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SIMULATION TECHNOLOGIES IN „AGILE RECONFIGURATION" OF ASSEMBLY PRODUCTION PROCESS

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Introduction

The concept of simulation technologies has descended from the area of cybernetics, which at partial usage of real components of some phenomenon and processes, made attempts of their modelling with the devices before decades known as calculating machines. Today's simulation technologies are using the definitely richer range of computing possibilities; they are created by the contemporary: computer *hardware* and *software*. Many undertakings related to the new type of simulation applications are first of all embarked on engineering sciences. Interpenetration of both areas *knowledge* however causes, that this tool is also used by the theory (*science*). The interesting example of knowledge interpenetration in scopes of *science* and *technology* is the field of management studies, within which two areas are coexisting: cognitive (*theory*) and applied (*engineering*). The essence of management engineering (belonging to area of *technology*) an ability to design, production and exploitation of: products, systems and processes. The organizational-technological progress generated by this field of management studies often discovers new phenomena and solves appearing cognitive problems, aspiring to the area of *science*. However, the organizational cognitive field of management studies combine the process of practical usage of its cognition descriptors, entering nearly automatically the area of *technology*. One would say that in such cases, *science* and *technology* act together. Nevertheless, the character of engineering management research tools is different from traditionally binding on the field of cognitive studies (*science*). Engineering investigations most often focus on creating methods of the solving problem resulting from the already known phenomena but in practice it is too complicated for finding a precise methodological solution of involving issues. Therefore, the engineering often uses the quasi-empirical methods unfamiliar to the classic understanding of *science*. Practical pragmatism of *management engineering*, caused by the need of finding solutions before *theory* explains certain phenomena, is forcing technologists as well as managers for variant solving practical problems based on knowledge, experience and intuition and next to test these solutions among others with the computer simulation. Professionals are particularly willing to reach for such computer support that results in effective and harmonious organisation of assembly production processes. Especially it refers to the cases of technological-organizational reconfiguration forced by "agile" requirements of the competitive customer market. The presented paper shows this problem (from the borderline of technology and production management of transport machines) in the convention of the managerial methodological generalization attempt in the form of the graphic model.

The enterprises carrying out assembly production processes of vehicles used in the mass public transportation are the recipients of presented further methodological issues (urban and vehicular) associated with the transportation of large groups of people ("passenger community" can be calculated in hundreds, not to say thousands). According to this, we discuss producers of: buses, trams and coaches as well as means of the railway transport. In further content of this study, for determining products of this type of transport a symbolic shortcut will be used: PTV (Public Vehicles Transport). This type of Polish industry of transport machines producers has a very good domestic and business international market position. On the principle digression one should only regret, the leadership market position of Polish shipbuilding holding was lost fifteen years ago, through incompetence of politicians (Pacholski, Piotrowski, 2008). This loss, effectively "strengthened" by next receivers and the distribution of justice, seems still to be compensated. The shipbuilding industry is showing certain similarities (but also differences) to the PTV industry branch. However, sceptics do not believe election assurances of the current politicians team ruling Poland concerning the revitalization of the holding mentioned above. Is that so, according to the American common opinion, they included politicians among the category: „used car sellers"?

Nevertheless, coming back to the industry of typical representatives of PTV producers, it should be noticed that there exist a lot of both technological, organizational as well as business similarities, associated with the assembly production processes of buses, trams and coaches as well as means of the railway transport. Within the notified methodological generalization, the three thematic threads will be developed: assembly production processes of PTV transport machines, the agile manufacturing concept as well as the simulation verification and explorations of the reconfiguration design of these machines assembly process.

Assembly production process

Increasing competition between manufacturing enterprises of building transportation machines PTV has focused main attention on the management of processes that enhance the final value of the product for the customer. It implies renewing and refining their innovation capabilities concerning manufacturing processes as well as effective information system (Kiełtyka, Jędrzejczyk, 2010, p. 69). In particular, the product development process has to ensure the productivity as well as the fulfilment of customer expectations in terms of technical performance, innovations and time of delivery. To achieve this, enterprises need to make a move regarding product variety, standardization and customization. Consequently, enterprises need to assess their product strategy in order to evaluate the importance of product architecture description, modularization, standardization and finally the use of simulation systems for assembly production processes. A typical body of PTV machine (e.g. coaches, trams, etc.) is a complex structure comprised of many subassemblies made of many parts. Moreover, the final shape of such assembly structures is not only affected by residual stresses in the individual stamped parts, but very often by the assembly process itself. The assembly technological process is most often terminated with phase of production process, in which connection of elements is running according to series of logically planned activities, so that assembly units and final products fulfil the quality requirements and define technical conditions imposed by the constructor and the ultimate recipient. One of the main tasks of planning assembly technological process is establishing an appropriate order of the course of assembly operations in defined organizational conditions including the time of their length and the required production tact.

The modern enterprises of building PTV machines carry out very complex assembly processes in conditions of unpredictable and turbulent environment, common globalization towards progressively higher quality requirements as well as the minimization of widely understood manufacturing costs. This requires organizations' constant improvement and development as well as introduction of technological flexibility while implementation automated manufacturing systems (Lonkwic, 2008). Correct designing or conducting modernization of the assembly processes in future in order to get expected economic and efficiency effects requires conducting simulation examinations including established parameters (e.g. efficiency length of the operation) and taking into account the possibility of interferences (e.g. breakdowns expressed with dedicated indicator). For simulation examinations to give measurable effects, should be conducted in the preliminary stage of design process, with taking into account the multi-variant of assembly concept system that will enable for establishing required parameters of designed system as well as for minimizing possible costs of subsequent changes (Sawik, 1996). So far, modelling and simulation of assembly processes were applied mainly in conditions of mass and long run production. Progressing fast development of computer systems, methods of solving operational research algorithms as well as common availability of professional software caused that simulation techniques had being successfully applied in the conditions of the individual and job-lot production (Zdanowicz, 2002).

Graphic model of assembly production process innovation

Let us assume hypothetically that one of a significant enterprises assembling PTV machines, drew up project of an assembly manufacturing process reengineering of it products. This project was a consequence of this enterprise's rapid development that systematically wins tenders for delivering their products to the EU market. The imperfections of the current work organization made the order processing difficult, taking into consideration the requested amount and quality. They complicated appropriate workforce usage as well as unfavourably affected on enterprises productivity results. Traditionally carried out the PTV assembly was conducted with methods that were based on technological-organizational spontaneity. Data concerning times and order of performed operations was not methodically standardized. Employees have not been often able to carry out operation in given working cycle and they carried them out on next workstations or finalized them only when other brigades finished their own work. The potential of many employees was not fully used at the simultaneous work overload of the other teams members (Kluska, Pawlewski, 2015).

Basing on agile manufacturing concepts, the management of enterprise made a decision concerning the expansion of a production unit with a new assembly hall as well as changes of work organization aiming at shortening time and road covered by the employees during assembly process. It lead to harmonizing assembly cycles as well as to improvement in productivity indicators, production quality and working conditions. The technological-organizational change consisted in converting from one PTV assembly line to three parallel lines working with temporary delay but in the synchronized way. The fundamental problem of verification and exploration of assembly reconfiguration design concerns balancing of production lines. It is a situation, in which all, connected into the series assembly workstations would have the same quantity work to do (Bartkowiak, Gessner, 2014; Scholl, Becker, 2003). Its complexity was connected with a fact, that almost three thousand activities were completed for a dozen type of products by over two hundred employees who carried out the assembly process on twenty workstations. It has to be added, that this enterprise will be able to offer even twenty different types of PTV for its customers (Kluska, Pawlewski, 2015).

The technique of production line balance assumes aspiration to minimize the number of workstations and total shortening duration of inactivity on these workstations at given production level. The problem of appropriate assembly line balance belongs to classical, multistage tasks of management engineering decision-making. It consists in allocation of determined acceptable set of operations at assembly workstations of this line, in determined discreet time moments called the cycle of assembly (Cox, Blackstone, 2002). The complexity of the problem presented in this study causes that both magnetic tables with Gantt graphs as well as Excel calculus applied in the production practice do not allow for solving such a complicated problem. However, accurate methods (e.g.. linear discreet programming, dynamic programming) and heuristics (e.g. scheduling and allocation algorithms) and approximating create the enormous computational problems. In this situation consulting the characteristics of simulation technologies such as speed modelling and relatively simple applying results in a decision to exploit them in practice which has been made as well about the verification and the exploration of the reconfiguration design of the assembly manufacturing process (Pacholski, Pawlewski, 2017).

The integrity model of the innovation of assembly PTV production process has been presented in Figure 1. However, the two crucial issues of this chapter: agile manufacturing and simulation technologies will be discussed in the next two subsections.

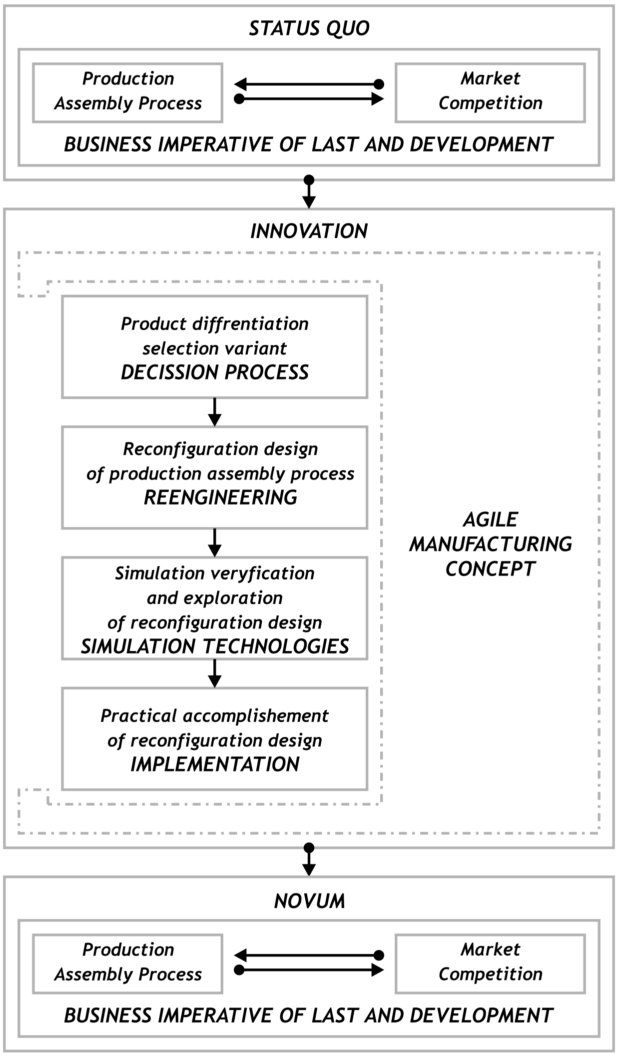

Figure 1. Graphic model of assembly production process innovation
Source: own study

Agile manufacturing

Agility is the concept which is relatively widely presented and discussed in literature (Kidd, 1994; Yusuf et al., 1999; Goldman et al., 1995). Although there are some differences among the definitions, it is worth noticing that widely understood flexibility is a base for them. According to the newest approach to the agility, the existence of an agile enterprise is justified by the presence of opportunities (Trzcieliński, 2013). Agile organisation is well positioned to take advantage of speed, by getting to the market before competitors with new products, and proactivity, by providing the products that will be required by customers just before the need arises (Yusuf et al., 1999; Włodarkiewicz-Klimek, 2016). In accordance with the meta concept of agility understanding as presented above, agile manufacturing along with *lean* and *flexibility* is interpreted as a strategy which "contains lean manufacturing and flexible manufacturing and addresses the business enterprise world" (Sarkis, 2001).

Agile manufacturing is the concept focused on the winning strategy to be adopted by manufacturers stimulating themselves for dramatic development to become national and international leaders in the market they operate The linkage of *lean, flexibility* and *agility* may provide a partial definition to agility understood as a meta concept which embraces many tools and method dedicated to lean. Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of lean manufacturing (Yusuf et al., 1999). According to this, the essence of agile manufacturing lies in achievement of supremacy in competition not by following the lean concept methodology used by Japanese companies, but by performing a dramatic improvement in quality and using solutions in the field of organisation and management that are not used by competitors (Trzcieliński, 2011). Agile manufacturing has been defined with respect to the agile enterprise, products, workforce, capabilities and the environment that give impetus to the development of agile paradigm. The main points of the definition of various authors may be summarized as follow: change in business processes, high quality and highly customised products, design development and manufacturing preparation, mobilisation of core competencies and employees importance, responsiveness to social and environmental issues, enterprise and environment interaction, synthesis of diverse technologies, response to change and uncertainty, intra-enterprise and inter-enterprise integration and capability for reconfiguration (Figure 2) (Sindhwani, Malhotra, 2015; Kidd, 1994; Yusuf et al., 1999).

To sum up issues which have been mentioned above, PTV enterprise enables new ways of running business to react quickly and effectively to changing market which is focused on customized PTV products and services. Nevertheless, also the significance of knowledge has to be taken into consideration. In that kind of specific market that PTV enterprises operate, the knowledge transfer is therefore a matter of primary importance for the management process (Swacha, 2015).

The essence of agile enterprise can be interpreted as the integration of information system, assembly technologies, working teams, business processes and facilities into a harmonious and flexible organization enabling to respond quickly to changing environment and circumstances (Włodarkiewicz--Klimek, Kałkowska, 2012). Agility is the concept which is dedicated to enterprises, however, agile enterprise needs a changeable environment as only such environment generates opportunities (Kałkowska, Włodarkiewicz-Klimek, 2015). Moreover, while using the opportunities, the enterprise should be bright, flexible, intelligent and shrewd. Brightness, flexibility, intelligence and shrewdness are understood as agility dimensions (Trzcieliński, 2011). These dimensions can also be used to determine the assembly process of PTV products.

Brightness of the PTV is understood as the ability to perceive quickly market opportunities and threats arising from the environment. The diversity of opportunities increases with the growth of changes in the environment, as the changes evoke events as well as the tangles of events create situations including opportunities. Brightness is a function that enable transforming the turbulent environment into the strip of potential market opportunities. Flexibility of PTV is a feature of resources available for the PTV enterprise, depending on possibility of extending the scope of their use, and the same on extending the repertoire of the task which can be executed in the frames of assembly process, with the use of these resources. Flexibility is a function that enable transforming the strip of potential market opportunities into strip of resource available opportunities. Intelligence is the ability to understand the situations in which the PTV enterprise is functioning and finding intentional reactions in these situations. The reactions depend on activating proper resources to eliminate or reduce dangerous influence of these situations (threats) or to use occasions (opportunities). The intelligent PTV enterprise use such resources like material, financial, people and knowledge. They are stimulated to move from one to other resource available opportunities. The intelligence is a function that enables transforming the strip of resource available opportunities into strip available opportunities. From the definition, opportunities are passing situations in the PTV enterprise environment. Shrewdness is the ability of PTV enterprise to use quickly the opportunities in beneficial mode. Shrewdness is a function that enables transforming the strip of opportunities into strip used opportunities (Trzcieliński, 2013).

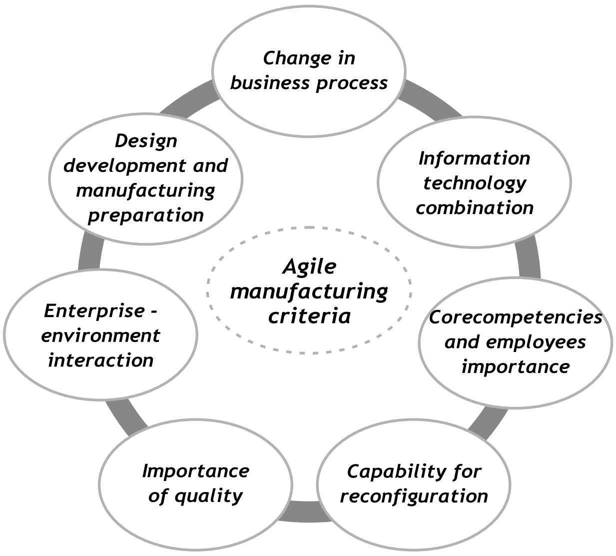

Figure 2. Selected criteria of agile manufacturing as a premises of „agile assembly" PTV
Source: own study based on (Sindhwani, Malhotra, 2015)

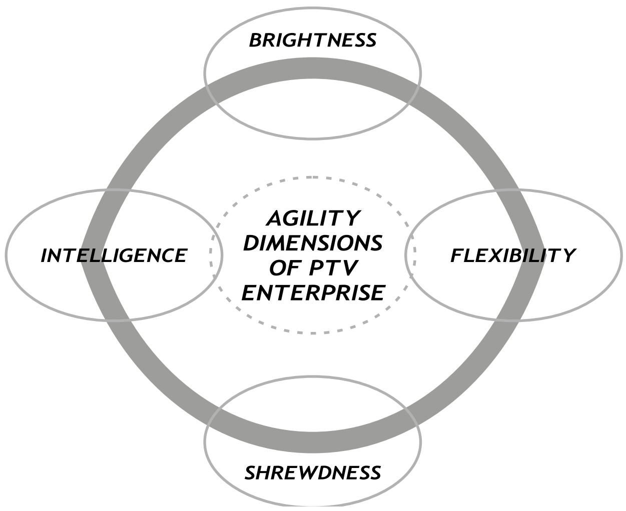

Figure 3. Agility dimensions of PTV enterprise
Source: own study based on (Trzcieliński, 2013)

Simulation technologies

The modelling and the simulation of a production process allows to create the computer virtual model of the real manufacturing system, on which (thanks to obtained reports) a sequence of experiments enabling the program development to (technological and productivity) change the existing design of the system reconfiguration. It is possible to improve the examined simulation model of the production system as well as to carry out next simulations on it for different variants. The modelling and the simulation of the manufacturing systems reconfiguration are applicable while obtaining the solution with analytical methods is formally complicated or when a labour consumption and costs of direct experimenting on the physical design are absurd. Simulation technologies are also applicable when other methods do not guarantee the required certainty level so that the real manufacturing system is retaining according to accepted design assumptions. In industrial practice, the most often sizes of outlays for the practical completion of the determined project of the reconfiguration of assembly production process, results in downright forcing into using the modelling and simulation technologies at the stage falling between the decision about the innovation realization and stage beginning of practical implementation of design solution.

The simulation verification and the exploration of the reconfiguration design let a'priori determine both strengths and weaknesses points and opportunities and threats associated with individual stages of the project implementation course. Regularly, the main goal of the simulations is an analysis of activities and achieved results as well as the attempt to get out of the already developed solution of change the new data and information (Pacholski, Pawlewski, 2017). Results of the simulation are most often presented in the form of indicators, animated and graphical forms of the system illustration as well as diverse graphs and tables. The similar, sequential transformations mechanism can be the source of creating potential variants describing specific, animated graphical presentations as well as graphs and tables. The high complexity level of the reconfiguration projects connected for example with random (accidental) sequence character of entries of determined tasks of components to the whole project is forcing to branch off from classics calculating for simulation attempts to test new operating states (Siebers et al., 2010). Developing the plan of this testing is a starting point for simulation testing. Such a plan is often summarized in the Gantt graph which embraces: the diagram illustrating the conceptual model, the conceptual model as well as the computer model. At present, the following software for manufacturing process simulation is used: eM-Plant, EDSS (Enterprise Dynamic Simulation Software), FlexSim Software, Lean MAST, SIMUL 8 Professional, Systemflow 3D Animator, EDS (Enterprise Dynamics Studio), Plant Simulation, ShowFlow 2 and many others.

The two kinds of knowledge are necessary in simulation testing: the problem knowledge associated with the technological-organizational essence of the project and knowledge concerning simulation technologies. The structure of the specific innovative project simulation testing corresponds to the PDCA Demings' cycle (P – plan, D – do, C – check, A – act (Figure 4).

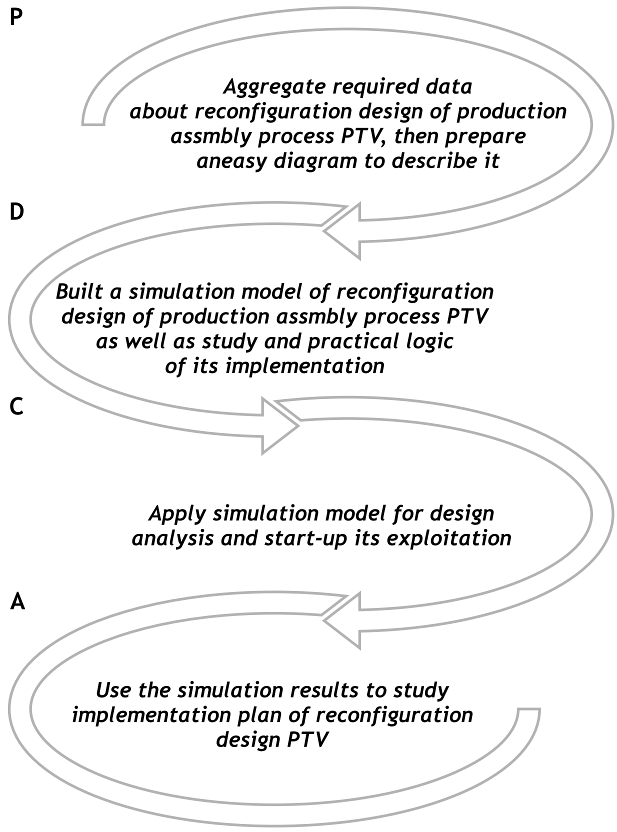

Figure 4. Structure of simulation testing of innovative project
Source: own study

The planning scope (P) of the simulation testing of the PTV reconfiguration design assembly includes the following activities: analysing the designed reconfiguration of the process and development activities, establishing goals, tasks and assumptions of this design, gathering required data about the reconfiguration of the assembly production process design, preparing the simple outline describing this design.

Building the simulation model of the PTV assembly reconfiguration design (D) includes the following activities: establishing the tenable base of the simulation, defining and design the user interface, spreading out the stages of the reconfiguration of the assembly design on-screen, determining, in what way the data about project will be used, study and implementing the practical logic of the assembly reconfiguration design (Beaverstock et al., 2011; Wróbel, 2012).

Check stage (C) of testing the simulation model includes the following activities: conducting validations and verifying the simulation model of the assembly reconfiguration design and starting exploratory experiments, conducting analyses of the implementation process simulation results of the assembly reengineering project (Hammer, Champy, 2003).

In a frame of act stage (A) involving the usage of the simulation results for the study of the practical implementation of the assembly reconfiguration project, there are undertaken the following activities: drawing up conclusions from simulation testing, presentation of test results as well as recommendations resulting from test simulation, obtaining an agreement for the plan and the realization of the implementation of the assembly reconfiguration project in real production conditions.

Following this subsection, the most important methodological problem of the structure and the simulation technology usage will be presented. It consists of the integration of simulation software for modelling work organization of work-teams with the system software tool modelling and the work delivered by operators of individual tasks of the PTV assembly process. The software DES (Discrete Event System) has been adequate for problems that consist of queuing simulations and a variability is represented through stochastic distributions (Siebers et al., 2010). This approach is applicable in simulating the PTV manufacturing and supply chain processes. DES models are characterized by a process oriented approach (they focus on modelling the system in detail, not the entities (Korytkowski, Karkoszka, 2016). They are based on a top-down modelling approach and have one thread of control (centralized). They contain passive entities (i.e. something is done to the entities while they move through the system) and intelligence (e.g. decision making) is modelled as a part of the system. In DES, queues are the crucial element; a flow of entities through a system is defined; macro behaviour is modelled and input distributions are often based on collected/measured (objective) data (Pacholski, Pawlewski, 2017). In case of PTV assembling operations, it can be assumed that the process approach is insufficient. Workers are task executers – "agents". The worker decides what he will do next basing on his list of tasks to do. Such assumption enables for the acceptance of an approach based on ABS (Agent Based Systems) (Allan, 2009). ABS modelling seems to be useful for modelling operators and forklifts, which have their own ability to complete changeable task lists. This approach is also referred to Task Driven (Cox, Blackstone, 2002). The task driven approach ensures that jobs can be undertaken in a realistic manner, e.g. an operator (mobile resource) has the job of performing a set of inspections of idle equipment when not otherwise engaged in process work. The task based approach allows for the creation of activities for an operator (mobile resource) which are totally independent of any processing activities and allows him to become engaged in a set of tasks which may require him to travel, acquire tools and remain "busy" for a period of time. Furthermore, using a task driven approach, resources can incorporate their own 'intelligence' to decide what kind of jobs should be done and when (Cox, Blackstone, 2002). Such a solution enables the visualisation and the verification of the work organization as well as the precise arrangement of workstations and PTV assembly teams with the approach constituting the DES (Discrete Event System) software with ABS (Agent Based Systems) (Pawlewski, 2015).

For the needs of the simulation verifying and exploring the designed version of „agile reconfiguration" of PTV assembly production process it is possible to use FlexSim Software (Beaverstock et al., 2011). This program offers the task sequence mechanism to model mobile resources. The modeller has possibilities to prepare the list of tasks for execution using special functions. The set of tasks includes following activities: travel, load, unload, break, utilize. FlexSim offers the special object called dispatcher to manage the set of operators. The list of activities to perform can be built based on an Excel file obtained from PTV company. It is possible to change the number of members of work-teams and to define new type of PTV. The model enables to perform experiments with following reports: work-team conflicts, situation when the work-team finish their work after the end of the cycle time, list of operations which cannot be performed because the time to the end of cycle is shorter than the time of operation, the list of idle time by work-team at the end of the cycle and the evaluation of the team work.

The examples of a screenshot of computer simulating visualisation (with the use of FlexSim software) illustrating the specific organizational and technological problems of the assembly process reengineering of buses have been shown in the next illustrations (Figure 5 and 6).

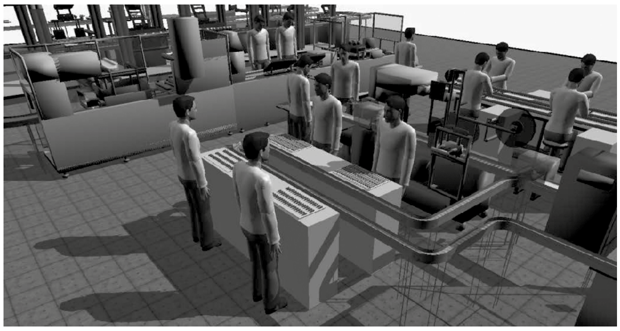

Figure 5. The example of assembly process reengineering studied in FlexSim software
Source: own study

Figure 6. The view of new assembly line simulation studied in FlexSim software
Source: (Kluska, Pawlewski, 2015)

Closing remarks

Management sciences are the area of interpretation in two scopes of *knowledge*: cognitive – *science* and applied – *technology*. Organizational and technological progress generated by the engineering course has its business source in the lasting development of industrial manufacturing enterprises. *Management engineering* pragmatism caused by the need to find solutions before *theory* will fully explain certain phenomena, is forcing technologists and managers for variant solving of practical problems based on the knowledge, experience and the intuition and next for testing these solutions with the computer simulation. Practice of effective and harmonious assembly production processes organization use this type of computer tools support. Especially it regards cases of their technological and organizational reconfiguration which imposes "agile" customer requirements. The study presents the attempt of methodology generalization of mentioned reconfiguration. The proposed method is being addressed to the enterprises carrying out assembly production processes of vehicles (so-called Public Transport Vehicles – PTV) being used for a transport of large groups of people.

The industry of typical PTV representatives of producers is showing a lot of technological, organizational and business similarities associated with the assembly course of manufacturing processes of busses, trams and coaches as well as the means of the railway transport. Operating in an unpredictable and changing environment as well as increasing competition between manufacturing enterprises of building transportation machines PTV have focused main attention on the management of processes that enhance the final value of the product for the customer. This require strong redefinition of their innovation capabilities concerning manufacturing processes. To achieve this, enterprises need to make a move regarding product variety, standardization and customization. The technological process of assembly is most often terminated with the phase of the production process, in which the connection of elements is running according to the series of logically planned activities so that assembly units and final products fulfil the quality requirements and defined technical conditions imposed by the constructor and the ultimate recipient. One of a main tasks of planning assembly technological process is establishing an appropriate order of the course of assembly operations in defined organizational conditions including the time of their length and the required production tact.

The two following thematic problems (presented on a Figure 1) of method of *assembly production process innovation* has constituted the merit contents of this study. There were the following ones: concepts of agile assembly manufacturing of PTV transportation machines as well as simulation verification and exploration of assembly reconfiguration design of this machines. For the purposes of elaborating methodological issue associated with these two problems it raises a hypothetical assumption: one of the significant of Polish manufacturing enterprises assembling PTV vehicles elaborated (being guided both by customers' expectations and competitive market pressure) the *reengineering* of the manufacturing process of its products based on the concept of *agile manufacturing*.

A formal reflection of this innovation was the conversion on the three PTV assembly lines instead of current one. The premises of *agile manufacturing* embraced (based on the four agility features: brightness, flexibility, intelligence and shrewdness) the following criteria: change in business and PTV production processes, high quality and highly customised PTV products and services, core competencies and employees importance, the PTV enterprise and environment interaction, synthesis of assembly technologies diversity, response to change and uncertainty, intra-enterprise and inter-enterprise identity and capability for reconfiguration.

It has been also established (according to the method proposed in this study) that the project of the *reengineering* of the assembly PTV manufacturing process, still before the stage of the implementation, should be (in the form of the virtual computer model) submitted for the simulation verification and the exploration aiming at determining strengths and weaknesses as well as opportunities and threats associated with the individual stages of the course of its practical accomplishment. The simulation stage enables also correction of the project and exploratory implementing of new design solutions.

According to the authors' viewpoint, this chapter presented the most important methodological problem of the structure and usage of the simulation technology consisting in connecting integration of *simulation software for modelling work organization of work-teams* with system software tool modelling the employee work as operators of individual activities of the assembly PTV process. The approach based on integration of the software *DES (Discrete Event System)* with *ABS (Agent Based Systems)* was proposed as a method of computing visualization and verification of work organization as well as precise arrangement and assembly PTV workstations and teams. It was acknowledged that it is possible to use FlexSim Software in assembly processes simulation of Public Vehicles Transport.

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Technologie symulacyjne w „zwinnej rekonfuguracji" procesów montażowych

Streszczenie

Życiowy pragmatyzm *management engineering* zmusza technologów i menedżerów do wariantowego rozwiązywania problemów praktycznych efektywnego i harmonijnego organizowania montażowych procesów produkcyjnych maszyn transportowych na podstawie wiedzy, doświadczenia i intuicji, a następnie do testowania implementacji tych rozwiązań między innymi za pomocą komputerowej ich symulacji. Dotyczy to zwłaszcza przypadków technologiczno-organizatorskiej rekonfiguracji procesów montażu pojazdów wymuszanej „zwinnościowymi" wymogami innowacyjności inżynierskiej oraz konkurencyjnego rynku klienta. W artykule przedstawiono próbę uogólniającego ujęcia metodologicznego takiej właśnie rekonfiguracji. Proponowana metoda adresowana jest do przypadku przedsiębiorstw realizujących montażowe procesy produkcyjne pojazdów służących do przewozu dużych grup ludzi. Dwa następujące wątki tematyczne tej metody stanowią merytoryczną treść tego artykułu: koncepcje zwinnego wytwarzania *Public Transport Vehicles* oraz symulacyjna weryfikacja i eksploracja projektu rekonfiguracji ich montażu.

Słowa kluczowe

zwinne wytwarzanie, technologie symulacyjne