Experimentation of a methodology to use modelling and simulation in the analysis of performances of an automotive industry production system

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Abstract. The simulation is almost always used as an integrated part of a system design process, as method to identify the improvements of an existing process, to evaluate an already developed model to find alternative solution for it or to compare working hypothesis. It represents an experimental technique that allows experimentation on models of the real system created using a specific simulation language. The knowledge accumulated during the experimentation on the model can be useful and applicable on the real system. Considering that, when it comes to talking about modelling and simulation it is talked about building a model of a real system and the experimentation possible on it. In this paper we will experiment a methodology to simulate the operating mode of a production system from the automotive industry, formed of several interconnected stages. The techniques and instruments used to make the activities in this methodology are in the fields of flow analysis and comparative analysis.

1. Introduction

With the help of simulation can be generated scenarios that in reality are not observable and the most added value is that it can also simulate conditions that don’t exist in reality, and which we want to test before implementation. The simulation implies the representation of a system of phenomenon, starting from a model that allow the analysis of its characteristics and its distinct behaviour in different hypothetical cases.

The modelling and the simulation are used to estimate the performance, to compare alternatives and to optimize systems design. Law and Kelton [1] in the paper on discrete-events simulation, discuss about the manufacturing systems simulation, pointing that these kinds of studies are done for a better understanding of the manufacturing systems behaviour, under different types of control or to determine the accuracy of analytical models.

By using models and simulations one can be mimicking the operating mode of a real process/system in a specific period of time and implies the generation of an artificial history of the system and the observation of the effects of this history to highlight the characteristics of functioning of a real system [2].

Although many types of systems can be modelled and simulated, when considering the manufacturing systems, usually the most encountered analysis are made on:
- Machining operations – simulations of the manufacturing workshop starting from raw materials that pass-through machining to the finish product, including or not the assembly perimeter;
- Assembly operations – simulations of the complex assembly workshops or other processes that involve the assembly of several components into a final product;
- Equipment of handling or logistic transport – it involves the analysis of movement of cranes, forklifts, electrical tractors, AGVs or other transport means;
- Storage – simulations of the storage process and the process of retrieving from stock, manual or automated, of the raw materials or finished goods;
- Maintenance activities – is linking the activities of maintenance to the functionality and availability of machines or other equipment, comparing different strategies of maintenance, preventive or corrective [3].

2. Research problem
This study is part of a larger research project of the authors. In this project is developed a methodology to improve the manufacturing flows of automotive industry. One of the results of this project is the developing of a laboratory where the concepts of layout design, modeling and simulation and lean manufacturing will be learned using the techniques of leaning factory. Considering that, the first part of the project that is the base for this paper was to develop this laboratory and an experimental product, in a diversity and quantity high enough to resemble the manufacturing of automotive industry. The assembly of the experimental product must contain manual activities and a high diversity of components.

The developing of this laboratory and the experimental product made possible the practical experimentation of different layout models designed during the project on the manufacturing system, figure 1, and figure 2.

![Figure 1. Experimental laboratory](image1)

![Figure 2. Experimental product](image2)

In the second part of the laboratory development it is wanted to build a learning platform for the correct use of modeling and simulation in the analysis of manufacturing systems. In the article “The development of a methodology of learning to use the simulation in the analysis of production system performances” was presented the first part of this platform, the methodology of learning the steps of a correct study using modeling and simulation.

In this article, the methodology will be applied on the analysis of 2 layout models of an assembly line that were tested in the laboratory on the experimental product developed in the research project.

3. Approach
In the context before mentioned, in this article, it is experimented if the steps of the modeling and simulation methodology can be used to analyze the performance of the assembly line that we built in the laboratory.

Step 1 Problem formulation: the problem that has to be studied with the help of simulation consists in choosing a layout for the workstations that will increase the performance of the process of manufacturing the experimental product.

Step 2 Analysis specifications: the main aim of this study is to compare two layout models of the workstations using two performance indicators system throughput and efficiency of used resources.
The analyzed perimeter is the room of the experimental laboratory that insure the necessary conditions to develop the normal work process: temperature, humidity, lighting and noise, other special parameters not being needed. The available surface and the general flow are shown in the figure 3.

![Figure 3. The available surface and the manufacturing flow](image)

The studied process is the technology to assembly a steering wheel on 5 steps, steps that are grouped in 4 operations.

**Step 3 Gathering of entry data:** The premises from where this analysis starts are presented in the followings:

- Bill of materials of the product, figure 4

![Figure 4. Bill of Materials of the Product](image)

| Part code | Part name                      | No. parts/ product |
|-----------|--------------------------------|--------------------|
| A         | Inferior body                  | 1                  |
| B         | Inferior cover                 | 1                  |
| C         | Screw M6x10                     | 3                  |
| D         | Nut M6                          | 3                  |
| F         | Mass Toroidal Body             | 1                  |
| G         | Toroidal body components       | 2                  |
| H         | Screw M5x20                     | 7                  |
| I         | Nut M5                          | 7                  |
| J         | Horn support                   | 1                  |
| K         | Claxon                          | 1                  |
| L         | Screw M4x18                     | 2                  |
| M         | Nut M4                          | 2                  |
| N         | Spring                          | 2                  |
| P         | Upper cover support            | 1                  |
| R         | Screw M4x14                     | 3                  |
| S         | Nut M4                          | 3                  |
| V         | Switch                          | 3                  |

- The takt time of the clients’ demand: in this study it is considered to be of 2 min, with considerable fluctuations (0.5 min);
- The means of production available: can be made manual activities, but also mechanized activities, as tightening;
- The assembly technology of the product means to go through 4 operations, as shown in figure 5;

![Figure 5. Process of product assembly](image)

- The means of transfer between operations are conveyers, and the product is transferred on pallets;
- Each workstation contains elements independent of the mean of supply (supports, devices, tools) and elements dependent of the mean of supply (dynamic rack for supply);
- The models of layout analyzed with the developed methodology are presented in figure 6a – all the workstations are arranged in a linear layout and 6b - workstations P1 and P3 are secondary flows that supply workstations P2 and P4.

![Figure 6a. Variant 1 of layout](image1)

![Figure 6b. Variant 2 of layout](image2)

*Figure 6a. Variant 1 of layout  Figure 6b. Variant 2 of layout*

**Step 4 Check and synthesis of entry data:** in this step are eliminated all the irrelevant data for the aim of the study:
- The way of work of the operator – for the simulation is relevant only the duration of execution;
- Information linked to the work environment.

Also, in this step are defined the variation laws of the two entry variables: the duration of activities of assembly – direct operation time, the time it takes for the operator to take the components from the dynamic rack – parts handling time, the time it take for the operator to transport the parts from one workstation to another – operator movement time. The law of variation used for the operation duration has a triangular distribution. The triangular distribution is commonly used in situations where the exact form of the distribution is not known, but estimates for the minimum, maximum, and most likely values are available. The probability distribution of these durations is shown in table 1.

| Workstation | Direct operation time | Parts handling time | Operator movement time |
|-------------|-----------------------|---------------------|------------------------|
| Workstation 1 | TRIA(13.5, 15, 16.5) | TRIA(42.75, 45, 47.25) | TRIA(10.8, 12, 14.4) |
| Workstation 2 | TRIA(25.2, 28, 30.8) | TRIA(50.35, 53, 55.65) | TRIA(7.2, 8, 9.6) |
| Workstation 3 | TRIA(18, 20, 22) | TRIA(60.14, 63.3, 66.46) | TRIA(10.8, 12, 14.4) |
| Workstation 4 | TRIA(20.79, 23.1, 25.44) | TRIA(11.68, 12.3, 12.92) | TRIA(15.3, 17, 20.4) |

In the model, are varied the levels of buffers between workstations.

**Step 5 Construction of the behavioural model:** To describe the behaviour of the system it was used IDEF0 method. In figure 7 and 8 is described as an example the workstation 3 in both variants of layout.
Step 6 and 7 Examination and Validation of model: The examination and the validation of the functional model made with IDEF 0 method is done together with the designer of the layout and with the one that developed the manufacturing system in the experimental laboratory.

Step 8 Conception and execution of simulation: The simulation of the research models is done using SIMAN language developed in the software Arena Rockwell, version 13.9, figure 9.

![Figure 9. Simulation model](image)

Step 9 the determination of warm-up period of the system and the simulation duration: to determine the warm-up period, loading with parts of the system, were simulated the two models 10 times for a period of 100 minutes, and along this period were made measurements each 5 minutes. The graphs obtained by representing the mobile averages are show in figure 10.

![Figure 10. Simulation warm-up](image)

From these graphs it can be observed that the systems start to level around 70 minutes, therefore, the warm-up of the two models will be 70 minutes. The period of simulation is determined by multiplying the warm-up with 10, giving a simulation time of 700 minutes.

Step 10 Review and validation of simulation: To validate the model it was used the specific animation of the Arena Rockwell software. To validate the simulated data in the system were simulated the models considering constant data instead of the entry variables. The value of productivity obtained by simulation was compared with the analytical calculus, giving an error of 0.15% for the first variant of layout and 0.19% for the second variant of layout.

Step 11 Construction of the experimentation plan: Considering that in this paper is wanted to compare the two layout models of the assembly line of the experimental product using simulation, it can’t be determined a mathematical expression. But with the help of simulation will be determined what is the influence of the layout of the line on the line productivity and on the workstation’s efficiency.

Step 12 Running of the simulation: The scenarios developed are presented in table 2, each scenario will be run 5 times.

### Table 2. Simulation scenarios

| Layout | Without buffer | 1 pallet buffer | 2 pallet buffer |
|--------|----------------|----------------|----------------|
| V1     | Scenario 1     | Scenario 2     | Scenario 3     |
| V2     | Scenario 4     | Scenario 5     | Scenario 6     |

Step 13 Mathematic modeling of simulation results: The result of simulations was optimized using the OptQuest module from Arena Rockwell and are presented in table 3.
Step 14 Analysis on the results of simulations: when analyzing the first variant of layout it can be observed that the productivity of the system decreases with 14.02% when is no buffer between workstations. The productivity is around maximum possible when there is a buffer of 1 pallet between each workstation and the increase to 2 pallets has little or no further effect.

| Table 3. Simulation results |
|----------------------------|
| **V1 Layout**              |
| No buffer                  | 1 pallet buffer | 2 pallet buffer |
| (Scenario 1)               | (Scenario 2)    | (Scenario 3)    |
| Throughput [products]      | 4330            | 5015            | 5015            |
| WIP (average)              | 5.1             | 7.3             | 9.3             |
| Operator workload 1        | 65%             | 76%             | 76%             |
| Operator workload 2        | 81%             | 93%             | 93%             |
| Operator workload 3        | 86%             | 100%            | 100%            |
| Operator workload 4        | 48%             | 55%             | 55%             |
| **V2 Layout**              |
| No buffer                  | 1 pallet buffer | 2 pallet buffer |
| (Scenario 1)               | (Scenario 2)    | (Scenario 3)    |
| Throughput [products]      | 3962            | 4528            | 4530            |
| WIP (average)              | 4.8             | 7.8             | 10.7            |
| Operator workload 1        | 64%             | 73%             | 73%             |
| Operator workload 2        | 74%             | 84%             | 84%             |
| Operator workload 3        | 88%             | 100%            | 100%            |
| Operator workload 4        | 44%             | 50%             | 50%             |

A similar thing happens in the second variant of layout. A loss in productivity of 13.08% with no buffer and around maximum productivity with a buffer of 1 part between workstations.

When comparing the two layouts hypothesis, is a decrease of 10.48% of production between the variant of layout one and the second one. This is mainly caused by the increase of operator movement, due to higher distances between the elements of the workstations.

4. Conclusions
The learning platform that is developed in the laboratory allows to use the concepts of learning factory in the training process of the workforce. With this learning platforms they will can learn how to use modelling and simulation in the analysis of manufacturing systems. The learning platform for modelling and simulation imply the cover two phases in the assimilation of knowledge needed to apply these concepts in the analysis of manufacturing systems. These phases are:
- The cover of methodology with all the steps of the process of modelling and simulation;
- The application of these steps in the evaluation of the performances of the assembly line developed in the laboratory and to design the simulations in the software found in the laboratory, Arena Rockwell and PlantSimulation.

Acknowledgments
This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0446 / 82-PCCDI-2018, within PNCDI III.

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