

Some of the organizations essential to the realization of aircraft can be considered as: design organizations, execution organizations, certification organizations and aircraft maintenance organizations. Due to the complexity of aircraft, both in terms of the number and diversity of parts, and the complexity of the requirements, their production depends on a large chain of suppliers, which makes the manufacturing process exceedingly difficult to manage.

To define and control this complex process, certification organizations play an important and decisive role in the certification of suppliers and at the same time of products, by introducing standards of the quality management system and not only, and by monitoring their compliance.

Government organizations have a particularly significant role to play in regulating aircraft production processes to ensure that a product is made that needs to operate safely. In the same context, the operation of aircraft within normal parameters and safe conditions, aircraft maintenance organizations play a particularly key role. Aeronautical organizations, from design, execution, certification, and maintenance, are a "global organization" that provides customers – or aeronautical organizations and passengers – with a high-quality product throughout the life cycle of the aircraft.

The commercial aeronautics field is on an upward trend of development, due to the increasing number of consumers (passengers). At the same time, organizations in this area are challenged to lower the cost of production of aircraft, using modern technologies of production and process management.

The specialized literature contains enough studies that address different perspectives on the structuring of past, current and future organizations, but we still manage to identify different perspectives, perspectives that generate research directions such as:

- The analysis and presentation of this 'global organization' created from several organizations with specific fields of activity, which, through-a set of complex mechanisms, realize the aircraft.

- Analysis and study of modern production processes and management processes necessary for the management of all activities, from the design organization to the maintenance organization.
- Detailed analysis of how aeronautical industrial organizations implement digital technical documentation in their manufacturing processes.

Quality can be defined from different perspectives, but the most comprehensive definition is that in the ISO 9000:2015 standard, quality management system, which defines quality as "the set of characteristics of an entity that gives it the ability to meet the expressed or implicit needs". In relation to the customer-supplier relationship, quality can be seen as the adequacy between the expressed needs of the customer and the service provided by the supplier by respecting a contract or commitment.

For the definition and documentation of a quality management system in an organization, quality documents are the key to the connection of the system with physical processes, both for guiding them and for their control and auditing. Also, the quality management system documents provide the support of the organization through which it transmits its strategic vision at all its levels.

To obtain quality products according to the requirements and repetitively, quality control is essential. Control of input and output parameters is the key to quality control of the entire process in an organization. Also, quality cannot be achieved without the commitment of the organization's management, starting from the definition of quality assurance – "to have and give confidence". Quality assurance can be achieved through the systematic planning of the activities involved in an organization, the purpose being not to produce nonconformities, to optimize costs and to ensure the financial resources necessary to carry out the processes.

Quality management is the cumulation of coordinated activities, management, and control of the organization to obtain quality, defined as the level of a set of characteristics of an object that ensures the fulfillment of requirements. In the design of the quality management system, the process-based approach involves identifying both the flow of processes/information in the organization and the interactions between them.

The concept of total quality, through its principles, methods, practices, and tools, ensures and provides organizations with a strategy to improve services and products. This will ensure the satisfaction of customer requirements. The total quality management offers organizations a system that allows them to realize products and services *(Pop G. I., Pop, Oprean, & Țîțu, 2021)* according to customer requirements, with minimal costs and through the involvement of the entire organization. The principle of "zero defects" means that all the activities of the organization must be carried out without errors assure that each time the same is done, without errors. This principle can be applied through preventive actions, systematically, at the level of the whole organization.

The aerospace industry is responsible for the quality of thousands of aircraft carrying millions of people around the world every day. Aircraft components have a service life of more than 50 years, which means that quality practices must be incorporated into every stage of design, production, operation, and maintenance to ensure reliable processes that can withstand intensive use. The globalization of the aerospace industry requires an investment in the quality management system to meet the final customer of the products, so the International Organization for Aerospace Quality (AIQG) has made many efforts to support this demand and has achieved a series of quality standards starting with EN AS 9100, based on the ISO 9001 standard. In addition to the quality management system, large aircraft manufacturers have defined standards of processes, products and even systems, which they require suppliers to implement, to ensure that they produce quality parts according to the requirements. Production organizations also consider the requirements of government organizations such as EASA, FAA, CAA, etc., creating difficulties in implementing and integrating them into a quality management system.

Its quality and management in aerospace industrial organizations is viewed to be applied similarly to the automotive industry. However, the difference is given by the volume of product quality requirements in this area in relation to the volume of production. In other words, the large volume of products in the automotive industry it is compensated in the aeronautical industry with the high volume of requirements. Thus, following the analysis of the current state in this field, several research directions have been identified, directions that can be approached in further research, namely:

- Development of a model for integrating the requirements of manufacturers with the requirements of the quality management system.
- Process-based approach, which can be a useful approach in the process of integrating processes within the quality management system.
- The use of methods for analyzing management processes and developing parameters for their measurement and control.

The current research was based on a demand for the improvement of industrial engineering processes within a burgeoning organization in the aeronautical field. This organization is involved in the process of implementing and correlating all quality management system requirements, product, process and management processes requirements of aeronautical customers and system requirements of government organizations.

Although in the automotive industry it is quite common, even mandatory in some cases, the implementation of the APQP methodology in the aerospace industry is recent, which is why the IAQG develops in 2016 the AS9145 APQP / PPAP standard, published in 2017.

Nowadays, in the context of the harmonization of legislation with that of the European Union, organizations are mostly faced with new requirements, and cantonment in a single traditional management system is an unacceptable risk. Modern management must be viewed in a systemic, integrative vision, having as finality both the increase of economic efficiency and quality, competitiveness in general, as well as the preservation of the life and integrity of employees, the protection of the environment, information, the general increase of the quality of life. The objective of the integrated management is to achieve the functioning of the organization in a manner in which the health and safety of the employees, as well as the protection of the population, respectively of the flora, fauna, water and soil are perceived as the very goals of the respective activity, of equal importance and in full compatibility with the profit- and quality-oriented objectives of the respective organization. The successful implementation of integrated management depends on the effectiveness of change management.

The integrated quality management system participates as an added value within the organizations, by implementing all the requirements and management methods in the realization of quality products and services. Without a synergy between systems and without the involvement of the entire organization, of all the people who compose it, in the realization of products and services, the added value can only decrease. Moreover, the lack of integration leads to an increase in the likelihood of losses occurring. The integrated quality management system creates the possibility for the entire organization to orient itself towards the quality of the product / service, to make it competitive. Access to modern technologies, which allow the realization of products / services at the lowest possible costs, is increasingly easier, which is why competitiveness is increasingly based on the realization of products / services at a high level of quality. Also, customers are increasingly interested in the level of integration of management processes with the requirements of their products / services in a single quality management system. The reason is given by the need to validate the quality of the product / service in a - competitive market.

If we look at the way of organizing industrial organizations in relation to the purpose of various departments, a multitude of management systems can be observed, which without proper integration led to the appearance of losses. These losses have been increasingly studied, identifying the integration of systems as the only solution.

For the integration to be implemented in a structured way, it is necessary to plan it. A lot of organizations have adopted the standards of the management system because of external pressures, based on customer requirements to implement a quality standard within the organization or based on external requirements to introduce an environmental system and / or occupational health and safety. In other words, the integration of management systems brings benefits to the entire business. Precisely for this reason, the essential concern should be to understand the goals and needs of the business, correlated with the mission and vision of the organization.

Industrial organizations in the aerospace field have adopted or are in the process of adopting the standards and specifications of management systems, such as AS9100, ISO14001, OHSAS18001, ISO/IEC27001, ISO22000 and ISO/IEC20000, either out of necessity or with the desire to be in line with current trends. Unfortunately, however, they are often faced with a set of independent systems that have different goals and objectives. Often, these systems are fragmented and documented unevenly, are under the coordination of different people and are audited individually. However, in most management systems there are common elements that can be used in an integrated way; and their basic principles, which are common, can be identified and constructively implemented within the business management system.

Quality throughout the aerospace industries, from commercial aviation to defense aviation, is measured against the AS9100 series of standards. The standard is universally adopted but has a different name on different continents. The AS9100 is used in the Americas, EN9100 in Europe and the JISQ9100 in the Asia-Pacific region. The integrated management system gives the management of an organization the opportunity to determine which are the directions for the purpose of effectively achieving the objectives set.

The first thing that an organization needs to achieve is to define the common requirements of management systems. Only in this way will it be able to respond to the continuous interest in the direction of an integrated approach to management systems and organizational risk management. The role of integrated management is also to support employees in the integrated implementation of processes.

To ensure customer satisfaction, aerospace organizations must continuously produce and improve safe and reliable products that meet or exceed both customer and regulatory requirements. The globalization of the aerospace industry and the resulting diversity of regional/ national requirements and expectations have complicated this objective. Suppliers face the challenge of delivering the product to customers who have different expectations and quality requirements. The AS 9100 standard includes the quality management system requirements for the aerospace industry. The establishment of common requirements for use at all levels of the supply chain by organizations around the world should lead to improved quality and safety and lower costs, due to the elimination or reduction of organizational requirements and variation as an inherent result of multiple expectations.

Practitioners in aerospace quality recognize the advantages of developing internationally accepted quality management system standards and the benefits of harmonizing the system requirements for aerospace suppliers. In practice, organizations must make considerable efforts to understand and implement the requirements effectively, thereby achieving production goals. Implementing the requirements will be a challenge for many manufacturing organizations. The reason is that in the past, IAQG has focused on "WHAT?" rather than "HOW?".

The aerospace industry must meet the highest levels of safety, whether it is the design, production or provision of screening and repair services. Focusing attention on process results highlights the usefulness of the process-based approach when the goals of improvement are to maximize added value and increase customer satisfaction. Through a process-based approach, continuous improvement can be extended to all processes related to the organization.

There is a significant difference between the process-based approach and the departmental approach. General speaking, all organizations are structured in a hierarchical manner, on a number of functional departments. Often, these departments are run vertically, and the responsibilities allocated to achieving their planned results are distributed among the various functional units. In this situation, the end customer or any other interested party is not always visible to all those involved in the activities carried out by the organization; therefore, problems arising in the interface between departments are given a significantly lower priority over that of the short-term objectives of those departments.

In general, organizations in the field of the aerospace industry are structured in this way, vertically. One of the main differences between vertical business organizations and those structured horizontally is that, in a vertical system, top-level management issues orders, and employees follow those orders without input or objections. Instead, employees in a horizontal organization are encouraged to make suggestions and provide ideas that can improve processes in the workplace and are given the authority to implement changes without having to obtain authorization. Although small organizations do not operate in a context such as the military-, where vertical control is essential for survival, some organizations find it beneficial to find ways to maintain a vertical structure and thus maintain their competitive advantage.

When we talk about planning and decision making, a significant role related to her position as a manager is played by the fact that he is in perspective and anticipating trends that could exert their effect on work efficiency. Since all the functions of the management process are interconnected and cannot be ignored, the management process has the role of designing and maintaining the environment in which the staff work, in a form in which the objectives that have been selected are achieved in an efficient way. The purpose of designing, adopting, controlling, and analyzing operational processes aimed at involving human resources, organizations and other sources of information is to support business processes through various methods, techniques, and software applications.

At the time when changes are felt within the organization or when the principle of operation of the organization must be argued, of real interest are the process maps. Because they are correctly made, the process maps are extremely useful in this respect, an idea also supported by the bibliographic material studied. They allow the visualization of the quality management system and the integration of the processes of the organizations, which is also a requirement of the standard. This map allows organizations to distribute, at the macro level, the responsibility of processes in the hierarchical structure of each organization. The six main processes of the Quality Management System are coordinated at the macro level following the principles of quality management. Subprocesses, on the other hand, are not as well documented, the standards proposing variants that can be used to a greater or lesser extent.

The process map is a particularly useful tool to be able to visually represent the relevant information about the value creation and interdependence that exists between processes, considering the role they hold in the value creation chain. Also, given the quality requirements of aeronautics, management systems in organizations must be aligned to ensure the traceability of products, the correct implementation of product requirements and the management of the risks of product realization throughout the entire process.

The main purpose behind mapping business processes is to help organizations become more efficient. A clear and detailed map or chart of the business process allows an outside organization to step in and examine whether current processes would improve or not. Mapping business processes has a specific objective, namely, to serve to measure and compare an objective to the objectives of the entire organization, to ensure that all processes are aligned with the values and capabilities of the organization.

Organizations in the aeronautical industry adapt the quality management system according to customer requirements, which can even be management systems specific to their products. Thus, Airbus has created its own supplier management system by which I ask them to integrate into their own quality management system specific requirements, to ensure the quality of the products they receive from them.

Any industrial organization wants to implement strategic requirements at all levels of processes, but the level of understanding of strategic requirements may differ between the organization's departments. Thus, different approaches may occur in defining processes with a higher degree of detail, which in turn lead to a non-functional system.

The technological flow of product realization, respectively of the technological processes, has a direct impact on the interaction between the support processes and the management processes. Analyzing the processes and the connections between them generates research opportunities, namely:

- Mapping processes within an aeronautical organization.
- Developing a flow of processes by identifying inputs and outputs on each individual process.
- Identification of the processes of the critical thread in the process flow, with a major impact on the quality of the products.
- Identification of areas with the highest risks, which can affect the quality of the product, and with the greatest losses in the time of implementation in production.

The approach to the global product engineering process in such an organization is even more complex, due to the high variety of technical production requirements that must be generated by this process. Now, the industrialization process tends to be a functional process, but with nonconformities that generate losses in terms of time, respectively financial, for which the approach of the process is important enough for the organization. The influence of human resources knowledge has a major impact on the results of the process, results that can be found in:

- Execution time: it can increase depending on the complexity of the products, but also in relation to the number of iterations to be covered if the production requirements have not been correctly or completely achieved.
- The production time of the products, as follows:
  - Processing strategy:
    - A machining strategy defining a blank with far too large dimensions leads to high machining times and much higher material and processing costs.
    - A machining strategy that does not use a requirement for optimal cutting tools that is durable, processes materials in a short time -and generates high surface quality.
    - A machining strategy that does not use standard product fasteners leads to excessive costs for the devices and sometimes to increased preparation/completion times.
  - Support devices for the production and inspection process:
    - The design of devices that require too long training times.
    - The design of unique devices for comparable products leads to increased preparation/completion times for multiple production batches and complicated planning.
  - Inspection strategy:
    - The approach of manual inspection for products that can be inspected in coordinates sometimes consumes much more time in trying to build supporting elements for the measurement system (path, arms, etc.).
    - Repetitive inspection of geometrical characteristics which are not subject to the final shape of the product may increase the production time.
- Costs of auxiliary materials to be used in production. Some materials, such as surface protection materials, are more expensive.

The process of transforming technical requirements into production requirements is applied in all industries. The current trends of optimizing this process are to virtualize the stages of the process (Industry 4.0), to provide organizations with all the necessary tools to reduce the risk of poor communication during the process, to provide all departments or various organizations with access to technical information, as it was designed. However, decisions and technical solutions are based on knowledge of human resources, which is why more often there is talk about Industry 5.0, where people are the center of the system. Applications can facilitate access to information, provide a visualization of technical data for resources with different level of technical knowledge, but they cannot replace the creative process carried out by people on both products and operational and support processes.

All the aspects presented in this part of the doctoral thesis led to a scientific research based primarily on a rigorous documentation, on an important qualitative contribution to the efficiency of manufacturing and the management itself within an industrial organization in the field of aeronautics. The processes within the analysis were carefully selected and led to a modeling carried out in such a way that in the end, solutions could be presented to improve the quality of the process management, as well as to reduce the nonconformities in the specific industry.

The research process of the current state in the specialized literature was carried out simultaneously with the process of analyzing the current state of the studied organization. In this regard, the following studies can be listed:

- Analysis of the quality management system and the interaction between processes, interpretation of the requirements of each process and how they are applied within an aeronautical industrial organization.
- Identification of factors of influence on each process to develop mathematical models of the analysis of the quality of outputs from a process according to the inputs in the process.
- Analysis of a key engineering process in an industrial organization, in terms of the sequences of steps in the process and their reliability.
- Impact analysis of each output in each step of the process, in relation to all outputs, to identify the greatest impact.

This documentation has generated a series of ideas and research directions from which the following can be mentioned:

- Evaluating all possible scenarios of the industrialization process so that the process operates with the minimum of risks in the shortest possible time.
- Analysis of the industrialization process from the point of view of interactions with external processes, but also the identification of the inputs from these processes and the impact they have on it.
- Evaluation of the industrialization process from the point of view of the level of integration in the quality management system within the organization, aiming at reducing the redundant stages and reducing the time required for this process.
- Assessing the impact of the knowledge used at each stage of the industrialization process, by identifying the knowledge needed to achieve each output with the greatest or even the most critical impact and quantifying it in relation to the appropriate stage or the entire process.
- Identifying the possibilities of reducing the production time for a group of products, following the CAM, CMM programming strategies and the design of the devices, can be considered another direction of research. In this case, the analysis of the production time in the current production process can be considered as a starting point, aiming at improving the time by analyzing the factors of influence and improving them.
- Developing a dynamic model of approaching the industrialization process, using its possible combinations. These combinations will relate to the industrialization times (the development times of the product production documentation) for the same category of products, and the result being to reduce the time, respectively the non-recurring costs of the products.
- The use of this model in the process of bidding products would provide a significant improvement within the current organization.

This research includes only a part of the research directions mentioned above, namely those directions that come from the perspective of the direct relationship between knowledge and product quality. Our approach is due to the professional experience gained in the field of engineering and management within an industrial organization in the field of aeronautics, specifically in the manufacture of metal structural components in the composition of aircraft.

Part II of this thesis addresses exactly this direction of research, namely the influence of knowledge from engineering processes on product quality.

PART II

CONTRIBUTIONS TO RESEARCH AND DEVELOPMENT OF A MODEL FOR IMPROVING PRODUCT QUALITY AND STREAMLINING ENGINEERING PROCESSES IN A KNOWLEDGE-BASED AERONAUTICAL INDUSTRIAL ORGANISATION

Chapter 6 DIRECTIONS, MAIN OBJECTIVE AND RESEARCH METHODOLOGY OF THE MODEL FOR IMPROVING THE QUALITY OF PRODUCTS AND STREAMLINING ENGINEERING PROCESSES

6.1 Directions of research

Addressing quality requirements and their interactions with the deliverables of engineering processes within aeronautical industrial organizations is a perspective that could be considered in the process of improving production processes. A main research direction would be the development of a model for the analysis of the quality requirements of metal structural products in aircraft composition and the interactions of these requirements with knowledge within engineering processes in industrial production organizations, with the aim to improve the deliverables of these processes.

Another direction of research is the graphical modeling of the global engineering process so that all the inputs and outputs of the component processes are identified and functionally modeled related to their mechanisms. The main purpose is to identify, for each activity of the process, the mechanism for transforming the requirements of the quality of the products into the deliverables necessary for the production processes.

Complementary to the graphic modeling, a mathematical model will be developed for all engineering processes, to quantify the quality level of the deliverables, and then the level of product quality.

Finally, a model for the implementation of this research within industrial organizations will be proposed, so that, regardless of the type of products made, their methods and sequence can be implemented.

6.2 The fundamental objective of the research and the specific objectives

The fundamental objective of this research is to develop within a knowledge-based industrial organization in the field of the aeronautical industry a dedicated methodology, specially created, to improve the quality management of integrated systems and to streamline the area quality of production processes.

The specific objectives set for this research are:

- Identifying the organization's processes and analyzing how to integrate into the quality management system using the basic principles of quality.

- Realization of a study on those processes that have the greatest influence on the requirements of product quality, increasing their interactions.
- Graphical rendering of the interactions of product quality requirements with the mechanisms of engineering processes, as an integral part of the improvement methodology.
- The development of a mathematical model complementary to the graphical model, to ensure the approximate calculation of the level of improvement in the quality of the products that are intended to be achieved.
- Validation of the mathematical model using experimental data from the engineering processes within the studied organization.
- The analysis of a logical flow of methods dedicated to achieving the proposed desideratum.

6.3 Research methodology

Figure 6.1 shows the logical scheme of the research methodology addressed in this thesis, namely the method of the six steps:

- Setting the objective.
- Analysis of the current state.
- Making assumptions.
- Conducting an experiment.
- Analysis of the results.
- Presentation of the final conclusions.

Starting from the establishment of the research objective, namely the identification of possibilities to improve the quality of the products made by the production processes through the engineering processes, a current state of knowledge in the field will be achieved. This research focused on the engineering processes within the organization studied, after they were in the quality management system. In this research, a study of the industrial organization and how the principles of quality currently known will be conducted. Also, as part of the state-of-the-art study, the processes aimed at managing the requirements and turning them into production requirements will be addressed.

These processes will be modeled by graphical methods to identify the links and interactions between them. By having these graphic models and using matrix interaction methods, one will track the mutual interactions between the deliverables of engineering processes. Interactions between product quality requirements will also be identified to determine the degree of mutual influence. In addition to these interactions in the engineering processes, a detailed study on the knowledge involved in the engineering processes will be carried out, with the aim of fully radiography of the mechanisms that maintain the engineering activities.

Having these studies and results, the following hypotheses can be issued:

- The realization of functional models of all engineering processes and their integration into a global engineering process using the IDEF0 methodology becomes a starting point in understanding the functioning of processes, individually and integrated.
- The establishment of mathematical relationships using the functional graphic model made by the IDEF0 method will allow the realization of an estimated calculation of the transformation of the quality level of the products through the knowledge existing in the engineering processes.
- There is a correlation between product quality requirements and knowledge in the global engineering process that can be defined and validated.

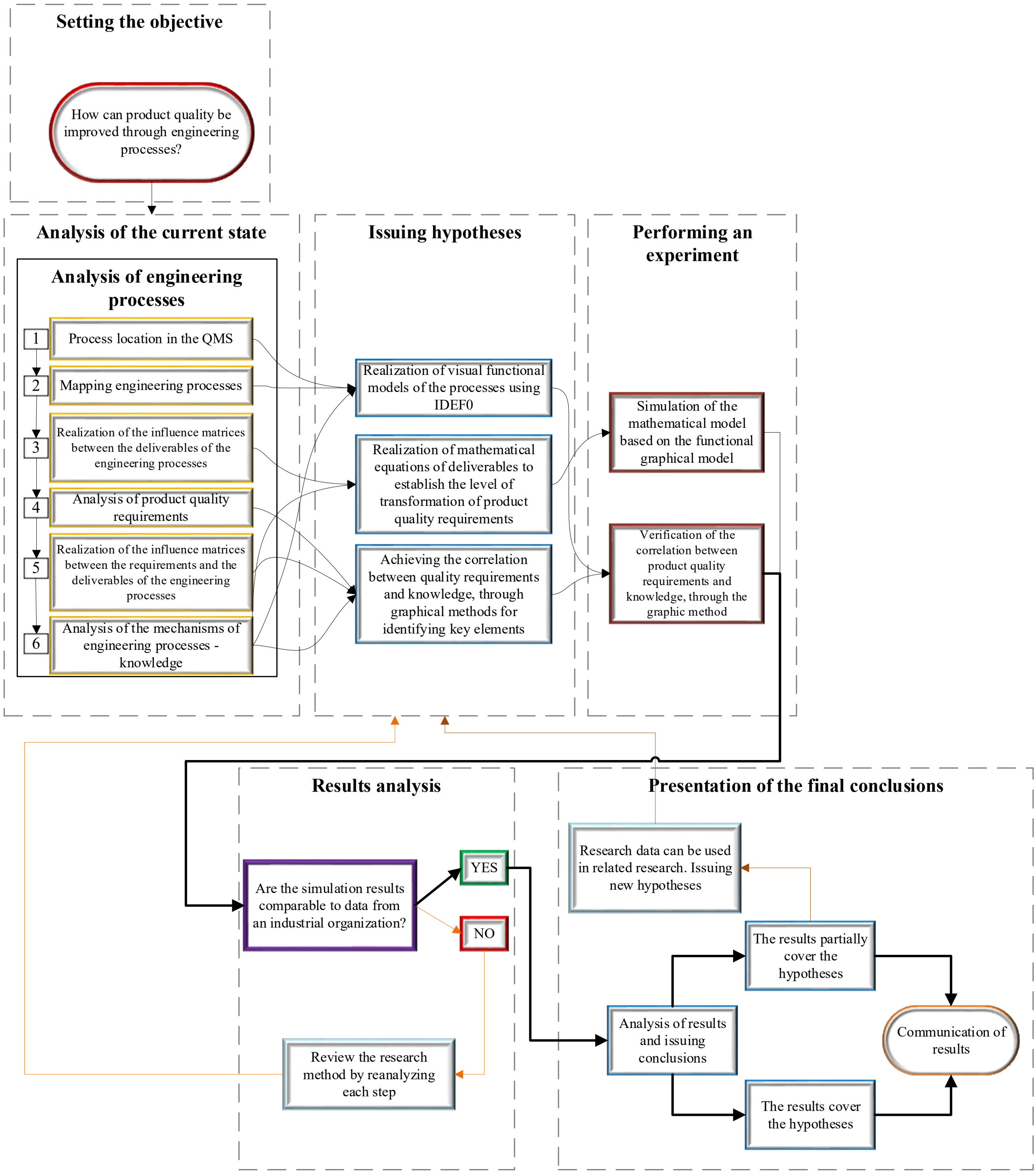


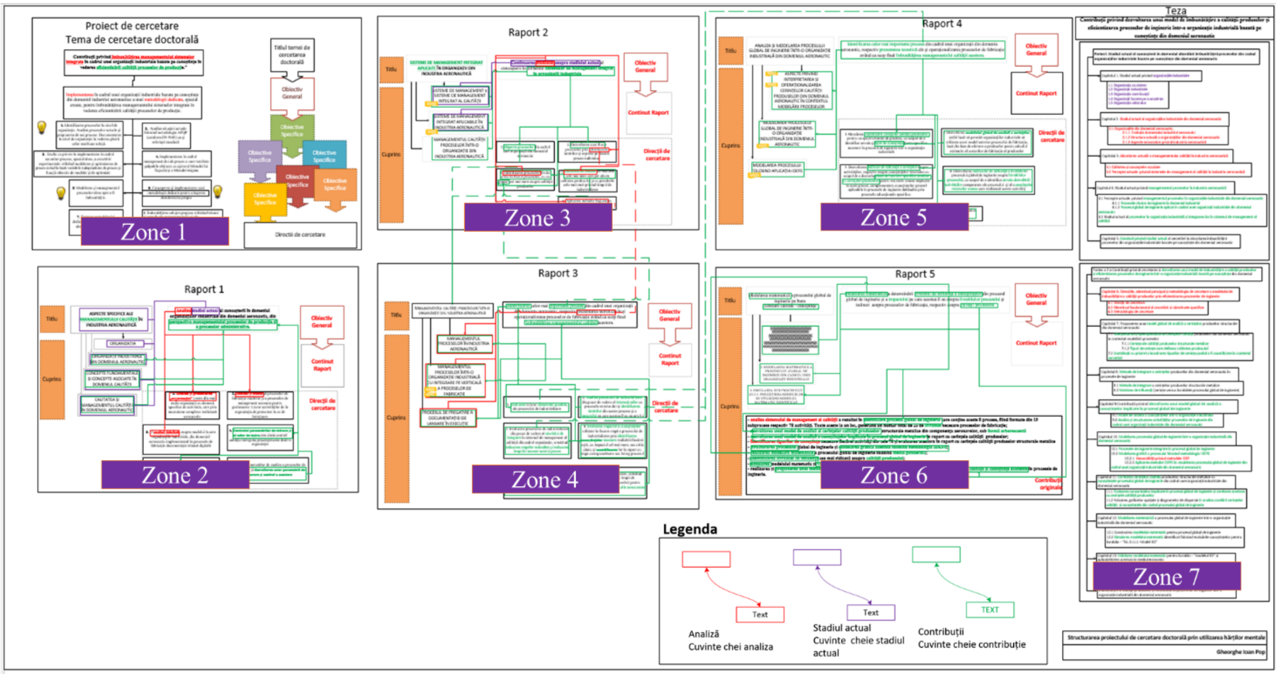
Fig. 6.1 Logical scheme of the research methodology approached

The next step in the applied research methodology is to carry out an experiment by simulating the mathematical model and achieving the requirements-knowledge correlation, using the same graphic model made.

The results of the simulation will be analyzed and compared with the actual data within the organization. If an inconclusive result is obtained from the analysis, the research method shall be reverted to arrive at a result that can be compared with the actual data. Within this thesis, given the experience of the researcher in the field and the knowledge of the actual data within the studied industrial organization, this iteration did not need to be applied.

Thus, having simulation results comparable to the results within the industrial organization, the last part of the research is carried out, the identification of the final conclusions, which can cover the hypotheses issued in full or only partially. If the conclusions only partially cover the hypotheses issued, new directions of research can be drawn up. If the conclusions fully cover the hypotheses, the results are communicated by means of this thesis and can be applied in industrial organizations.

The research method was completed during the research and the five research reports using the mind maps method (Annex 2), proposed, and developed also by the authors Ionescu N. and Vişan A. in the book on inventive problem solving (*Ionescu & Vişan, 2016).* This method is the one that allowed, starting from the main objective and the specific objectives of the research project, the development of the fields of study for the current state – the areas directly connected with the main objective – to sketch the logical thread of the research.



extract of Appendix 2 - first page – Mind map used in the development of research

Each keyword in each report was developed into research directions and research objectives for the next report, and finally for the constitution of the logical thread of the thesis. The research method is original and designed for this thesis, but it can be successfully applied in any research process.

Chapter 7 PROPOSING A GLOBAL MODEL FOR THE ANALYSIS OF THE REQUIREMENTS OF AERONAUTICAL STRUCTURAL PRODUCTS

7.1 Interpretation and operationalization of the quality requirements of metallic structural products in the aeronautical field in the context of process modeling

7.1.1 Requirements of the quality of metallic structural products

As for the life cycle of the aircraft, manufacturers have established a life cycle of about 25-30 years, referring not only to the market demand, but also to the operating cycles.

The term *structural component* is attributed to that part or part that is part of the aircraft's resistance structure. The requirements of metal structural products can be grouped, as can be seen in figure 7.1, depending on their source.

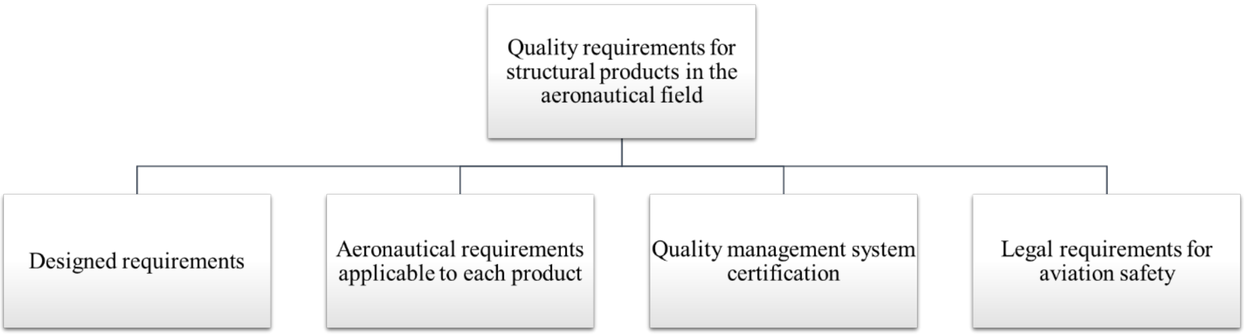


Fig. 7. 3 Quality requirements for aeronautical structural products of level I

Projected requirements of each product (Fig. 7. 3) constitute those requirements related to its form and functioning. They are correlated with the requirements of the production processes, also designed for this purpose, so that all the geometrical characteristics of the products can be achieved by predefined production processes. To be able to achieve this, production processes are controlled by quality requirements relating to:

- Technologies for making materials.
- Technological processes of mechanical processing.
- Technological processes of over-face treatment.
- The processes of testing the materials used in chemical processes.
- Assembly technological processes.
- Inspection technologies and validation of the designed requirements.

Aeronautical-specific requirements (Fig. 7. 3) the following may be considered:

- Certification of production sites regarding the methodology for carrying out production processes for a given product group, in relation to standards designed by aircraft manufacturers.
- The certification of the technical data management system along the supply chain. For example, aircraft manufacturer Boeing requires all suppliers to be DPD certified *(http://www.boeingsuppliers.com/, 2020),* thus ensuring that the requirements of products modeled in the 3D Catia V5 environment are identified, made, and verified by suppliers. These requirements are defined according to the standard.
- Requirements on how the planning and manufacture of products is conducted.

Because of the long chain of suppliers in this field, aircraft manufacturers impose requirements on each product in addition to the one it is designed. These requirements are the condition of each supplier for *the certification of the quality management system* and for *the production authorization* received from the industry-specific certification agencies (Fig. 7.3).

Having this set of requirements for each product, industrial organizations must ensure a quality of conformity of products, in this case quality being defined as a "***compliance with the requirements***" *(Crosby, Quality is free: if you understand it, 1979).* The conformity of the achieved product with the requirements requested by the customer is given by the quality level measured for each requirement.

For a better understanding of the product quality requirements shown above, in figure 7. 4 the graphic representation of a method of quantifying the quality of metallic structural products in the aeronautical field was made. Thus, each requirement, individually, is part of the final quality of the product. Once each requirement is achieved, through the production processes and processes related to it, the quality of the product can be measured on each requirement, and compliance with the original requirements will be validated.

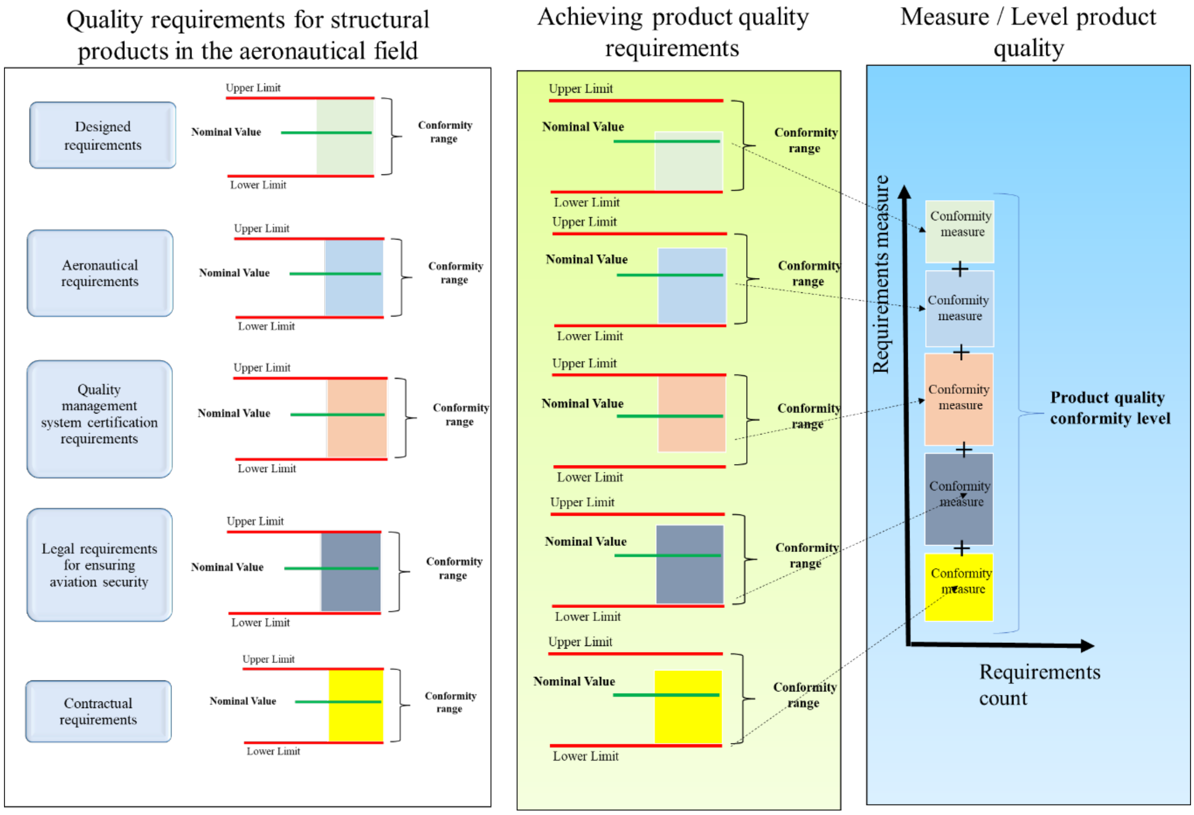


Fig. 7. 4 Establishing the level of product quality according to the level of quality of individual requirements *(Țîțu & Pop, Approach to Product Quality Requirements in the Context of Aeronautical Domain Process Modeling, 2021)*

In this research it is highlight the importance of all the requirements of a product, as a cumulation of requirements that must be fully complied with. In other words, ***each requirement has a weight in the quality level of the final product.*** All these requirements that define the quality of products are address in industrial organizations through the prism of their interpretation, using the knowledge of available resources. For a better understanding of these requirements, their classification makes it possible to systematically approach the study, with the aim of analyzing the process that deals with their management in industrial organizations.

7.1.2 Types of requirements that define product quality

Various explanations of the requirement types have been identified in the literature, but the closest explanation to the field of the present research is that in which it is stated that the requirements expressed are those that are transferred from the beneficiary to the manufacturer in *an obvious* form.

Addressing unexpressed requirements is a topic that involves not only technical knowledge from producers, but also socio-economic knowledge - necessary to successfully deduce those requirements that are not explicitly communicated.

Measurable requirements (fig. 7.7) are the requirements most clearly expressed by the customer to the manufacturer, and they do not give the possibility of interpretation. These requirements are also the easiest to clarify in the process of managing non-compliances.

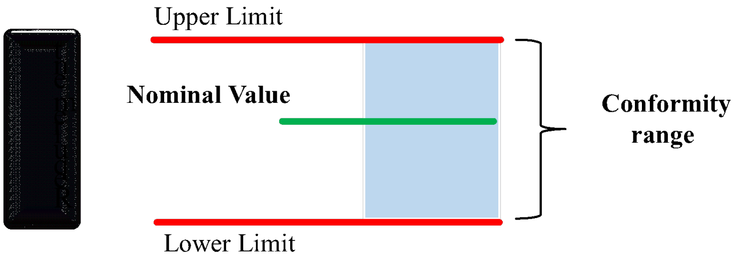


Fig. 7. 7 Representation of the field of compliance of the measurable requirements

A concrete example of the immeasurable requirements (fig. 7.8) is that, to achieve a benchmark, the customer asks the production organizations to check whether the color of the paint is compliant. In this case, even if the color code and all paint production requirements is good, there may be differences in hue, which can be interpreted differently by the inspection staff. These differences may occur even if samples received from customers are used, due to the subjectivity of the inspection method.

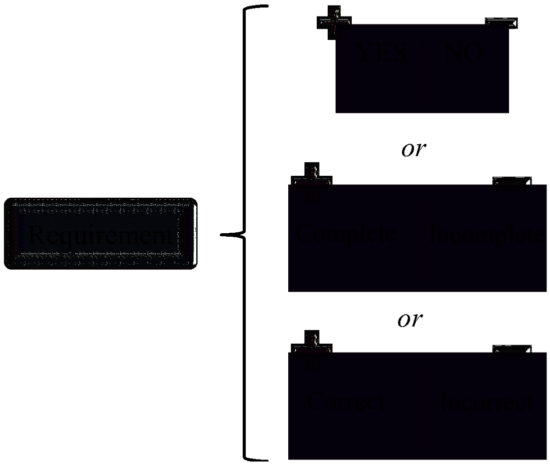


Fig. 7. 8 Types of non-measurable requirements

7.2 Contributions on the framing of the types of requirements possible to be quantified in the context of the research

The professional experience of the author of this thesis in managing the quality requirements of metallic structural products in their implementation in the production processes in an industrial organization in the aeronautical field led to the development of a perspective on how these requirements could be grouped.

By matrix approaching requirements and dividing them from the highest level, we have proposed a model for the analysis of product requirements, with the aim of enabling industrial organizations to quantify the level of product quality. To the same extent, the method allows the assessment of all the requirements defined by the customer, in terms of the type of requirement, to estimate the production costs in relation to the complexity of each requirement. At the same time, different share of the requirements is shown, depending on the perspective on the requirements of the products; in other words, on various levels of breakdown the share changes, so it must be approached in a unique way.

Chapter 8 METHODS OF INTEGRATING THE REQUIREMENTS OF AERONAUTICAL PRODUCTS INTO ENGINEERING PROCESSES

8.1Methods for integrating the requirements of metal structural products

In this research, the quantification of the quality of structural metal products in the aeronautical field is the totality of the product requirements, expressed or unexpressed. To achieve the maximum quality level of the product, namely 100 %, each requirement that makes up this whole must be complied with. The justification for this approach given by the fact that a product is as non-compliant even if only one requirement is not complied with, regardless of its type. Even if there are clearly met a few of requirements, but only one requirement is not met, the product is still considered non-compliant.

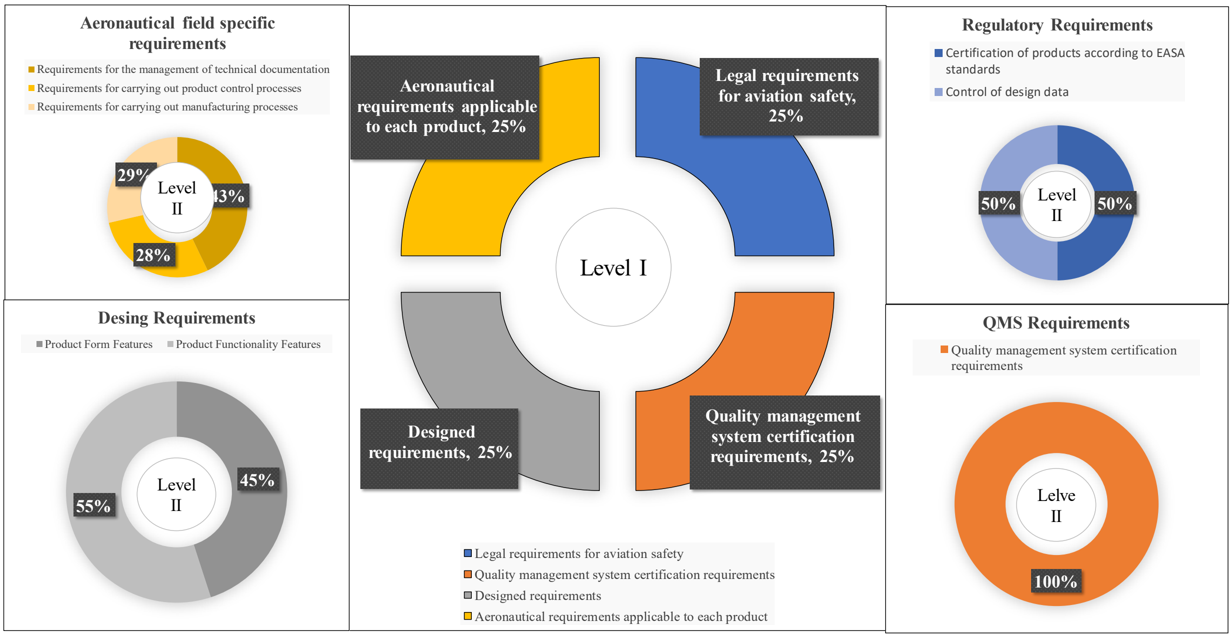


Fig. 8.1 Percentage distribution of structural product requirements in the aeronautical industry of level, I and II

Figure 8.1 presents its own approach to the importance of structural product quality requirements in the aeronautical industry, highlighting different perspectives generated by various requirement types and their levels of breakdown. Based on the detailing of the requirements on various levels, a percentage distribution can obtain on each requirement. For each product, the overall quality management system, and legal requirements for aeronautical safety occupy 50% of the total product requirements.

The method of analyzing all product quality requirements on hierarchical levels, using the proportions method to understand the level of impact on the final quality of the products made, provides aeronautical industrial organizations with a path to the implementation of the "zero defects" concept. Moreover, the management of organizations can evaluate the level of effort required to implement these requirements, and to make the right decisions.

With the method of analyzing the requirements of product quality, the next step is the integration of product requirements into production processes. This step performed through engineering processes, depends on the capabilities and capabilities of organizations Production processes for metal structural components classified in the aeronautical industry is in accordance with the applied production technology.

The current trends in the field of engineering, of virtualization of the designed technical documentation and of the production one, lead to the adaptation of the engineering processes and the methods of integrating the requirements into the production processes.

In this chapter are presented methods applied within an industrial organization in the field of aeronautics in the global engineering process and integrated in the quality management system. However, the need for improvement exists and can be achieved through more detailed research into how to manage the requirements and their transformation process. Further, the research will aim at an even more detailed analysis of these requirements, respectively of their engineering processes.

8.2 Influence matrices (requirements versus deliverables of the global engineering process)

The development of influence gives industrial organizations the opportunity to understand as correctly as possible the applicability of the product requirements in the processes that make up the global engineering process. The integration of the control of the requirements in the working procedures and instructions is much easier, due to the visibility generated by this way of mapping the requirements.

The results demonstrate that some requirements are applicable to all engineering processes, which is why the implementation of some methods of their control in the quality management system becomes obvious.

The percentage values of the level of influence of quality requirements on engineering processes were calculated by the formula (8.1) for a total of twenty-three deliverables of the global engineering process.

$$N_{inf}(\text{influention level})\% = \frac{[(1 \cdot L_n) + (1 \cdot L_2) + \cdots + (1 \cdot L_n)]/100}{L_1 + L_2 + \cdots + L_n} \qquad (8.1)$$

The analysis of the interaction between the requirements of product quality and the deliverables of engineering processes led to the establishment of links and their influences in the first stages of product implementation in the production processes within the organization.

In the industrial field, the establishment of methods for measuring processes is a widespread practice. This need arises from the need for continuous evaluation of each activity conducted within the processes, in relation to quality planning. In this context, the activities of engineering processes require to evaluate yourself and measure yourself. By identifying those product quality requirements that have the greatest influence on engineering processes, it can consider that the assessment of the conformity of these requirements in production processes is the measure of the quality of engineering processes.

The complexity of the analysis of all engineering processes within the global engineering process is all the greater as more details of these processes addressed, respectively the interactions between requirements and deliverables. It is also of interest to generate deliverables to address the mechanisms underlying their generation. In the case of those production processes where the deliverables are the products, that is, concrete, tangible objects, the mechanisms are well known. In the case of engineering processes, the mechanisms are based on knowledge, way of thinking (decision making), organizational culture.

The methods of analyzing their processes and mechanisms are very varied, from simple methods such as block diagrams and connection arrows to analysis methods using complex diagrams and specific symbols on types of activities, databases used. From all these methods we chose a visual method and at the same time sufficiently detailed, which uses diagrams and logical flows, the representation of mechanisms and control methods on each process, respectively activity. This method, which helps to create functional models for the analyzed processes, is presented and applied in the next chapter.

Chapter 9 PROPOSING A GLOBAL MODEL FOR ANALYZING THE KNOWLEDGE INVOLVED IN THE GLOBAL ENGINEERING PROCESS

9.1 Model of knowledge analysis in an industrial organization

The approach of intellectual capital within industrial organizations is a complex topic, and the research in this field mentions the need to identify the peculiarities of the study in the analysis of intellectual capital. Thus, the approach in this research focuses on the analysis of the intellectual capital that exists and used in the global engineering process within an industrial organization in the field of aeronautics.

The global engineering process, being a functional process in the studied industrial organization and integrated in a quality management system, considered as "frozen", i.e., a process that modified only through an improvement process, according to quality management system requirements. However, any process can continuously by improving or developing the intellectual capital used in that process.

Engineering processes within industrial organizations operate based on a mechanism based on an intellectual capital oriented towards the technical and software field. Complementary to these areas, major influence in the functioning of processes have knowledge of processes within the quality management system and knowledge of communication. Once the type of knowledge in the global engineering process that we evaluate has been established, a model de analysis can be proposed with the aim of identifying all the knowledge involved in transforming the requirements of the quality of the products.

The model proposed in this research is to detail the processes taking place in the industrial organization, from the level of the global process, integrated in the quality management system, to the level of the activities conducted for each individual process. Thus, having information on all the activities, with their entrances and exits, it can identify type and knowledge necessary for the execution of the activity, respectively for generation Exit. each activity Taken individual.

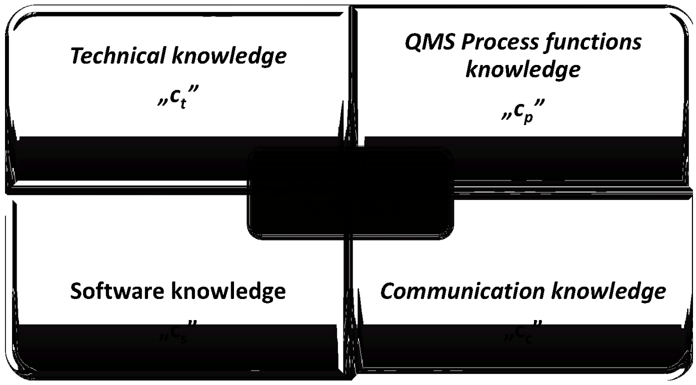


Fig. 9.2 Types of knowledge involved in engineering activities

Following the application of the model of analysis of the global engineering process *(Pop & Țîțu, 2021),* it was identified the knowledge necessary for the analysis of the activities. These were atheistic group in four categories (Fig.9.2).

Once the types of knowledge used in the global engineering process have been established, the next step taken will be to analyze the activities that generate the deliverables with the greatest impact on the entire process, respectively on the requirements of product quality. The proposed model of analysis, evaluation and correlation of the knowledge involved in the global engineering process aims to identify the distribution of the types of knowledge in the process and to highlight that knowledge with the greatest impact on the process, respectively on the quality requirements of the products managed by this process.

9.2 Analysis and structuring of engineering processes activities within an industrial organization in the field of aeronautics

Due to the large volume of information on these activities, it was developed a model of information coding. The purpose was helping the researcher in identifying the activities during the research. The code of each activity is allocated according to table 9.3, identifying each activity with the process, respectively the group of processes to which it belongs. A similar method of coding deliverables is shown in Table 9.4.

Tab 9.3 Task encoding

Example	**g1**	**.1**	**.1**	**. A**	**1**
Code sequence	*1*	*2*	*3*	*4*	*5*
Description	Process group	Process number	Subprocess number	Activity	Sequential number of the activity

Tab. 9.4 Coding of deliverables

Example	**g1**	**.1**	**.1**	**. It**	**1**
Code sequence	*1*	*2*	*3*	*4*	*5*
Description	Process group	Process number	Subprocess number	Deliverable	Sequential number of the deliverable

The result of the study on the global engineering process, as presented in Table 9.5 and in Annex 3, highlights the large volume of activities that take place within the organization.

Tab. 9.5 Summary of the content of the global engineering process

Group Processes	**Processes**	**Subprocesses**	**Activities**	**Deliverables**
3	8	19	70	23

Tab. 9.6 Coding of the types of knowledge involved in the global engineering process

Category	**Bloke**	**Serial** (numeric)
C- acquaintance	TG – general technical knowledge T Product – technical knowledge of the product T Process – technical knowledge of the specific process in the field of aeronautics	1...n
	P – knowledge of the internal process within the QMS	
	S - knowledge of software use	
	C- knowledge of communication techniques	

The next level of detail of the engineering processes was that in which for each activity the types of knowledge necessary for its realization was identified. Thus, for each category of knowledge a code was assigned, according to the example in table 9.6, the coding aiming to identify the distinct types of knowledge, both in graphic and mathematical modeling.

The identification of the types of knowledge achieved through the analysis of the working procedures and instructions within the global engineering process. The functioning of the global engineering process, within the framework of industrial organizations with the field of activity in the processing of structural components in the field of aeronautics, is based on the knowledge of the resources involved in this process. The level of knowledge available in the process at a given time has a direct impact on the products, which are the result of putting into practice the knowledge-based thinking process.

For a better understanding of how knowledge engages in the component activities of the global engineering process, the study of this process identified for each individual activity the knowledge involved. By boarding each subprocess with its component activities, one can observe the variety of technical knowledge involved and the presence of each category of knowledge.

Annex 4 presents, for each activity within all sub-processes, the knowledge involved in carrying out the activities, as identified in the overall engineering process. This matrix of knowledge involved in the global engineering process for each individual activity creates the possibility of evaluating and improving the process from various perspectives such as:

- Raising the level of knowledge within industrial organizations.
- The rapid identification of knowledge shortages when new products bring with it new requirements within industrial organizations.
- Creating a perspective on existing intellectual capital and that of the one to be developed.

Chapter 10 MODELING THE GLOBAL ENGINEERING PROCESS IN AN INDUSTRIAL ORGANIZATION IN THE FIELD OF AERONAUTICS

10.1 Engineering processes integrated into the global engineering process

The goal of the processes or engineers is within the industrial organizations is to ensure the design of the production technology that ensures compliance with the requirements of the quality of the products, as the customers require them. Engineering processes cover all activities necessary for the implementation in production of new products and at the same time actively participate in improvement projects that are related to production processes.

However, the present research has arisen from the need to analyze and detail this process, following the mechanisms for transforming the quality requirements into deliverables. This need is related to the impact that the process deliverables have on the quality of the product both qualitatively and economically.

10.2 Graphical modelling of the process using the IDEF0 methodology

10.2.1 General information on IDEF methods

IDEF0 is a methodology for functional modeling of business processes, to be analyzed, developed, rethought, and integrated. IDEF0 can also be defined as a graphical modeling of a system to create a functional model that describes both the functions of the system and its structure. In the same way, is highlighted the flow of information and materials that link the functions of the system.

10.2.2 The application of the IDEF0 method in the modeling of the global engineering process within an aeronautical industrial organization

Within organizations, among other basic tasks, management functions also involve the function of system maintenance. To be able to maintain a system, managers need to know it both from a general perspective and in detail. To get to the details of a system, the methodology for modeling system functions through the IDEF method is one of the handiest techniques.

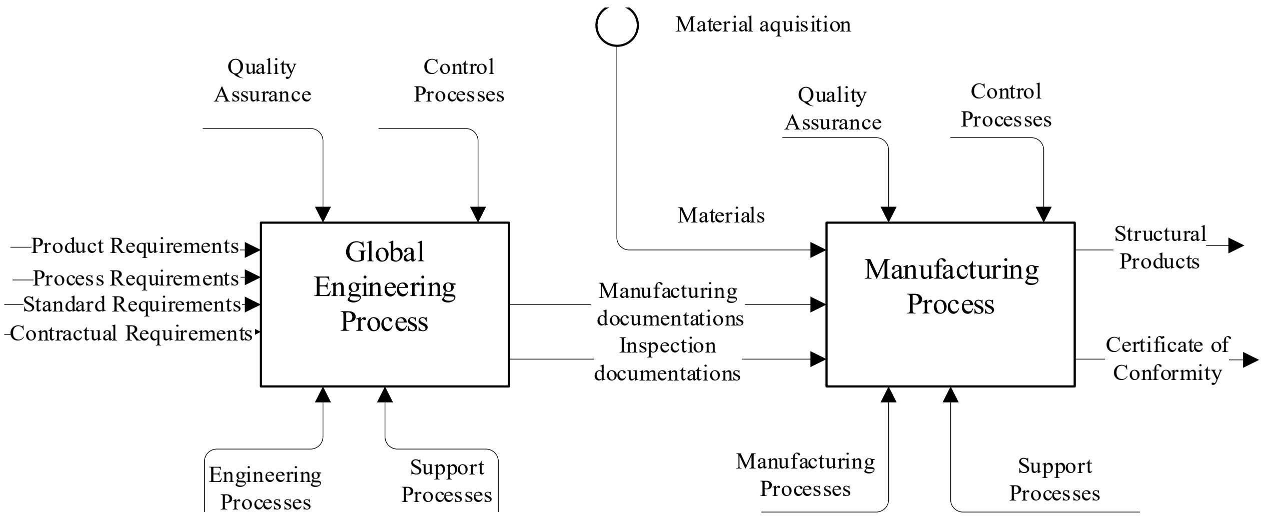


Fig. 10.7 Functional model for the global engineering process and the production process

The very general method (process map) defined by the quality management system standard allows the visualization of processes at a global level, but not the visibility of process details and their interactions within the system.

The process approached for this study, i.e., the global engineering process, is precedent processes production reason the impact it is on the final product in terms of quality it is major. As it can be seen in figure 10.7, processes production within the operational processes executes the internal technical requirements generated by the global engineering process, which is why any deviation of the interpretation of the requirements in this process will lead to the realization of non-compliant products.

For the realization of the products and their certification, the production processes need, as input, materials and technical documentation of execution and inspection. Using as a mechanism the production and support processes, under the control of the processes of control and quality assurance of the products, are create the compliant products. To be able the use in production, the technical execution and inspection documentation must go through the overall engineering process. The input elements of this process are the cumulation of product requirements, processes, in-process, and contractual standards. All this, through the mechanism of the component processes of the global process and under the control of specific processes of requirements control and quality assurance, creates the above-mentioned outputs for the manufacture of products.

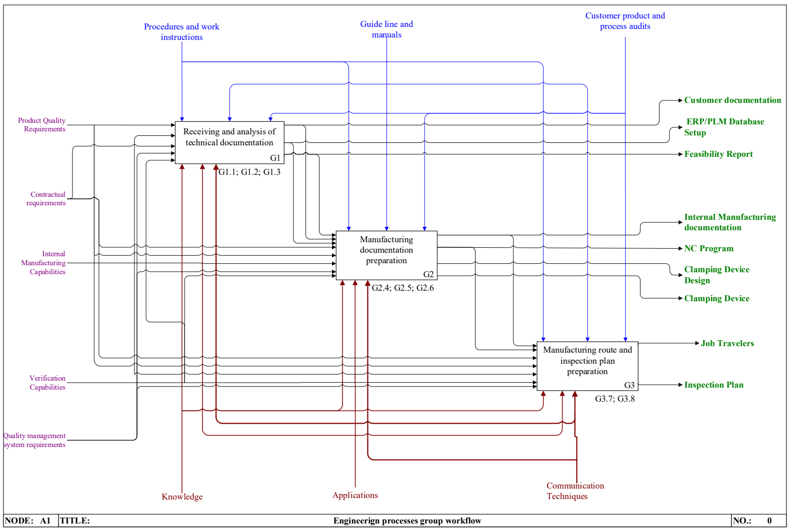


Fig. 10.11 Functional model of the process groups level I of the global engineering process

Methods of control play a key role in this process, which is why the level of detail of the interpretation of product requirements must be in direct relation to the level of knowledge of the resources conducting this process.

In the present research, the modeling method described here (fig. 10.11) was applied to all processes, subprocesses and their activities, according to the same model. In this way, functional graphic models were obtained to transform the quality requirements of the products into deliverables. All of these can be found in Annex 5.

Chapter 11 CORRELATION OF THE QUALITY REQUIREMENTS OF METALLIC STRUCTURAL PRODUCTS WITH THE KNOWLEDGE OF THE GLOBAL ENGINEERING PROCESS WITHIN AN INDUSTRIAL ORGANIZATION IN THE FIELD OF AERONAUTICS

11.1 Assessment of the knowledge involved in the global engineering process and its correlation with the requirements product quality

Industrial organizations, regardless of their field of activity, need a period to be able to accumulate the knowledge necessary to understand and interpret the requirements of product quality.

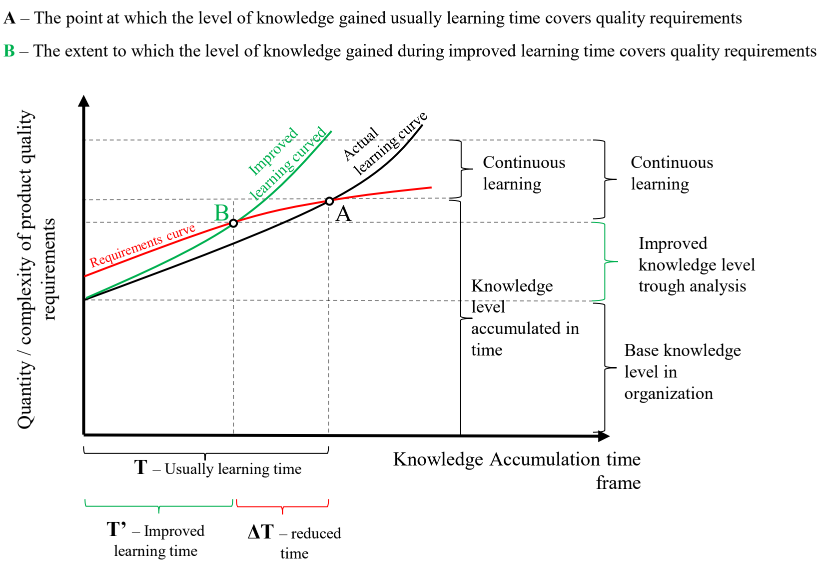


Fig. 11.1 Interaction of product quality requirements with knowledge within industrial organizations

As we can see in Figure 11.1, this period may vary a depending on the level of basic knowledge and complexity of product quality requirements. In this research, the question arises of identifying a possibility to improve the existing knowledge within industrial organizations, in a shorter period and with a higher efficiency. In Figure 12, point A one can see as the point of intersection between the product quality requirements curve and the learning curve. At this point, after going through a T period, the level of knowledge within the organization is equal to the requirements of product quality. The reduction of the learning time ΔT to the shorter T' interval can only be achieved by optimizing the way of accumulating knowledge within organizations. Only in this way can you obtain the point of intersection of the curve of product quality requirements with the improved learning curve at a lower time interval, T'. By here result that the moment when the requirements are correlated with the knowledge of the organization is critical for reducing the type of their assimilation. The efficiency of this correlation is related to the level of detailing the requirements, respectively of the knowledge, in the shortest possible period.

The quality requirements of aeronautical metal structural products, addressed in research, cover all the common requirements of this type of product. Of the five levels of detailing the requirements, those on the last level are correlated with the knowledge of the global engineering process.

11.2 The use of spatial graphs and dispersion diagrams in the analysis of the correlation of quality requirements and knowledge within the global engineering process

The activity of analysis and correlation of quality requirements can be performed by various methods and techniques of analysis. In the previous subchapter, the matrix method, and the analysis of frequencies of interactions between requirements and knowledge helped us in issuing conclusions. However, there are several factors that affect this correlation, and their concomitant analysis can be performed using spatial graphs. For these analyses s-a chosen MODDE® application, which is part of the Umetrics® suite of statistical analysis solutions. Using the MODDE® application, for deliverable G1.1.1L1 s-a obtained graphically (fig 11.5) a result of the quality of the deliverable which verifies the assumption that between requirements and knowledge there is a correlation Direct. Thus, we can say that to obtain quality products it is necessary that both the level of quality requirements and the level of knowledge in engineering processes be high.

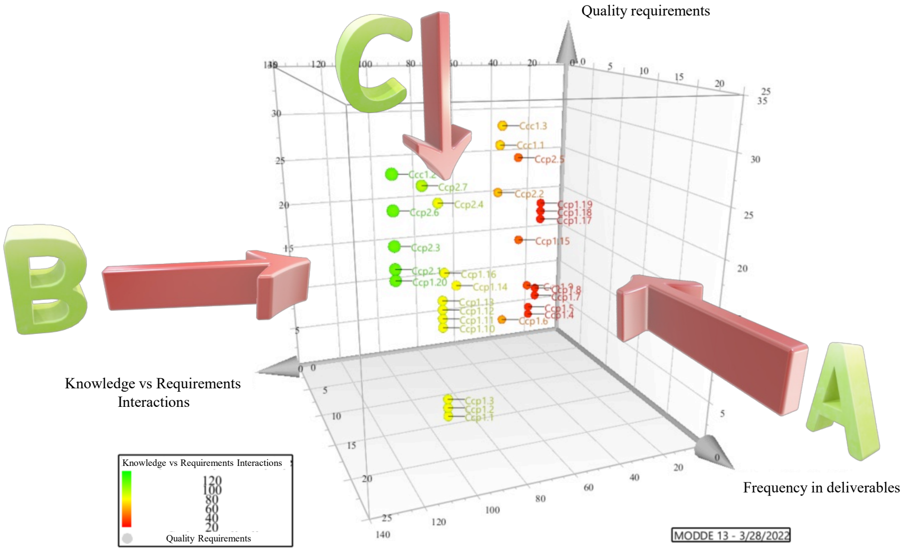


Fig. 11.5 Diagram of dispersion of quality requirements in relation to frequency in deliverables and interaction with knowledge

In the next chapter, the mathematical model of this correlation was made, to propose a way of indirect calculation of product quality by directly calculating the deliverables of engineering processes.

Chapter 12 MATHEMATICAL MODELING OF THE GLOBAL ENGINEERING PROCESS IN AN INDUSTRIAL ORGANIZATION IN THE FIELD OF AERONAUTICS

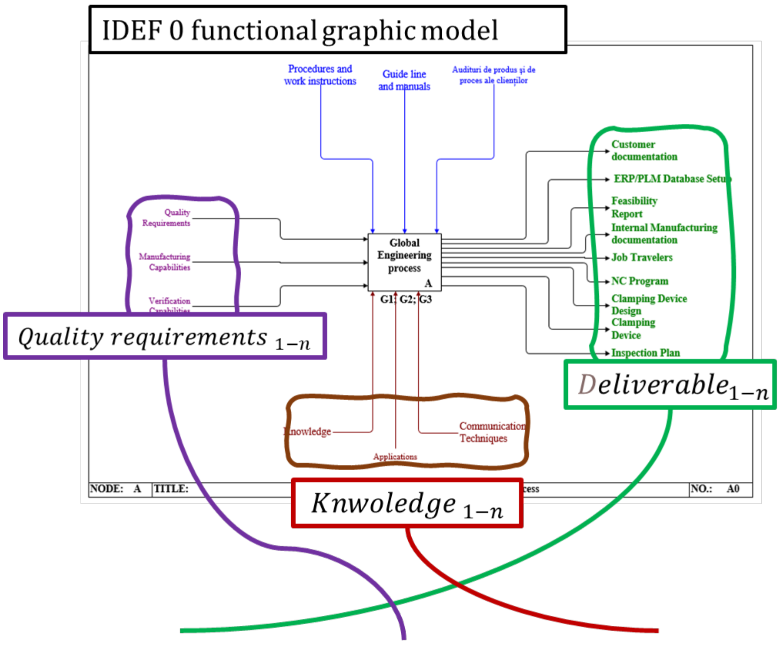
12.1 Building the mathematical model for the global engineering process

It was conducted the mathematical modeling of the global engineering process with the aim of assessing the quality level of all its deliverables in relation to the requirements of the product quality. The mathematical modeling of the global engineering process was performed to evaluate the quality level of all its deliverables in relation to the product quality requirements. The modeling was based on the correlation of product quality requirements with the knowledge required for engineering processes. Using the IDEF0 modeling to achieve the graphical functional model (Fig. 12.1), the mathematical model proposed in this research describes the transformation function of this model (12.1):

$$Deliverable_{1-n} = Quality\ requirements_{1-n} \cdot Knowledge_{1-n} \quad (12.1)$$

where:

$Deliverable_{1-n}$ represents the cumulation of deliverables of the global engineering process.
$CQuality\ requirements_{1-n}$ – the quality requirements of the products.
$Knowledge_{1-n}$ –the knowledge involved in the global engineering process.



$$Deliverable_{1-n} = Quality\ requirements_{1-n} \cdot Knwoledge_{1-n}$$

Fig. 12.1 Construction of the mathematical model based on the functional graphic model

Next, we have the mathematical modeling for each deliverable resulting from each subprocess, considering the individual inputs, and influencing factors, namely the knowledge involved in the entire process. The sequence of approach to deliverables it has made, from the first stage of the process to the last stage.

The first sub processed is G1.1.1 – *receipt and registration of documentation*, of which the deliverable book is G1.1.1.L1 or *the product technical documentation registered in the PLM.* Thus, we considered that the deliverable is a function of transforming the requirements of the product quality through the component activities of the subprocess (12.2):

$$G1.1.1.L1 = f\left[(Cc_{p1} \cdot G1.1.1_{A1\ldots A4}), (Cc_{p2} \cdot G1.1.1_{A1\ldots A4}), (Cc_c \cdot G1.1.1_{A1\ldots A4})\right] \qquad (12.2)$$

where:

$G1.1.1_{A1\ldots A4}$ is the cumulation of the component activities of the subprocess G1.1.1.

Wanting to find out the degree of influence of the activities on the deliverable, we can express the mathematical equation of this accumulation of activities by establishing the influence weights of each activity using the equation of the weighted average, as follows:

$$G1.1.1_{A1\ldots A4} = \frac{\begin{pmatrix}(G1.1.1.A1 \cdot p_1) + (G1.1.1.A2 \cdot p_4) + (G1.1.1.A3 \cdot p_4) \\ +(G1.1.1.A4 \cdot p_4)\end{pmatrix}}{p_1 + p_2 + p_3 + p_4} \qquad (12.3)$$

where:

G1.1.1.A1 represents the activity "*accessing the technical documentation of the product in the customer's system*";

G1.1.1.A2 – the activity "*downloading files and saving in the right location, in the internal network*";

G1.1.1.A3 – the activity "*registration of technical documentation in the internal PLM application and sorting of documents by the point of view of the document type*";

G1.1.1.A4 – the activity "*communication of the confirmation of the registration of technical documents in the PLM system*";

$p_{1 \ldots 4}$ – the weights of the numbers of the values of the terms in the equation (12.3) where $p_n \in R$

Each activity being carried out on the basis of the knowledge involved in it; we can consider the activity expressed through a mathematical equation as the percentage product of the knowledge involved.

...

Due to the high level of influence on the quality of the product, it was considered opportune to simulate the application of this mathematical model on a deliverable of its "G1.3.1.L1 - Model 3D", a deliverable widely used within the studied organization. This simulation it is show in the following subchapter.

12.2 Simulation of the identified mathematical model using knowledge assessments for the deliverable "G1.3.1.L1 - Model 3D"

In the global engineering process, the "preparation of the 3D model" represents a step with a remarkably high impact factor since its deliverable represents the virtual model of the product to be made. This 3D model used as a reference in all subsequent subprocesses. At this stage, the projected (geometric) receipts of the product quality, are transferred as received from the customer to the virtual environment. The importance of understanding the level of knowledge in this subprocess and the impact it can have on production processes, respectively on product quality, can be demonstrated by the results of the simulation of the mathematical model identified in this study.

The matrix for correlating the requirements of product quality with the knowledge involved in the global engineering process allows us to identify those requirements, respectively the knowledge necessary for the realization of the evaluation questionnaires. This evaluation is aimed at identifying the state of play of the level of specific knowledge and at the same time of the basic ones directly connected with the requirements of the quality of structural products.

...

Based on the mathematical modeling of the global engineering process, the deliverable equation of subprocess G1.3.1 is expressed by equation (12.20):

$$G1.3.1.L1 = f[(G1.2.2.L1 \cdot G1.3.1_{A1 \ldots A4}), (G1.2.2.L2 \cdot G1.3.1_{A1 \ldots A4}), (G1.2.3.L1 \cdot G1.3.1_{A1 \ldots A4}), (CC_{P1} \cdot G1.3.1_{A1 \ldots A4}), (CC_{P2} \cdot G1.3.1_{A1 \ldots A4}), (CC_C \cdot G1.3.1_{A1 \ldots A4})] \quad (12.20)$$

where input parameters are the product quality requirements and deliverables of previous sub-processes:

- $Cc_{p1} = 1$ means 100% compliant product quality requirements.
- $Cc_{p2} = 1$ means 100 % of the accuracy of the conformity of the process.
- $Cc_c = 1$ means 100% compliant contractual quality requirements.

- G1.2.2.L1 = 1 means the product technical information corresponding to each 100 % compliant product.
- G1.2.2.L2 = 1 means 100 % information on the material needed to produce the conforming product.
- G1.2.3.L1 = 1 means the product technical documentation attached to each product in the compliant ERP system at a rate of 100%.

Having the values of knowledge obtained through evaluation, we can simulate the identified mathematical model. By replacing the coefficients of the equations of the types of knowledge for each activity, respectively the weightings of the values obtained, we obtain the weighted average of the knowledge involved in carrying out the activities. This weight can be considered as the value of the impact of the knowledge on the outputs corresponding to each activity within the subprocess.

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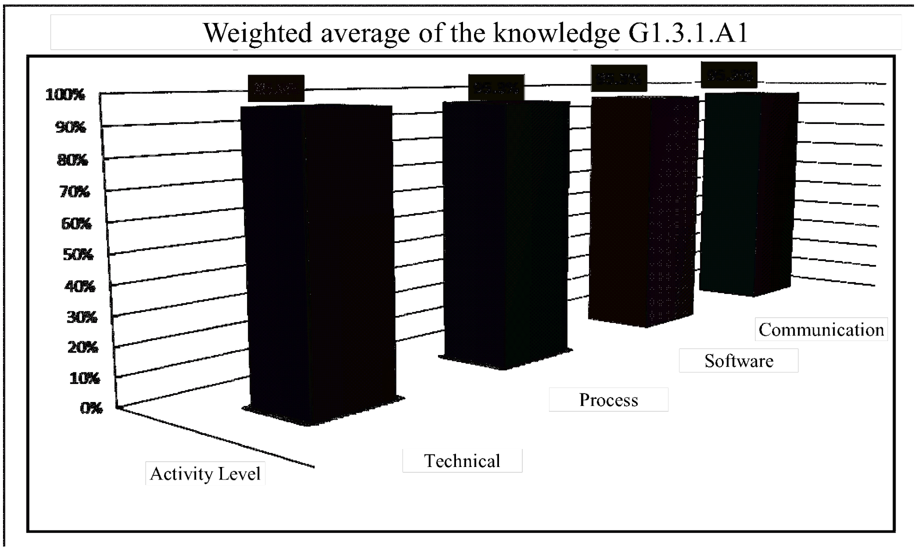

Fig. 12. 3 Distribution of knowledge levels involved in the activity G1.3.1.A1

As can be seen from Figure 12.3, the level of technical knowledge has the highest share in this activity, an important aspect to consider because the deliverability of this process (establishing the technical documents applicable to the product) is technical, which in the field in question, due to the distribution of product information in multiple documents, is important.

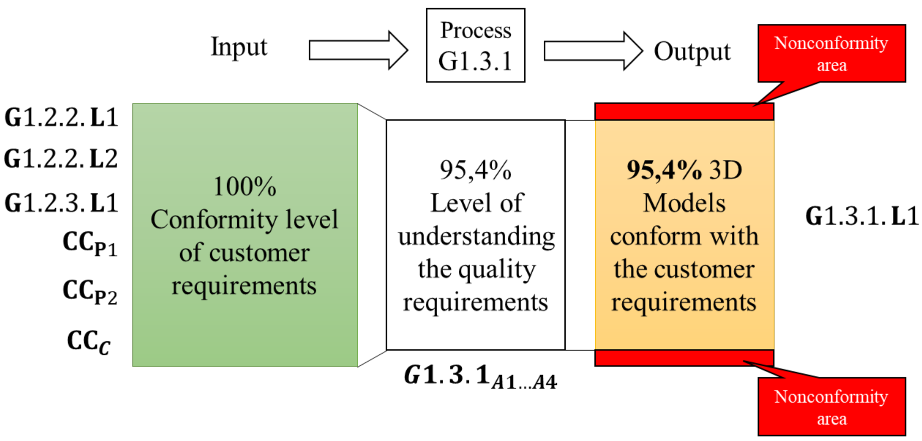

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Fig. 12.7 Graphical representation of the result of the function of the deliverable G1.3.1.L1

The result obtained after the simulation of the mathematical model can be represented graphically as in figure 12.7, where each input of this subprocess is transformed through the knowledge involved in a percentage of 95.4%. Thus, the inputs of the subprocess, represented by the product quality requirements, specific to this subprocess, are 100% compliant; through a level of related knowledge of approximately 95.4%, compliant deliverables of 95.4% can be obtained. Approaching this result from the perspective of industrial organizations, it is interpreted that the probability of obtaining non-compliant deliverables is approximately 4.5% (red zone). The value obtained can be used in industrial organizations to assess the error rate of deliverables. This represents the number of non-compliant deliverables compared to several deliverables achieved. The identified mathematical model simulates this error rate by the weighted average, obtaining a percentage value. Thus, regardless of the number of deliverables to be made, the error rate can be transformed into the number of possible non-compliant deliverables.

This method of evaluation, respectively of simulating the capability of the resources within the subprocess to manage the requirements of the quality of the products, can be used in the industrial organizations in the aeronautical field for early evaluations of the quality of their products to be conducted, implicitly for the realization of plans to prevent their nonconformities.

Chapter 13 VALIDATION OFTHE MATHEMATICAL UI MODEL FOR THE DELIVERABLE "3D MODEL" AND ITS APPLICABILITY IN THE ECONOMIC ENVIRONMENT

13.1Assessment of the impact of engineering processes in an industrial organization

To demonstrate the result obtained by simulating the identified mathematical model, real data were collected from an aeronautical industry organization on the generation of the deliverable "3D model" in the global engineering process.

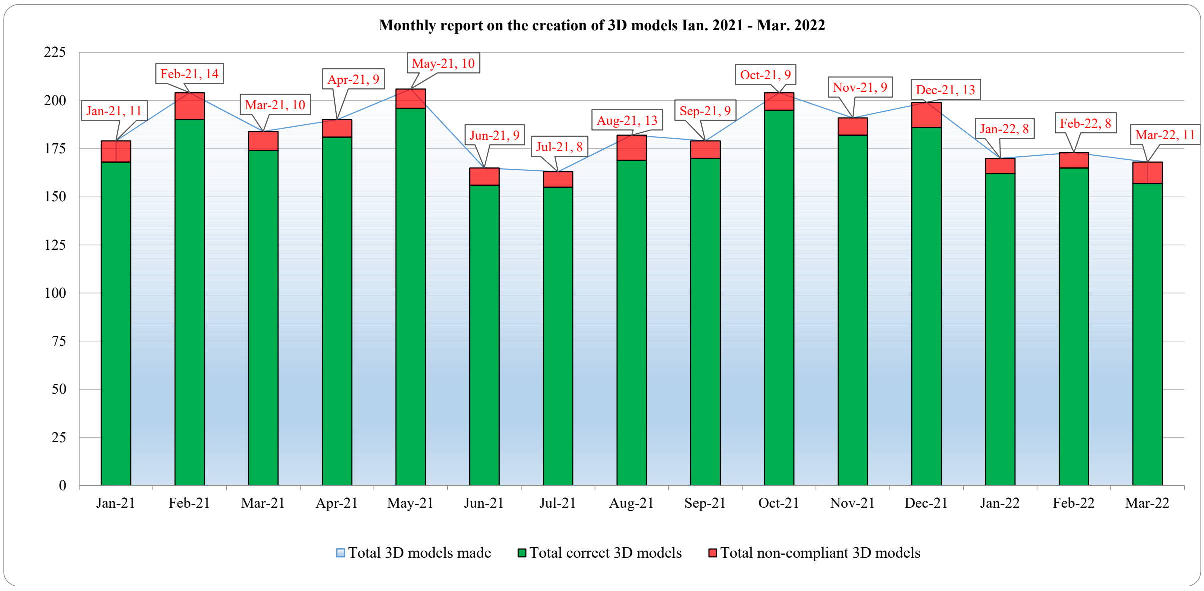

Fig. 13.1 Monthly report on the realization of 3D models, in an industrial organization

Figure 13.1 shows the total number of 3D models made each month, i.e., the number of 3D models internally declared as non-compliant, represented in red, and the total number of correct 3D models. The result of about 5% of non-compliant products validates the result obtained by mathematical simulation. Analyzing data on the realization of 3D models in terms of costs, we can highlight and clearly identify the impact of errors generated by insufficient knowledge of the human resource within an organization.

Figure 13.4 shows a comparison of the estimated costs of correcting 3D models using the existing cost-saving method (red curve in Figure 13.4) and the one in which the methodology identified in this research project (green curve in Figure 13.4). As can be seen in Figure 13.4, using the methodology developed in this report, to address the improvement of knowledge in relation directly to the requirements of product quality, the time required to reduce costs is about 10 months

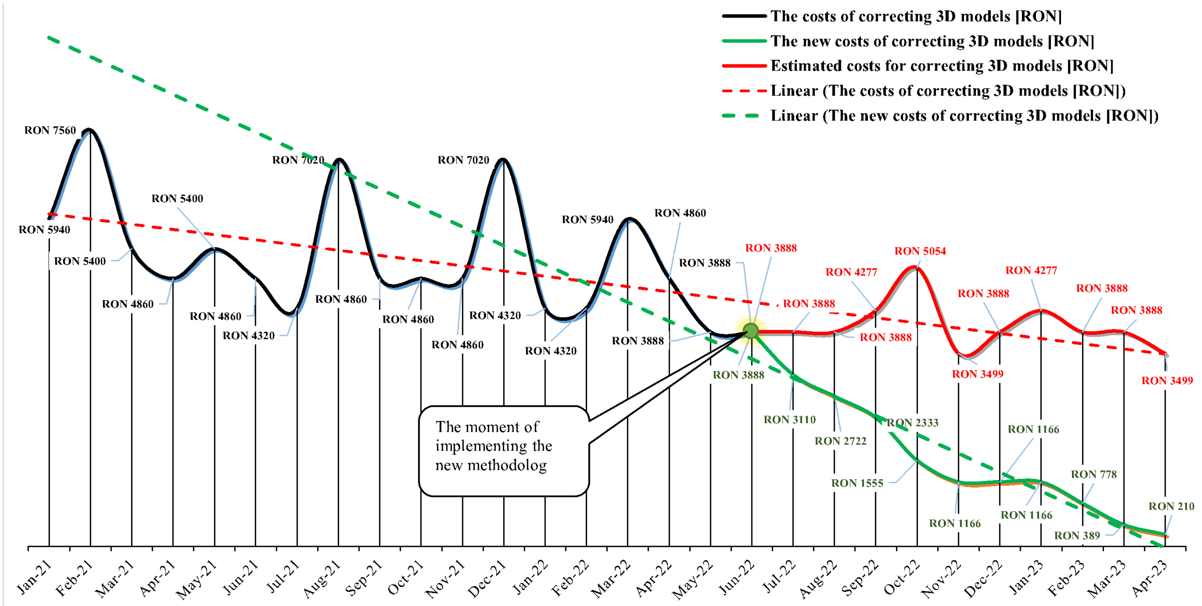

Fig. 13.4 Comparison of the estimated costs of correcting 3D models between the classical method of process improvement and the method proposed in the research

compared to about 49 months, which would be the time needed to reduce costs using the current learning process. This method of analysis is a method of joint management within industrial organizations, especially during periods when annual budgets, project budgets are established, and for planning improvement projects.

The cost analyses conducted clearly demonstrate that improving the knowledge of the resources involved in the overall engineering process has a major impact on industrial organizations.

13.1.1Proposing a methodology for the implementation of the developed model

The methodology developed in this research can be applied in any industrial organization or, more broadly, in any organization that manages the requirements of product quality through various internal processes that usually use knowledge as the main resource, globally intellectual capital.

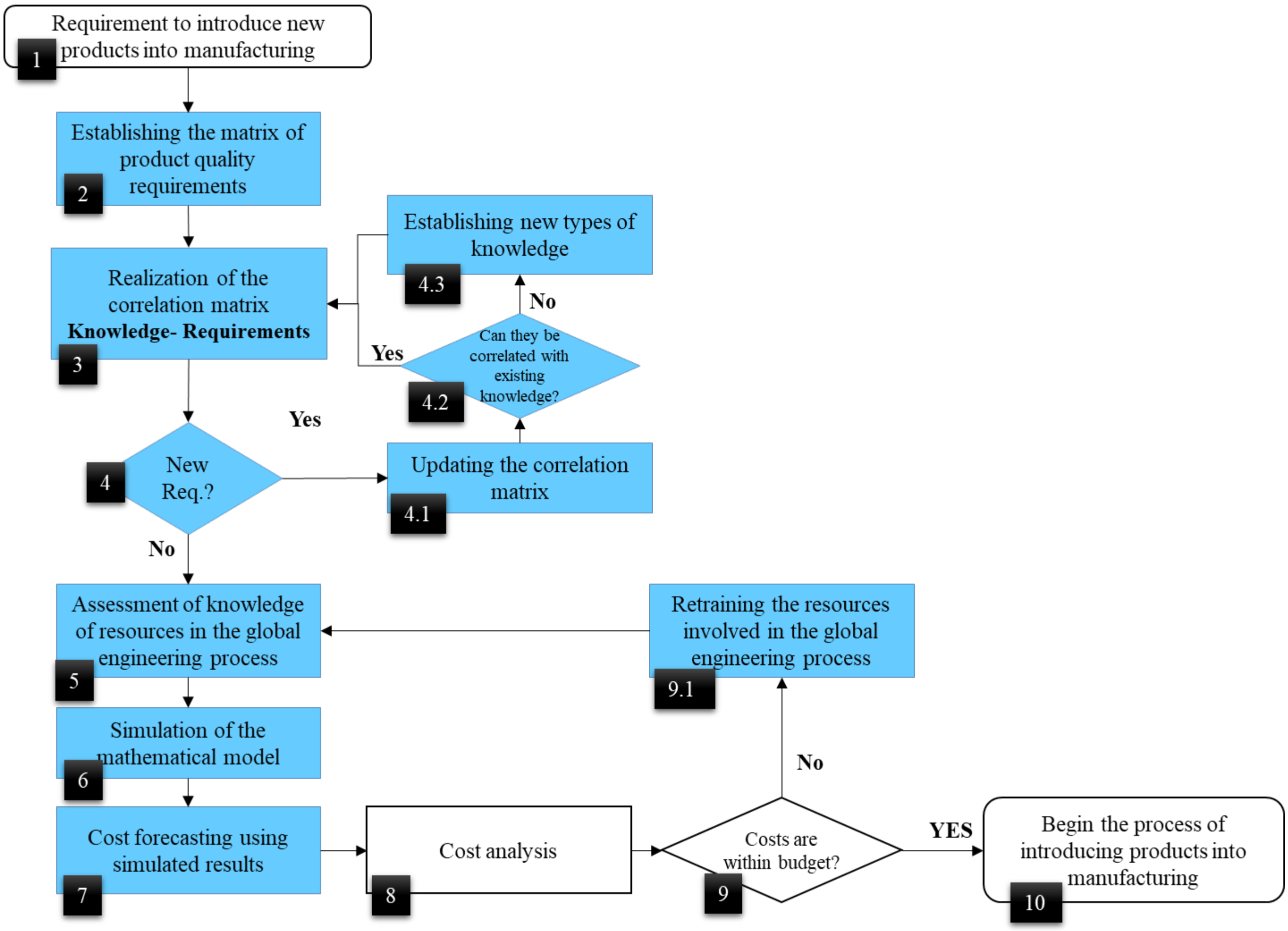

Fig. 13.7 Flow of methodology and improvement of product quality by directly correlating product quality requirements with the knowledge existing at the level of the organization

Figure 13.1 shows how the methodology described by us can be used in the processes of industrial organizations, in the phase of introduction of products into production, more specifically at the time of management decisions on the necessary cost assessments, respectively the planning of the realization of these products. The tool identified together with the flow of application of this methodology, is in fact the purpose of the present research, which, together with the conclusions of the next chapter, formed the basis for the present doctoral thesis.

Chapter 14 FINAL CONCLUSIONS AND MAIN CONTRIBUTIONS TO THE DEVELOPMENT OF A MODEL FOR IMPROVING PRODUCT QUALITY AND STREAMLINING ENGINEERING PROCESSES IN AN INDUSTRIAL ORGANIZATION IN THE FIELD OF AERONAUTICS

General conclusions

The general objective of this research, regarding the improvement of the quality of the products by streamlining the quality of the production processes, was achieved indirectly, by improving the deliverables used in the production processes. Deliverables are the result of the transformation of product quality requirements by engineering processes, through the intellectual capital allocated to them.

To locate as correctly as possible this source of quality improvement, a study of knowledge in the field was conducted over the course of four chapters of Part I of this thesis.

Thus, in Chapter 1 we analyzed the current state of industrial organizations and their structuring, managing to identify a number of types of organizations and current trends in their development. It was mentioned and highlighted how the organizations work, what the industrial organizations represent, how the organizations develop using intellectual capital and what is what the researchers mention as the organization of the future.

Starting from these exposures of knowledge in the field of industrial organizations and based on the professional interest of the researcher for the aeronautical industrial field, during chapter 2 a current state of knowledge in this field was outlined.

The approach to the historical evolution of aircraft complexity has led to the presentation of the development over time of the product quality requirements that are managed by industrial organizations in this field. In parallel with the increasing complexity of aircraft, respectively of their components, the increase in market demand for the number of aircraft has led to the globalization of component production processes. These two aspects identified show the additional effort to which industrial production organizations in this field are subjected.

The additional effort generated by the complexity and volume of product quality requirements has a direct impact on their quality, which is why during chapter 3 a study was carried out on quality and perceptions of quality nowadays. Using the study of the domain-specific bibliography, we have identified applicable concepts, regardless of the field of activity. Most of the work in the field recalls definitions of quality and the importance of a quality management system within organizations, the purpose of which is to ensure that organizations fully understand what quality represents. In turn, the concept of total quality explains in sufficient detail and logically the importance of quality, but it is quite difficult to fully implement in industrial organizations. The success of organizations from this point of view depends on the level of implementation of quality, which is why this research also aims, along with all the others in the field, to highlight how quality can be evaluated and improved.

Improving the quality of a product can be achieved by addressing the improvement of the mechanism that makes that product. Within organizations, these mechanisms are represented by processes. The analysis of the current state of process management within organizations, presented in chapter 4, aims to highlight the similarities between the different organizations regarding the type of processes and the management of these, regardless of their nature.

Process modeling methods and the importance of the process map are a particularly important process in the conception of this research. Their importance is given by the fact that through these processes it can be visualized and understood as the function of the entire mechanism of the organization, like connected electrical circuits for a single purpose. Mapping the processes of organizations, the result of which is the so-called *process map*, is a basic requirement in the quality management system standard, being also used by audit organizations to understand the functioning of organizations.

Also, this process map demonstrates that every process within the organization has an impact on the final quality of the products. In the perspective of the entire process, the maximum impact on the qualities will be found in the processes with the most connections or, in other words, in the node processes in the organization's system. This perspective on the level of impact on product quality was also the starting point of this research.

Also, as part of the current state, in chapter 4 a study was made on how to organize processes in a current type of organization – which practically represents the current state of the quality management system in an organization. It also represents the current state of the art of the processes and the way in which they are managed to obtain quality products.

Although the quality management system is certified and the products made are brought to the level of quality required by customers, the effort and costs required are quite high; hence the need to address the improvement of the quality of processes to improve the quality of products.

The current state approach started from more general perspectives on the industrial field and then focused on the area studied, creating the possibility of highlighting the logical thread and directing the research towards the proposed objective. More detailed conclusions on the state of play are set out in Chapter 5.

In the second part of the thesis, the main objective of the research was developed in relation to the proposed research directions. A specific objective has been defined so that between the study gul to be approached by going through a logical flow. In the same way, the research methodology provides the overview of the research process.

Complementary to the six-step research methodology, the method of mental maps, presented in chapter 6 of this thesis, was used. The method provides the researcher with the possibility to simultaneously follow several topics, the results of which converge towards the same goal.

Chapter 7 is the result of the study on the variation of the quality requirements of the metallic structural products in the aeronautical field used in the studied industrial organization. The structuring of the requirements on levels of detail is based on the analysis of over 15,000 benchmarks implemented in the production process over approximately nine years.

In Chapter 8, with the result of the analysis of product quality requirements, a study on the methods of use of the requirements in the organization was conducted. The goal was to identify the interactions between quality requirements and process deliverables within the organization. The analysis was applied to engineering processes within the organization, as they were previously identified as the connection nodes for transferring requirements from the customer to the production processes within the organization.

Identifying the interactions between quality requirements and deliverables of engineering processes is only a step in improving product quality. These interactions only localize the points with the greatest impact, where the improvement effort would have maximum results. The next logical step was to study how engineering processes work when transforming requirements into deliverables, that is, to identify the mechanisms of these processes.

In chapter 9, identifying the mechanisms of engineering processes as the knowledge applied during the realization of activities, a model was developed that allows the identification of knowledge for all engineering processes and component activities. Thus, a matrix model of knowledge structuring was developed for each activity within the engineering processes.

Due to the large volume of combinations of processes, subprocesses, activities, deliverables and knowledge, the result of analyzing the knowledge involved in engineering processes brought the research to a point where the approach to improving the quality of products became difficult to address. For this reason, a study on methods of modelling and simulation of processes was used, the most appropriate being considered the IDEF0 methodology.

The IDEF0 methodology has been designed for modeling and simulating complex and multi-level systems, depending on the intended purpose. In chapter 10 we have achieved the graphic modeling of the engineering processes, starting from the realization of the simplified functional model of the organization to the graphical modeling of the activities within the engineering processes, highlighting the inputs, outputs, mechanisms, and controls of each activity.

The results of the interactions between the quality requirements and the knowledge of the engineering processes in the process of making deliverables, achieved through the two methods, matrix and graphic, were then analyzed also from a statistical point of view, to confirm the correlations between the requirements and the knowledge. Thus, in Chapter 11, a graphical correlation was made, identifying the requirements and knowledge with the greatest impact on the quality of the products. The production of surface graphs and dispersion of interactions confirms the direct correlation between requirements and knowledge.

Due to the need for mathematical modeling of this correlation, it was proposed in chapter 12 a mathematical model that allows the calculation of the quality level of the deliverables of each process according to the weight of the quality level of the product quality requirements, respectively of the knowledge in the engineering processes. The mathematical model was developed for each deliverable of the global engineering process, also considering the calculated level of quality of deliverables used in other deliverables from previous processes.

The last part of our research, presented in chapter 13, proposes a simulation of the mathematical model and the validation of its results by comparison with real data from the studied industrial organization. The simulation of the mathematical model was based on the assessment of knowledge within a specially chosen process, based on a questionnaire developed within the framework of this research. The result of the simulation being close to the real data within the organization, the conclusion that is required is that the mathematical model is a valid one, which can be used in the context of the studied organization.

Also, in Chapter 13, several considerations of an economic nature were conducted, aiming to highlight that the improvement of the level of knowledge within the organizations increases the level of product quality.

Original contributions

The original contributions of this thesis, which were disseminated during the research program through scientific publications, are:

- A study was carried out on the current state of knowledge in the aeronautical industrial field, following the development of the complexity and volume of quality requirements of metal structural products in the structure of aircraft.
- An analysis of the quality management system within an industrial organization in the aeronautical field and the identification of areas for improvement in relation to the concepts of quality was performed.
- The engineering processes within the industrial organization were mapped and grouped according to their role, under the umbrella of a single process, called the global engineering process. Thus, for the studied organization, three groups of processes were identified, eight processes, nineteen subprocesses, seventy activities necessary to achieve twenty-three deliverables.

- A matrix model for the analysis of the quality of metallic structural products was made, applicable to all metal components in the aircraft composition.
- A model has been developed to identify the levels of importance of product quality requirements from multiple perspectives, depending on their level of detail.
- A matrix model of analysis of the global engineering process was made, starting from groups of processes to the level of activities, respectively of the knowledge necessary for each activity, in the context of the subprocess in which they are used.
- A model for identifying the knowledge applied in the activities of the global engineering process has been proposed. Thus, four groups of knowledge were identified, namely:
    - Technical knowledge, of which:
        - Twenty-five types of general technical knowledge.
        - Eleven types of technical knowledge specific to metal structural products in the aeronautical field.
        - Four types of technical knowledge specific to the production processes in the aeronautical field.
    - Knowledge of aeronautical specific production processes, 20 types.
    - Software knowledge, nine types.
    - Knowledge of internal or external communication, three types.
- The types of knowledge most often applied to the entire global engineering process have been identified. From their interactions with the quality requirements, it was possible to establish the processes that can be improved in the shortest time and with the most obvious results.
- The correlation between quality requirements and knowledge in engineering processes has been established, using multiple methods (matrix and statistical).
- A graphical modeling of the engineering processes integrated in the global engineering process was performed, using the IDEF0 methodology. The level of detail of this modeling has been taken to the activities and knowledge that make these processes generate deliverables needed for production processes.
- A mathematical model for calculating the quality level of the deliverables of the engineering process with a direct impact on the quality level of the products made based on them in the production processes was made and proposed. This mathematical modeling was done for all twenty-three deliverables of the global engineering process.
- A questionnaire was conducted to assess the knowledge of the engineering processes directly connected with the quality requirements of metallic structural products in the aeronautical field.
- The proposed mathematical model was simulated and validated with data from the studied organization, regarding the quality level of the deliverable of the virtual 3D model of the product.
- A methodology was developed to approach the improvement of product quality by correlating quality requirements with knowledge from engineering processes. This methodology was partially applied during the research by the author, obtaining positive results.

- An economic analysis of the possible result was carried out following the application of this methodology in the process of continuous improvement.

Further directions of research

- Application of the model for the analysis of product quality requirements for other types of products in industrial fields like the aeronautical one, to identify the levels of greatest influence on production processes in the process of continuous improvement.
- Continue the development of the model for the analysis of product quality requirements for several aeronautical product groups, for high-cost products.
- Analysis and identification of other node processes within the QMS, like engineering processes, for the analysis of their mechanisms and the establishment of areas to be addressed to improve quality and decrease costs, respectively.
- Continue the application of the IDEF methodology in the engineering processes, having as a starting point the first stage of this method, IDEF0, applied in the present thesis. Conducting the simulation of functional models and comparing them with the result of the mathematical model identified in this thesis.
- Development of the mathematical model, to consider the knowledge related to the technical ones, directly connected with the product quality requirements, as they are graphically modeled in the functional models IDEF0.
- Performing simulations of the mathematical model and for other deliverables within the global engineering process, the results being then checked with the actual data within the organization, for the validation of the identified mathematical model.
- Statistical analysis of the data obtained by simulating the mathematical model, considering a range of variation of the level of quality of the requirements, respectively of the level of knowledge in relation to these requirements, the results being compared with the actual figures in the organization.
- Development and implementation of the methodology proposed in this thesis for other types of products, respectively other industrial fields.

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