The development of a methodology of learning to use simulation in the analysis of production system performances

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Abstract. Considering the dynamic environment in which the present companies work, global market, fierce competition, frequent changes of techniques and technologies, more diverse demand from clients, changing norms and ethics, it is a pressure that rises. To cope with these complex factors, the modelling and simulation of production systems became a main approach in the middle of 20th century. To develop a model and to later use it in simulation is an “artistic” balancing of opposites that demand finesse and skills; on one side the model must be easy to use, that meaning it must involve a level of abstraction from reality, on the other side the model must be a faithful representation of the system it mimics. Therefore, in this article we will develop a learning platform for a methodology to use the modelling and simulation in the analysis of production systems performances. The platform and the methodology will be later experimented and validated, leading to a higher level of research quality.

1. Introduction

The enterprises face an environment that is in continuous change. Market globalization and fierce competition, frequent changes of techniques and technologies, more and more diverse requests from clients, new governmental request and ethics challenges are only a few examples of the pressures that are on the enterprises of the day.

New paradigms and new forms of enterprise organisation appeared as a response to the continuous changes of the business environment. The classical organisation of the enterprise made way to new forms like the extended enterprise and the virtual one, as ways to adapt to the new technological revolution. To cope with all these complex factors, modelling and simulation of manufacturing systems became an important tool at the middle of 20th century.

Today, the engineers that work in planning and production control face beside the external changes, also internal evolutions of the enterprise. They must manage the manufacturing system that makes products with a shorter life cycle, products with higher diversity and they also must integrate technologies that change with a more rapid and efficient pace [1]. In plus they face external factors as clients from the global market that demand more innovative products, more customization and faster delivery time [2]. These factors lead to difficulties in production management, cause of orders change in priority or even cancellations of orders that come from the clients. And certainly, this stormy environment does not accept any less guaranteed quality.

Also, these changes of the business environment impose numerous and rapid optimization of processes, like the decrease of manufacturing durations, the increase in products diversity and complexity. Mainly, the assembly lines are the most affected by the changes, considering that this line
is the first interface with the client and must respond continuously and immediately to the changes that come from it [3].

Considering all the above, a correct model of the assembly system is a valuable tool to manage the complex structure and its continuous change. Also, it will allow for a better understanding of the different interdependent elements of the enterprise, elements of infrastructure and manufacturing products, and the continuous planning, adaptation and optimization of processes [4]. Therefore, a model of the real assembly line, that contain the manufacturing elements, that also includes the characterization of elements in their interdependency, in a transparent and complete way, is very useful. The model has data and knowledge needed to analyze scenarios and to make sure a better communication between all the involved partners [5].

Modeling and simulations are a base for experimental investigation with a low-cost and in less time than by implementing the changes in the real system. The value of the model results also from the improvement of the understanding of the behavior of the system, that is not so obvious from a direct observation of it. A behavioral model of the real system can give information at a lower cost.

The further modeling and simulation of a system, with all the relevant data and information, is a needed task that involves time and knowledge and that allows to obtain faster results in conditions impossible to observe in real life [6].

The work of design of a model and simulation has an “artistic” side on balancing the contraries, that demand acuteness and skill; on one side the model must be simple to use, that involving a certain level of abstracting from the reality, on the other side the model must be a faithful representation of the system it represents.

2. Research problem

This study is part of a broader research project that has as aim to develop a methodology for manufacturing flow improvements, in the automotive industry, by integrating methods, techniques and instruments of production management. In this project it is wanted to develop a laboratory where to use learning factory concepts, there will design learning platforms for layout techniques, modeling and simulation and lean manufacturing. To experiment on this learning platforms, and to mimic an assembly line as close as possible to the industrial environment, in the laboratory it was designed an experimental product (steering wheel) and an assembly line to manufacture this product.

The learning platform for modeling and simulation is being designed to teach the correct use of modeling and simulation in the analysis of production systems. This platform is divided in two parts:
- In the first, it is wanted to teach the steps of making a correct study of modeling and simulation by implementing a methodology;
- In the second, this methodology is implemented to analyze the performances of the assembly system from the experimental laboratory, using simulation software from it, Arena Rockwell and PlantSimulation.

3. Approach

In the previously mentioned context, in this paper is wanted to show the elements of the first part of the platform, to create a guide that contains the learning methodology for a correct use of modeling and simulation in the analysis of a manufacturing systems.

The modeling and simulation are always done as part of the design process of a system, as method of finding the improvement needed in an existing system or are used in the evaluation of an already developed model to identify alternative solution for it.

The methodology for learning the correct use of modeling and simulation in the analysis of manufacturing systems, presented in this article includes 14 interrelated steps, shown in fig.1, and explained in the followings.
Figure 1. The methodology of modeling and simulation

Step 1 is the Problem formulation. Each study with the purpose of analysis on the performances of a manufacturing system, by using simulation, must start with the problem enunciation. This is mandatory for a good understanding of what to do, and the limits of perimeter.

Step 2 – is the Analysis specifications. In this document are limited the simulation goals and the exact perimeter of the analysis. Also, are identified: the studied solutions, the performance indicators targeted and the needed resources. If this step is not well-considered and developed the risks are:

- To start a useless study;
- To use over simplified hypothesis;
- To study unrealistic solutions.

Step 3 is the Gathering of entry data. This step is time-consuming and is advised to start it with the initialization of the model. It is a critical step in the development of simulation because when gathering data, the data quality can directly influence the results of the simulation. It does not matter how well the
design of the model is done, if the entry data are insufficient or of poor quality, the results of the study will be misleading. The data gathering is considered as being the most difficult part of the simulation process.

*Step 4* is the **Check and synthesis of entry data.** In this step the researcher will have to filter the relevant from the irrelevant data and to remove the systematic and abnormal errors, to calculate the main statistical parameters and to determine the probabilistic distribution laws for the entry data (e.g. the law of variation of mean time between failures – MTBF or the mean time to repair - MTTR). This step is repeated until all the data are correct and relevant for the study purpose.

*Step 5* is the **Construction of the behavioural model.** In this step is built a model of the system that allows to get information about the behaviour of the analysed system and to structure the image towards the analysed system. The methods used to build the models are many. We presented seven types of modeling in table 1.

**Table 1. Methods of system modeling**

| Methods | Object of model | Description |
|---------|----------------|-------------|
| IDEF 0  | Activities     | IDEF0 is a graphic method conceived to model decisions, actions and activities of a system. IDEF0 is useful to establish the area of an analysis, especially the functional analysis. |
| IDEF 3  | Process or objects | IDEF 3 is a graphic method of description of a manufacturing system based on processes and objects. |
| SADT    | Activities and objects | SADT is a method that manages two categories of information used in system modeling: first is about transformations, functions, activities and steps that are met under the generic name of activities, the second is about articles, objects, data, information, materials that are handled in activities, included in the generic group of data. |
| GRAI    | Information     | GRAI is a method that dissociates the technologic data of organization of the information system from the decision-making one and bases the system analysis on the static knowledge of the enterprise, represented by the GRAI grid. |
| MERISE  | Information     | MERISE is a method that approaches the enterprise trough a data model (information) that circulates and considers the organization of data as being defining for the globalization of enterprise. |
| PETRI   | Objects and the interaction between them | PETRI networks are a graphic representation that provides a powerful way of communication to user and client. The complex request of the analysis specification can be represented graphically by using PETRI nets instead of ambiguous text descriptions or other mathematical difficult descriptions that are hard to understand by the client. |

Modeling is consolidated on the capacity to abstract the essential characteristics of a problem, to select and change the hypothesis of characterization of the system and after, to elaborate the model until the reach of the needed useful results. To avoid the useless consumption of resources, is not adequate to create a model that copies with precision the reality, but to use only essential data that help in the solving of the problem.

*Step 6 and 7* are **Examination and Validation of model.** The examination is referring to the correct functioning of the system and the validation is referring to the rectitude and the importance of the entry data for the modeled scenario. Therefore, this process is repetitive, until the built model is correct from the functional point of view and until is proven that the data from the analysis specification is relevant for the object of simulation.

*Step 8* is **Conception and execution of simulation.** Considering that the majority of real systems lead to complex models that need a considerable quantity of data and elaborate calculation, the models are transposed in a computer simulation program. To analyze the manufacturing flows, the most uses simulation software are: Witness, Arena Rockwell, Dynamic Enterprise, PlantSimulation etc.
Step 9 is the determination of warm-up period of the system and the simulation duration. The period of loading with parts of the system (warm-up period) is the time-lapse when the simulation runs without registering statistical data. The warm-up period of the system is determined using Welch method. This is a graphic method that needs a significant number of simulations runs. Welch method consists in the following steps:

- Running n simulations, n ≥ 5, each simulation being run for a period m. Being Yji, i = 1…m, j = 1…n, the result of the simulation;
- It is calculated the arithmetic average for the simulated duration. This will be \( \bar{Y}_i \) where:
  \[
  \bar{Y}_i = \frac{\sum_{j=1}^{n} Y_{ji}}{n} \quad \text{for } i = 1...m; \tag{1}
  \]
- These averages are leveled with the help of a mobile average, \( \bar{Y}_i(w) \), where w is the number of periods that will be calculated and \( w \leq \lceil m/4 \rceil \)
  \[
  \bar{Y}_i(w) = \begin{cases} 
    \frac{\sum_{i=w}^{w+2w} Y_{i+w}}{2w+1}, & i = w + 1, w + 2, w + m \\
    \frac{\sum_{i=1}^{w} Y_{i}}{w}, & i = 1, 2, \ldots, w
  \end{cases} \tag{2}
  \]
- It is represented graphically \( \bar{Y}_i(w), i = 1 \ldots m-w \), and is chosen the warm-up period \( W_p \) that is equal to the value of \( i \) from where \( \bar{Y}_i(w) \) shows convergence.

The simulation duration is determined by multiplying the warm-up period for the system with 10.

\[
Ps = Wp \cdot 10 \tag{3}
\]

where:
- \( Ps \) is the simulation duration, in [hours];
- \( Wp \), the warm-up period, in [hours].

**Step 10** is Review and validation of simulation. The review is referring to the model simulation program, if it is performing enough and if the behavioral model was transposed correctly. By iterative testing of the program it can be observed if the entry data and the logical structure of the model are accordingly transposed in the computer program, case when the review is ended. The validation implies to find the level of accuracy of the representation of the real system in the simulated model. The validation is obtained by calibrating (fine tuning) the simulation – also an iterative process of comparing the behavior of the simulated model with the real system, the analysis of discrepancies between them and the search of improvement points for the model. The process is repeated until the accuracy of the simulated model is considered to be acceptable.

**Step 11** is the Construction of the experimentation plan. In this step are determined the mathematical formulas and the procedural entry variables, parameters and exit variables of the system. The mathematical expressions are determined usually by regression analysis.

**Step 12** is the Running of the simulation. In this step are simulated the different scenarios and are identified eventual new scenarios for testing. Considering the results of the runs, is determined if more runs on the scenarios are needed.

**Step 13** is the Mathematical modeling of simulation results. In this step are made the analysis on the variation of exit results function of the entry data (e.g. ANOVA). For this analysis is recommended to use specialized software (e.g. MiniTab) and the technique of data processing Six Sigma.

**Step 14** is the Analysis on the results of simulations. In this step are shown and implemented the obtained results and is made the documentation of the reports of the process of modeling and simulation. The success of the implementation depends on the quality of the previous steps. Also, the implementation is conditioned by the level of involvement of the end client in the design and analysis steps; if the end user is not involved and does not understand the nature and the results of the model, he will have problems in the implementation and consolidation of the directions given by the results.

The documentation and reporting are needed if the program will be used again, by the same users or by others, and will be needed to understand the functioning of the program. This increases the level of
trust in the program and the rectitude of data extracted from it. This type of documentation is very useful also if the program needs to be changed. Another reason to document the program is to ease the use of the model or entry data checking and to observe the exit results, by giving the possibility to reverse to the state of reference.

As are shown in figure 1, the 14th steps of the methodology can be resumed in 5 big phases:
I. The phase of discovery and orientation – steps 1 and 2 – the first definition of the problem is unclear and the initial aims are in significant changes. This phase consumes around 10% of the duration of the study.
II. Gathering, checking and synthesis of data – steps 3 and 4 – consumes around 30% of the study duration.
III. The design of the behavioral model of the system – steps 5, 6 and 7 – need in average around 20% of the study duration.
IV. The design and the exploitation of the simulated model – steps 8, 9, 10 and 12 – this phase consists in the construction of a well-documented experimentation plan with the help of simulation model, taking up to 20% of the duration of the analysis study.
V. The mathematic modelling – steps 11, 13 and 14 – this phase involves the mathematic analysis of data and simulated model results, and it takes in average 20% of the total duration of the study.

4. Conclusions
By constructing this platform of modeling and simulation we want to highlight two very important aspects in designing a correct study for modeling and simulation. The first aspect is that a simulation can’t give correct answers if the data that base its construction are not validated and significant to the aim targeted. The second aspect is that the results of the simulation can’t solve the studied problem if there is they are not correctly processed. Considering that, the time dedicated to this step is about 60% of the total duration of the study.

The learning methodology of the correct use of modeling and simulation in the analysis of a manufacturing system, developed in this paper, allows us to obtain precise simulation results. This is because: the data imputed in the simulation were correctly chosen, the model was correctly tested, checked and validated (the duration of simulation and the duration of system warm up were correctly determined) and the model helped to the better understanding of the behaviour of the studied system.

To finish the learning platform, the methodology of learning the correct use of modeling and simulation will be experimented and validated by applying it on the analysis of the performances of the manufacturing system developed in the experimental laboratory.

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