PLM in a Didactic Environment: The Path to Smart Factory

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Abstract

Universities around the world are teaching PLM following different strategies but most of them limited to design applications. This paper presents a didactic manufacturing plant where design and production are managed in a PLM environment. During the course, students are exposed to the complexity of managing the production of a modular chess set while at the same time they are asked to fulfil design requirements and meet production, quality and cost goals. Course description and achieved results are analyzed thoroughly. Moreover, the efforts to achieve the smart factory are presented.

1. Introduction

The Republic of Colombia is the fourth largest economy in Latin America and due to security improvements, steady economic growth, and moderate inflation, it has become a free market economy with major commercial and investment ties to the United States, Europe, Asia, and Latin America [1]. For this reason, Colombian companies are now struggling to increase their competitiveness. A strategy that would allow companies to faster achieve these results is Product Lifecycle Management (PLM), an essential tool for coping with the challenges of more demanding global competition, ever-shortening product and component lifecycles and growing customer needs [2]. The concept of PLM appeared later in the 1990's with the aim of moving beyond engineering aspects of a product and providing a shared platform for the creation, organization and dissemination of product related information (cradle to the grave) across the extended enterprise [3].

However, PLM is still unknown for most of the national industries and also for most of the country's universities that have not included these topics in their curricula. Therefore, EAFIT University has decided to foster industry knowledge by introducing PLM topics in the master program of production engineering. The purpose of going ahead industry needs is to promote a new type of expert who will have complex technical abilities. It is expected that these new engineers will help industry to face the new challenges of a free market.

The big questions for universities are which goals and objectives should be included and how these concepts should be taught. Thus, this article presents a thorough revision of the state of the art in PLM education (section 2). Then, the design of an original PLM laboratory focused in the development of a chess set is shown (section 3). Next, course definition is analyzed (section 4). Achieved results and further developments are presented in section 5 and 6 respectively. Finally, conclusions are stated in section 7.

2. State of the art in PLM education

In recent years PLM education has received a lot of attention from universities all over the world. However, there is not a standard for defining the necessary skills and capabilities for a PLM expert and therefore it is impossible to define the educational path for new engineers. In this confusion, every university has decided to apply its own approach. Purdue University has been engaged in PLM related research since 1999 [4]. Purdue offers a certification program based in three main aspects of the PLM: CAD, Configuration and Change Management (CCM) and Virtual Manufacturing [5]. Michigan Technological University (MTU) participates to the PACE program [6], an international design competition in collaboration with other universities where students participate annually to showcase innovative design solutions. Oakland University has created the Centre for PLM Education to develop an academic infrastructure supporting PLM, ERP, and MES [7]. Politecnico di Torino has introduced PLM in a bachelor course of automotive engineering [8] and has implemented a short portable PLM course that covers the product development process [9]. ENSAM ParisTech is mainly working on the earlier design phases of PLM [10, 11, 12]. ITESM has introduced PLM on the development of a didactic flexible manufacturing cell [13]. Universitat Politecnica de Catalunya has designed a PLM strategy to develop new products in an academic environment [14]. However, there is no evidence that the strategy has been implemented with students.

Among consultants, CIMData is offering a certificate program for industrial users. Integware [15] proposes PLM training divided in four modules: PLM framework, foundation, engineering and advanced integrated automation.

In Colombia, the first steps have been taken by EAFIT [16] that used an open source PLM solution to improve teamwork performance in a product design course. The National Service of Learning (SENA) is also offering short specialized PLM training around the country.

Most of the courses and training activities presented before deal exclusively with virtual product development. Also, the majority of the courses are limited to design applications. When product production is involved, it is restricted to few prototypes or the fabrication of a one single unit. This paper extends the state of the art by including design and production process in a PLM didactic framework.

Educational institutions are now being requested to prepare future engineers for working with human-oriented automated manufacturing solutions that require well-developed analytical skills for optimisation of manufacturing processes and associated usage of energy and materials, as well as the related costs [17].

The basic idea behind the project is to behave as a small production company where students could complement theory and practice. Students are exposed to the complexity of managing a production while at the same time they are asked to fulfil design requirements and meet production, quality and cost goals. Moreover, in order to develop students' collaborative skills a PLM strategy is used.

3. The chess set company

The product

The proposed product is a modular chess set. In Fig. 1.a is presented the original design of the product. It is composed by a wood table (280x280 mm) and 32 pieces of two different colours. The piece composition is shown in Fig. 1.b. All parts are composed by at least 3 components (base, body and head) and in the case of the bishop, queen and king a second base is also employed. The piece design respect the Design for Manufacturing and Assembly (DFAM) principles since components are universally inter-mixed with other figure components if tolerances are met.

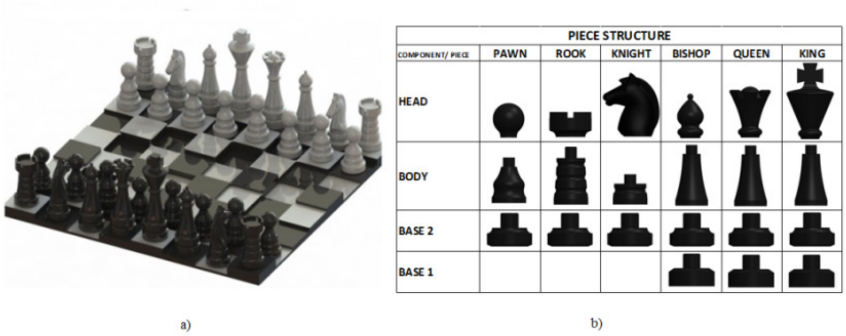

Figure 1. a) The chess set b) Piece structure.

The manufacturing plant

The didactic manufacturing plant is located in the main building of the engineering faculty. It is composed by three main areas: engineering, production and assembly. In the production area there are two production lines provided with raw material racks, four lathes CNC EMCO Compact, four Sherline machining centres, and one wood router. In Figure 2 the lay-out of the manufacturing plant is presented. This facility is still under development, some details are not yet fully completed due to budget constraints.

Figure 2. Didactic plant lay-out.

4. Course definition

The didactic plant is part of the laboratory activities of the Advanced Manufacturing course of the Master of Science program of Production Engineering. The course lasts 80 hours divided in 48 hours of frontal teaching and 32 of laboratory activities. Every semester the course is attended by 40 students.

During the course, students perform the role of a production engineering team. The job is arranged in groups of five students. The exercise follows the flow shown in Figure 3. The team receives the production order and the product requirements. The former document contains the quantity to be produced, the material specification and time constraints; the latter encloses the detailed design information. The team analyses the requirements and produces a first deliverable (product analysis) that is going to become an input for the second stage.

In the production planning stage, the team has to take into account the process technology which is available, to confirm the right quantity of the raw material, to check tool availability and to plan the production according to the machine availability. The outputs of the stage are the production plan that contains the activity description of every part; the CNC programs which should be transmitted to the machine, the assembly plan and the quality specifications.

The heart of the exercise is the production control step where students fabricate the parts. Every group receives two bars (one white and one black) of Ultra-high-molecular-weight polyethylene of 2 m by Ø25.4 mm and a wood table of 600x300x20mm. In order to operate the machines in a secure and easy way, students are assisted by a group of technicians. The stage ends with the production of a deliverable that states the quantity of produced parts and eventually encountered problems. Next, the team realizes the assembly of the product and generates an assembly report. Then, a product inspection is performed together with the responsible of the course in order to identify and correct product deviations. Lastly, the product is delivered.

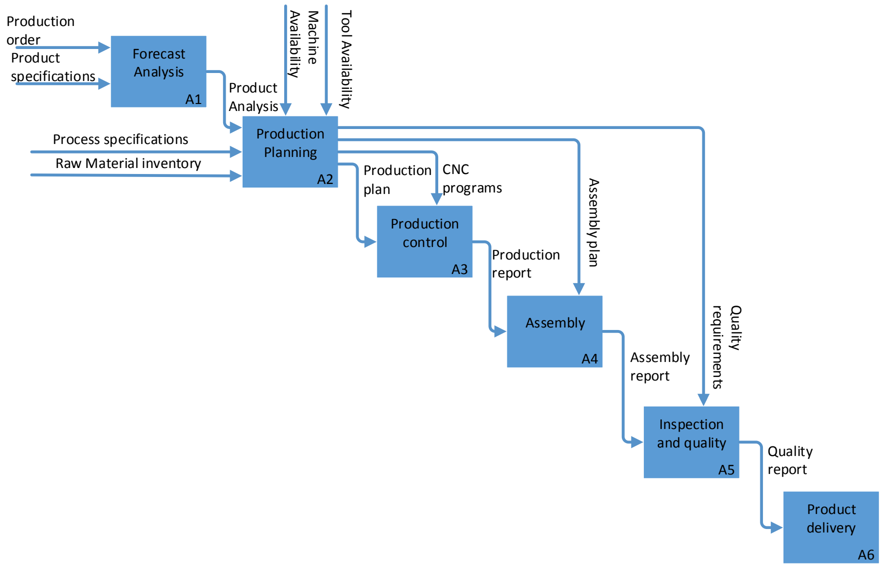

Figure 3. Exercise flow

Some errors (i.e. interference among parts) have been intentionally introduced to the design. Students should identify and correct the mistakes. In order to achieve this, the available CAD/CAM/CAE software for the development of the activity is NX 7.5. With this tool, students can perform a virtual validation of the dimensions, tolerancing, product interferences and assembly constraints. It is also possible to simulate the turning and milling operations. Once the errors have been found, the team is asked to complete a design change. This procedure is done by following a Configuration and Change Management procedure in the PDM platform Teamcenter 8.3. In this way product traceability is secured. The selection of the platform resided in the Siemens product because at the state of the art this is the only product that allow a good integration with the shop floor, including MES, which is the final scope of the didactic plant.

Once the product design is under control, a process improvement is performed (see Figure 4). Students are requested to evaluate the behaviour of the production line and to identify the Value Stream Mapping (VSM). The decision of modifying or moving work stations in order to improve the facility's productivity is quite risky and decisions must be strongly supported. Therefore, students realize a Discrete Event Simulation (DES). The combination of VSM and DES is a powerful strategy that is called dynamic VSM [18]. After carefully analysing simulation results, students suggest process improvements. Finally, students validate process improvements by going again into production. All process modifications should be maintained in the PDM environment.

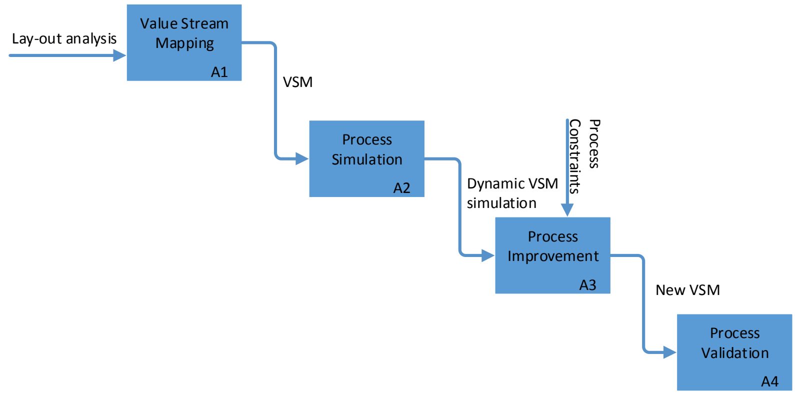

Figure 4. Process improvement

During the development of the exercise students use different modules of the Teamcenter software: the structure manager, to manage the EBOM and request design changes and the manufacturing process planner, to define and maintain the MBOM. A series of customized workflows have been created in order to assure collaborative work, to release the parts and to ask for product and process changes.

5. Results

At the moment of writing this paper two iterations of the course have been completed and a third is undergoing. A total of 10 chess sets have been produced (Figure 5). The design information has been successfully managed and controlled in the PDM software.

From the experience gained on the first two iterations, several design changes have been introduced. In Figure 6 the actual design is presented. In this new design there is only one kind of base shared by all pieces. There has been a reduction of the number of the part due to two main conditions: 1) time constraints: students were not able to complete the exercise because of the great quantity of part that should be machined; 2) budget: by reducing the number of parts there has been a reduction in the quantity of raw material.

Figure 5. a) A fabricated chess set. b) Lab activity.

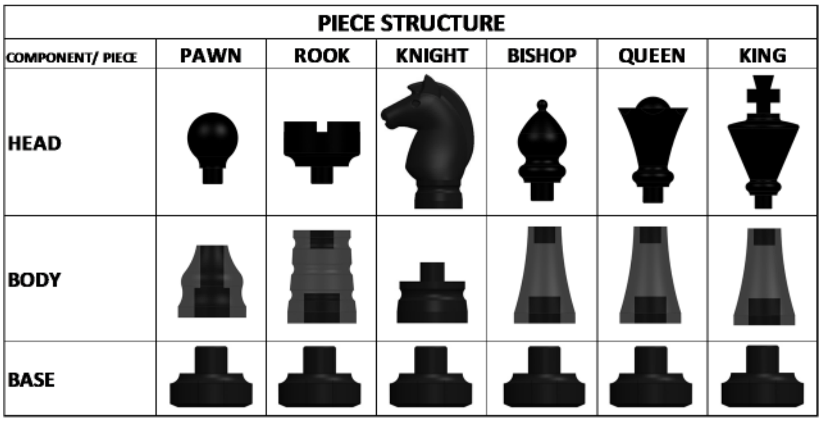

Figure 6. Design modifications

From the process point of view several improvements have been made. These developments have created also design changes. The knight head presented some quality issues (Figure 7.a). Since this part presents the bigger challenges from the manufacturing point of view, it was not possible to fabricate it with a traditional turning operation, in its place a thermoforming process was selected. The material (resin) used in the fabrication of the white knight has a different texture and colour from the parts produced by turning. Consequently, students decide to add an additional painting operation.

Furthermore, in the original design the pawn and the knight heads had female connectors, thus a drilling operation was needed. Due to their round and irregular shape, both holes were difficult to realize and process reproducibility was poor. Consequently, two fixtures were designed, demanding more budget and time to be produced (see Figure 7.b). Nevertheless, the hole location of the pawn head represented the worst quality issue. Hence, a design modification was introduced and a male connection was given to the new part , while the knight kept its original design. Afterward, in order to standardize the production, female connections were given to all the bodies (except from the knight), while male connections were given to the base and heads . Since the bodies have two holes and assembly errors should be avoided, the diameter of the holes that are coupled with the base are bigger than those assembled with the heads.

Figure 7. Knight quality issues a) Colour difference b)Fixture for hole drilling.

The knight quality issue and its solution normally should be addressed during the design/testing phase, and not in the production stage where the product design should be validated. However, it was an objective of the course to teach students how to interact with the software and ask for design and process changes.

6. Further developments

The final aim of the didactic plant is to achieve the "Smart Factory". This means to monitor physical processes, to create a virtual copy of the physical world and to make decentralized decisions [19].

Following this track, the first steps have been taken. A group of students has started to virtualize the whole manufacturing process. This activity includes the 3D modelling of the machines, fixtures, stools, tables and all resources needed in the production. The virtual models are now being managed and shared in the PLM systems. The next task is the development of the kinematic models of the actual machines along with their CNC post-processors. This will help students to virtually validate the production processes.

In a further step, a Manufacturing Execution System (MES) strategy should be employed. MES is a layer of communication that enables data exchange between the organizational level, usually supported by an ERP, and the shop-floor control systems, in which several, different, very customized software applications are employed [20]. Consequently, the machines of the didactic plant must be upgraded with a full set of sensors that will allow the complete monitoring and control of the process. Data collected by these devices across the production line will provide meaningful information to take decisions.

Finally, the integration among PLM and MES systems will allow to create a feedback information mechanism that can enhance the performance of the production process and the quality of the manufactured parts.

7. Conclusions

Traditionally, university curricula are defined according to industrial needs. In Colombia, few companies are using PLM and its benefits are unknown for most of the industries. The introduction of PLM into an university course is expected to be a breakthrough for the enhancement of the Colombian industry. EAFIT is generating a pushing condition by introducing high-skilled engineers to the work market. It is expected that this new pool of engineers will promote the advantages of PLM in industry.

The success of PLM and new industry developments, as the Smart Factories, implicate new paradigms for engineering education. Theoretical education is not any more sustainable and new professionals should be trained in almost-real conditions. The didactic plant, presented in this contribution, puts students to the difficulties and constraints that they will find in the industry. Moreover, collaborations skills are stimulated by working in teams and sharing information in the PDM platform.

The chess set has demonstrated to be an excellent example for students training because several processes and technologies are employed during its production. The product also allows to put into practices the Design for Assembly and Manufacturing concepts.

The attained results have brought improvements to both the design and the process: fixtures have been designed, quality issues have been solved, new operations have been introduced and product design has been enhanced. The implementation of a PLM strategy has been crucial to keep track of all these changes.

Even if evidence shows that the work is going in the right direction there is still a long way to go in order to reach the smart factory. Further steps have been taken and the virtualization of the laboratory is almost complete. The MES and its integration with PLM are key element to reach the final goal.

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