Application of the IDEF0 Management Method in the Global Engineering Process within an Industrial Organization in Aerospace

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Abstract
IDEF0 is a methodology for functional modeling of business processes, to be analyzed, developed, rethought, and integrated. The analyst's perspective and understanding of the studied process are directly reflected in the way the process is represented. In this way, the process can be represented as an overview with a lot of information, being difficult to follow, or it can be approached gradually from a general level to a more detailed one. This research aims to analyze the global engineering process in terms of the entire organizational system, using functional modeling of the organization's systems using the IDEF0 method. This analysis was performed following the hierarchical structure of the systems and component processes of the industrial organization. The approach adopted highlights the common input/output elements, represented in models of systems and processes, regardless of the hierarchical position they occupy within the organization. In other words, the manufacturing processes within the operational processes execute the internal technical requirements generated by the global engineering process, the reason for which, any deviation of the interpretation of the requirements in this process will lead to the realization of non-compliant products. Due to the complexity of this process, the structure was approached, grouping the processes according to their purpose. It was also detailed - down to the level of sub-processes, the first part of this global process, to highlight the importance of paying attention to some processes - not very complex in terms of engineering knowledge, but with a major impact on the trial.

Keywords
IDEF0, global process of engineering, subprocess, industrial organization, aerospace.

Introduction

Volkova et al. (2017, p. 727) and Fu et al. (2018, p. 1443) considers that IDEF0 is a methodology for functional modeling of business processes, to be analyzed, developed, rethought, and integrated. IDEF0 can also be defined as graphical modeling of a system to create a functional model that describes both the functions of a system and its structure (Han & Weston, 2003, p. 35; Liu et al., 1999, p. 3). To the same extent, the

flow of information and materials that link the functions of the system are highlighted by Yang et al. (2015, p. 49), Li et al. (2020, p. 28), and Hyuk et al. (2019).

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Within organizations, among many other basic responsibilities, management functions also contain the function of systems maintenance (Ragavanantham et al., 2021, p. 778), (Unai et al., 2020). To maintain a system, managers need to know it both from a general perspective and in detail (Shunmugavel et al., 2017), (Zhou, Wenbin; et al., 2021). To get to the details of a system, the methodology for modeling system functions through the IDEF method is one of the handiest techniques (Thang, Kwon, & Foster, 2021).

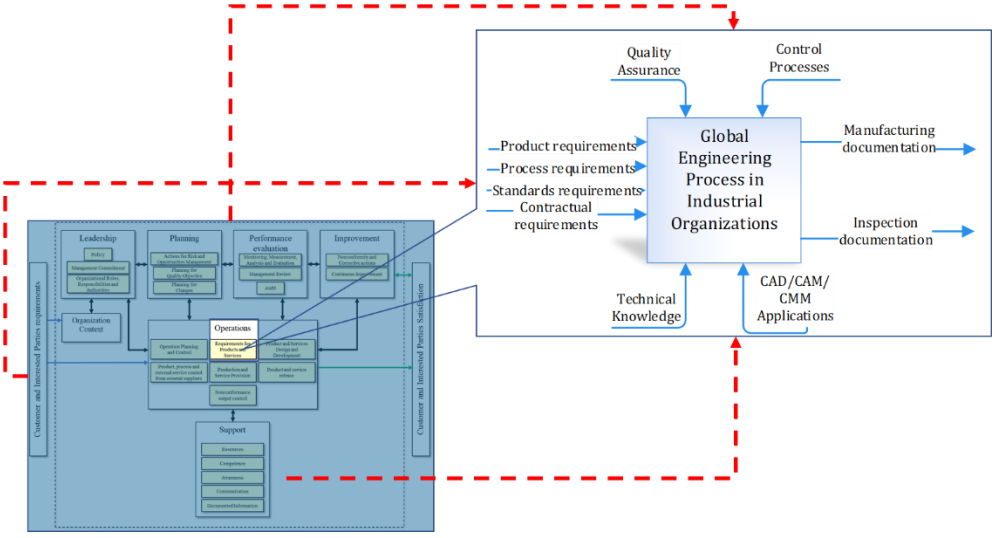

Figure 1. Global engineering process perspective: process map vs. IDEF0 methodology
(original contribution)

Figure 1 exemplifies a different perspective of the same process. This presupposes a perspective of the process map within the quality management system, on the one hand, and, on the other hand, the perspective of the global engineering process manager. It regards the process as one that transforms the product quality requirements into the technical execution and inspection documentation. Using the IDEF0 method you can create the graphical representation of all processes and at the same time of each process, ensuring traceability between them.

Research methodology

For this study, I chose to use the Microsoft Visio application. Masten (1984), Boyer, (1996), and Rebolledo (2011) consider that the analyst's perspective and understanding of the studied process is directly reflected in the representation of the process. In this way, the process can be represented as an overview with a lot of

information, being difficult to follow, or it can be approached gradually from a general level to a more detailed one. To analyze the global engineering process (Abollado, Shehab & Bamforth, 2017, pp. 80-85) through the prism of the entire organizational system, functional modeling of the organization's systems using the IDEF0 method can be achieved by following the hierarchical structure of the component systems and processes industrial organization (figure 2). This approach highlights the common input/output elements, represented in models of systems and processes, regardless of the hierarchical position they occupy within the organization (Wu et al., 2019).

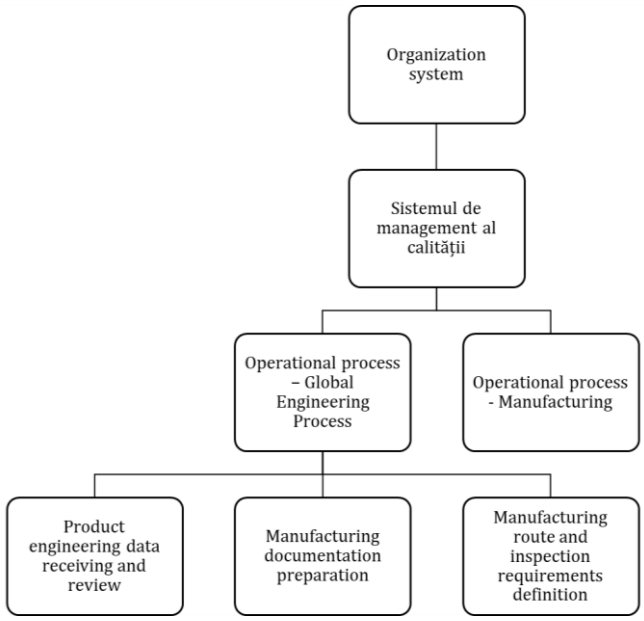

Figure 2. The perspective of approaching the analysis of systems and processes within an industrial organization
(original contribution)

Approaching the organization at a lower level, at the level of the quality management system it is found that customer requirements and the context of the organization are processed through the mechanism of support processes and process management through procedures and instructions (Alblawi, Nawab, & Alsyaari, 2018; Queiruga-Dios et al., 2018). The purpose is to provide the organization with an organizational structure and at the same time certification of the functioning of the organization's system; all this being done under the control of the audit processes and the coordination of the leaders of the organization.

Continuing with the deepening of the organization's structure towards engineering processes (Kassotaki, 2019; N'Cho, 2017), the functional model of operational processes was created (Figure 3).

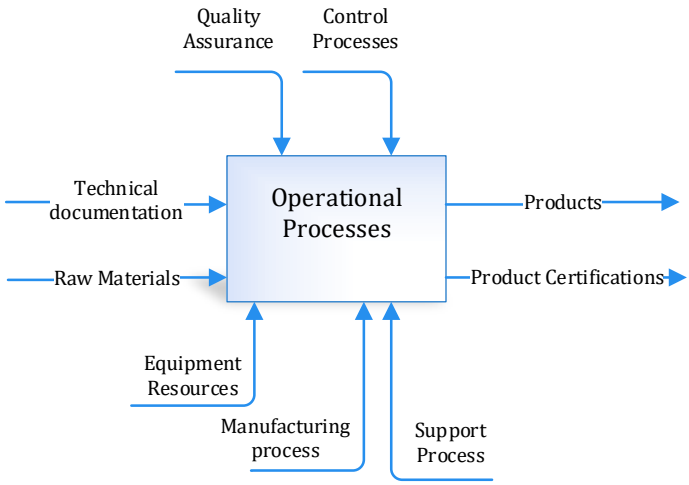

Figure 3. Functional model of operational processes within aerospace industrial organization
(original contribution)

Functional model of operational processes

The functional model of operational processes highlights how technical documentation and materials are transformed into products certified in terms of conformity to be used in aircraft construction (Arpentieva, et al., 2017; Kovrigin & Vasiliev, 2020; Rajamani & Punna, 2020). The global engineering process is a process before the manufacturing processes, which is why the impact of this process on the final product, in terms of quality is major. Going through all the levels within the organization's system (Figure 4) each system and process, to achieve its goal, use the product quality requirements as an input element. Exceptions are manufacturing processes within operational processes that use the requirements transformed by the global engineering process. With the observation of the major impact on product quality represented by the impact of the global engineering process, the functional modeling of this process becomes more and more important.

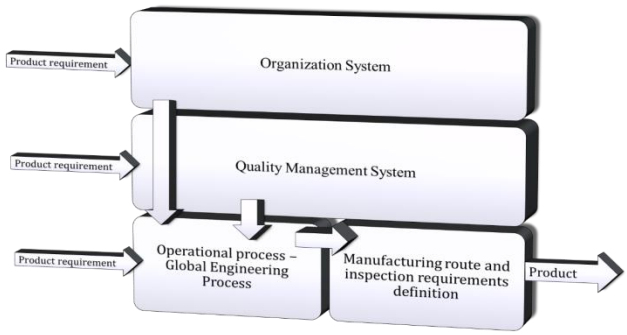

Figure 4. The influence of product requirements on the organization and their use in the manufacture of products
(original contribution)

Figure 5 shows the input elements of this process: the requirements of the products that through the engineering processes and support processes generate as outputs - manufacturing requirements and product inspection requirements. The control processes specific to each component process and those of quality assurance, represent the controls of this functional model.

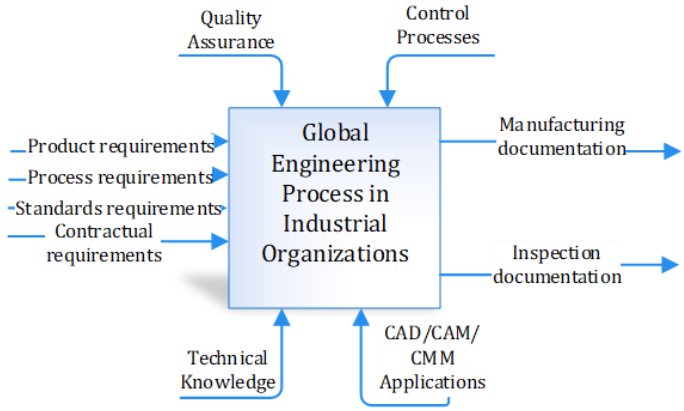

Figure 5. The functional model of the global engineering process in an industrial organization
(original contribution)

The global engineering process composed of several processes is considered to be approached on several levels of detail. The levels are set according to the basic transformations of the product requirements. With the transfer of requirements within industrial organizations, they go through three basic steps which must then be applied in the manufacturing processes:

- the documentation is inventoried and analyzed;
- requirements are transformed into manufacturing technologies;
- establishing the technological itinerary and the inspection methods of the product requirements, in the manufacturing process.

For the application of the IDEF0 methodology on this global engineering process, the representation on levels of detail is considered in this study, to highlight the interactions between inputs, of this process, product quality requirements, and process mechanisms, respectively its controls, technical knowledge. procedures and work instructions integrated into a quality management system.

Distribution of the global engineering process on levels of detail

Figure 6 shows the distribution of the component processes of the global engineering process on 3 levels. To ensure process traceability within the IDEF0 methodology, each group of processes, processes, and sub-processes was coded.

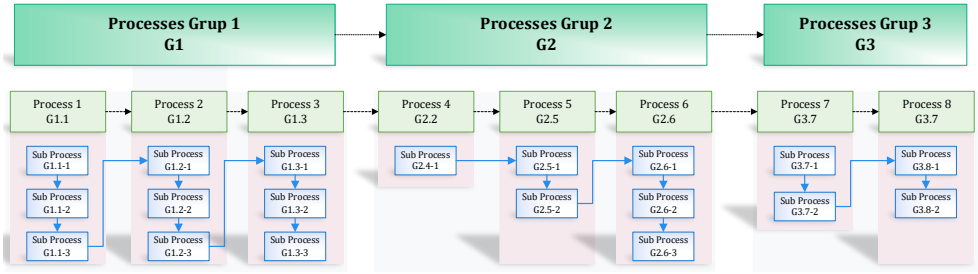

Figure 6. Distribution of the global engineering process on levels of detail
(original contribution)

The codes of each process are set as follows:

- G1, G2, G3 - Number of process group;
- .1, .2, .3, .4, .5, .6, .7, .8 - the process sequence in the global engineering process;
- -1, -2, -3 - the sequence under the process within the process part of the global engineering process.

The grouping of processes allows the IDEF0 methodology to manage several inputs and outputs as small as possible so that through the graphical representation can be highlighted for each process, all inputs, outputs, mechanisms, and controls. Figure 7 shows the functional model of the global engineering process detailed at the level of process groups.

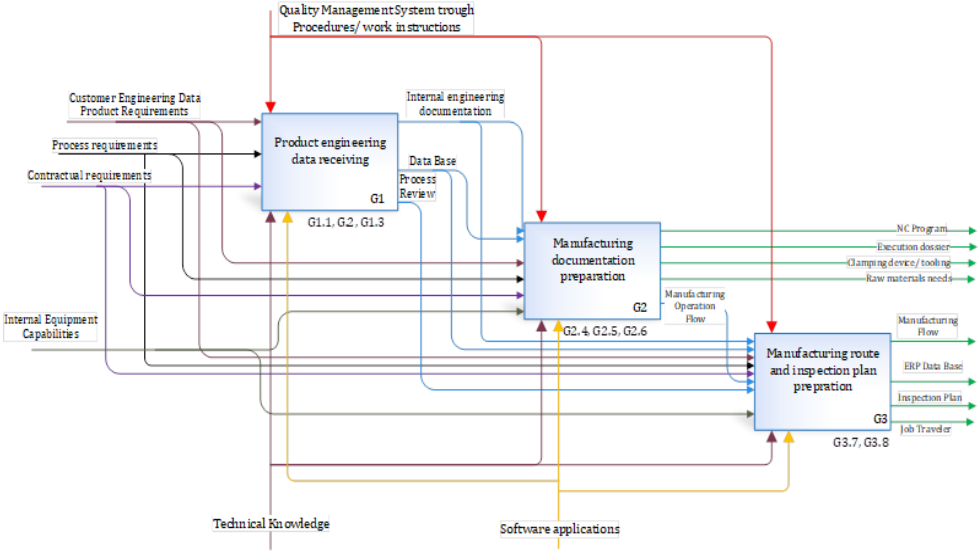

Figure 7. The functional model of the global engineering process in an industrial organization
(original contribution)

Process group G1

The requirements of the products in the form of technical product documentation and manufacturing processes and the contractual requirements corresponding to the products represent the entries in the process group G1-the processes of receiving and managing the technical documentation.

The outputs of the G1 process group become inputs for the G2 process group - the global engineering process. Also, as an input to this group of processes, the capabilities of the organization are considered. They allow resources to establish process manufacturing strategies in relation to their equipment and capabilities. Product requirements, in the form of internal technical documentation, prepared by previous processes and capabilities organizations are transformed by the resources associated with these processes, having the necessary knowledge and IT applications, into manufacturing documentation. All these deliverables are generated and controlled according to internal procedures and instructions.

The last group in the global process - G3, is the one that defines the technological itinerary of products and the definition of inspection requirements. The component processes of this group have as inputs:

- technical documentation of products;
- technical documentation of manufacturing and inspection processes;
- contractual requirements;
- database updated in the ERP system;
- internal execution documentation;
- the sequence of technological operations, corresponding to mechanical processes;
- analysis of all processes applicable to the product;
- the capabilities of the organization in terms of equipment.

All these inputs are used to generate the technological itinerary of the products in the ERP system and then the inspection plan for each individual product.

Detailing the process group G1 (figure 8), the following processes can be observed with the sub-processes respectively the corresponding activities:

- The process of receiving and analyzing the documentation;
- The definition process in the internal ERP system;

The process of preparing the supporting documentation for the manufacturing processes.

In aerospace, the technical product documentation - over 95% for structural products, is made by customers in CAD design environments, namely Catia V4 and Catia V5. For this reason, these applications are used in this process to identify the applicability of product requirements.

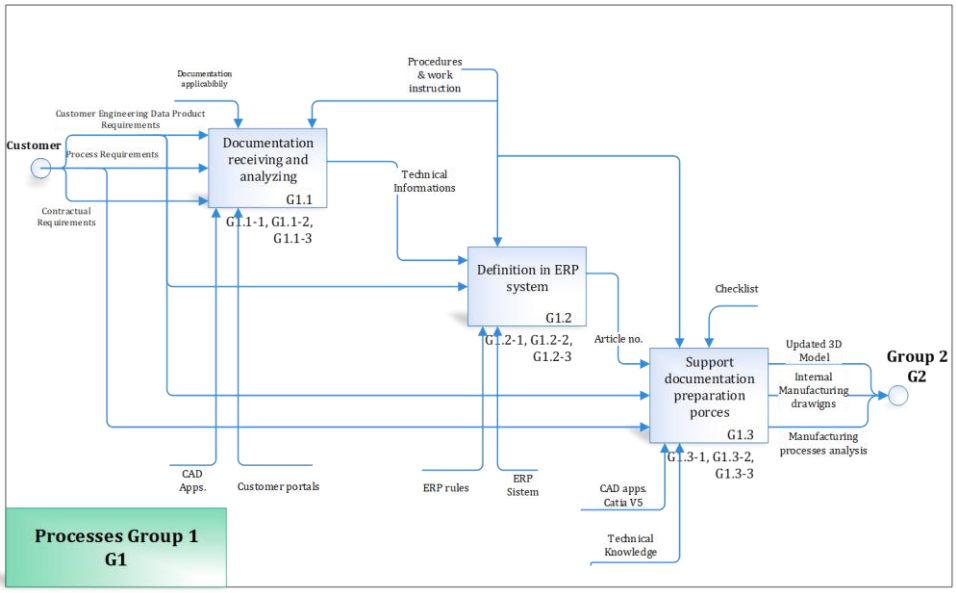

Figure 8. Graphic representation of group 1 of processes - receipt and analysis of technical documentation
(original contribution)

Once the technical documentation of the products is transferred and structured within the organization, the process of defining the product data in the internal ERP system (G1.2) can be performed. This process is performed strictly through ERP applications and product definition rules, being controlled by the working methodology defined in the procedures and instructions specific to this process.

In this process, the introduction of product data into the ERP system is a critical activity for industrial organizations. The reason is that these data become the reference data of the products. These data are the first requirements for product quality, requirements that are used throughout the engineering process and in manufacturing processes, including in the product certification documentation.

Control methods play an important role in this product, which is why the level of detail of the interpretation of product requirements must be directly related to the level of knowledge of the resources that carry out this process.

The outputs of this process are represented by:

- identification of each product with a unique item in the ERP system;
- the technical documentation attached to each article.

The third process in group 1 of processes G1.3, in turn, composed of 3 sub-processes, the process of preparing the supporting documentation for manufacturing processes, is also critical in the global engineering process, because it is the first process that transforms the quality requirements of the products received from the customer into internal requirements, specific to the organization.

Thus, the outputs of this process are:

- updated 3D model;
- internal execution drawings.

Process group G2

Process group G2 is composed of 3 processes: G2.4, G2.5, and G2.6:

- the process of realizing the transformation strategy of the semi-finished product;
- the process of creating numerically controlled programs for CNC;
- the process of designing and making the devices.

The first process G2.4 - the realization of the semi-finished product transformation strategy represents that process which, based on the product quality requirements, respectively the process inputs, conceptually establishes a product manufacturing methodology. This methodology contains the mechanical and chemical operations necessary to transform the semi-finished product into the final product. This process can only be achieved through knowledge specific to mechanical and chemical operations.

The outputs of this process are (figure 9):

- the succession of technological operations;
- CAM strategy;
- the concept of the device.

Through the second process G2.5, the numerically controlled program for the numerically controlled machine tool is realized. This process is a process that uses the deliverables of the first group of processes, namely the 3D model and internal execution drawings so the 3D model is the source of geometry used in CAM applications that helps the programmer engineer to define machining tool paths, choosing the type of cutting tools and cutting regimes. In aerospace, the cutting regimes are predefined by specific standards for each customer on each type of alloy and the degree of hardening. These requirements are considered as process requirements corresponding to the quality of the products.

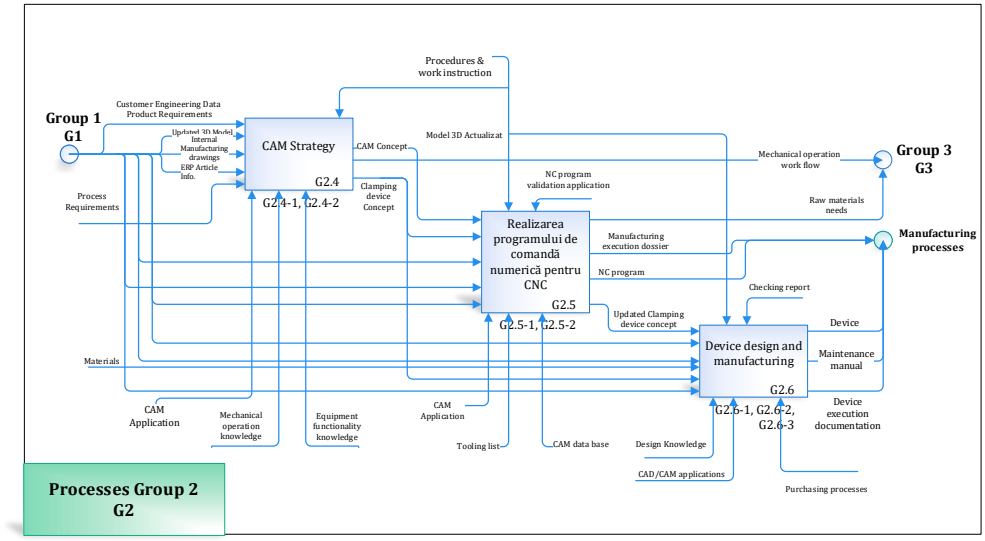

Figure 9. Graphic representation of group 2 processes - preparation of manufacturing documentation
(original contribution)

The outputs of this process are (figure 9):

- NC program;
- updated device concept;
- the technological execution file;
- required semi-finished products.

All these outputs are generated by sub-processes G2.5-1 - realization of the cutting processing program and G2.5-2 - Update of the device concept and preparation of the execution file. These sub-processes will be detailed in further research. This process is controlled by specific working procedures and instructions, developed to ensure the compliance of products with the lowest possible costs.

G2.6 - the process of designing and making devices contains several levels of detail, but in this study will be mentioned only the first level of the process with sub-processes G2.6-1 - Device design, G2.6-2 - Development of device execution documentation, and G2.6 -3 - Manufacture of devices.

The mechanisms of this process, due to its complexity, in addition to the technical knowledge with a high level and the knowledge of CAD / CAM applications are also represented by the processes of material acquisition or even subcontracting manufacturing activities.

The outputs of this process are:

- device/devices;
- device maintenance plan;
- device execution documentation

This process is controlled by specific working procedures and instructions, developed to ensure the compliance of products with the lowest possible costs. The outputs of these processes are mostly used directly in manufacturing processes, which is why in industrial organizations, these processes are best documented and developed in terms of technical knowledge, due to the major impact they have on costs.

Going through the global engineering process, once the technical documentation has been transferred to the internal system and the mechanical operations strategy has been established, the realization of the processes from the last group of processes can be done.

Process group G3

The G3 process group involves the establishment of the manufacturing route and the inspection requirements. This group of processes consists of two processes that complete the overall engineering process by the final transfer of the requirements in the technological manufacturing route of the products and then by creating the inspection plan corresponding to all the requirements.

The outputs of this process are (figure 10):

- technological manufacturing itinerary in the ERP system;
- the need for material defined in the system;
- inspection plan.

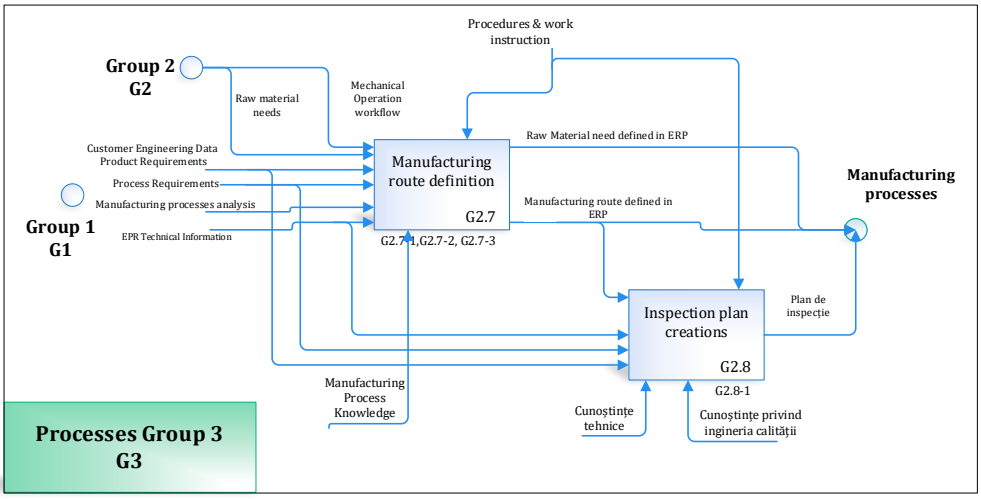

Figure 10. Graphical representation of group 3 processes - determination of the manufacturing route and inspection requirements
(original contribution)

Approaching the first process, G1.1 (figure 11), we can identify the 3 component sub-processes:

- G1.1-1 - receiving and registering the technical documentation;
- G1.1-2 - Documentation analysis.

- G1.1-3 – Feasibility assessment in terms of manufacturing.

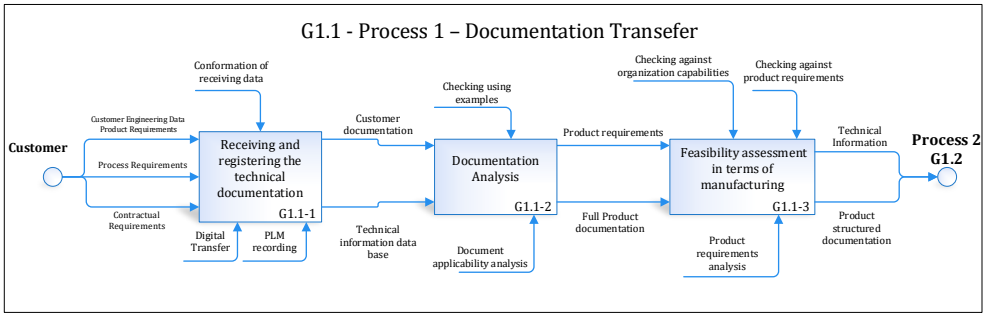

Figure 11. Process G1.1 - receiving and analyzing product documentation (original contribution)

Sub-process G1.1-1 ensures the transfer of technical product, process, and contractual documents by electronic transfer and using the PLM application within the organization. How this process is controlled is represented by a written confirmation activity of the receipt of the documentation. The control method at this level of detail can be a simple activity or a procedure, respectively a work instruction.

Sub-process G1.1-2 is the process in which, based on the technical knowledge of the applicability of the technical documentation for each structural product, all applicable documents are identified and added to the PLM system. The purpose is to be able to be used later as product requirements. The control method is based on visual aids developed for each client and different projects.

The outputs of this sub-process are represented by the complete product documentation and product requirements in the form of technical information in the database, structured and updated.

Sub-process G1.1.3-achieving the feasibility of manufacturing processes - is the process in which all manufacturing processes defined as requirements for structural products are identified. In aerospace, each manufacturing process for structural components is controlled by major aircraft manufacturers, by creating specific standards.

The outputs of this sub-process are represented by:

- updated technical information;
- technical documentation corresponding to the product - in the PLM system it is updated with technical documentation of processes and contracts;
- analysis of the processes applicable to the product.

These outputs are transferred to the process G1.2 - definition in the ERP system. This process is composed of 3 sub-processes, namely (figure 12):

- G1.2-1 - defining the product number in the ERP system;
- G1.2-2 - transfer of technical data in the database of the ERP system;
- G1.2-3 - attaching the technical documentation in the ERP system.

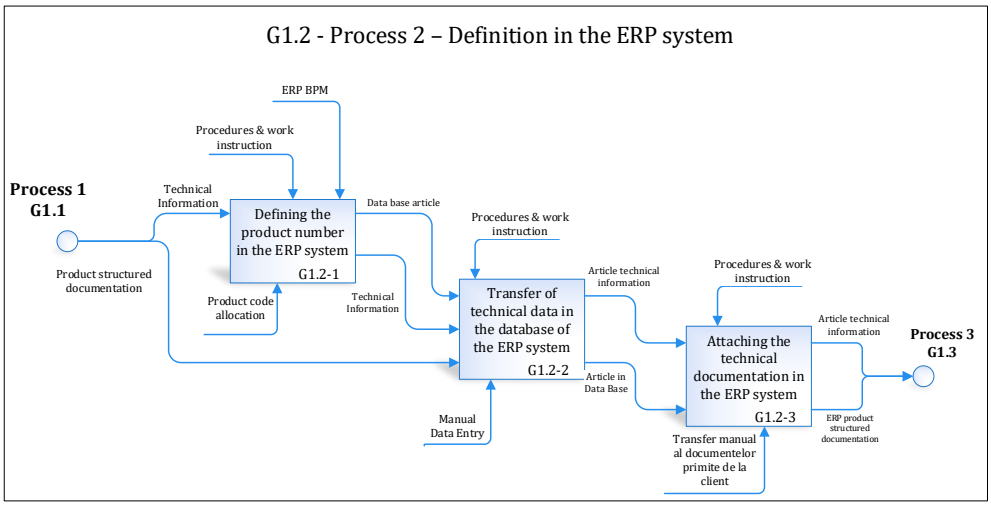

Figure 12. Process G1.2 - definition in the ERP system
(original contribution)

Sub-process G1.2-1 uses technical information and product-structured documentation to establish and define in the ERP system an internal product number, specific to that product. Using the knowledge mechanism on product coding within the organization, the resources that are involved in this process generate product numbers in the database and technical information specific to the organization (project information, logistics, and financial). All this is done through the control generated by the applicable procedures and instructions and also by the constraints of the ERP application, such as the obligation to complete certain information in the system to generate the product number.

Once the product number is created in the system and the technical information is prepared, sub-process G1.2-2 has the necessary entries to start the activities of transferring the technical data from the technical documentation of the product, received from the customer. This sub-process is critical due to its impact on the entire global engineering process and its deliverables. As shown in Chapter 1, the database is the main source of information in the process since it was created. Therefore, the technical knowledge required for this process must be correlated with the entire manufacturing process of structural products.

This sub-process has as an identified mechanism, knowledge of the necessary technical data in the ERP system. It generates outputs - the product database specific to the organization and the internal product number, used as an identifier in the internal ERP system. The procedures and working instructions of this sub-process ensure control.

The G1.2-3 sub-process for attaching the technical documentation received from the client in the ERP system ensures the sub-processes and subsequent processes structured access to the technical documentation. Document transfer is accomplished through document management knowledge in PLM and ERP applications; the control method being the applicable working procedures and instructions.

Process 3 (figure 13) for preparing the supporting documentation for the manufacturing processes consists of 3 sub-processes:

- G1.3-1 - Preparation of 3D models;
- G1.3-2 - Preparation of manufacturing drawings;
- G1.3-3 - Preparation of drawing instructions for painting processes.

Sub-process G1.3-1 is the first sub-process that manages the formal and functional requirements of the products by transforming them into internal requirements necessary to be used in the design processes of manufacturing and inspection technology.

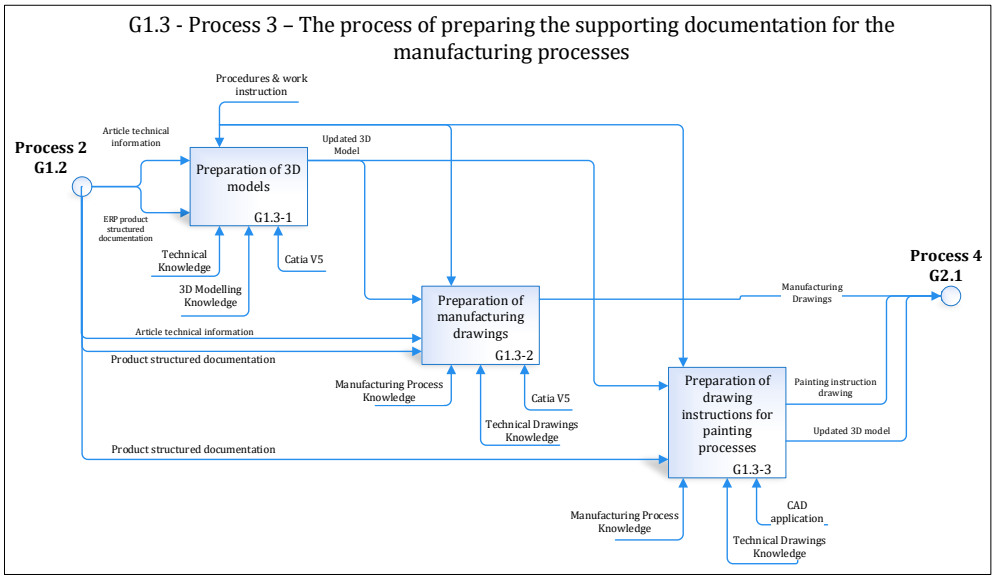

Figure 13. Process G1.3 - the process of preparing the supporting documentation for the manufacturing processes
(original contribution)

In aerospace, the basic application used for product design is Catia V5 due to the possibility to perform different design activities in the same virtual environment. For this reason, for this sub-process, knowledge in using this application is required and is part of its mechanism.

The output of this process - the updated 3D model, is similar to the database - a deliverable that has a direct impact on product quality. The non-compliant 3D model may generate non-compliant products that can only be verified in the certification process or in-aircraft product assembly process. The control methods of this process are based on working procedures and instructions. Sub-process G1.3-2 for making manufacturing drawings represents the process of transferring and collecting technical information in internal execution drawings, using as inputs the updated 3D model in the previous process, the database, and the technical documentation received from the customer, specific to each product.

The main purpose of this deliverable is to ensure the easiest possible access to the requirements of the products of the manufacturing processes. The control of this sub-process is performed based on internal procedures and instructions. Sub-process G1.3-3 for drawing preparation - instructions for surface protection processes are similar to sub-process G1.3-2, only that the information is structured to respect the sequence of technological operations. These drawings are made using knowledge of surface treatment processes and the specific requirements of each product for surface protection. The metallic structural products in the composition of the aircraft, depending on the functional role, may have different requirements that lead to the creation of specific drawings - instructions. The control method of this sub-process is represented by specific procedures and instructions. The outputs of this process have a large impact on product quality because it is the source of product quality requirements for processes in the global engineering process and manufacturing processes.

Conclusions

The IDEF0 methodology allows access to hierarchically structured process information, from a general perspective on processes at a more detailed level. Applying this method in the analysis of the global engineering process, the mechanisms of the engineering processes have been identified that prepare and validate the deliverables necessary for the manufacturing process in an industrial organization in aerospace.

Technical data entry processes - group G1, in the databases of industrial organizations, can directly affect the quality of products, which is why the level of knowledge required for these processes must be developed in relation to the requirements of the products.

Risk management in this area of entry highlights the rather high impact on the organization, which is why the implementation of procedures and work instructions for component activities is the first step. Correlating the complexity of requirements with the possibilities of IT systems would be a preferred system approach especially if the volume of information is very large.

The processes of preparing the manufacturing documentation - G2, require a very high level of technical knowledge, specific to industrial organizations, which is why organizations pay special attention to this area, allocating the most specialized resources in this field. However, analyzing the global engineering process, through the IDEF0 methodology, we can see that these processes take over and transform the requirements of the products processed by the initial process. Thus, an inadequate requirement received will continue to be used and will generate non-compliant products. In this context, the high level of knowledge in the processes of preparation of manufacturing documentation cannot correct this requirement.

The processes in the last group of processes - G3 require a level of technical knowledge on manufacturing processes specific to aerospace. Also, in the process of carrying out inspection plans, in addition to advanced knowledge of product requirements and how

they can be validated, knowledge of statistical analysis of the results of the requirements, measured in manufacturing processes, is required. This knowledge is needed to manage process control systems and to identify those product and process characteristics that need to be added to the inspection plans, in addition to the initial ones.

Analyzing the global engineering process at this level, it can be seen that in each process, the process mechanisms are based on technical knowledge. Even if there are applications that facilitate the process by automating some activities, the process itself is performed by human resources.

Industrial organizations operate on these process models, being at the same time in accordance with the requirements of the quality management system. However, the efficiency of the processes depends on the level of technical knowledge available and this efficiency has a direct impact on the quality of the products. Quantifying the level of knowledge for each process in relation to the requirements of the product can generate solutions to streamline processes.

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