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BALANCING OF PRODUCTION LINE USING DISCRETE EVENT SIMULATION MODEL

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Abstract: *The paper is a central theme of research in the field of industrial engineering, which has as main objective the optimization of the flows in a flexible manufacturing system by configuring workstations required and the dynamic control of the rhythm and the manufacturing stocks based on modeling discrete event systems. The work presented in this paper is based on a real problem, with the purpose of optimizing and balancing a manufacturing line. In this article aspects of the whole production process are presented, which can be improved by using currently available equipment and software. Thus, a simulation using Delmia Quest software was introduced. Therefore, the topic of this paper is centred on material flow simulation and optimization. The objective of the simulation model was to determine bottleneck locations and to offer an alternative for improving the manufacturing line.*

Key words: *simulation, productivity, Delmia Quest, bottleneck, optimization.*

1. INTRODUCTION

The productivity of manufacturing systems is one of the most important elements for an enterprise's competitiveness. When a manufacturing system has been implemented, the enterprise must carry out a permanent performance improvement to enhance the production efficiency of the systems in operation. This activity is mandatory for enterprises to maintain their competitiveness, because there are always productivity decline factors in the systems, such as worker/product changes, new technology development and process planning revision [1].

A lot of ideas can be tested on a single model. It is preferable to make some errors on the computer simulation, where the costs are almost nonexistent. Therefore it is said that modeling and simulation avoids the term of reboot.

A simulation model presents a detailed representation of the characteristics of the system, being analyzed through the control of machine operation, flow of materials and sequence of work operations. The Quest software proved to be a powerful tool in assessing the changes that should be made for a manufacturing line before incurring manufacturing improvements.

In this article an implementation of the simulation technologies using Quest software is presented. An industrial case study is examined to validate the efficiency of the proposed bottleneck detection method. The manufacturing process was simulated and analyzed, the bottleneck in the production line being found, which can be used to optimize the manufacturing line.

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2. OPTIMIZATION PROCEDURE BASED ON SIMULATION

2.1. Problem definition

Modelling and simulation process is used to develop a manufacturing system with new, efficient and performed production strategies [2].

While experimenting, the *best* solution is searched for. *Best* can have many different meanings − highest throughput levels, lowest costs, highest services levels, etc. Usually, it means a specific combination of these types of factors. The key to define what the best solution looks like is within the optimization. This is encapsulated in an objective function which can be as simple or as complex as required.

A successful simulation process must include all the simulation objects in production field as shown in Fig. 1 [3].

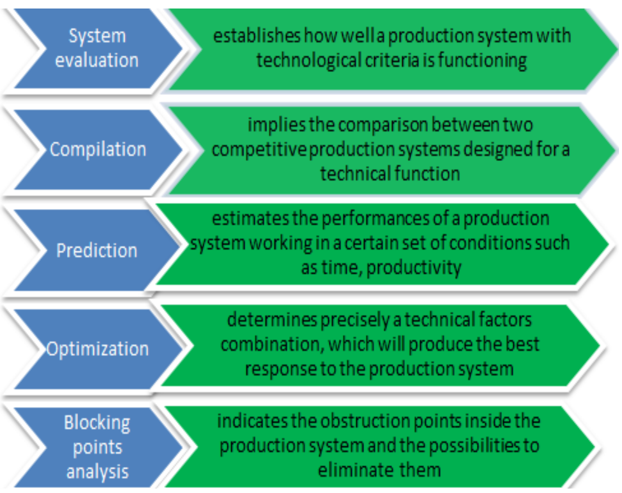

Fig. 1. Simulation objects.

2.2. Simulation using Delmia Quest software

Today it is inconceivable to design only by classical method. For designing flexible manufacturing system, one of the software used is Quest, from Delmia Corporation.

In this research work, DELMIA QUEST (Queuing Event Simulation Tool) software tool has been employed to carry out Discrete Event Simulation activities on manufacturing systems.

QUEST provides a complete solution for all aspects of manufacturing planning from the evaluation of strategies and plant floor layout to the programming of automation equipment. This simulation technology can be applied to flexible manufacturing systems (FMS), Just-In-Time (JIT), business re-engineering, team labor, cost, and a host of other issues facing [4, 5].

Delmia Quest software provides simulation environment based on the delivery of materials, processing and storage. It contains material element for rapid modeling such as machine tool, buffer, treatment process, failure rate, maintenance, operator, path and material export, which can help users simulate and analyze the process flow in 3D factory environment.

With powerful visualization and import / export functions, Quest becomes the best solution of the production process simulation and analysis.

3. CASE STUDY

3.1. Problem description

While making a feasibility analysis of a manufacturing line, we need a simulation for justifying and quantifying the required investment. In this case, the simulation is a tool to highlight the costs and expected performance. The simulation also aids to specify and define the Technical Specifications in pre-contracting and contracting phases. On this occasion, the size of the manufacturing line will be taken into account to meet, in this way, the foreseen package order. In other words, in this phase, it is determined:

- the number and type of necessary machines;
- nature and size of deposits (storage units, shops, power systems, storage);
- nature and size of the parts handling system, tools, blanks.
- amount of labor required.

The statistical characteristics create, for instance, the possibility to diagnose the bottlenecks areas in the production line and to define the solution in order to avoid them. In later stages of manufacturing line design, more complex simulations allow the adoption of detailed solutions and their validation. Among others, some simulation results allow, at this phase, the definition of the technological flow piloting: the choice of the flow − pulled or pushed. By simulation, it is possible to study the influence of the flow stops upon the manufacturing line performance.

The case study is related to a manufacturing line of a car headrest support work piece (Fig. 2).

The operations of the line manufacturing (headrest support) are shown in Table 1.

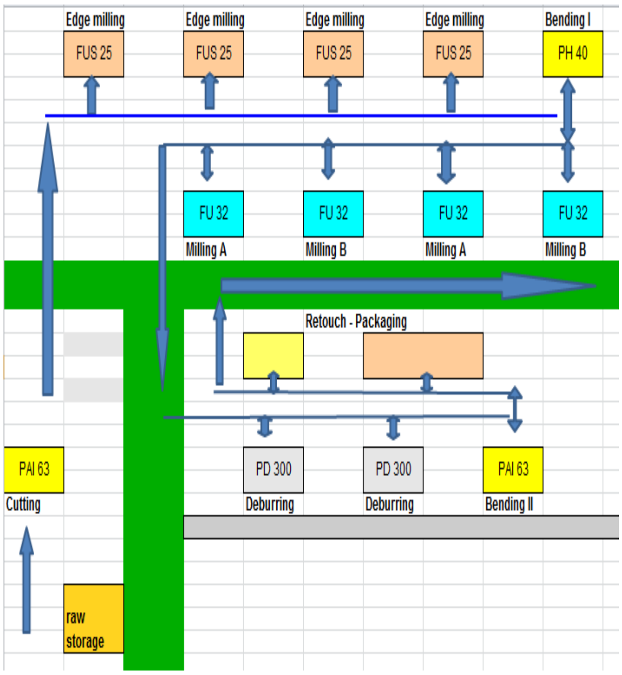

Fig. 2. Layout of a manufacturing line case study.

Table 1

Description of operations

Name of operation	Description
1	2
Cutting	- Sourcing raw materials: steel bar calibrated Ø =11,67h9; L = 3825mm - Cut to L = 762 + 1mm by acting the press by the limiter flaps
Edge Milling I + II	- Sourcing raw materials: half cut, L = 762 + 1mm - Adjust the length limit to get 761.5 ± 0.2mm
Bending I	- The distance between the two arms: 110 ± 0.5 mm
Milling ROD B / ROD A	- Sourcing raw materials: half bent. Cleaning the burr out of the surface by compressed air for each piece - Adjustment quota for milling device 121.2 ± 1 is checked twice per shift and each shift of the milling module
Deburring	- Sourcing raw materials: half milling - Deburring by sandpaper and wire brush on both arms
Bending II	- Sourcing raw materials: half milling - Angle =7.6 °
Name of operation	Description
Retouch	- Cleaning - 100% by linen cloth on the workstation - Visually: part does not present mechanical shocks, burrs, cracks - Retouch is done by sandpaper, then by cloth

Table 1 (*continuation*)

1	2
TQC-final	- Check the quota of 162.7 ± 1 and angle = 7.6 - Check the quota of 122.5 ± 1 at the edges of the arms A and B. - Check the parallelism imposed ± 0.5 between arms A and B. - Check the quota of 110 ± 2. - Check the quota of 21.6 ± 1 for the two arms A and B
Packaging	- Check the conformity of parts (visually).

3.2. Simulation of the manufacturing line

As a first step we use structural elements to model the manufacturing architecture [5]:

- Parts are the entities that flow through the model, as they move from element to element and they are processed. In the manufacturing context, these would be the physical parts processed within the system, from the raw parts to the finished products;
- Source: A source will be created for this model to serve as a mechanism by which the parts can enter the model. Sources are the elements designed to create the parts that will be processed by the other model elements. They represent the *point-of-entry* of parts into a model. They are flexible elements that offer a wide range of options;
- Machines: Parts are created at the source and are processed on machines. Machines represent the system elements responsible for parts processing; The time a machine is operational and thus not in a state of failure is called the "uptime". The remaining time is 'downtime', this being when the machine is under repair. Each machine is defined by three characteristics: Cycle time, mean time to failure (MTTF), and mean time to recovery (MTTR).
- Failures are described by their MTTF and MTTR. MTTF is the average time until a failure occurs in the system. MTTR is the average time it takes a machine to recover from a failure. Adding the MTTF and the MTTR equals to the MTBF (mean time between failures). This is the average time between two consecutive failures: MTBF = MTTF + MTTR. Availability = MTTF / (MTTF + MTTR) − the percentage of time that a machine is not failing.
- Processes define what happens to a part as it moves through an element. There is a number of different processes that can be assigned to different QUEST elements. Once defined, the process is associated with an element class, thus giving that element class the possibility to carry out that process. It depends on the element classes logic whether the specified process will be carried out or not.
- Buffers: The buffers will be created for this model, one for each gap, between the source and machine, and another − between the machines and the sink. Buffers represent the locations where parts are stored or where they queue before accessing to other resources, such as machines. Thus, a buffer might represent a storage location in a warehouse, the buffer's role being to feed the parts into a machine. Buffers are created to prevent parts from blocking elements due to differences in the cycle and inter-arrival times or as a result of machine downtime;
- Conveyors: A conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another. Conveyors are especially useful in applications involving the transportation of heavy or bulky materials;
- Labors: Labor is required by the processes defined for the machines in the model. Each machine needs a laborer for its entire cycle time. Labors are the elements that move around the system, meeting process requirements, transporting parts, and loading and unloading parts at various locations;
- The labor controller is the main decision taking element. There may be many laborers in a model, decision points, and elements requiring labor.The controller coordinates the functioning of these different elements to accomplish a task set. The controller's behavior is defined by its process logic and due to the coordination and decision-taking nature of the controller, this process logic is more complex by comparison to other elements;
- Sink: A sink needs to be created for this model to serve as a mechanism by which part can come out of the model. Sinks are designed to destroy parts at the end of the production process. For this reason, they can have inputs but no outputs. Although the parts are destroyed in the sink, all the statistics related to these parts are preserved by the software and may be accessed at any time - during or after the simulation run [6, 7].

Having all structural elements represented, we can introduce the manufacturing parameters into the system considering the required manufacturing processes. In order to analyze the system's behavior in terms of production flow, the simulation model of the system was set up with the layout in Fig. 3.

Then, connections between elements were created in the virtual mode. They have strong influence in determining the behavior of the system as they represent the

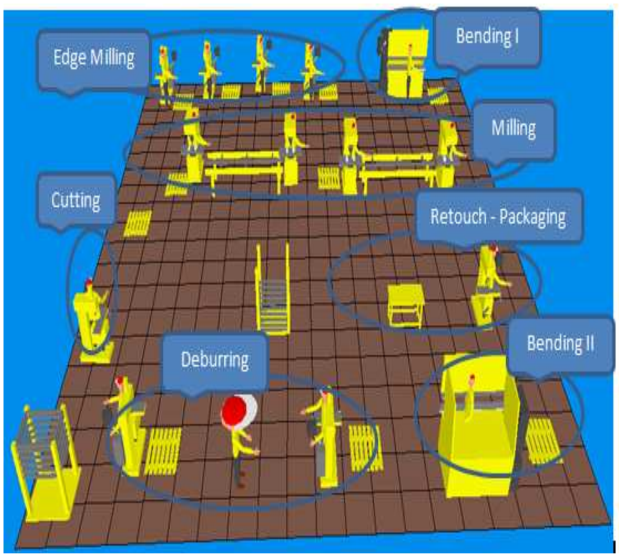

Fig. 3. Discrete Event Simulation Model.

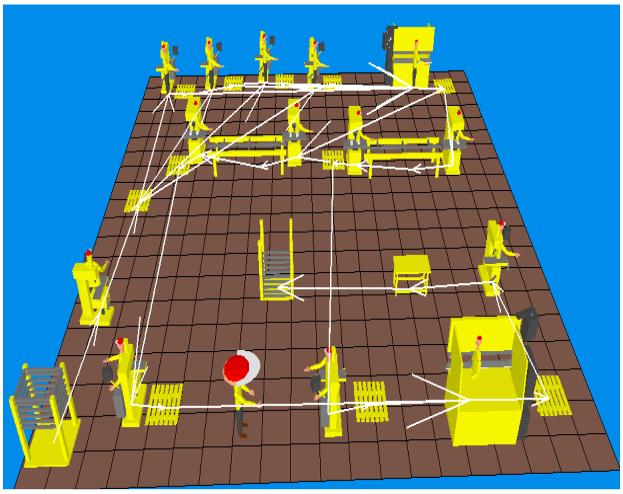

Fig. 4. Part flow.

Table 2

Sequence of operations

Operation name	**Cycle Time [min]**
Cutting	0.077
Edge Milling	0.565
Bending I	0.200
Milling B	0.343
Milling A	0.343
Deburring	0.600
Bending II	0.220
Retouch	0.19

logical links between elements, providing the mechanism for parts to move from one element to another (Fig. 4).

Finally, processes (including cycle processes, setup processes and load / unload processes) were created by indicating time and resources needed for all the operations in the cell. They were associated to the corresponding elements in order to define what happens to each type of part while moving through that element (Table 2).

Before starting the material flow simulation and optimization we must set the simulation period of time. In our case, the manufacturing process will run for a period of 8 hour (28 800 seconds).

A shift schedule describing the length of the operating shift and corresponding breaks during the shift will need to be defined. The shift schedule can then be applied to all the possible model elements to define the time patterns of the operations of those elements.

Labor works during 7.5 hours per shift (2 breaks once in 5 minutes per day and a break once in 20 minutes have been introduced).

By removing the break time, we can calculate the work time interval (1):

$$WT = WST - B, \tag{1}$$

where WT is Work Time; WST − Work Shift Time; B – Breaks.

$$WT = 28\,800 - 1\,800 = 27\,000[\text{sec}]. \tag{2}$$

Also, we noticed a difference between the operators efficiency in the work time. To correct it, we introduced a fatigue factor (3):

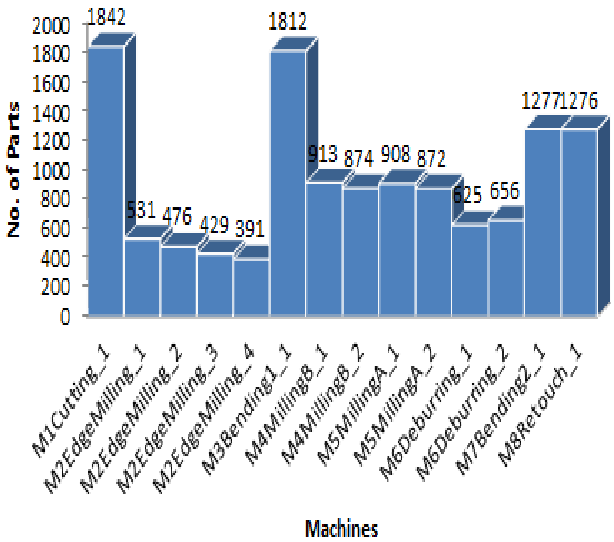

Fig. 5. Number of obtained parts using the system.

$$FF = 0.9. \tag{3}$$

The real work time interval (4) is now calculated using the equation [8]:

$$RWT = WT \cdot FF,$$

$$RWT = 27\,000 \cdot 0.9 = 24\,300 \text{ sec.} \quad (4)$$

A schedule downtime can be used to describe the effective working time of a machine and the time of repair or maintenance. This schedule can then be applied to all the possible model elements to define the downtime patterns of these elements [9].

The distributions to describe the time between failures and the time to correct these failures are defined: Exponential from the Distributions, a Mean value of 1 hour. The time for repairing is defined using Uniform Distributions: a Minimum Value of 180 sec and a Maximum Value of 300 sec.

After a run simulation of 8 hours working time, it is noted that the number of finish parts are 1 276 (Fig. 5).

3.3. Bottleneck detection

Discrete-event simulation models are commonly used in the industry for the following purposes:

- Capacity calculations.
- Analyzing throughput and lead times.
- Layout-planning.
- Balancing production.
- Supporting investment decisions and as risk-management tool.
- Identifying bottlenecks and testing out control techniques.

A bottleneck may be defined as a machine whose performance impedes the most the overall system performance. Technically, a bottleneck is defined as the most sensitive machine for the overall system performance.

The bottleneck is the resource that affects the most the performance of a system. For a given differential increment of change that has the largest influence on the system performance [10].

To see how the machine times affect the line productivity, the bottleneck needs to be evaluated.

The controller makes decisions on how to mitigate the bottleneck to reduce variation of production and improve the system performance. Generally, the controllable parameters in a real production line include machine repair time and cycle time. As cycle time is difficult to adjust for a paced manufacturing line, the focus of our research is the reduction of downtimes.

The bottlenecks in our study are (Fig. 6):

- Machines idle in the manufacturing process;
- Machines overloaded and sequential inputs;
- Parts passing to their operation from one cell to another (this is the biggest inter-cell movement resource).

As can be seen from the above simulation results, the utilization of some station is too low and production line is in an unbalanced state. The purpose of modelling and simulation is to find the bottlenecks in the production line. If there is a bottleneck station, several measures can be taken to solve it, such as to increase the number of equipment, to divide one operation into several parts.

If there is a station where its components are stacked severely, some stacking space can be added to improve it. Speeding up the transport frequency to next process can also be improved, if necessary [11].

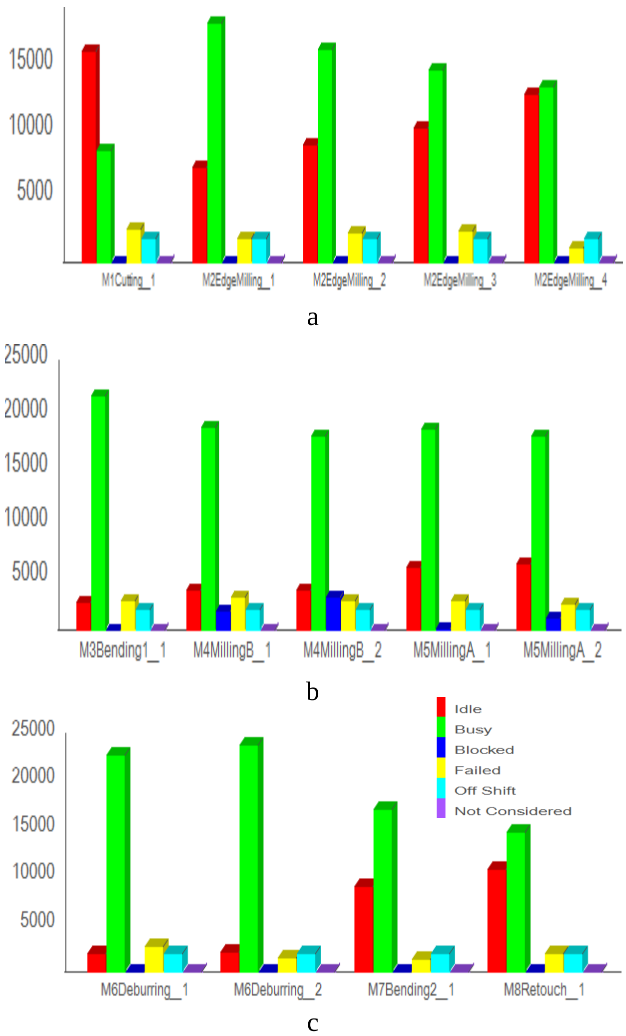

Fig. 6. Case study machines utilization: *a* – cutting; *b* − bending; *c* – deburring.

3.4. Optimization of the manufacturing line

It is not known from the beginning if the simulation of a situation is profitable. But if we make 10 simulations, one of them would generate gains superior to other nine.

By analyzing the simulation results, several possible issues were identified in order to improve the productivity and efficiency of the manufacturing line through its reconfiguration. The bottleneck of the system is easily identified as the element having the highest utilization.

To see how the machine times affect the line the bottleneck needed to be determined. As this is a linear system where every part has to go through a number of operations in a specific order the bottleneck is simply the place where the parts get piled up. The pile appears indirectly in front of the deburring machine. So it was very easy to determine that deburring machine was the bottleneck in the line.

In order to improve the manufacturing line, we propose the following alternative − adding a new workstation to the bottleneck area (Fig. 7).

The recommendation is to add a new workstation to the bottleneck station in order to reduce the buffer quantity [12, 13]. The company has to decide whether adding another deburring machine to the production line would increase the productivity. In this way, one more deburring machine was added to the simulation model in order to simulate the new production system. As a result, the output was stimulated from 1 276 units to 1 661 units with an approximate increase of 30.17 % (Fig. 8).

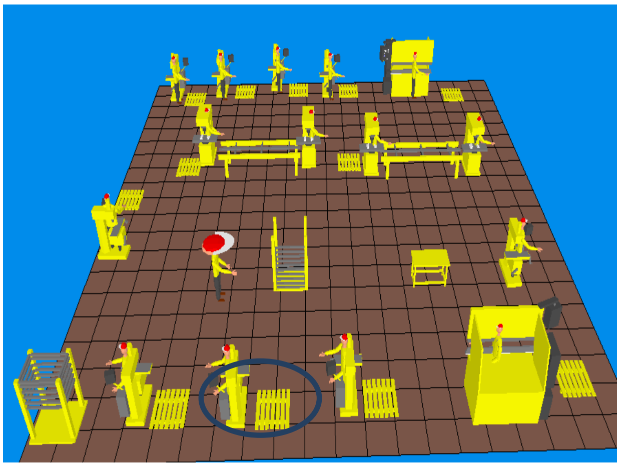

Fig. 7. An alternative to line optimization.

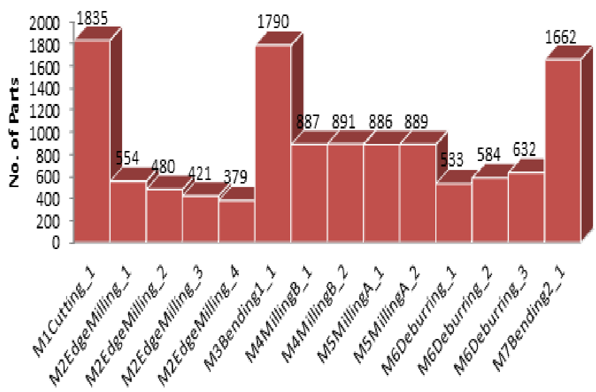

Fig. 8. Output of elements during production.

4. CONCLUSIONS

Simulation has become today one of the most useful methodologies in industrial engineering field and it could be used also for dynamic analysis, before implementation of the production system, in order to reduce at minimum the costs and the stocks.

In this paper the simulation of the manufacturing line (headrest support) is presented using DELMIA Quest software in order to simulate, to optimize and to balance the line of production system.

The aim of this paper is to improve the layout of production system and consequently reducing idle time on machines, organizing tasks to operators and adding a new workstation in the bottleneck area. The solution found for better organizing the production line is to add a deburring machine that can increase the productivity with 30%.

By using Quest to simulate the production flow we obtain a good understanding of how the manufacturing line behaves and how it responds to changes. The software gave the possibility to compare one result to another thanks to the charts and graphs obtained automatically with the program. To get proper results using simulation software DELMIA Quest the authors recommend to have a very good understanding of the study case production line and good knowledge of the flow simulation theory using discrete events.

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REFERENCES

[1] W.K. Ham and S.C. Park, *A framework for the continuous performance improvement of manned assembly lines*, International Journal of Production Research, Vol. 52, No. 18, 2014, pp. 5432–5450, http://dx.doi.org/10.1080/00207543.2014.911420;

[2] C. Ispas, C. Mohora, O. Calin (2002), *Simulation tool of manufacturing optimisation*, Pakistan Journal of Applied Scinces, No. 2., , ISSN 1607–8926.

[3] C. Mohora, D. Anania, O.A. Calin, *Simulations strategies using Delmia Quest*, Annals of DAAAM & Proceedings, 2009 ISSN: 1726-9679J.

[4] G. Pasca, I. Maniu, *Synthesis of the design of flexible manufacturing system using Delmia Quest software*, Annals of DAAM & Proceedings, Ian 2009, pp. 695;

[5] Z.M. Bzymek, M. Nunez, M. Li, S. Powers, *Simulation of a Machining Sequence Using Delmia/Quest Software, Computer-Aided Design and Applications*, 2008, CAD Solutions, LLC, pp. 401−411, http://www.cadanda.com.

[6] C. Wang, C. Qiu, *Virtual Simulation of the Job Shop Scheduling System Based on Delmia/QUEST*, In System Simulation and Scientific Computing, 2008, ICSC 2008, Asia Simulation Conference-7th International Conference, IEEE, pp. 1129−1132.

[7] M. Yoshimura, S. Yoshida, Y. Konishi, K. Izui, S. Nishiwaki, Y.Inamori, T. Inagaki, *A rapid analysis method for production line design*, International Journal of Production Research,Vol. 44, No. 6, 15 March 2006, pp. 1171–1192.

[8] F. Chiscop, C. Enache, M. Chiscop, C.E. Stoica, S*tudy for zero breakdowns and productivity increase*, Proceedings in Manufacturing Systems, Vol. 8, Iss. 4, 2013, pp. 193−198, http://www.icmas.eu/.

[9] S.S. Sana, *Preventive maintenance and optimal buffer inventory for products sold with warranty in an imperfect production system*, International Journal of Production Research, Vol. 50, No. 23, pp. 6763–6774.

[10] C.E. Betterton and S.J. Silver, *Detecting bottlenecks in serial production lines – a focus on interdeparture time variance*, International Journal of Production Research, Vol. 50, No. 15, 2012, pp. 4158–4174.

[11] H. Lu, X. Liu, W. Pang, W.H. Ye, , B.S. Wei, *Modeling and Simulation of Aircraft Assembly Line Based on Quest*, Advanced Materials Research, Vol. 569 (2012) pp. 666−669, available at: www.scientific.net.

[12] H.W.M. Wan, M.N.A. Rahman, M.D. Baba, J.A. Ghani, *Improving Production Line Performance: A case study*, Applied Mechanics and Materials Vols. 44−47 (2011), pp 4136−4140, available at: www.scientific.net.

[13] L. Li, Q. Chang, J. H., S. Biller, *Real time production improvement through bottleneck control*, International Journal of Production Research, Vol. 47, No. 21, pp. 6145–6158.