Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), March 3 – 5, 2015

Product lifecycle management, digital factory and virtual commissioning: Analysis of these concepts as a new tool of lean thinking

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***Abstract*—This paper presents and analyzes new tools to reduce wastes according to lean thinking. These tools, PLM (Product Lifecycle Management), Digital Factory and Virtual Commissioning have differences and similarities and they are defined with a brief discussion of the status and outlook. It is proposed a model showing the correlation among Virtual Commissioning, Digital Factory and PLM and it allows understanding limits, benefits and influences among these concepts. After that, the model proposed by Kühn presenting the effort and benefit of conventional approach and Digital Factory is analyzed. Moreover, a new model a new factor, the Virtual Commissioning, shows that this one demands more effort in implementation but provides higher returns that can be translated in less development time and low product cost or, in a few words, more competitiveness for organizations. These analyses show that PLM, Digital Factory and Virtual Commissioning must be considered an important tool to lean improvements in industrial organizations.**

Keywords—Product Lifecycle Management, PLM, Digital Factory, Virtual Commissioning.

I. INTRODUCTION (*HEADING 1*)

The industrial productivity evolution has happened in waves through many decades, based on the evolution of concepts and equipment, both of them supporting each other. The development of steam engine has created conditions to the emergence of factories and later has made possible the assembling line and mass production implementation [1]

After mass production supremacy, lean production has appeared in Japan and become the worldwide paradigm of high productivity. In the beginning it was understood as opposition of mass production but now lean manufacturing is seen now as an evolution of mass production with continuous wastes identification and elimination [1].

Simultaneously of lean system production development and implementation, another revolution has happened in management technology by application of computers and software. In a theoretical way they are independent of each other. Nevertheless, in real world, information technology has increased the speed of implementation of new strategies of control, project and production. Lean principles and information technology merged and created new concepts that, in fact, is considered a new step of lean thinking [1]

Besides that, information technology has also been applied in product project. With the target of to eliminate manual and redundant work, these new strategies left limits of companies and involved customers and suppliers in an approach from cradle to the scrapyard. This treatment of product information is usually called Product Lifecycle Management (PLM) and many companies are applying it in different levels and approaches, always with the target to increase the competitiveness through development cost and time to market reduction [2]. In fact, the main idea of lean is to avoid wastes and PLM is an important tool to exchange waste of time, energy and material by information [1].

Other concept researched in this paper, this one strongly based on information technology, is the Digital Factory. It is a very effective tool to improve safety in industrial environment in addition to increase productivity [2].

The third and last important concept is the Virtual Commissioning. In this strategy the target is to make virtual world rely on the real operation. It aims to reduce time to project, assembly and test automated production lines [3].

This paper makes a bibliographic research reviewing these three concepts considering basic definitions and making some contribution based on recent technological and conceptual developments.

II. Product Lifecycle Management – PLM – Concepts

Since the beginning of industrial production, steps of a product lifecycle have not changed too much. Nevertheless, to treat all these steps a continuous process is a new approach.

It has been a challenge and a responsibility of company to create and produce products and to support customer's needs as well. However, the utilization and final destination of the product were not a concern to the company. In the beginning of XXI century, concepts have changed and companies were forced to take care of all stages of the product lifecycle and in this new environment the concept of PLM was born. Therefore, to understand each step of this cycle has become vital to develop this concept.

Reference [4] has defined five phases in product's lifecycle, as in fig. 1.

The main idea is that in each of these five phases the product is in a different state. While the imagination step, the product is just an idea in design team's heads. During the definition step, the ideas get converted into detailed description. By the end of the realization stage, the product exists in its final form in which it can be used by customers. During the use/support phase, the product is with the customer who is using it. Eventually the product gets to a period in which it is no longer useful. Then the product is withdrawn and disposed by the company re

The main idea is that the product must be managed in all these steps. That means managing the product throughout its lifecycle, "from cradle to grave" [4].

Comparing with other concepts used in industry and in management, PLM is quite new and its definition is not yet well established. Nevertheless it is important to note that there are not big differences among them in literature.

The PLM is defined by [5] as a basic concept for managing and developing products and its related information. PLM offers tools to manage and control the product process throughout the product lifecycle, from the initial idea to the junkyard.

Reference [1] has defined PLM as an integrated process that includes people, processes/practices and technology to all aspects of product´s lifecycle, from its conception through development, manufacture and maintenance, culminating in the product´s removal from service and final disposal.

According to [6], the PLM concept integrates a variety of disciplines, methods, tools and systems, ranging from the Product Development and the Management of Manufacturing Systems, with all their activities and tools (Computer-Aided Design – CAD, Computer-Aided Process Planning – CAPP, Computer-Aided Engineering – CAE, Computer-Aided Manufacturing – CAM, Product Data Management – PDM) to Management Systems (Enterprise Resources Planning – ERP, Manufacturing Resources Planning – MRP, Customer Relationship Management – CRM, Supply Chain Management – SCM).

Product´s Lifecycle				
Beginning of Life			*Middle of Life*	*End of Life*
Imagine	Define	Realise	Use/Support	Retire/Dispose

Fig. 1. Product´s lifecycle [4]

PLM normally becomes in engineering area, but can spread improvements in all organization through better product information flow. With correct information the correct product is produced as well and it is avoided to make mistakes like to produce wrong products with high productivity. Moreover, PLM can affect the revenues not only by cutting costs but increasing innovation, functionality and quality of products [1].

III. Digital Factory Concepts

Digital Factory is a specific environment where digital manufacturing and simulation are spread, ideally throughout product lifecycles. Virtual simulation can be integrated with all kinds of information systems providing a total control of product lifecycle [2].

The Guideline 4499, part 1 by the Association of German Engineers, defines Digital Factory as a "[…] generic term for a comprehensive network of digital models and methods, including simulation and 3D visualization. Its purpose is the integrated planning, implementation, control and on-going improvement of all important factory processes and resources relating to the product." [7].

Moreover, according to the Guideline 4499 - part 2, "Digital Factory Operations... aim to safeguard and shorten the start-up process as well as to continuously improve the running series production. This requires a realistic representation of individual production systems and complex production facilities and processes including the information and control technology." [8].

The mechatronic library is the most important tool of the Digital Factory, because it allows that machinery and equipment can be assembled with mechatronic components pre-described by means of geometry, kinematics and logic (control programs) [8].

Users of Digital Factory normally indicate as more significant benefits of this environment things like better planning, higher product quality, a shorter time-to-market, a faster launch and ramp-up, more ability for innovation, less changes and errors and a lower product cost, also the minimization of the number of process, resource and product changes required [2].

Nevertheless there are also barriers to adopt the Digital Factory. The most substantial is training. Unlikely the ordinary software used in offices, these tools are not intuitive and to dominate them lots of training is needed, and of course, money to invest in a new technology. This concept is not yet part of academic educational culture and engineers are beginning now to consider this methodology as a standard procedure [2].

IV. Virtual Commissioning Concepts

The Virtual Commissioning combines real PLC, devices and robots with digital models in order to validate the control programs. It integrates real and digital components into a single system. The main requirement of the Virtual

Commissioning is to ensure that the mechatronic systems of the virtual cell correspond exactly to the real system. The PLC and robot controller cannot detect any difference between the model and reality [7].

Important industrial organizations like automotive ones, where speed and precision of assembling line are critical success factors, are implementing Virtual Commissioning through some enterprise solution to reduce the time of facilities [3].

In the traditional development process, production equipment and their programs are deployed at same time, but when they are put to work together important differences appear. Normally it happens because in virtual environment there is no air resistance, temperature variation, friction between parts and other items that affect the speed or the precision of movements. This lack of consistency causes a significant increasing in project time of a production line because it becomes necessary to make several adjustments.

The use of Virtual Commissioning allows engineers to define, plan, create, monitor and control the production processes. Besides that they can validate the availability of an assembly process by checking range of robots and prevent collisions considering all real factors that exist in production environment. In the construction of a production cell usually the PLC and robot programs comes at the last stage, when the mechanical and electrical components are already finished. This is a time consuming and expensive activity. With the Virtual Commissioning the automation engineers can develop and verify the PLC and robot program while the production cell is being constructed [3].

The robots programs can be simulated and verified in real life with the PLC programs. The PLC must be connected to the Virtual Commissioning software via an OPC protocol.

Benefits of Virtual Commissioning are not limited to cell construction time. While the production life, it is also possible to integrate new components to a working production cell without stopping it for a long time. In fact, in a few minutes is possible to change old programs by new ones, instead of some hours or days. The integration and interaction of many parts and systems can be done and checked in the virtual process and only then the real cell will be stopped. This way the production loss can be minimized [7].

V. Comparison among PLM, Digital Factory and Virtual Commissioning

Concepts of PLM, Digital Factory and Virtual Commissioning seem similar and are often mistaken with each other. This paper proposes a model to identify similarities, differences and relations between them.

The Digital Factory and Virtual Commissioning concepts are contained in the PLM, which deals with the entire product lifecycle, from product conception up to its disposal. The Digital Factory does not manage the product conception, utilization or disposal. The Digital Factory begins when the 3D model of the product is generated and finishes on the production, covering production planning, launch and ramp-up of the product. Digital Factory allows going into details of the manufacturing process, assembly analysis, factory layout and process, robotics and ergonomics simulation, as shown in fig. 2.

The Virtual Commissioning is a stage of the Digital Factory. Virtual Commissioning makes possible validating simulations of the Digital Factory in a real production cell, as described before. The Virtual Commissioning does not detail with the manufacturing process. It starts from the assembly

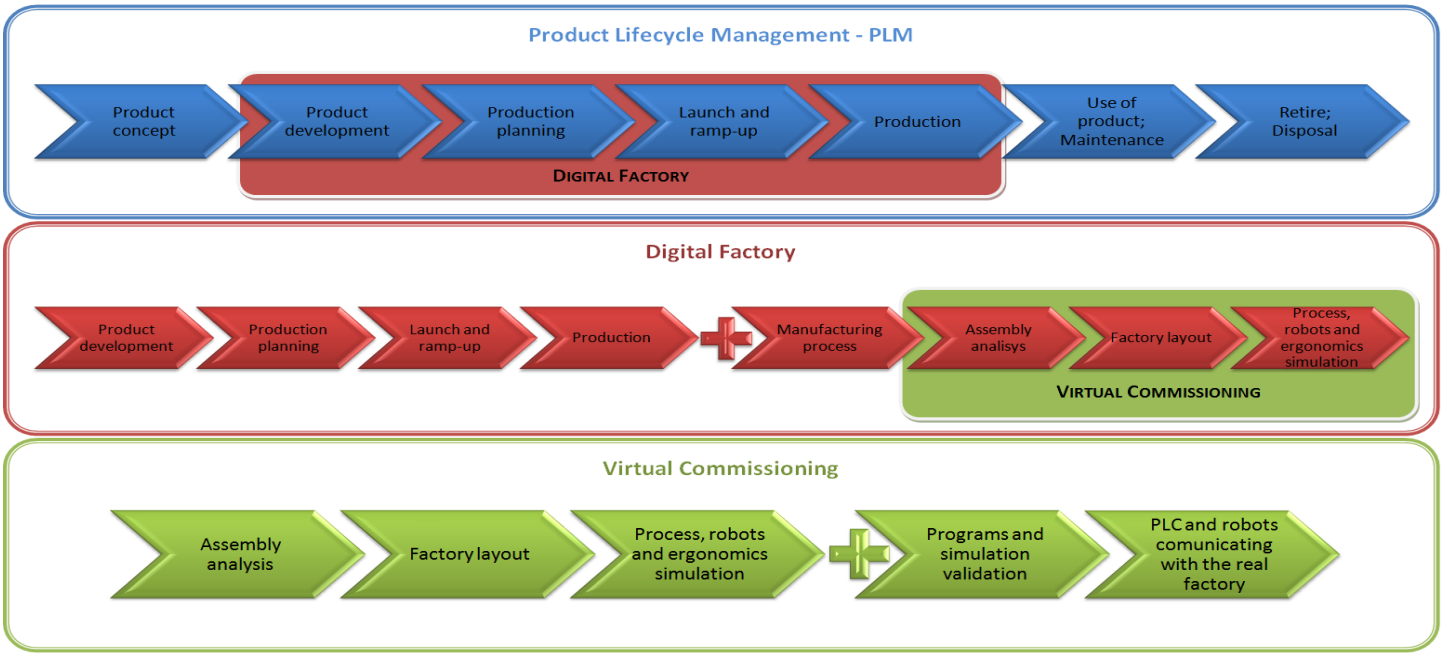

Fig. 2. PLM x Digital Factory x Virtual Commissioning [10]

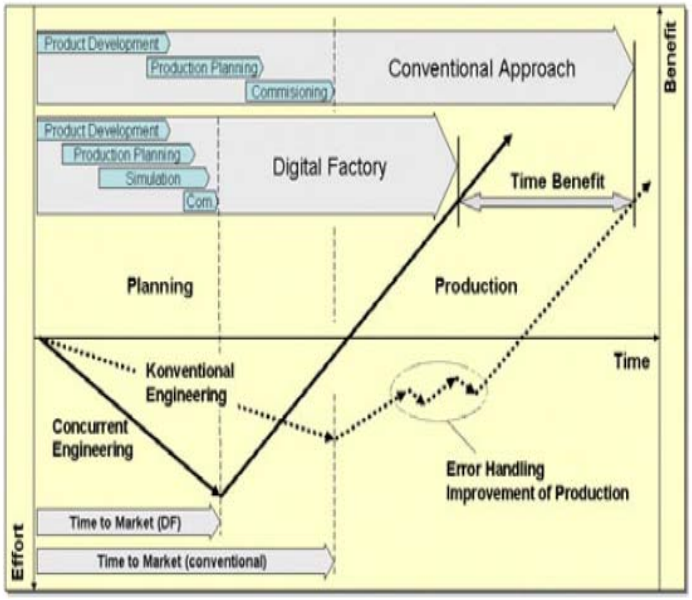

Fig. 3. Digital Factory - benefit and effort [9]

analysis and finishes on the communication of the virtual environment to the real environment, through the factory layout, process, robotics and ergonomics simulation and validation of simulations and programs, as shown in fig. 2.

It is possible to conclude that the concepts of PLM, Digital Factory and Virtual Commissioning complement each other and the mutual application of these three concepts can generate a reduction in time and cost of product and process development. Therefore, they are important tools for competitiveness of organization as they provide lower costs and/or better profit and the opportunity to launch new products faster.

VI. Relating Conventional Engineering, Digital Factory and Virtual Commissioning

In 2006 Wolfgang Kühn in his work "Digital Factory - Simulation Enhancing the Product Engineering and Production Process" [9] proposed a study model to demonstrate the benefits and effort of Digital Factory compared to conventional engineering. With the purpose to contribute with Kühn's model, this paper proposes to add the concept of Virtual Commissioning in it.

The model proposed by [9], (fig.3), shows the effort required to implement the Digital Factory and the benefit generated by it. The implementation of Digital Factory demands a bigger effort when compared to conventional engineering concerning to design and production of a new product. However, the generation of benefit occurs faster and can eliminate errors while handling the improvement of

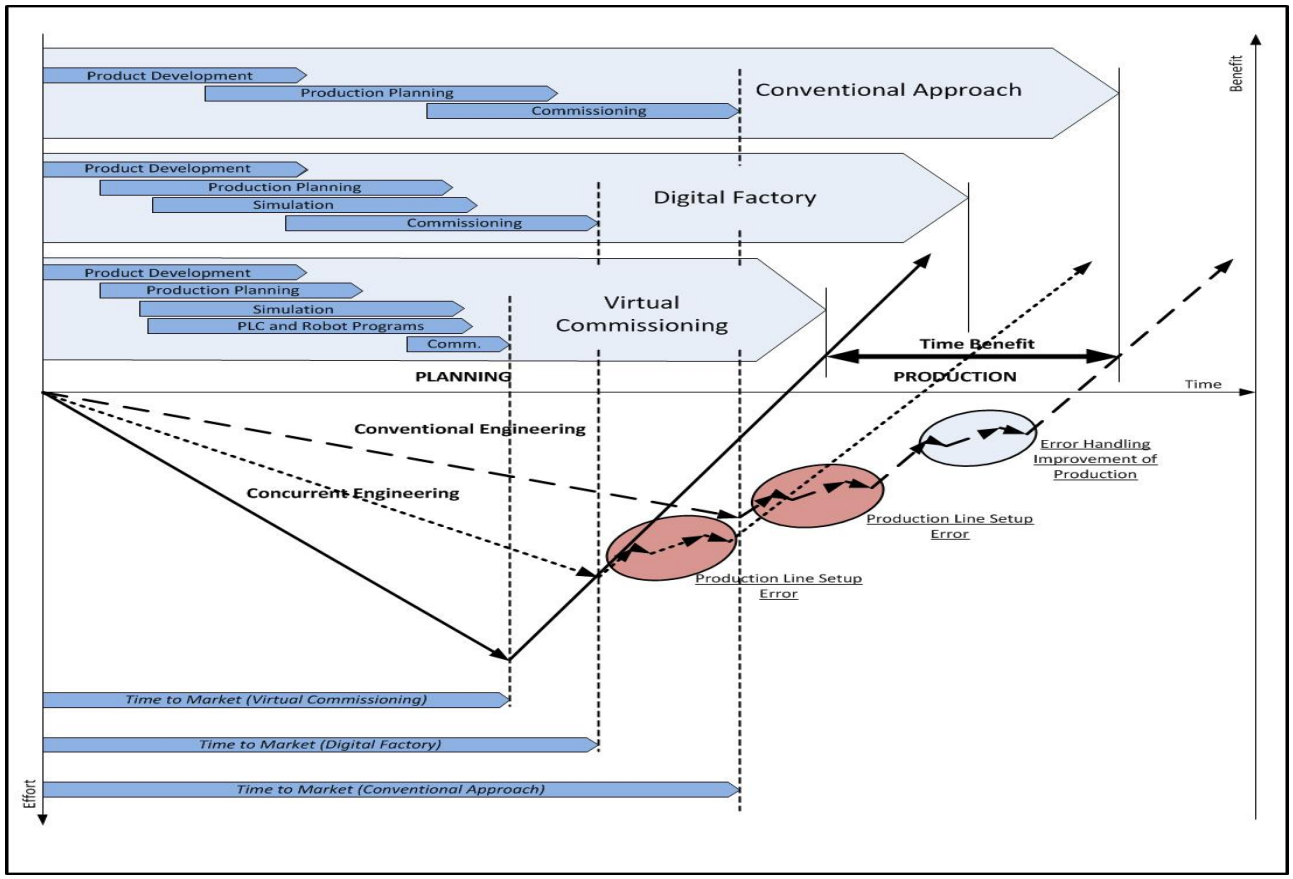

Fig. 4. Virtual Commissioning - benefit and effort [10]

production. Thus it is possible to have a lower time-to-market and therefore reducing Costs.

Reference [10] has proposed an evolution of Kühn`s model by adding the concept of Virtual Commissioning (fig. 4). In this new model, the effort should be even higher, since it requires more knowledge and technology. Nevertheless, the conclusion of the project happens faster.

Kühn´s model [9] did not considered the inherent possibility of error in programming PLC and robots installed in cell production. In the concepts of Digital Factory and conventional engineering, PLC's and robots are programmed after all mechanical and electrical parts of the cell are already installed. Therefore, the company has a finished industrial cell, but without function, which generates costs while waiting for programs.

Applying the Virtual Commissioning it is possible to eliminate errors and waiting time, since the PLC's and robots are programmed during the design and construction of the industrial cell.

In this way, programs are finalized at the same time of physical parts of the cell, just needing fine adjustments to start operation. This concept provides a strong decrease of the time-to-market, also reducing the costs associated with the product and process development and affecting in positive way the revenues of the organization.

VII. Final Notes

This paper has shown differences and similarities of PLM, Digital Factory and Virtual Commissioning. Any of them can be applied separately, but better results can be achieved if they were used together and in an integrated way. A strong synergy can be achieved and resources can be used in a more productive way.

A Kühn`s model concerning digital factory has been analyzed and an evolution of it has been presented, with Virtual Commissioning inclusion and it shows that organization makes more effort during production process definition but, on the other hand, reduces strongly the time-to market of the product, making possible to increase sales and profits. In this way, it is clear that PLM and its components, Virtual Commissioning and Digital Factory are consistent with lean thinking since they contribute with waste reduction and revenues increasing of organizations. The lean thinking has found in PLM an important tool to make improvements where it seemed impossible after decades of waste reduction with traditional lean tools.

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