# Product Reliability Management throughout the Life Cycle on Transition to Industry 4.0

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Abstract: The article deals with the actual problem: ensuring the reliability of technical systems in the digital era and at the transition to Industry 4.0. The authors reviewed the existing positive international experience and opportunities for digitalization, as well as particular qualities of the factories of the future and production during the transition to Industry 4.0. It is shown that focusing on customer needs can create problems in the field of ensuring the technical systems reliability. In addition, in such conditions it is important to shorten the duration of various processes. As a particular example, the authors consider the process of conducting strength tests. To reduce the time of testing, the article authors developed a DSS for document management in a central strength laboratory of an automotive company. Although the authors investigated a specific example, but this technique is universal and can be used for similar processes and for other sectors of the economy.

## 1 INTRODUCTION

The main trend in the economy and society development, with which reasonable and rational management and development of all activity areas, including the automotive industry, is currently associated is intellectualization. Technologies that experts consider the most promising provide a transition to the digitalization era. In the rapid development conditions of technique and technology, processes digitalization and intellectualization, it is necessary to apply new management methods.

The internet penetration in all activity areas, the methods emergence for finding optimal sustainable solutions, is associated with the fourth industrial revolution, which is the main trend in the automotive industry development.

The high motorization level and markets globalization are forcing automakers to search for new solutions, constantly improving both the vehicles design and production technology, as well as new ways to attract customers.

Internet development, sustainable communication channels, cloud technologies and digital platforms, as well as information “explosion” of data, provided a transition from enterprises’ local automation to open information systems and global industrial networks which go beyond the individual enterprises' boundaries for cooperate with each other.

Such systems and networks transfer industrial automation to a new, fourth, industrialization stage. Digital technologies will make factories more efficient, intelligent, flexible and dynamic. Breakthrough developments in areas such as artificial intelligence, nanotechnology, and others lead not only to the creation of new market segments, but also to a fundamental change in existing business models.

The combination of increased Internet penetration, mobile devices, data analysis, the “Internet of things” and machine learning change the expectations and demands of consumers. Digitalization helps to focus on the customer, so mass production of a new type allows industrial production of an individual product.

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# 2 STATE OF THE PROBLEM: INTELLECTUALIZATION OF MANAGEMENT AT ALL STAGES OF THE PRODUCT'S LIFE CYCLE

## 2.1 Digitalization as One of the Fourth Industrial Revolution Directions

Economy's digitalization is a new, real and objective world trend that is replacing the previous "society's informatization", which is positioned as "technonomy" - the result of an electro-calculation coup and technological breakthroughs of the late twentieth and early twenty-first centuries. People use global digital platforms to train, search for work, showcase their talent and create personal networks. In the globalization digital era, large companies can manage their international operations in a more economical and efficient way, as digital platforms contribute to the labor market globalization. Data streams open up for economy the ideas, research, technology, talent, and best practices from around the world. Many countries have developed national digitalization strategies that highlight the transition challenges to a digital economy. Each country in the such programs framework determines its priorities. Within the global economic system, Germany and Europe are located between the dominant digital models of China and the USA. In the American model, digital platforms with global reach are becoming a new competition to existing companies. On the contrary, the Chinese model relies on the domestic market, which enjoys greater protection from the state. From a European point of view, it makes sense to copy some successful aspects of models from the USA and China.

The American neo-industrialization model - the industrial Internet model - is rigidly embedded in the things existing order in new technologies and is looking for solutions to compatibility and security problems in the future (Bledowski, 2019). The USA economy is being digitized quickly, but unevenly. Geographically, digitization is everywhere, but its progress varies greatly. The digital economy is driving an unprecedented expansion in the increasingly smart cities number with closer ties. Ultimately, when the Internet is actively developing, the Internet sector gives great hope to cities to use technology for build a more inclusive, innovative economy. It is becoming increasingly clear that cities are leading the national innovation agenda.

The "Made in China 2025" program envisages numerous initiatives ranging from the advanced technologies development in the robotics field and the industrial Internet to programs to modernize labor-intensive industries through automation (Butollo, 2017). Thanks to the impact on the emerging IoT, as well as parallel efforts to dominate the electric vehicles industry, China's 5G efforts are a particularly serious problem for German and Japanese automotive and semiconductor companies. At present, the Chinese model is particularly competitive from an economic point of view. The Fortune Global 500 companies are increasingly diversifying, particularly in Asia, while their number in the United States is declining. This may indicate that the Chinese business model based on secure domestic markets and government subsidies with global reach and relevance is more successful than the US business model based on creative destruction. In the technological competence area, including standards, a further eastward shift is also clearly visible. In September 2017, the UAE government presented the UAE Strategy for the Fourth Industrial Revolution, which focuses on key areas; some of them are innovative education, artificial intelligence, intelligent genomic medicine and robotic healthcare.

The European approach is based on global reach and on the digital business models expansion which based on future technologies and on European skills. From a technology perspective, it is necessary to master two critical requirements aspects for the future of digital business in Germany and Europe. First, the future technologies understanding and the experience development in them: AS (Autonomous Systems), AIoT (Artificial Intelligence of Things) and AR (Augmented Reality), what by orders of magnitude will expand technical capabilities and, therefore, underlie constant technological changes. Secondly, the emphasis is on safety and reliability, since it provides a rationale for the European differentiating factor and competitive advantage. From the European point of view, it makes sense to copy some successful aspects of the California and Chinese models. In particular, they include a domestic markets reassessment or the national programs of excellence implementation, such as the DARPA in the United States or the Talpiot program in Israel. Many countries have created national initiatives and campaigns to digitalization their industries and economies. The best-known campaign Industrie 4.0 from Germany (Pfeiffer, 2016), which aims to promote the new technologies development, the typical factories creation and reference solutions, as well as the standards definition. Due to the high level of public and private investment and a participant's large number, its was able to achieve a significant effect. Similar projects exist in other countries: Smart Factory in the Netherlands, Usine du Futur in France, High Value Manufacturing Catapult in the UK, Fabbrica del Futuro in Italy. Poland, so far, ranks 23rd out of 28 on the digital economy and society index in the EU, significantly lagging behind in all areas: from using social networks by enterprises (only 9 percent) to subscribing to fast broadband access throughout the country. However, the priorities and indicators set for the Digital Poland program are in line with the EU 2020 Strategy and, in particular, the European digital agenda. The program focuses on the high-speed broadband deployment and the electronic services development for public administration, and also supports initiatives to improve the citizen's digital competence.

In Russia, the program "Digitization of the economy" includes six federal projects (The Digital…, 2019): (1) digital environment normative regulation; (2) personnel for the digital economy; (3) digital technologies and projects; (4) information infrastructure; (5) information security; (6) digital state. Similar programs were adopted by Belarus and Kazakhstan (About…, 2019), which identified key areas: (1) digitization of industries; (2) transition to a digital state; (3) implementation of the digital Silk Road; (4) human capital development; (5) an innovation ecosystem creation.

## 2.2 Smart Factories: Problems and Prospects

Enterprises based on the principle of Industry 4.0 are needs-oriented production, i.e. must respond directly to consumer demand. Thanks to the data collected, it will be possible to predict user behaviour and integrated this data into a production information environment, including human resource planning (Brettel, 2014). Artificial intelligence will allow you to control the entire product life cycle - from the demand marketing study, production and operation, to utilization. Industry 4.0 implies the use of the Internet of Things (IoT) (Zawra, 2018) and Big Data (Santos, 2017) in production, when any components of the system are interconnected with the help of the World Wide Web, and also independently find ways to reduce costs. At the same time, it is very important that the production processes do not become more expensive: by connecting all elements through the network, it becomes possible to find the optimal, non-costly way to realize orders. Industry 4.0 assumes the rational use of natural and technical resources, the most efficient energy saving, the all waste recycling and the receipt of new goods, raw materials or energy from them. It is assumed that intelligent materials and devices will help reduce equipment downtime and the need for maintenance personnel, increase level of equipment use, which will lead to technological and logistic processes optimization and increase production efficiency. In addition, Industry 4.0. suggests the concept of digital twins. For example, the creation of a virtual process and its connection with the actual physical process in the enterprise (Żywicki, 2018) allows you to explore the processes parameters by exchanging data between the virtual and real processes, saving time and money on assembly and commissioning. In addition, the creation of a system of virtual simulators will allow staff to work out the actions that need to be taken in the system in virtual workplaces.

The concept of an intellectual factory is based on a highly automated, and at the same time flexible, cyber-physical manufacturing system, which is characterized by quick response to customer requirements. This requires innovative and intelligent solutions not only in terms of objects (for example, the Internet of Things), but also for processes (for example, Knowledge Based Engineering) (Górski, 2016). That is why smart design and production control must be necessary elements of an intelligent factory of the future, capable of implementing a mass customization strategy (Zawadzki, 2016; Mueller, 2012). Only then it will be possible to fully use the production potential of the company, which owns modern technical resources, in accordance with the concept of Industry 4.0 (Gorecky, 2014).

The production stage of the life cycle is one of the most important, because exactly at this stage ideas and projects turn into finished products. Besides, the quality of the product depends on the quality of manufacturing. It means that at this stage it is determined if the targeted audience is large enough, if the product is competitive in the market, how effective and safe are the stages of operation and service. The main goals to Industry 4.0 transition are process optimization by reducing losses and customer focus. The need for production systems' constant adjustment to customer variable requirements ensures the introduction of new methods within the framework of process organization or production control (Trojanowska, 2011). Transformation into industry 4.0 requires highly efficient and flexible production planning processes. Automated production processes require complex computer planning processes. These are the so-called CAx systems (computer technologies), such as CAD (computer-aided design), CAM (computer automated production), TLM (tool life cycle management), DNC (distributed numerical control), CAPP (computer automated process planning) and functions - such like process modeling. The production strategy implementation in accordance with the individual customers' needs is also a serious problem for the production planning organization and control processes. Therefore, it is necessary to apply optimal solutions for each of the processes: production planning, monitoring material flow or decision support. This is necessary for the effective use of available resources while meeting the individual needs of clients (Kujawińska, 2016; Żywicki, 2017; Trojanowska, 2017; Gangala, 2017; Rewers, 2017). If constant adjustment of changes is necessary, then production planning can be called Fast Dynamic Scheduling (Kujawińska, 2009).

Options preparation for the material flow is one of the elements that should be considered when planning. This will determine the most efficient product flow that meets the expected criteria, for example, optimizing production resources or reducing delivery time. In order to realize customer requirements, accepted planning methods should take into account the production resources availability, allowing to organize the necessary goods production. This allows you to respond quickly if there are new orders or new factors that make it impossible to use resources. This requires careful integration of production planning and control with product design (Makarova et al., 2018a; Szuszynski, 2015; Żywicki, 2017, Makarova et al., 2018b).

A completely new engineering approach - digital enterprise models, the so-called "factories of the future", involve the integration of computing, networks and physical processes. At the same time, built-in computers and networks monitor and control physical processes, with feedback, where physical processes influence calculations and vice versa.

In Smart Factory, production processes will be organized differently: whole production chains - from suppliers to logistics to product lifecycle management - are closely linked between corporate boundaries. Separate production steps will be easily connected. Impact processes will include: (1) factory and production planning; (2) product development; (3) logistics; (4) Enterprise Resource Planning (ERP); (5) Management of Production System (MES); (6) Management Technologies; (7) separate sensors and actuators in the field. Despite the fact that there are numerous software platforms for processes' intellectualization throughout the product life cycle, however, there are a number of difficultly formalized processes associated with the information search and processing. The duration of such processes depends on the "human factor", therefore the task of their intellectualization remains relevant. These tasks are specific to each company, so the software is designed individually for a particular case.

Despite the presence of a large number of enterprise management systems, there are still the processes that, for various reasons, are difficult to formalize within the existing management systems. Therefore, it is necessary to develop special software modules that are "embedded" in the management system that exists in the enterprise. This may be a DSS for any enterprise's department, receiving information from both the external circuit and other enterprise's departments itself.

# 3 RESULTS AND DISCUSSION

Competitiveness issues are solved at all product's life cycle stages. To a large extent, competitiveness depends on the speed of updating the model range and the products reliability during operation. Since the vehicle is a complex technical system consisting of many parts, its reliability depends on how reliable these parts are. Although there are not so many details limiting reliability, however, the issues of increasing their reliability and predicting possible replacement periods are relevant. Therefore, there is a need to test both at the new product design stage, and in the case of finding out the reasons for repeated failures. The requests' execution speed to testing depends on many reasons, among which the human factor plays a significant role. Therefore, the best solution to the problem could be the DSS.

The product reliability is the competitiveness basis, since it involves trouble-free and safe operation. In the transition to Industry 4.0, this direction becomes more actual, since in product uniqueness case, made for a specific customer, problems may arise with reliable statistical information about failures of units and parts of a complex product during operation. The situation is aggravated by the presence of a large number of suppliers of components and spare parts, which in varying degrees provide durability and product maintainability. In such conditions, the product manufacturer should be able to plan and conduct additional tests more quickly. These processes are accompanied by a large number of heterogeneous documentation, which differs both in its source and in its purpose. This determines the type of information. The processing of such data, the search for documents and their design is performed manually. To speed up the workflow processes in such cases is possible with the help of a special intelligent system.

To identify the time reserves, the data flows' processes diagrams (Figure 1, 2) of new vehicles models' designing, testing, starting mass production and operation beginning were constructed.

In the activities of the scientific and technical center of PC KAMAZ, an important place is occupied by the Central Strength Laboratory (CSL). Here, all the tests of vehicles detail and aggregates, applications for which are received from other departments, are performed.

The problem with the requisitions processing and tests planning is that a large part of the information necessary for work is on different information media. This method of storing information increases the access time to it and complicates its analysis, since the search for the necessary document, as a rule, is carried out in manual mode. In addition, the risks associated with information corruption and loss of its integrity is increasing. Creating a DSS, which allows structuring this information and creating a common information space, is an important task to speed up and optimize the testing process. The DSS structure provides a consolidated documents database will be filled in by the staff of the CSL department. DSS will display information from the database in predetermined forms that are convenient for work and analysis. This will allow analyzing the test results in the event of problems at the stages of the product life cycle, as well as with the appearance of new vehicles models and modifications of its components and aggregates. In addition, the acceleration of the testing process and access to information through the creation of a common information space will provide an opportunity for a deeper analysis of the reliability of vehicle parts and assemblies, for example, choosing a better vehicle parts supplier.

The following information should be stored in the database: (1) Grounds for work (requests for tests and schedules); (2) Data on parts and components entering the tests; (3) Data on requests in the invoices form required to obtain parts from the warehouse and their further write-off after testing; (4) Test reports (summary of test results); (5) Acts of write-offs (contain information about the details written off).

The conceptual DSS scheme is depicted in Figure 3. Working documents contain information coming from external sources, as well as emerging from the various technological processes implementation. Document types are listed above. With the help of an Interpreter, requests that are formulated by the staff of the CSL find the information necessary for the tests. The speed of query execution depends on the adequacy of the interpreter of documents. To store information about documents, a relational data structure is used, for implementation of which Microsoft SQL Server is chosen. The interpreter is implemented as a software module in Delphi 7. The user interface of the module contains several tabs and buttons for switching to data entry forms in the database. There are different program windows for data entry, as data in related documents can be entered at different times (Figure 4). Convenient search and filtering of data in the database provides a simple and intuitive interaction with DSS, which allows its use even to unprepared users.

Test examples were created for DSS verification. To verify the DSS work correctness, information was searched for the parts obtained for testing in accordance with the request entered in the Database. The necessary request and the invoice for receiving the details found by the request results confirmed the correctness of the program's work. Further, it was necessary to check the DSS use effectiveness for speeding up the processes in the CSL. This can be done using a virtual experiment on a simulation model. To do this, we determine the time spent on conducting similar test before and after the implementation of the DSS using the developed simulation models.

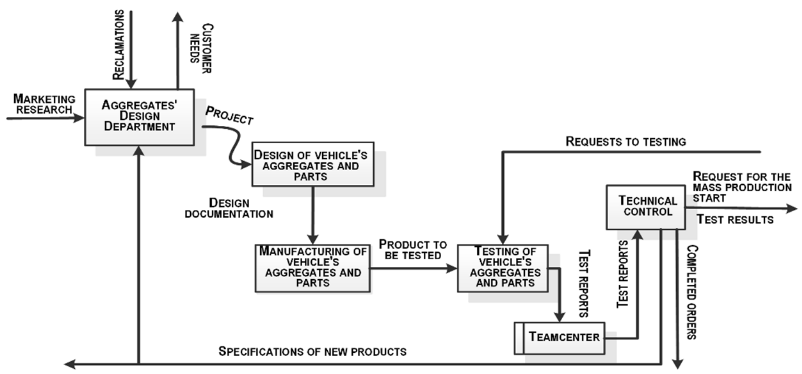


Figure 1: Data flows' processes diagrams of new vehicles models' designing, testing, starting mass production.

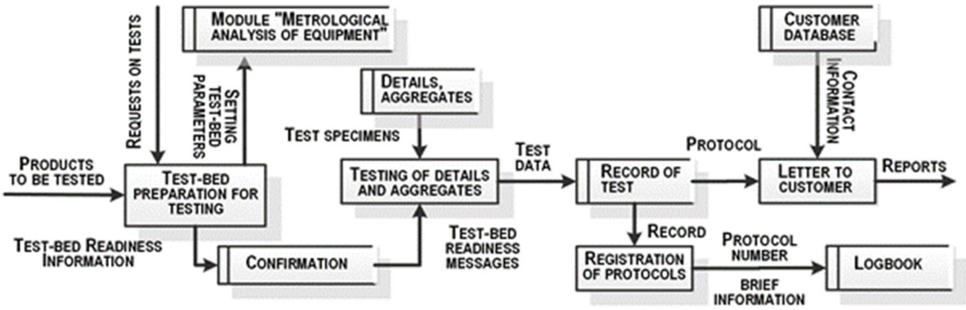


Figure 2: Diagram of data flows of the process “Testing of units and vehicle parts”.

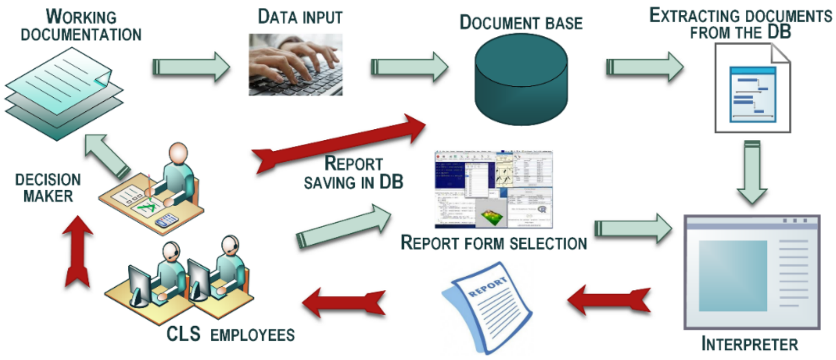


Figure 3: Conceptual scheme of DSS.

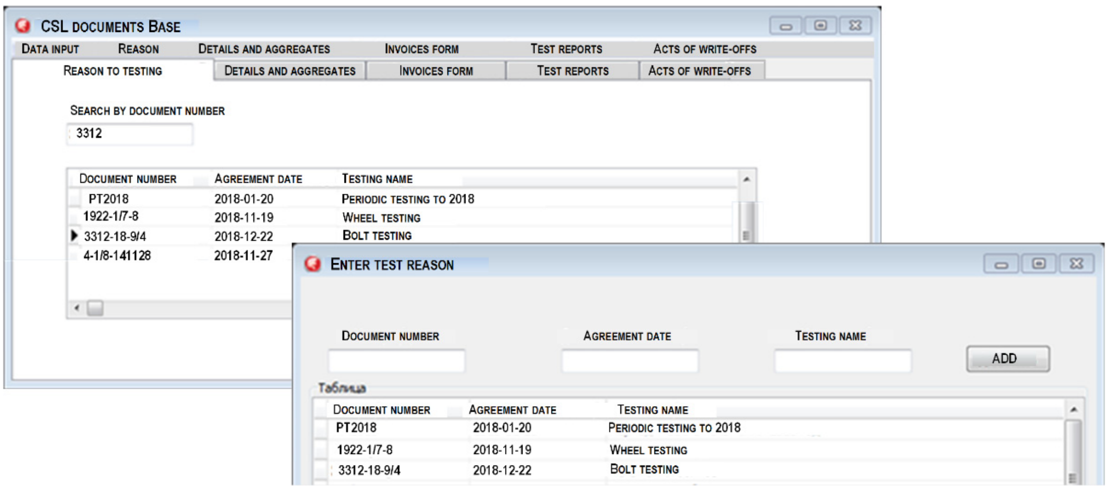


Figure 4: User interface for data entry and search.

## 4 CONCLUSIONS

The article shows that the use of DSS for document management in the central strength’s laboratory of an automotive company reduces the total time spent on testing. The processes model after DSS introduction is shown in Figure 5. Figure 6 shows a graph of the performance assessment of the DSS. As a result of the conducted simulation experiments, it was obtained that the testing process duration before DSS using is from 20 to 36 days, and after - from 18 to 34 days.

The schedule of time spent on testing is shown in Figure 7. Thus, the DSS usage allows to speed up the testing processes, by accelerating the work with the documents during the preparation of the tests and after their completion. This method is universal and can be used for similar processes and for other sectors of the economy.

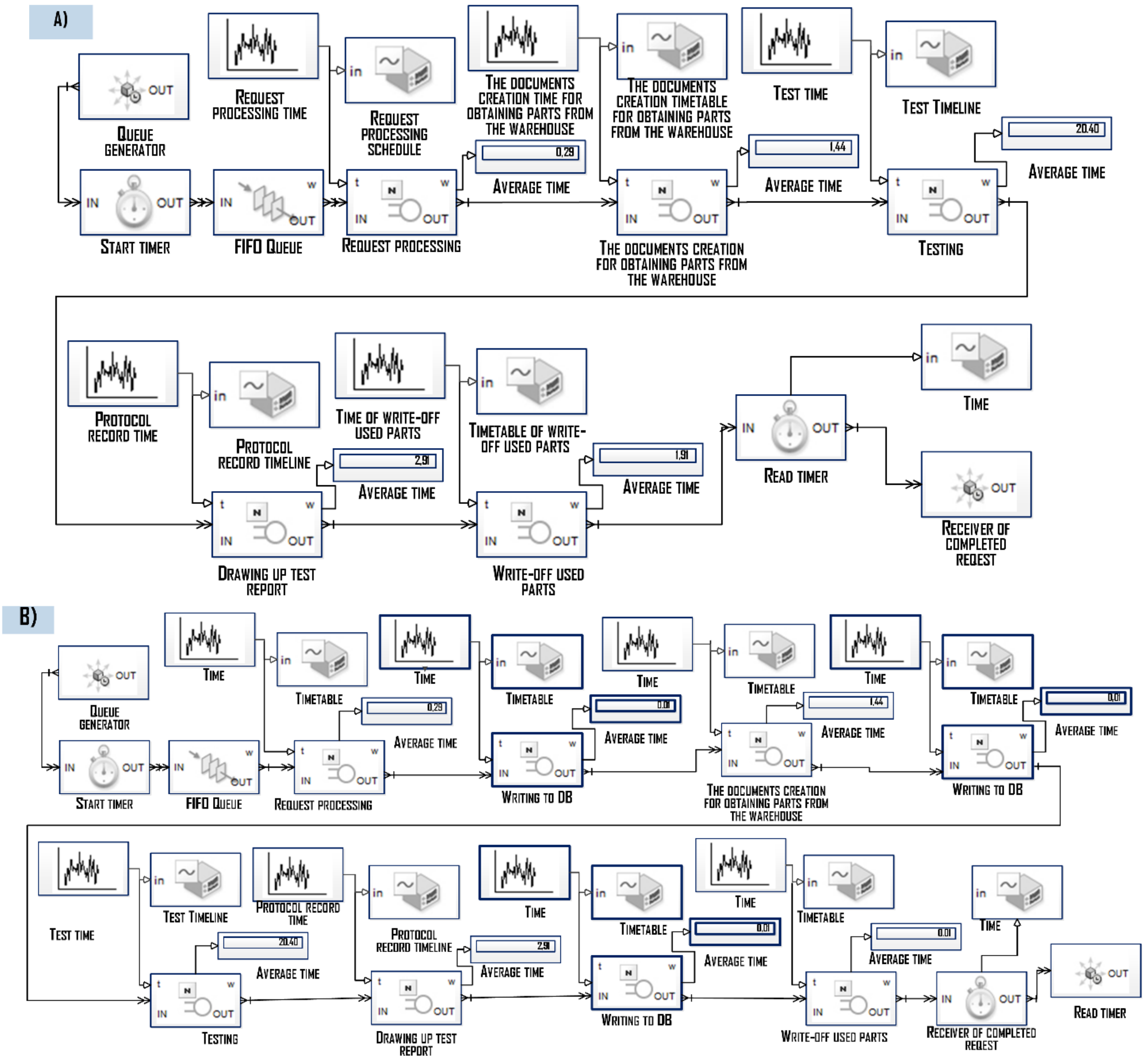


Figure 5: Process model a) before b) after DSS introduction (the record in the DB is distinguish with thick lines).

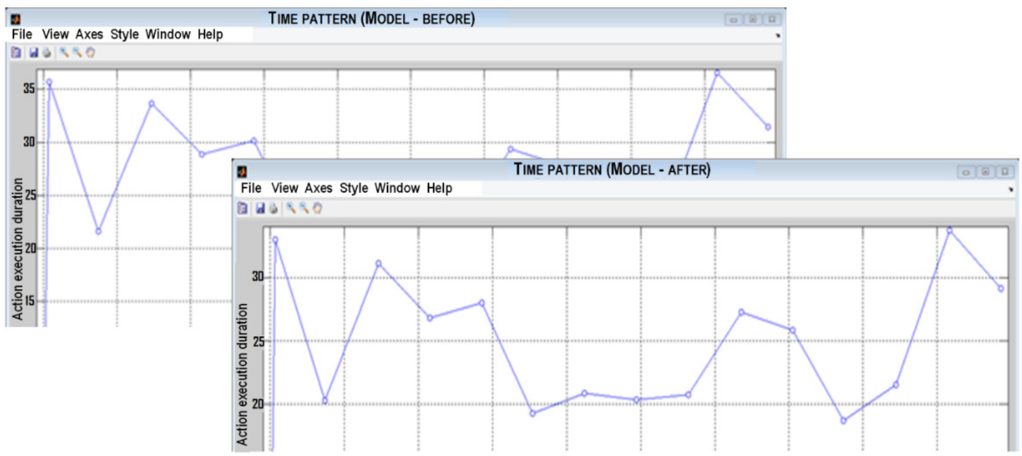


Figure 6: Graphs working time.

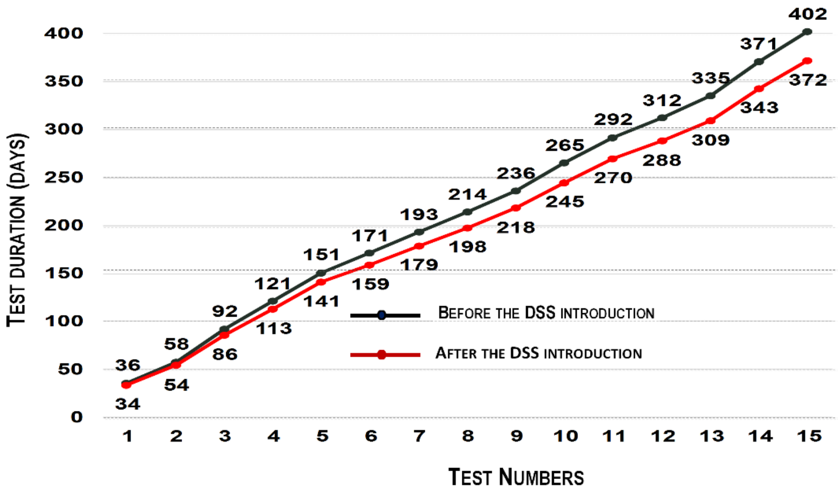


Figure 7: Performance evaluation of the DSS.

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