APPLICATION OF A SIMULATION MODEL IN THE PRODUCT DEVELOPMENT PROCESS IMPROVEMENT

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Summary: The article presents an attempt to apply a simulation model in a product development process. The aim of the completed research was to improve a documentation flow process in the product development department in one of the big companies from the automotive industry. Changes in the process were proposed on the basis of results coming simultaneously from the simulation model and Failure Mode and Effects Analysis. This paper discusses the way in which simulation modeling can become a helpful tool in improving documentation flow process by finding bottlenecks and developing scenarios. The scenarios enable forecasting selected figures that depend on certain, predetermined conditions.

Keywords: simulation model, product development process, FMEA.

1. Description of the Product Development Process (PDP)

Nowadays, business is mainly a global business, and companies that are active on this scale have to develop products for global markets. The whole globalization process is a major market trend today, characterized not only by increased international competition but also extensive opportunities for firms to expand their operations beyond current boundaries. Effectively dealing with this important change, however, makes the management of global new product development a major concern. To ensure success in this complex and competitive endeavor, companies must ensure a stable and optimized product development process [1].

In the global economy, product innovations and the pace of work on their development are becoming increasingly important. Business experience shows that covering customers' needs is insufficient to ensure success of a new product. Increasingly, it appears that the critical condition for the success of a new product is company's greater efficiency in the use of its own core competencies [2]. In addition introducing innovations is fundamental for firms to enhance their competitive position and to safeguard their long-term success. Innovations, that can be defined as new products that involve substantially new technology, offer substantially greater customer benefits relative to existing products, and demand considerable changes to consumption or usage patterns, need to be introduced to the market efficiently and ably. This is why the optimization of a product development process is extremely important and often decides on company's market success. Product development process is crucial in the whole production cycle. This is why minimization of the lead time, especially by eliminating time wasted in queues, leads to the optimization of the whole process and enables a significant increase of efficiency. Besides, in an environment of accelerating technology and short product life cycles, quick and efficient product development process is essential to ensure the fastest way for an idea or a concept to become a product available on the market.

Product development process can be defined in many ways. From an engineering point of view the product development (PDP) process begins with technical and economic assumptions, includes all the phases of the product's development, its exploitation, service, structure and modifications and it ends with a product's repair and recycling.

In order to improve a product development process in one of the big companies from the automotive industry several actions were taken. At first the existing product development process was analyzed and the documentation flow process was researched. Secondly empirical data from a part of the process was collected. 226 documents coming from thirteen months were analyzed [3]. Monthly average of approved documents is 134 and weekly average is 30.10. The process is quite simple. A constructor begins a product development process. Then each document is checked and approved on four levels of control, called A and B (level 1), C and D (level 2), E (level 3) and F (level 4) (Fig. 1).

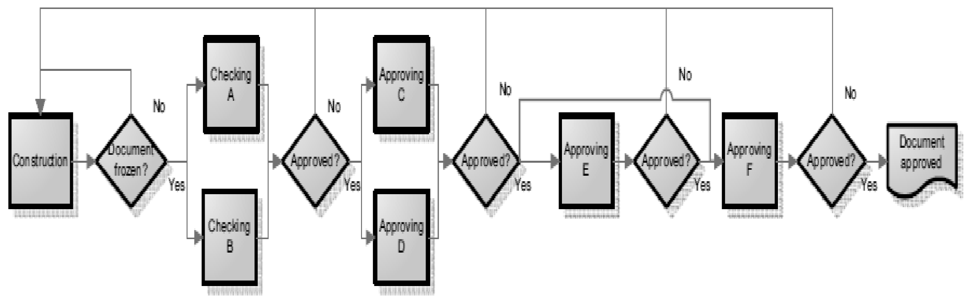

Fig. 1. A part of a product development process (PDP)

There are nearly 30 constructors in the office. After constructor finishes his work, he freezes the document with all necessary drawings and data attached. Subsequently, the information about frozen document is sent simultaneously to checkers' mailbox (A and B level). There are two checkers in the product development department. Each of them is responsible for checking both – A and B. According to the process all the documents are checked at the workplaces A, C, D, F and only some of them (about 40%) are checked at the workplace B. At the third (level E) less than 8% of all documents) is checked. From each of the levels the document can be returned to the constructor. If a document is approved at all levels, the process of design documentation development is finished.

2. Failure Mode And Effect Analysis of the PDP

Having analyzed 226 documents, average total time of developing one document was calculated. What need to be underlined is that presented total time includes not only working time, but also leisure time, weekends, holidays, etc. Nevertheless, a comparison of average total time and maximum real processing time presented in the Fig. 2. shows that the vast majority of the time an average document spends in queues waiting to be checked and approved. This is why real processing time takes only little part of the total time.

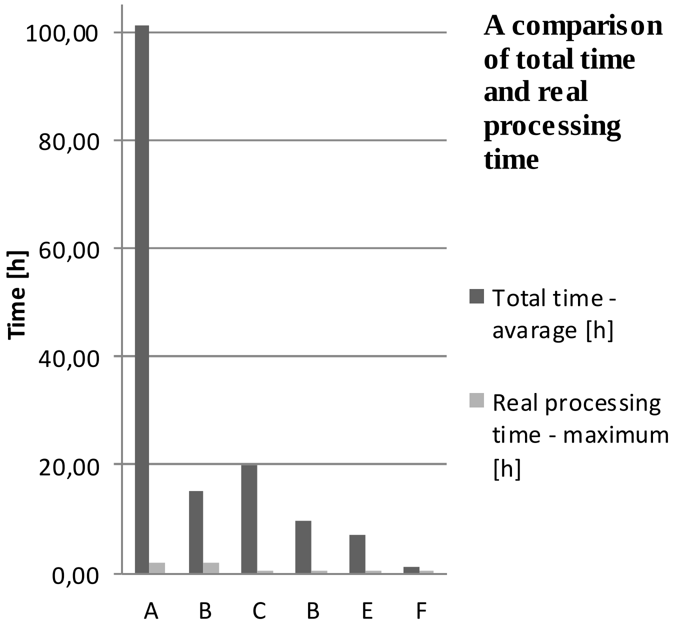

Fig. 2. The comparison of total time and real processing time at particular stages of the PDP

That situation shows clearly and directly that there is a lot of waste in the process, which according to all rules of the Lean Management and Lean Manufacturing methodology definitely should be eliminated. In order to find urgent problems that needed solving, Failure Mode and Effects Analysis was performed. The FMEA is a methodology that enables finding errors in a process and errors causes and therefore is the basis for further process improvement [4].

The aim of the FMEA analysis was to identify potential flaws based on past experience and to design solutions for problems having high risk priority number. The FMEA was carried out in seven-person team.

On the basis of process map a set of process flaws was pointed out. Having all the flaws written down, all significant effects and causes were indicated. Subsequently risk priority numbers (RPN) were calculated. Flaws burdened with the highest level of risk were chosen. They were:

- Undetected error in documentation at A and B level; potential cause: periodically reduced time for documentation checking and documentation backlog; RPN = 420,
- Undetected error in documentation at A and B level; potential cause: poor ergonomics working conditions (lack of air conditioning, noise, etc.); RPN = 350,
- Incorrect technical documentation at the construction level, potential cause: inadequate planning and wrong time and resources management; RPN = 280,
- Documentation approved without verification at the C,D and E level; potential cause: hurry, time pressure, inadequate planning; RPN = 280,
- Incorrect technical documentation at the construction level, potential cause: lack of knowledge and experience; RPN = 240,

- Setting wrong number at the construction level, potential cause: lack of constructor's motivation; RPN = 162,
- Setting wrong number at the construction level, potential cause: the constructor has been misinformed; RPN = 126.

The final step of the FMEA was to determine the set of recommended actions, implementation of which would minimize the risk and enable the elimination of the process errors. Included in recommended actions were :

- Awaken constructors the risk, which is caused by not introducing, even considered to be trivial, basic data, accounting of assigned tasks and drawing the consequences,
- Implementing a project management system,
- The introduction of the new work standard on which the new constructor or consultant will always work in a project with an experienced designer in the certain field,
- The introduction of the new work standard on which constructor will freeze a document always exactly a week before planned approval date,
- Insertion of partition walls,
- Air conditioning installing,
- Verification of lights location,
- Implementation of regulation, which would said that while having a telephone conference wearing headphones is mandatory,
- Use of the whiteboard, which would contain all the information concerning the weekly responsibilities and tasks of individual employees. Such a solution would eliminate duplication of responsibilities. Besides each employee would know on what work remained employees.

Having finished the FMEA and having analyzed empirical data, the concept of a simulation model was developed.

3. Simulation model of the PDP

William E. Deming once said *All models are wrong. Some models are useful*, nevertheless it is important to do everything that is possible so that built models were less wrong and more useful [5].

The simulation model was built using Discrete Event modeling methodology. The software used to develop the model supports all the most common simulation methodologies in place today: System Dynamics, Process-centric (Discrete Event) and Agent Based modeling. The flexibility of the modeling language enables capturing the complexity and heterogeneity of business or manufacturing process to any desired level of detail. Graphical interface, tools, and library objects allow to model diverse areas such as manufacturing and logistics, business processes or human resources. The object-oriented model design paradigm supported by the software enables developing modular, hierarchical, and incremental construction of large models. Discrete Event modeling is fully supported by the software. It includes the Enterprise Library which allows creating basically any kind of discrete-event model. The Enterprise Library has default animations for every block but it also enables developing any necessary 2D or 3D animation of any complexity which could animate the modeled process and allow to manage model parameters in run-time. The Enterprise Library is designed to support Discrete Event simulation in manufacturing, supply chain, logistics and healthcare areas. Using the Enterprise Library objects real-world systems in terms of entities like transactions, customers, products, parts, vehicles or processes like sequences of operations typically involving queues, delays, resource utilization and resources can be modeled. The processes are specified in the form of flowcharts. The basic construction used to define process in Discrete Event modeling are process flowcharts. Statecharts are used mostly in Agent Based modeling to define agent behavior, but they are also often used in Discrete Event modeling. The language of the described software also includes: low level modeling constructions (variables, equations, parameters, events etc.), presentation shapes (lines, polylines, ovals etc.), analysis facilities (datasets, histograms, plots), connectivity tools, standard images, and experiments frameworks.

The construction of a simulation model of the part of the product development process consists mostly of some basic objects from the Enterprise Library, such as *ActiveObject* classes, *ResourcePool*, *Service*, *Source*, *Sink*. It also includes *sliders*, *ports* and *plots*. The duration of each operation is presented in the model as a triangular distribution. The model depends on the following variables: number of constructors <0,29>, number of checkers A and B <0,4>, number of approvers C <0,4>, number of approvers D <0,4>, number of approvers E <0,4>, number of approvers F <0,4> and arrival rate <0,12>. These variables can be controlled directly from the model presentation, whereas from the model itself, time distributions, queues capacities and duration of a simulation can be changed. The model includes also a simplified layout, where workplaces of constructors, checkers and approvers are shown. If a resource is busy it is illustrated by a red picture and if it is idle by a green one. The model presents also queues with accumulating documents. There are also many plots including those showing encumbrance of each workplace, cycle time, time in queues, processing time and delay time. What is more, model's presentation displays minimum, average and maximum cycle time [h], minimum, average and maximum processing time [h], average time in queues [h] and the difference between planned and real approving time. The model presents only working time.

After the simulation model was built, it had to be verified. The results from the verification process are shown at the Fig. 3.

Comparison of data from the model with actual data shows that the average number of documents approved per week calculated based on 10 simulations differs only by 4% from the actual number of documents approved per week in product development department. The monthly average number of approved documents calculated based on 10 simulations differs only by 3% from the actual data. Given results permit to state that the model correctly reproduces the documentation flow process.

Next step was to analyze how much time does an average document actually wait in queues and for how long is processed. Results of 10 simulations are shown at the Fig. 4. An average document spends 93.65% of the cycle time in queues, while processing time takes only 6.35%. The results clearly indicate that the process of documentation flow needs some improvements.

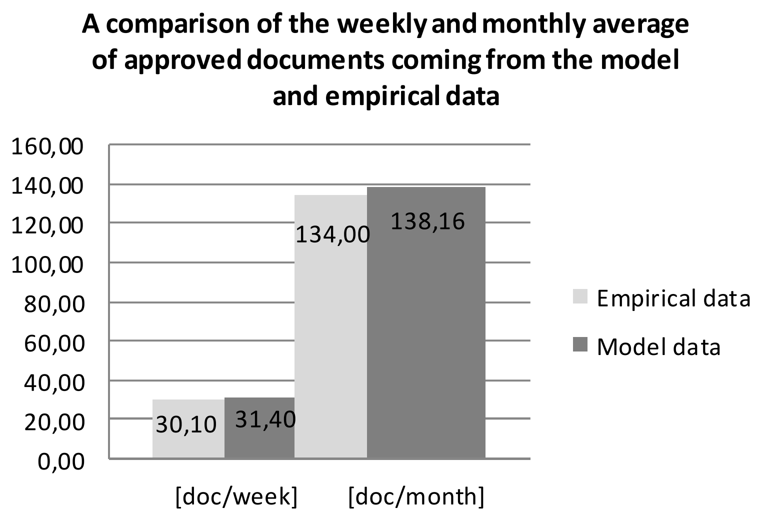

Fig. 3. A comparison of the weekly and monthly average of approved documents coming from the model and empirical data

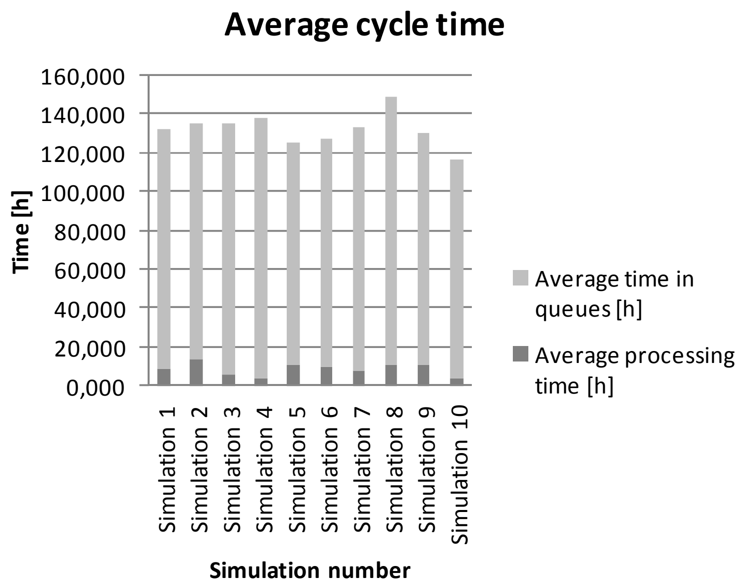

Fig. 4. The share of time in queues and processing time in the cycle time

There are many different models of the PDP described in the literature. However the model analyzed in this paper resembles a Stage-Gate model, which is an example of the integrated approach of the new product development process modeling. Stage-Gate model, also called as a Phase–Gate process, is a project management technique in which an initiative or project (e.g.: new product development, process improvement, business change) is divided into stages (or phases) separated by gates. Stage-Gate is a widely used product innovation process for managing portfolios of new product development projects. The process enables companies to minimize uncertainty by helping them identify – at various stages or gates – the "wrong" projects before too many resources are invested. A Stage-Gates process involves a conceptual and operational map for moving new product development projects from idea to launch and beyond. It consists of a series of stages wherein a project team undertakes the work, obtains the necessary information, and performs data integration and analysis. Each stage is followed by a gate at which the continuation of the process is decided (a *go/kill* decision is made) by an appropriate member of the process.

4. Scenarios of the PDP models

A process of analyzing possible future events by considering alternative possible outcomes is called a scenario analysis. It is a method that presents consciously several alternative future developments. Consequently, a scope of possible future outcomes is observable.

In order to elaborate how does the model behave in different circumstances, a set of scenarios were prepared. Parameters of each scenario contains Table 1. For each scenario 10 simulations were performed. The criterion for comparison between different scenarios is weekly average of approved documents. The first scenario shows what would happened if all constructors in product development department spent their working time only on developing analyzed documentation. In this case weekly average of approved documents equals 38.86. It appears that increasing number of constructors twice in comparison to original model, results in only 23.77% increase of weekly average of approved documents. The second scenario shows what might happened if arrival rate was doubled. In this case weekly average of approved documents rose to 52. However, this resulted in very large queues and the simulation was stopped three times because the number of waiting documents exceeded 1000. This simulation allowed to identify the bottleneck in the process. It is the first level of approving (A and B workplaces). Next scenario points out that absence of half of all working checkers and approvers totally paralyzes process flow (weekly average of approved documents = 3). The fourth and fifth scenario were designed to verify what would be the maximum system performance, if there were 29 constructors and 4 checkers/approvers on each level. In the fourth scenario weekly average of approved documents is equal 75.24 and in the fifth 87.86.

Tab. 1. Model parameters for six different scenarios

Scenario number	Number of constructors	Arrival rate	Number of checkers/approvers	Number of simulations
1	26	1	2	10
2	26	2	2	10
3	29	1	1	10
4	29	2	4	10
5	29	3	4	10
6	5	1	2	10

These results indicate that process efficiency increased by over 58% compared to the original model when it comes to the fourth scenario and by 64% when it comes to the fifth. The last, sixth scenario, shows a situation when the number of constructors falls twice in relation to the original model, while the other parameters remain unchanged. In this case weekly average of approved documents decreases to 20, that is by over 36% in relation to the original model.

5. A new model of the PDP

The results given by the analysis of empirical data, the FMEA and the original model, indicated that the process of the documentation flow needs some improvements. This is why changes in the model were proposed in order to find solutions that would help to optimize a real process. The most important areas that need to be improved include: to long time that documents spend in queues waiting to be checked and approved, inadequate planning of work by constructors, repeated documents' freezing and unfreezing by constructors, periodic accumulation of documents requiring approval, lack of detailed and clear instructions describing proceedings of proper documentation filling. Considering all mentioned problems two basic changes were proposed in the model.

Firstly, the B workplace was eliminated from the process. This decision was dictated by two reasons. First of all, in the actual process, in the product development department, the number of documents that are sent to be checked at the B workplace gradually decreases due to the fact that the total elimination of this phase of verification is planned. The second reason stems from the fact that there are the same two people responsible for checking at A and B workplace. This is why it seems illogical that the same people had two different functions simultaneously. So each checker instead of verifying a part of a document as a worker A and part as a worker B, should check the whole document at the same time as a one worker, call it A. The existing division into two workplaces appears to be in this case artificial, illogical and unnecessary. The second change in the simulation model comes directly from the FMEA. The suggestion that constructors will freeze documents always exactly a week before planned approval date, was implemented in the model.

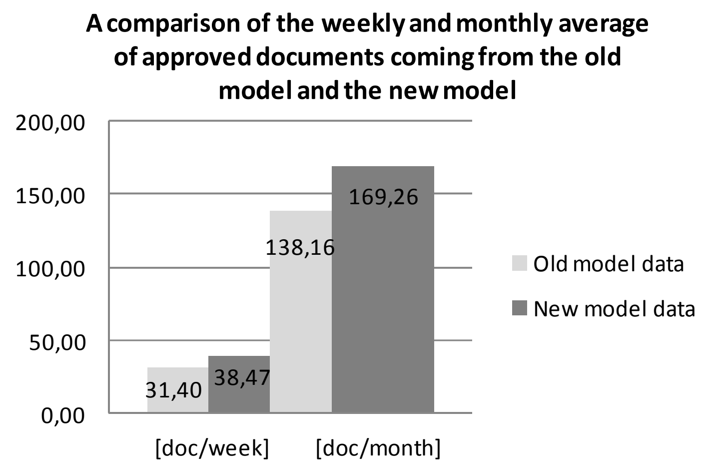

Fig. 5. A comparison of the weekly and monthly average of approved documents coming from the old model and the new model

Compared to the original model, results from the new model indicate 18% increase in efficiency. In the original model, the average number of approved documents per week was 31.40. In the new model it equals 38.47 (Fig. 5).

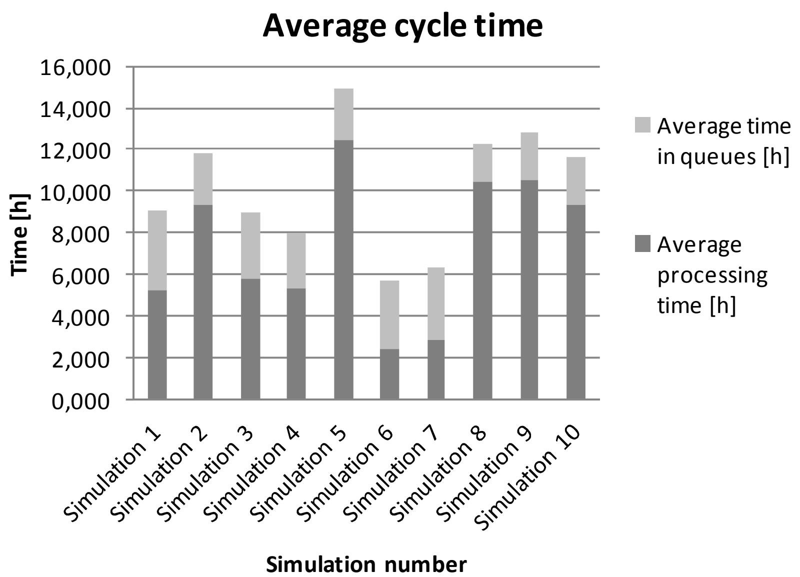

Fig. 6. The share of time in queues and processing time in the cycle time – new model results

Again the share of processing time and time in queues in the cycle time was calculated (Fig. 6). Results of 10 simulations show that an average document spends now only 27.45% (2,787 h) of the cycle time in queues, while processing time takes 72.55% (7.366 h). The results from the new model prove that the proposed changes will significantly increase the efficiency of the process and largely eliminate time that a document would spend on waiting in queues.

6. Summary

The purpose of this research was to develop a simulation model of a part of the product development process. The paper discusses the way in which simulation modeling can become a helpful tool in improving documentation flow process by finding bottlenecks and developing scenarios. The scenarios enable forecasting selected figures that depend on certain, predetermined conditions.

On the basis of the analysis of the empirical data coming from the real process, a model of the PDP was built. Subsequently the model was verified. Comparison of the modeled process with the real PD process showed that the data coming from the model differ only by 4% from the actual data. Given results allowed to state that the model properly reproduces the real documentation flow process. Having developed the model of the product development process, a set of scenarios was analyzed to verify how does the model behave in different circumstances. The elaborated number of scenarios allowed to predict (depending on the given parameters) inter alia weekly average of approved documents, average cycle time, processing time and time in queues. After analyzing empirical data, the Failure Mode and Effects Analysis and the results coming from the set of different scenarios, improvements in the documentation flow in the product development department were proposed. Additionally, factors affecting the increase in process efficiency were identified. On the basis of proposed improvements a new model was developed. The results from the new model simulations lead to a conclusion that a few minor changes introduced to the process significantly increase its efficiency. It occurs that while the waiting time in the queues is reduced by three times and the average cycle time and is shortened, the number of average weekly documents approved increases by nearly 20%.

On the basis of the obtained results it can be said that the use of simulation modeling in the area of product development allows to identify the critical factors affecting efficiency of the process and to improve the process so that waste is substantially eliminated. The analysis of the wide range of scenarios allows to predict results coming from the process without interference into real process. In addition, it can be noticed that the Failure Mode and Effects Analysis helps to find qualitative factors, which make the whole analysis of the process complete and more precise. The FMEA chart filled with workers from the analyzed area helps properly understand the researched process. Detailed interview with workers often enables finding ready solutions for the problems that occur in the process. In conclusion, it can be said that the process optimization in the product development department, should be carried out on the basis of both – the results coming from the simulation model and qualitative analysis.

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