CAPÍTULO 23. **ANALYSIS, MODEL AND SIMULATION OF MANUFACTURING AND PRODUCTION SYSTEMS IN ENGINEERING**

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1. INTRODUCTION

Production and manufacturing systems require constant review to be more competitive and effectively adapt to the changes that surround them. Currently, the European Green Deal proposes a strategy towards which to guide the new competitiveness of companies in the production and manufacturing sector ("A European Green Deal | European Commission," n.d.; "What is the European Green Deal?," n.d.).

The industrial sector, within its production and manufacturing systems, develops a transformation system. In this they take a series of resources to transform them into products, which can be both goods, services, as well as a mixture between them, depending on the sector where they are developed. Likewise, production systems are affected by a series of external variables, which may include regulations and laws that are applicable to their activity, to more specific and contextual elements such as weather effects, variable taxes, prices of variable energy, other competing companies, other nearby non-competing companies, urbanization of the area, unpredictable production failures, etc. Likewise, in order to model the production system, and above all, to be able to propose improvements, there are a series of feedback variables. With them, it will also be possible to implement the aforementioned improvements, verify their degree of implementation and the effects they produce, and based on them, make an improvement in the effectiveness and efficiency of the constant process, (Amor Del Olmo et al., 2018; Hipólito & Marín, 2000; Maldonado Villalva, 2008).

Within the proposals for the industrial strategy for a competitive, ecological and digital Europe, ("A new Industrial Strategy for a globally competitive, green," n.d.), a series of guidelines are contemplated for companies that develop different production and manufacturing systems in Europe. The two main axes of providing competitiveness to the business and industrial sector revolve around the green transition and the digital transition.

In the case of the green transition, it is about making use of resources and processes that are more sustainable with the environment that surrounds us. This includes both the use of non-polluting energies, as well as their responsible and efficient use. It also includes the effective recycling and reuse of materials in production processes. The use of alternative transport and machinery is also included, which contribute to the sustainability of the site and the locations where the transformation processes are carried out and the various products are transported, in each of its phases within the supply chain (Hainsch et al., 2022; Kemp & Never, 2017; Kougias, Taylor, Kakoulaki, & Jäger-Waldau, 2021; Li, Wei, Zhen, Guo, & Chen, 2019; Pianta & Lucchese, 2020).

With this, the factor of sustainability comes into great consideration and how this affects all productive agents. With the guidelines of sustainability, a production system must first adapt the suppliers of its raw material to be transformed. Thus, will have to look for competitive prices, but also analyze how they are obtained and how they fall within the sustainability guidelines. Next, the transformation process itself must be analyzed, the machinery it uses, the specific tasks carried out by its workers, as well as the operation and preventive maintenance of the installation. Finally, the characteristics of the final produced object, as well as storage, are taken into account. Other feedback agents (analysis and improvement of the process) as well as external agents (the Green Deal itself, regulations, competences, the context and the situation, etc.) additionally affect

In the case of digital transformation, it focuses on the application of ICT tools and information management within all the variables that affect the production and manufacturing process (Andersson & Eidenskog, 2020; García Vaquero, Sánchez-Bayón, & Lominchar, 2021; Musango, Brent, & Bassi, 2014; Ossewaarde & Ossewaarde-Lowtoo, 2020; Sharma, Lopes de Sousa Jabbour, Jain, & Shishodia, 2022; Yang, Moon, Jeong, Sin, & Kim, 2022).

This includes both telematic communication with suppliers and other agents. Likewise, the digitization of all records, reports and, in general, data obtained and monitored during the process is included. The management, analysis and decision-making based on this data can also be digitized, efficiently managing large amounts of data, which would be inefficient, slow and expensive to do with conventional means. Also included within digitization is the use of robotics and automation within processes, so that times and accidents are reduced and production is increased and with them the benefit of the system. Likewise, within the digital transition of production and manufacturing systems, attention is paid to the modeling, digitization and simulation of systems.

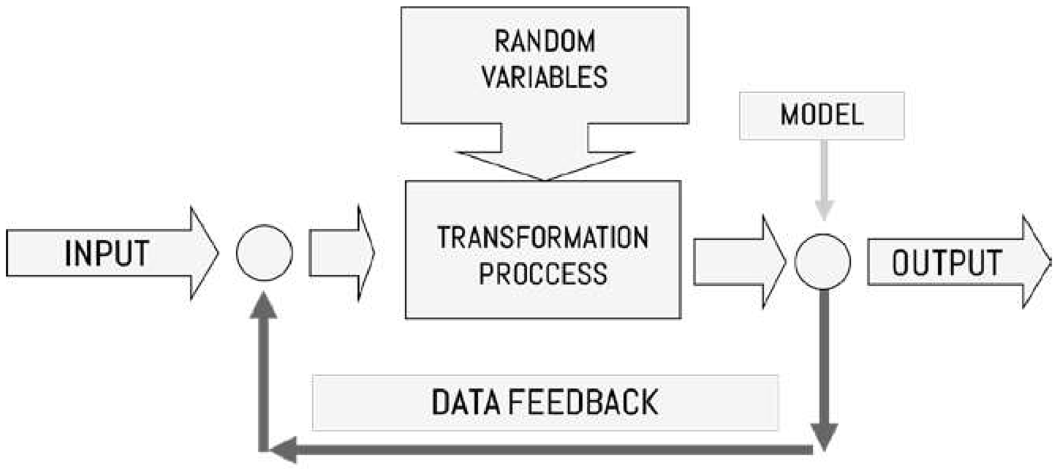
And it is in this sense that the main objective of this project is framed, where engineering students start from the analysis of various transformation systems, which make up a production and manufacturing system, in accordance with the objectives of the Green Pact. Based on the analysis carried out, they implement a digital model on which to analyze practical results and propose additional improvements to the system.

Thus, this work seeks to contribute to the central objective of the strategy for industrial competitiveness in Europe, which based on the improvements to be implemented, mainly in the green transition and the digital transition, seeks to build an industry that leads the new competitiveness at a global level, not only adapting to new technologies and contexts, but also leading the new trend, thus providing a great competitive advantage over its production and manufacturing processes.

2. DESIGN AND APPLICATION OF THE TRAINING

In this work, the analysis of a production and manufacturing process is applied, with different techniques of mechanical engineering, applied within the training of engineering students. During the process, they not only carry out the different transformation processes, limiting it to handling the machine, but also analyze all the external and internal variables, taking into account factors of efficiency and competitiveness.

Figure 1: Diagram of the transformation system to be analyzed and modeled by engineering students

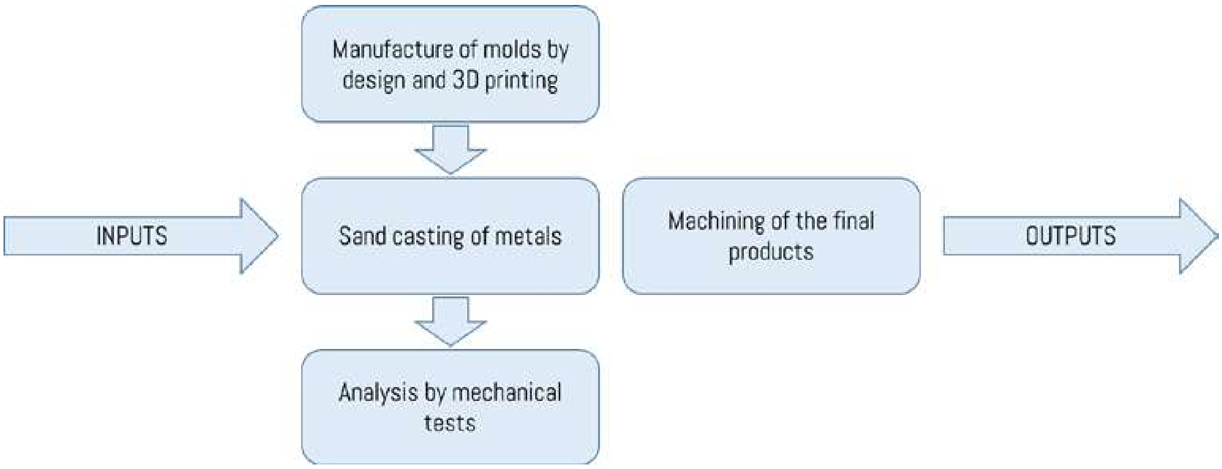


Source. Own elaboration

Below is the work scheme to be followed for the analysis of the process by the students, Figure 1. In this there is a series of input elements, which in their case, will be mainly the raw materials used in the mechanized process to be carried out. , including different metals, foundry sand, etc. Within the transformation process, the processes carried out during the experience will be taken into account, including 3D printing, casting and machining, as well as the specific machinery used. At the output, there will be the products obtained from each of these transformation processes, within the production system, as well as how they are managed, stored or transported. The random variables will consider energy and contextual factors, as well as failures and preventive maintenance. Finally, the feedback of the data will be taken into account, based on which to be able to analyze the improvements in the system, as well as to be able to record the necessary information to implement the model.

The transformation processes contained in the production and manufacturing system proposed to the engineering students are shown below in Figure 2. They must be able to analyze all the intermediate resources, the necessary procedures, the transformation machinery, transport and storage. They are mechanical processes that are already known, but that have never been analyzed from the perspective of the process and therefore no models have been made with which to update them.

Figure 2: Diagram of specific processes



Source. Own elaboration

This contains first of all the manufacture of the molds by 3D printing. Students analyze material used, printer and printing process, printing times, as well as design optimization. The manufactured mold deteriorates over time, so the quantization and calculation of the necessary replacement of the molds directly affects this process. The application of this process is shown in Figure 3. This includes both the 3D design, developed on a design engineering software, and the 3D printed piece. This is the piece that will be effectively used as the mold for the process analyzed in this proposed work.

Next comes a metal sand casting process. For this, previously designed molds are used. In this process, engineering students analyze the origin of the metals, the amount of sand used in the process, the energy used in the foundry and its source, as well as the quality of the manufactured parts and possible failures. Within this process, a priori manual, the times of processes, transport, storage and possible failures that may affect the processes and their corresponding preventive maintenance are also analyzed in great detail. The application of this process is shown in Figure 4. This shows the metal being poured on the sand, previously prepared with the mold, from the 3D printing piece of the previous step. Different operational values as temperature along self-protection equipment need to be also analyzed in this step, so a safe process of manufacturing this metal pieces is guaranteed.

Figure 3: 3D design and printing

Source. Own elaboration

For the subsequent analysis of the casting process, a series of mechanical tests are carried out, where the characteristics of the production are effectively verified. The number of pieces intended for this purpose, the frequency and how they can be reused must be considered. The application of this process is shown in Figure 5. This figure shows the specific device intended to carry out the different mechanical tests. Through this process, not only are the pieces obtained tested, verifying certain parameters, which can be previously defined within a desired quality range. In addition to this, the characteristics, and therefore capabilities and limits of the material obtained after the casting process are also characterized experimentally, and with great precision. With these characterizations, introducing them in an analysis of a large amount of comparative data, with typical big data tools, it is possible to represent different diagrams of the process, such as scatter diagrams, through which to verify how they affect the material obtained. the different changes introduced. This can include direct factors such as melting temperature or time, as well as the raw material used, or plant factors such as how often certain consumable parts are cleaned or replaced in the melting furnace. It can also include direct factors, but belonging to previous stages, in terms of the type of filament used, the temperature or precision used in the 3D printer, the layers of the design and in general everything that refers to the possible changes that are introduced in the mold. Other indirect factors can also be quantified or stratified, such as the results obtained at different times of the day, seasons of the year, climates, different operators in charge of each process, frequency of preventive maintenance tasks and different incentives of the participants in the process. productive analyzed. Thus, the proposed mechanical tests correspond both to the feedback part of specific data, and with the indicated proposal, they become a valuable process control tool. In this way, each change, desired or inevitable, is characterized, and based on this the system can be updated and propose new designs in it, including changes in both material elements (raw material, tools, etc.) and personal ones, as well as a relative quantification of how various random variables affect the systems, such as the type of energy used, given that depending on it, the temperature operating ranges designed with different speed and efficiency can be reached.

Figure 4: Metal casting

Source. Own elaboration

Figure 5: Mechanical testing

Source. Own elaboration

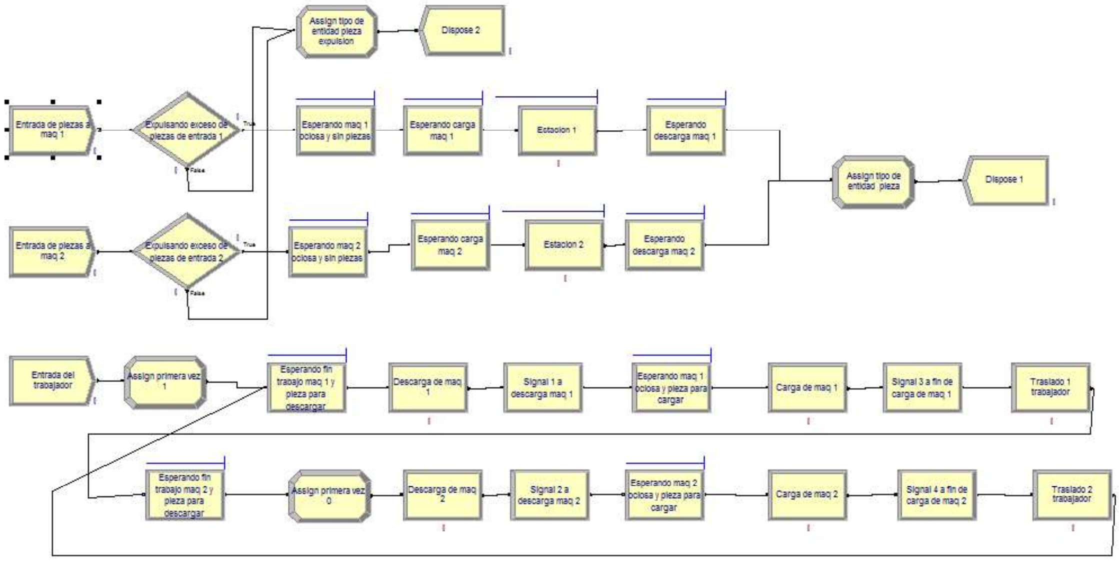
Finally, a machining process is taken into account, where the pieces go through a final process of improvement and adaptation to the specific application for which they have been designed. The application of this process is shown in Figure 6.

Figure 6: Machining of final product

Source. Own elaboration

In a second phase of the training, and with the previous data obtained from the applied experience, the complete system is modeled in a discrete event simulation software for the optimization of complex processes (López Hernández, 2016; Moreno Arispón, 2021), as shown in Figure 7.

Figure 7: Model of production systems for analysis through simulation and statistics



Source. Own elaboration

In the first place, from the modeling of the System, and its corresponding simulation, the engineering students obtain a series of system statistics, with which to present in reports all the random variables that affect the system.

Secondly, the modeling and simulation of the system allows a specific comparison of the results obtained from previous experience. Since it is based on a series of calculations and estimates, without digitizing them, this phase will give better estimation results, and therefore better application.

Next, and based on the model made and the results obtained from it, the engineering students propose a series of improvements to be applied and a report detailing the specific plan for their implementation, monitoring, assessment and rectification.

With this, they obtain statistics of their process, compare them with the results obtained from experience and propose a series of specific improvements to the production and manufacturing process.

3. EVALUATION

The evaluation of the results of this experience goes through the specific assessment through personalized monitoring and the specific quantification through rubrics of the following parameters:

- Justification: motivation, variables, calculations, analysis that justify the proposed improvements on the production systems.

- Feasibility: reasoning and justified estimation of the degree of possible implementation of the proposed improvements, including a specific implementation plan with associated times, resources and costs.

- Monitoring: methodology for recording and analyzing data obtained from the process, as well as the proposal for rectification of the proposed measures.

- Competitiveness: consistency of the proposed measures with the digital transition, the green transition and the analysis of the competitive advantages provided by each of them.

In this way, the specific training in process engineering aims not only to evaluate the external analysis of a production and manufacturing system in the industry, but also to start from a specific and quantified analysis, with concrete estimates and expected behaviors in the different stages based on both calculations and observation. Likewise, the training addresses that, after obtaining the preliminary results of the model carried out, it is analyzed again, detecting failures, bottlenecks and variables and processes that generate reducible costs. From this, improvements to the model are proposed, and in parallel how to put them into practice, with a specific implementation plan. This plan is based on calculations, specific based on the results of the initial model and the improved model. The implementation plan is accompanied by a control plan for the same, so that it is established how it is going to be physically verified how these improvements affect the processes, which must also be contextualized largely within the competitive objectives in terms of to the green transition and the digital transition, which revolve around the new concepts of total quality,

4. CONCLUSIONS

This paper analyzes an industrial teaching experience applied to engineering students. During their development, engineering students analyze industrial processes from the perspective of production and manufacturing systems, in each of the specific transformation processes. Based on this, they model the system, and through a series of simulations they verify the model and propose a series of improvements in line with the green transition and the digital transition, according to industrial competitiveness in Europe. This proposal constitutes a real application of the industry to engineering studies, as well as an improvement in digital skills with the use of system modeling. The proposed methodology is applicable to many transformation processes, since they are specific processes present in building and industry.

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