A MODEL FOR MANUFACTURING SYSTEMS DEFINITION AT EARLY STAGES OF DESIGN PROCESS

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ABSTRACT

The automotive industry has improved its manufacturing processes, especially with the lean manufacturing tools development. However, these improvements are implemented on the advanced phases of new product development or even during serial life. During the very beginning phase of product development, just a few assumptions are considered regarding manufacturing system. Thus, very often, there are inconsistences between what was forecast and what actually occurs, in terms of manufacturing activities. These can lead to either lack of competitiveness of financial losses. Therefore, this paper provides an approach to define the manufacturing system for a product on the initial stages of its development.

Initially, the IDEF0 framework is applied. All the stages needed to define a manufacturing system are mapped and the inputs, outputs, mechanisms and controls are formally declared. Field information and procedures from a company that manufactures plastic parts are also examined. Then, a proposed approach to define a manufacturing system, with its stages and tasks, is set.

The suggested approach allows a: i/ better estimation of the manufacturing system parameters and related processes; ii/ anticipation of potential hard points for time study, line balancing and layout definition.

This paper is included on the field of manufacturing systems technology and represents an innovative model for develop manufacturing systems during the design process, in order to achieve a sustainable growth of the automotive industries.

Key words: Product development process, manufacturing system, IDEF0, manufacturing development

INTRODUCTION

The development of a new product is a recurrent activity on the industry field. Every year, month and even day new product are launch on the market and the development of these products is an activity that takes more attention every day.

One of the steps to define a new product is to determinate the production process related to this product and build the manufacturing system that will implement this product. Usually, the development of a manufacturing system occurs when the product is fully developed and needs to be manufactured. One the very beginning stages of a product development, production considerations and hypothesis are made, but, the definition of how the product will be produced takes place in a more advanced stage.

Due to that, several gains that could be obtained since the beginning of the product development are postponed. Also, there is a big possibility of error, once that there is not a systematic method to develop a manufacturing system. Usually, on the initial stage of a new product development, only estimations are done regarding the manufacturing of the product, which could lead to errors and financial losses to the company.

Thus, having a method to develop a manufacturing system, with the information available on the initial stage of a product concept will imply on several gains. Based on that, the aim of this article is to propose a model to define the manufacturing system of a new product on the beginning of its development. Also, a case study will be performed in order to validate the model proposed.

PRODUCT DEVELOPMENT PROCESS

According to Back et. al. (2008) the concept of product development is understand as all transformation process of needed information to identify a demand, a production and the use of a product. Thus, the productions systems of a product are linked to its development, and it is important to understand the product development process (PDP).

In the classic PDP methodologies might be mentioned Back, Rozenfeld and Pahl and Beitz. The first one is based on three main phases: i. project planning ii. product project iii. pilot batch (BACK et. al. 2008). The model of Rozenfeld et. al. (2006) is based on experience, methods and cases studies and is also divided into phases. It comprehends informational project, concept project, detailed project, production preparation and launch.

The third classical methodology to be mentioned is Pahl and Beitz (2006) which is also divided into phases (task clarification, concept project, preliminary project, detailed project). Through analysis the classical PDP methodology, it is clear that they do not take in consideration the manufacturing system of the product that is been developed, on its first development stages. The PDP methodologies are focused on pure product development, and there is a lack when it comes to manufacturing systems development during the very beginning phases of PDP.

MANUFACTURING SYSTEM DEVELOPMENT

The development of a manufacturing system can be understand as to determinate all the parameter linked to the production process, how the production process will interact between itself (station between station) and how it will interact with the factory.

The very beginning of a manufacturing system definition is the production times determination. All the construction of a production process begins with the determination of the production times. It could be performed through stopwatch analysis or through MTM analysis.

Stopwatch consists in measure the time needed to execute an operation, according to a specific method (Toledo e Bueno, 2004). When someone will determinate the production times of a new manufacturing system by stopwatch, he/she does it trying to compare the operations with similar ones, which already exist on the factory, and, by that, determinate the time for one operation.

Otherwise, the MTM is an analysis of movements that the operator does. Each hand or body movement has a time associated to it, and, through that, is possible to determinate the time of an operation by watching the operator (MTM Handbook, 2010). The advantage of this method is that is not needed the production line implemented. The production time can be determinate on a virtual way, by simulating the operations that the operator does. Thus, it is an adequate method to this study.

With the production times established, is necessary to split the operations between stations and build the line balancing. Caux et. al. (2000) brought a model to optimize the production flow and line balancing. Moghaddam et. al. (2010) performed also a line balancing study, but more focused on of process parameter analysis. He proposed a model to optimize several parameters in the same time, to achieve an optimal production line. Donnini et. al. (2010) performed a study of line balancing on automotive industry and demonstrated that the line balancing can adequate the production pace to the line demand.

The last step is to determinate the production layout. That can be done manually, based on the experience of who is building the process or can be done by a mathematic model. Chiwf et. al. (1998) demonstrated a mathematic method to build production layouts. Other methodology applied is brought by Silva (2009), which applies the evaluation of lean manufacturing concepts to determinate the production layout.

According to Melton (2005) the lean manufacturing concept begins at Japan, on 1940. The concept was to have a production flow. Now a day, the industries apply in a large scale this concept, that consist basically in to reduce production waists. Moore (2007) lists the main characteristics of a lean process. The main concept is that a modern production process must attend to the lean manufacturing concepts, in order to reduce waist and be optimized.

HOT PLATE WELDING PROCESS

A production process that will be studied on this article is the hot plate welding process. This consists into welding two plastic parts by heating both of them by a hot plate and then gathering them applying a specific pressure. The hot plate welding process is divided into phases, as shown on the figure 1.

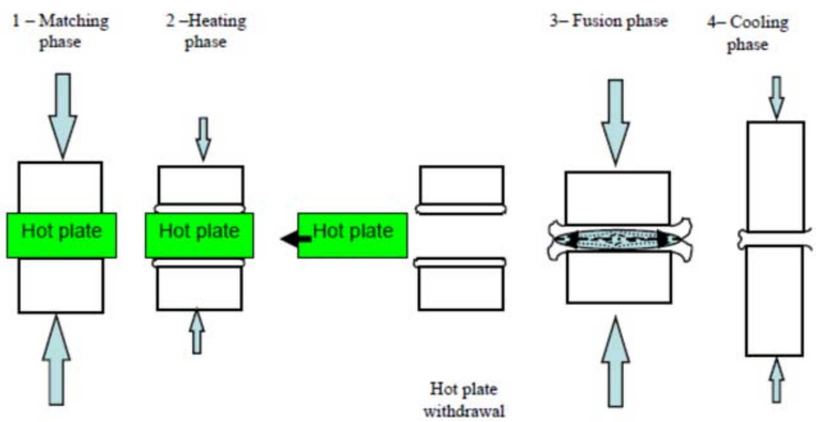

Figure 1: Hot plate welding process, Source: Hot Plate Welding (2006)

IDEF0

In order to build a model to development of manufacturing systems, the IDEF0 model will be applied. The IDEF (integration definition) is a technique originated on 70's decade by Douglas T. Ross and is a graphic approach to a system definition (Oliveira, 2010). In 1981, the American air force created the IDEF0, which consist on a standardization of IDEF model.

Basically, the IDEF0 consist on a model to define processes. It is functions, to transform "entrance" in "exits", by applying "mechanism", orientated by "controls". The figure 2 illustrates an IDEF0 diagram.

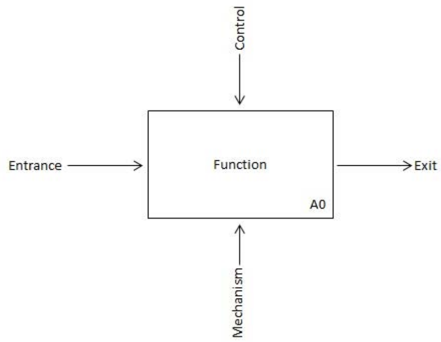

Figure 2: IDEF0 diagram, Source: OLIVEIRA, 2010

CURRENT SCENARIO ON MANUFACTURING SYSTEMS DEVELOPMENT

On the current industry scenario, the manufacturing system development on the beginning of the PDP process is usually done by estimations. This occurs on the production times and on the determination of the worker quantity and the layout. Usually the input data is only a product draft with some industrial data, and, based on that, the responsible for the production process estimates a manufacturing system. Some facts are related to the development of production process on the beginning of PDP:

- Lack of time to develop a manufacturing system;
- Input data imprecise;
- Lack of a structured model to define times and line balancing;
- Layout done based on the experience of the production process responsible.

Through the IDEF0 model is possible to describe the current scenario on the manufacturing system development. The figure 3 demonstrates a model based of IDEF0.

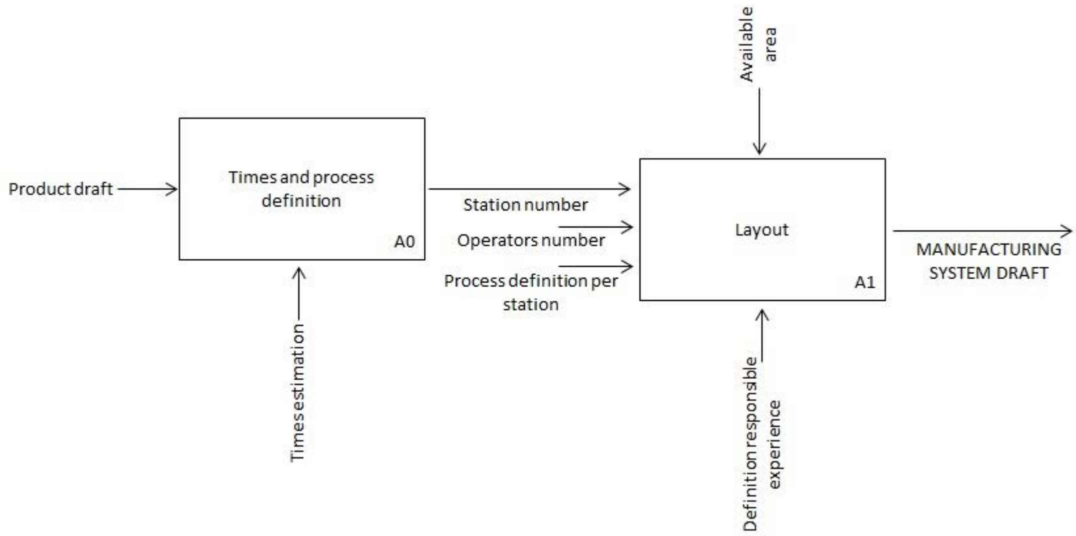

Figure 3: IDEF0 diagram representation of current manufacturing system scenario

On the figure 3 is possible to note that only a few data is processed and most part of the tasks are done by estimation. This leads to an opportunity.

A structured model, based on the input data of the very beginning phase of the PDP, for developing manufacturing systems could generate saving in terms of development lead time, could avoid mistakes on the determination of the production times and worker quantity and could advance gains that are only seen on advanced stages of the product development, generation money savings to the company.

MANUFACTURING SYSTEM DEFINITION MODEL

Based on the IDEF0 model, is possible to define a generic model for the definition of the manufacturing system. For that, some restrictions are defined:

- Machine times are known or possible to be estimated;
- The model does not consider the plant logistic. It defines only the internal working of the production line, not its interaction with the factory;
- There is no restriction on operator quantity;
- There is no restriction on station number;
- There is no restriction on layout configuration.

Based on these restrictions and on the IDEF0 model, for the definition of a manufacturing system, a generic model is proposed. The generic model is shown on the figure 4.

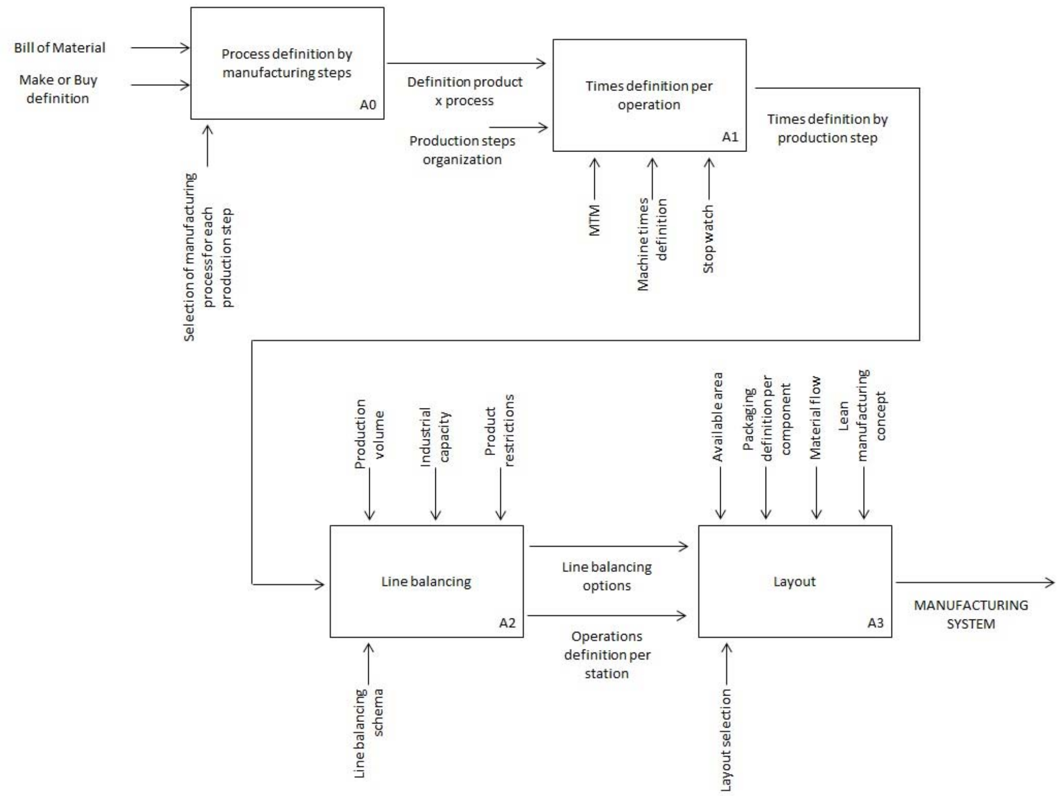

Figure 4: IDEF0 diagram proposed for a manufacturing system definition model

The first function (A0) is when it is defined the production steps and the related process for each step. On the A0, with the input of the bill of material and make or buy, for each subcomponent of the product is defined a related process. The output of this function is the definition of the process for each product step, that means for each product subcomponent a related manufacturing process is defined.

After that, the next function is the definition of the production times. That is split in two parts. The first one is the machine times definition, which will come from a calculation method or by comparison with a similar process. The second one is the operator times, which will come from MTM or stop watch of similar operations.

With the output of the function A1 is possible to perform the line balancing. For this, the controls of production volume, industrial capacity and product restrictions are needed. The volume and industrial capacity are needed to define the line pace and the product restriction are needed to define which operation will be gather in the same station. The output of this function are the line balancing option and the definition of the operations per station, thus the main structure of the manufacturing system will be built.

The last function is the construction of the layout. For that, a process of layout selection is necessary. Also, some controls must be applied, especially regarding available area and lean manufacturing concept. This last one is very relevant, because the lean manufacturing concepts are the main driver of a modern production process.

An evolution of this generic model is proposed, based again on IDEF0 model and also on the hot plate plastic welding process. The hot plate welding process is chosen to perform a specific model and then a case study because is a large applied process on industry, with characteristics that can be measured and translated to a model.

The figure 5 shows the manufacturing system definition model, applied to the hot plate plastic welding process.

The main functions are the same of the generic model, but with different controls and process related to it. For the function A0 the welding area and component geometry are needed, because those are important parameters to define the process steps. Also, for the function A1 the times for each step of a hot plate welding is needed, in order to determinate the times per operation. The other functions are similar than the generic model.

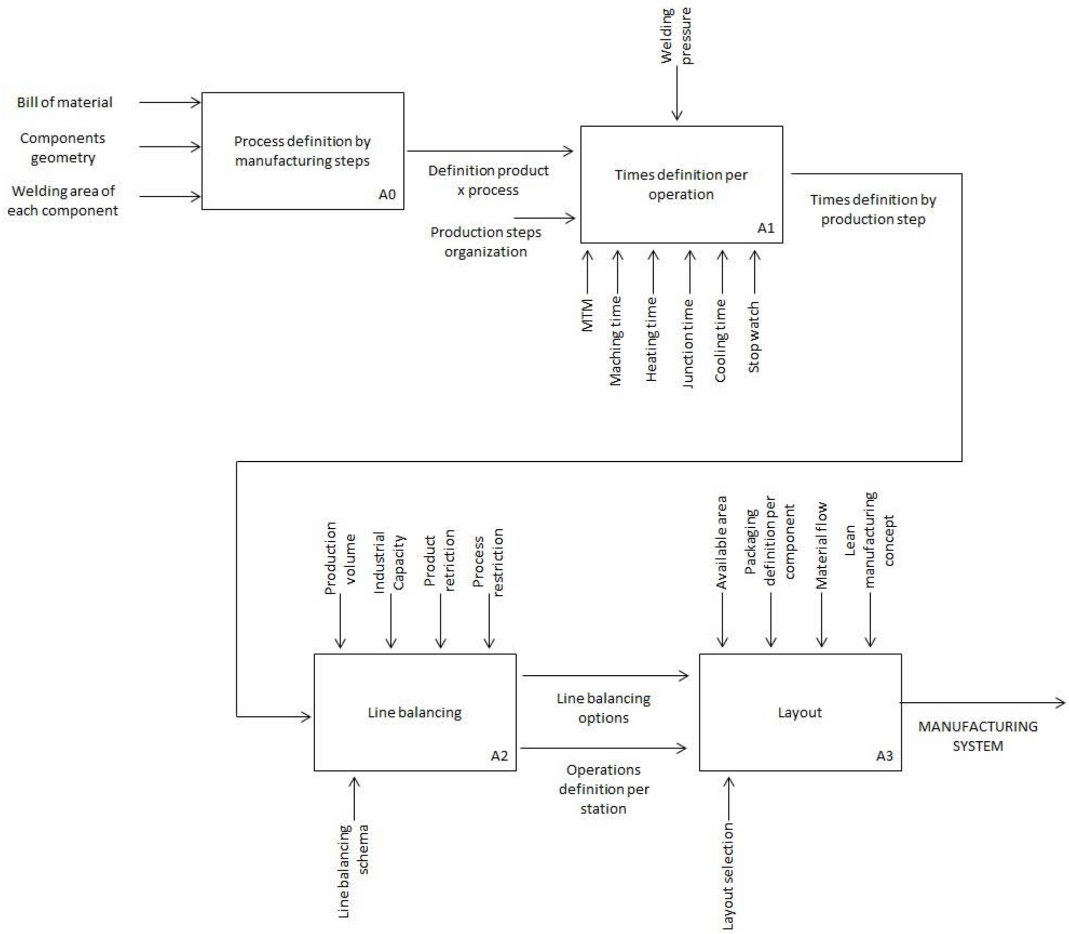

Figure 5: IDEF0 diagram proposed for a hot plate welding system

CASE STUDY

In order to validate the proposed model and test its efficiency and adherence to the real factory, a case study is conducted. For that, a company that manufacture welded and assembled fuel tank is selected. This company applies the hot plate welding technology, thus is possible to test the specific model.

An excel file was built to translate the IDEF0 model on a computer model that will be tested. On the excel model, the user will input the main project data, as production volume and line pace. Also, the user will split all the process operations between manufacturing stations and based on that, based on the machine times (which are a input on the excel file) and based on a MTM analysis, the user will determinate the times per operation and per station.

The machine time will be an input, considering that it must come from an analysis of similar operations. For instance, to weld a circular component, with 14mm² of area, the matching, heating, junction and cooling times must come from an existing process of a component with same geometry and area. If there is no such similar component, a mathematic tool must be applied to determinate the welding times.

After the times definition, the excel file will automatic balance the line (based on the user input of what operator goes on what station) and give the number of operator and number of stations. Finally, a layout must be selected. For that, the excel file propose a graphic with layout options and selection criteria, based on lean manufacturing concept.

The figure 6 illustrates the excel file for applying the model.

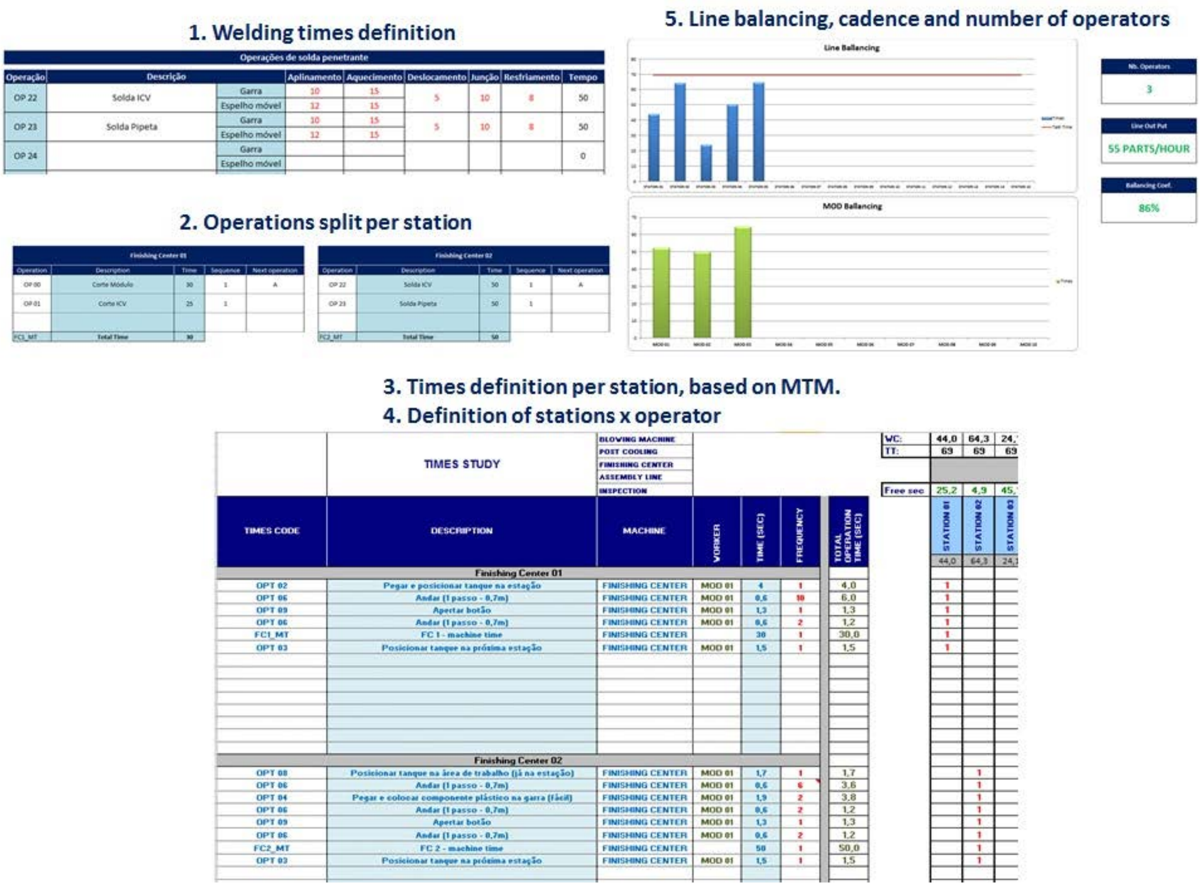

Figure 6: Excel model to perform a case study

It was selected two products, current on serial life, with the line well defined and balanced, to compare the real line result with the model application. The excel model was applied to these two products, what means, with the input required were defined a manufacturing system to these product by applying the excel model. The result of this were compared to the result of the real line in order to determinate the precision of the model and the error margin in terms of number of operator, line balancing and production times. The figure 7 shows the result obtained.

	Product A		Product B	
	Model	Real Line	Model	Real Line
Station 01	44 sec	46 sec	61 sec	63 sec
Station 02	64 sec	63 sec	69 sec	72 sec
Station 03	24 sec	25 sec	66 sec	68 sec
Station 04	50 sec	55 sec	53 sec	53 sec
Station 05	65 sec	69 sec	43 sec	52 sec
Station 06			59 sec	64 sec
Station 07			47 sec	56 sec
Total Time	247 sec	258 sec	398 sec	428 sec
% Deviation between model and real line	4%		7%	
Operator 01	52 sec	60 sec	69 sec	72 sec
Operator 02	50 sec	54 sec	53 sec	53 sec
Operator 03	65 sec	67 sec	43 sec	52 sec
Operator 04			59 sec	64 sec
Operator 05			47 sec	56 sec
Total Time	167 sec	181 sec	271 sec	297 sec
% Deviation between model and real line	8%		9%	
Line balancing	86%	90%	79%	83%
Number of stations	4	4	7	7
Numbe of operators	3	3	5	5

Figure 7: Case study result

The result of the case study shows proximity between the data achieved by applying the model and the real line. Through this, it is confirmed that the model is valid and works for a real line. An analysis of the difference between the times achieved using the model and the real times demonstrate a deviation of 6% average. The result obtained by the model is lower times, in 6% average, than real line. That's because the MTM does not capture small movements that the operator does on the line. Thus, is recommended that after applying the model, an adjustment on times of 6% be applied.

The result also shows that the real line is better balanced than the result of the model. That occurs because after the line start running, the operator naturally adjust the pace one to each other, leading to a better balanced line. In terms of number of stations and operators, the results are the same, showing the model efficiency. The model also proposes a graphic for select the layout, based on the number of operators and production pace. The figure 8 illustrates the graphic.

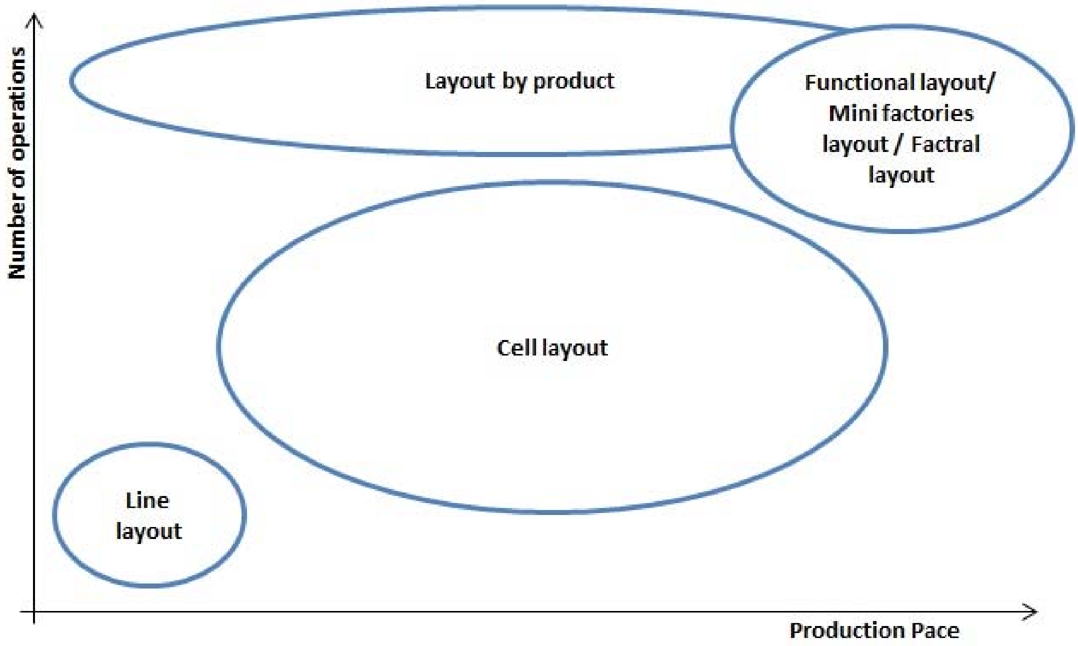

Figure 8: Graphic for layout selection

Through the analysis of the graphic, it is possible to propose a "U shape cell layout" for both products, due to a medium number of operations and also a medium production pace required by the line. That is a difference for the real line, because both products have "line" layout, due to factory area restrictions. That corroborates the fact that the area restriction is a control required on the phase of layout determination.

FINAL REMARKS

It has been noticed that there are some difficulties to provide a cost estimation of the production process for a product at its early stages of development.

Classical approaches demand a level of maturity for the product which in many cases can not be reached for the demanded lead time. Therefore, it is necessary somehow to be precise if forecasting the processes and their costs.

This paper aims to describe an approach to define a manufacturing system, with its stages, tasks and cost estimates, at early stages of the product development process. Despite the fuzziness of the data available at this stage, with the product assumptions set in the model associated manufacturing inputs from practice, coupled with IDEF0 model, it is possible to define the production system with a certain level of precision.

When the results from the model are contrasted with those from an actual case study, some differences are observed. These differences are defined and the model is refined. In this case, a fit factor is suggested in the paper.

The preliminary results indicate that the proposed model translate with high level of confidence the estimates that had been performed in practice.

Additionally, from the case study it was observed that the proposed model can be applied when the costs estimation for a process system for a new product is required. The process system can be correctly defined at the beginning of the PDP, inducing to economic savings.

As a suggestion for further works, it is proposed to evaluate the MTM application in order to narrow the gap between standard time definition and what occurs in an actual production line. Furthermore, it is suggested to evaluate the layout selection criteria, to improve the rigor in the layout selection process.

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