21

Using Petri Nets to Model and Simulation Production Systems in Process Reengineering (case study)

Pawlewski Pawel
Poznan University of Technology
Poland

1. Introduction

Research presented in this chapter was performed in a marine diesel engines factory. The production process characterizes very long production cycle of at least 6 to 9 months. The products and production processes are unique, and based on specific customer orders. One of the main issues in the production process is occurrence of various disturbances, such as, for example, machine breakdowns, parts inconsistent with specifications, changes of customers requirements, etc. The manufacturer has identified the need to reengineer the production process of a marine diesel engine crankcase in order to increase responsiveness and final product quality. Using simulation in the reengineering process planning was extremely beneficial, as any changes in the actual production process induce considerable costs, primarily due to physical product size and use of the highly specialized processing tools. The aim of the simulation was to provide the guarantee that the solution chosen would be suitable for the company. The Petri Net methodology was applied in simulation development. Due to the fact that the outputs obtained from simulation process were not sufficient to make final decision, additional information was collected with Rapid Re methodology. In the paper conclusions from these approaches concerning modeling and simulation are presented in context of reengineering methodologies.
The chapter is organized as follows: in section 2 production process of a marine diesel engine crankcase is identified and theoretical research framework regarding modeling methods is discussed. The methodology based on Petri Net with discussion about other methods is described in section 3. Section 4 presents comparison of approaches to reengineering using a cycle of organized actions defined by Le Chatelier as the point for analysis. In section 5 additional research based on methodology Rapid Re is presented and hybrid solution based on Petri Net and Rapid Re including activities classification applied in ASME (American Society for Mechanical Engineers) methodology is proposed in section 6.

2. Manufacturing process identification

HCP is a factory established in 1857 in Poznań (Poland), and named by its founder Hipolit Cegielski. Nowadays it is the biggest ship engines producer in Europe. HCP produces slow speed-rotation engines for transport ships. The ship engines are built to special orders of customers. Even two engines of same type may have some differences depending on a customer's wishes. HCP builds about 25 – 35 engines per year.

The engines are built under the license of Sulzer Brothers (Wartsila) and Burmeister & Wain. These two license-providing companies are the largest and most significant ship engine constructors. In the late 80's, power plants using combustion engines produced by HCP were built in several Greek islands. Since its establishment till 2008, HCP company produced approximately 1600 diesel ships and stationary engines. The dimensions of such engines are impressive: over 4 meters wide, over 20 meter long, almost 16 meters high. HCP company is the only in Poland and the largest in Europe manufacturer of engines of this kind.

In HCP company, the ship engines are produced to specific orders of customers. Most orders are from the Polish shipyards in Gdynia, Gdansk and Szczecin. The engines are also produced for export, mainly to Germany. A ship engine is a product of a very high capital intensity, and that is why financing its production must be supported by guarantees and bank loans. Therefore, in the company there are two sale schedules: customer sales schedule and optional sales schedule. The customer sales schedule takes into account those engines which are secured by bank guarantees. The optional sales schedule includes the engines which do not have the guarantees yet. Due to the length of the engine production cycle, the customer sales schedule is prepared two years before it is introduced, and the optional sales schedules even three years before the introduction. Obviously, in the meantime the schedules are modified, since owing to the instability of the shipyard industry frequent modifications are necessary.

At the moment, HCP company produces approximately 10 types of engines. An average length of the production process runs at the level of nine months. The manufacturing process in the enterprise takes place in four divisions: welding shop, processing, assembly and packing department. A particular stage of production is assigned to each of the divisions.

In the welding shop the most important and the largest parts of an engine, i.e. motor base and crankcase, are welded. Each of these parts weighs even up to 120 tones. The welding cycle for each of the parts lasts about three months, and therefore, at the same time a few motor bases and crankcases are being welded.

The next stage of a ship engine production is processing. This stage of production lasts about 2 to 3 months. At this stage uncomplicated parts such as e.g. head screws are produced, and crankcases, motor bases, sleeves and cylinder blocks are processed. The processing division is equipped with simple, commonly-used turning lathes as well as planer mills rarely found in industry, due to their size. The planer mills are used for the processing of motor bases, crankcase and cylinder blocks.

The assembly stage can be divided into two smaller stages, i.e. assembling of particular components and final assembly. At the first stage the components of an engine are assembled, and at the final assembly stage the ready-made engine is assembled. The primary assembly stage finishes with an acceptance test. Assembling of components lasts for a month and the primary assembly takes a month and a half.

The last stage of an engine production consists of taking an engine into pieces and dispatching it to a customer. Due to the large size of an engine it is not possible to dispatch it as a whole. The disassembly and dispatch stage lasts from two to four weeks depending on the engine size.
At the moment there is a distinct trend to order smaller ship engines purposed mainly for ships used to transport cars. This tendency brings certain organization problems to the company. The difference in labor consumption in the production of small and large engines runs up to 30 per cent; as for processing in the strategic machines the difference runs at the level of 10 to 15 per cent. In such circumstances, the company enters more contacts in order to maintain the steady level of employment. It results in an increase in the load of strategic machines. An average total cycle of processing a crankcase, cylinder blocks and a motor base lasts for 25 – 30 days. It can be easily calculated that in a year scale the company is able to manufacture twenty such sets. Therefore, it is necessary to optimally use the production potential of the strategic machines.

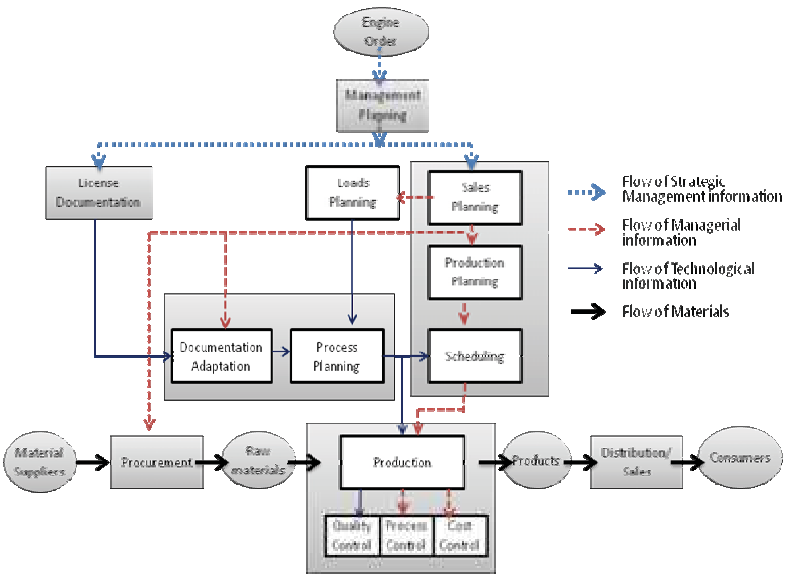

Fig. 1. Framework of relation of the basic functions involved in marine diesel engine factory (source: HCP)

Flow of the materials presented in figure 1, is an integral part of a ship engine production process. Initiating the research the method of modeling the production process must be choose.
The choice of the modeling language was made taking into consideration the results of projects implemented in the years 2002-2006 as a part of 6th EU Framework Project. One of the reports (Lucas et al., 2005) applied to modeling language comparison. 70 languages were selected for the comparison: ADELE-TEMPO, ALF, AMBER, APPEL, APPL/A, ARIS, Articulator, BAM, BPEL4WS, BPML, Chou-UML, CIMOSA, Converstion Builder, CSP, CSPL,E3, EAI, ebXML, EDOC, EEML, ENVI12204, EPC, EPOS, EVPL, FUNSOFT, GEM,

GRAI, GRAPPLE, Hakoniwa, HFSP, IDEF, IEM, ITM, JIL, LATIN, LOTOS, LSPL, MARVEL, Melmac, Merlin, MVP-L, OIKOS, OORAM, PADM, PEACE+, Petri Net, PMDB+, Process Weaver, Promenade, PSL, RAD, REA, Rosetta Net, SDL, SLANG, Socca, SPADE, SPELL, SPM, STATEMENT, System Dynamics, TEMPO, UEML, UML, UML2, UPM,Woflan, WPDL, XPDL, YAWL . Eighteen criteria were defined in the Project – table 1.

Code	General requirements	Inclusion/exclusion criteria – Rule
L01	Formality	Semi-formal
L02	Expressiveness-Information	Attributes and structure
L03	Expressiveness-Actors	Actors as external entities (environment) and entities implied in the process
L04	Expressiveness-Dynamics	Representation of behavior of entities
L05	Expressiveness-Process	Representation of process features
L06	Expressiveness-Real Time	Do not needed: exclude
L07	Graphical	Visual views of models. Visual interface
L08	Textual	Textual descriptions of model elements. Semantics
L09	Abstraction and modularization	Different levels of abstraction. Modules containing logical set of model elements
L10	Extendibility	Modeling elements to change function or semantics of the model basic elements obtaining new representation elements
L11	Executability	Do not needed: exclude
L12	Analyzability	Do not needed: exclude
L13	Evolution ability	Do not needed: exclude
L14	Multiple conceptual perspectives/views	Different kinds of views of the same process under the corresponding modeling interests
L15	Computer support	At least one computer tool to support the language
L16	Availability	Free specifications and tools
L17	Maintainability	At least a permanent nonprofit organization (Open Source). Commercial corporations would be the second choice
L18	Standardization	The language is a standard de facto or is a OMG, ISO standard

Table 1. Inclusion/exclusion criteria for modeling language comparison (Lucas et al., 2005)

The languages were compared on the basis of these criteria. The language which met the criteria best was IDEF0. As a result of the reviewers' suggestion, another comparison was made (with the UML language) and the results of this work were presented in a report

(Galan et al., 2005). The basic argument in favor of the choice of IDEF0 was the clarity of the model structure and the facts that IDEF0 models are easy to comprehend. It should be noted that the authors of the report (Galan et al., 2005, pp. 18) conclude that UML definitely is not the best solution unless the software development is the main purpose. These conclusions correspond to the works which were presented at MOSIM2008 (Pawlewski & Fertsch, 2008) conference and by others authors (Romero & Agost, 2008).
The description of the IDEF0 language can be found in (Zakarian & Kusiak, 2001) and its full definition is included in the standard (Processing 183, 1993), (U.S.Air Force, 1981). One of its features is hierarchical absorption and decomposition capacity depending on the point of view. This feature is illustrated by Fig. 2.

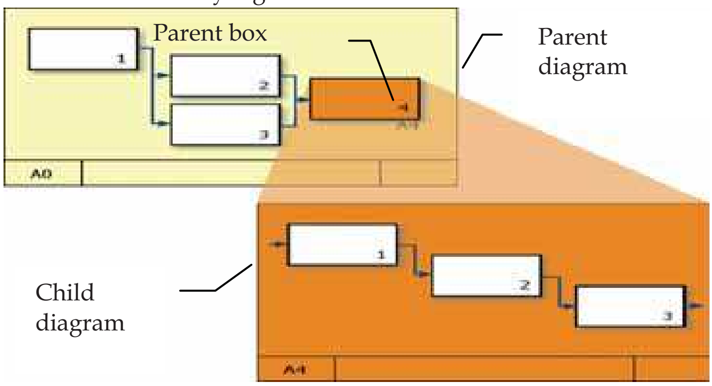

Fig. 2. Hierarchical decomposition in the IDEF0 language (Processing 183, 1993)

The capacity of hierarchical absorption in the IDEF0 language is a great advantage of the language because it can correspond (Pawlewski et al., 2008) to the complexity of the production units expressed by their classification. According to the complexity level, the following production units can be distinguished:
Zero level complexity production units – workstations. These are machines, storage and handing tools area, equipment for handling materials and/or containers with materials within a workplace, area where workers and operators stay to perform their job, the staff operating at a workstation.
First level complexity production units – in the American and European model of production organization there are numerous forms of production units of the first complexity degree (job shops). They consist of production units of zero level of complexity, transport ways, area for storing materials. The typical forms are: lines, seats, workshop, work crew.
Second level complexity production units – divisions. They consist of production units of the first level of complexity and supportive and service units, such as tool distribution shops, material warehouses, tool handling warehouses.
Third level complexity production units – departments. They comprise of all the above-mentioned production units as well as administration units, supervising units, i.e. planning section, repairs-maintenance section
The project was based on 6RTA62U ship crankcase manufacturing process. The engine is manufactured by HCP (Hipolit Cegielski Poznan) and licensed by Warstsila. It is a slow-rotation two-stroke engine for cargo ships. The engine works with the speed of 92 to 115

rpm. The engine has 6 cylinders, diameter 620 mm. The horsepower of the engine is 15 550. Its size is 10.63 m of height, 5.25 m of width and 7.5 of length. The manufacturing cycle is about 7-8 months. Figure 3 presents the crankcase element of a ship engine.

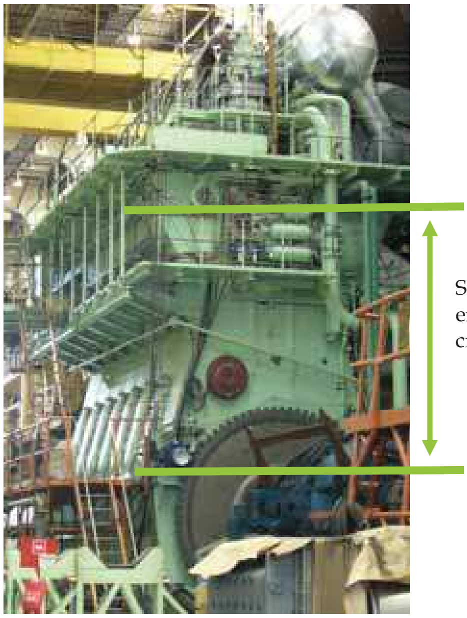

Fig. 3. Crankcase element of ships engine. (source: HCP)

At the stage of identification a process card is designed. It is a fundamental template for data collection, as it includes activities carried out within the ship engine crankcase manufacturing process. Based on the information presented in the form of process cards, a process map can be developed. IDEF0 methodology is a tool for map drawing up, using software tool AIOWin from KBSI Company – www.kbsi.com.
Figure 4 presents the main sub-processes of ship crankcase construction process: burning, execution of prow part, execution of stern part, joining prow and stern parts, treatment.
The whole process is composed of 58 operations - figure 5 shows the part of the process structure in a form of a tree graph.

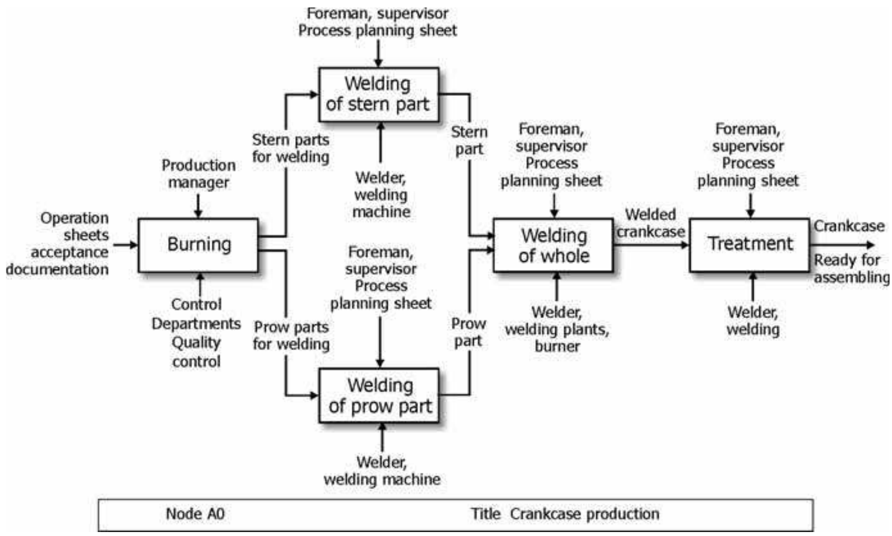

Fig. 4. Graph (IDEF0) of five main sub-processes in ship crankcase manufacturing process (source HCP).

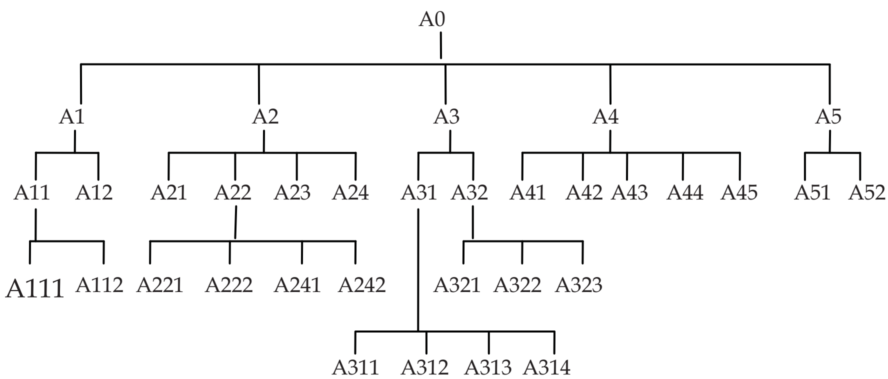

Fig. 5. The part of tree graph of ship crankcase manufacturing activities (source HCP).

3. Methodology based on Petri Net

Based on the paper (Jansen-Vullers & Netjes, 2006) standard modeling and simulation procedure is described as follows: "Regarding the simulation of business processes a number of steps can be distinguished. First the business process is mapped onto a process model, possibly supplemented with process documentation facilities. Then the sub processes and activities are identified. The control flow definition is created by identifying the entities that flow through the system and describing the connectors that link the different parts of the process. Lastly, the resources are identified and assigned to the activities where they are necessary. The process model should be verified to ensure that the model does not contain errors. Before simulation of a business process, the performance characteristics, such as throughput time and resource utilization, need to be included. For statistically valid simulation results a simulation run should consists of multiple sub runs and each of these sub runs should have a sufficient run length. During the simulation, the simulation clock advances. The simulation tool may show an animated picture of the process flow or real-time fluctuations in the key performance measures. When the simulation has been finished, the simulation results can be analyzed. To draw useful and correct conclusions from these results, statistical input and output data analysis is performed."

In case when the simulation is used to confirm the choice of improvements for process reengineering, modeling and simulation procedure presented is insufficient. Applying simulation to reengineering process was beneficial as all the changes in real production process are connected with high costs, due to big size of product and application of the highly specialized processing tools. Based on performed researches definition of following requirements for simulation is possible:

- precise process definition ,
- multi process simulation where use of many processes is possible,
- observation of the situation where the processes "chase one another",
- interactions between processes,
- simulation of disturbances.
- formal verification of simulation model – reduced role of heuristic methods.

Based on literature review (Jansen-Vullers & Netjes, 2006) first decision – choice of Petri Net methods was correct. These methods provide formal semantics which enable precise and unambiguous description of the behavior of the modeled process and verification. Conclusion that many modeling techniques lack for formal semantics and thus powerful analysis methods and tools is in (Aalst & Hee, 1996). Conclusion that there are three good reasons for using Petri Net based methods which appear to be critical in large Business Process Management projects is in (Aalst, 1996). These reasons are:

- the existence of formal semantics despite the graphical nature,
- the state based diagrams instead of event based diagrams (as can be encountered in many workflow products)
- the abundance of analysis techniques.

Discussion and evaluation of tools for process simulation is presented in (Jansen-Vullers & Netjes, 2006). From many tools like ARIS, Arena, CPN Tools etc. based on results of evaluation, the tool CPN Tools was selected. Authors of this papers benefit a lot from the formal verification techniques.

One of presented requirements for simulation is simulation of disturbances. It is problem hard to solve using Petri Net especially with respect to problem of dynamic changes in process structure. It is reason why research in area of reconfigurable manufacturing systems was performed. In detail the logic control design methodologies were reviewed. Today a vast of industrial logic controllers are performed under computer named Programmable Logic Controllers (PLCs). The PLCs are specially designed to respond to use as controllers on industrial processes. A recent research work (Johnson, 2002) published on Control Engineering Journal shows that 96% of those polled programs are using leader diagrams. Ones of principal inconvenient of leader diagrams is shown in the complexity of manufacturing systems. Several alternatives have been developed to lead diagrams to PLCs programming. In particular the standard IEC61131-3 publication and IEC61499 is directed to resolve some above problems (Lewis, 2001). The two formalisms more used for control manufacturing system are the Finite States Machine (FSM) and the Petri Net (Genc & Lafortune, 2003), (Park et al., 1999). However the real complex controller cases design though Petri Net are few (Gollapudi & Tillbury, 2001).

The state charts are an alternative framework that allows to describe the behavioral of a complex system in a compact form (Harel & Naamad, 1996), (Harel et al., 1987). Similarly to a Petri Nets they have a good concurrence. The complexity of semantic of execution does that the verification of control systems modeled with state charts be a hard task (Gruer et al., 1998). On the other hand the supervisory control theory (Ramadge & Wonham, 1987), (Ramadge & Wonham, 1989) resolves problem in specific cases, when a supervisor creates exactly the desire behavior in a close loop, even when the controller cannot control or observe all events (Cassandras & Lafortune, 1999), (Kumar & Garg, 1995). Supervisor control theory could be not adequate to be used in developing of complex manufacturing control systems reading (Charbonnier et al., 1999). The principal reason is that the controllers of supervisor control theory are designed to prevent the effects by already events despite of to try controlling the reasons that they create. The work (Trujillo, 2004) proposes solution for studying system by behavioral description. A principal reason has been the behavioral description of logic control in complex manufacturing plants. The FSM framework is unavailable to represent adequately complex systems, since its required representation millions of states (Endsley & Tilbury, 2004). Proposed solution (Trujillo, 2004) has properties that allow developing a method thought Virtual Supervisor tree, which identify all possible sequences in a control process. These sequences rapidly can be verified outline, and composed in a safe and fast form obtaining feasible pattern sequences (Trujillo, 2004). Pattern sequences are capable to compose for a new control reconfiguration.

A Petri Net (Aalst et al,. 2000), (Chen, 1990), (Peterson, 1981) is one of the several mathematical representations of discrete distributed systems. As a modeling language, it graphically depicts the structure of a distributed system as a directed bipartite graph with annotations. As such, a Petri Net has place nodes, transition nodes, and directed arcs connecting places with transitions. Petri Nets were presented in 1962 by Carl Adam Petri in his Ph.D. thesis.

Nets enable a survey of system features and they are applied for a description and study of information processing systems. Their theory is becoming one of the basic research directions. They are mostly applied in data analysis, software engineering, work organization, parallel programming. Lately, a large number of research and theoretical works concerning the application of a Petri Net in the business process modeling has been published (Aalst et al., 2000). These publications provided a strong impetus for the project presented.

For the purpose of modeling the ships crankcase manufacturing process with a Petri Net, the following procedure has been drawn up:

STEP I - Choice of the process that is to be modeled

STEP II - Definition of the initial stage – In this case, initial stages are technological processes and process maps

STEP III - Definition of the place - places represent such factors as: communication methods, conditions or states. In the analyzed process, the following places are distinguished: finished sheets, burning process

STEP IV - Definition of transitions – Transitions define such variables as shifts, events, transformations e. g. burning process, control
STEP V - Definition of tokens - Tokens represent such objects as: human resources, machines, goods, states of objects, conditions, information, state indicators (e.g. indicator of the state in which a process or object is)
STEP VI - Modeling of relations between places, transitions and tokens with tree graphs. It consists of a division of crankcase manufacturing process into successive production stages, which are parts of the ship crankcase manufacturing process. They are connected by means of arrows
STEP VII - Definition of attainable states – an attainable state is a state which can be achieved from the current state, arising because of starting the sequence of possible shifts, i. e. shifts between tokens and transitions. In the analyzed case, the attainable states are: burning process, manufacturing process of the crankcase stern part, manufacturing process of the crankcase prow part, process of joining prow and stern parts
STEP VIII - Definition of dead states – a dead state is a state in which no shift is possible. Such states are not distinguished in the conducted research
STEP IX - The model is transferred to Visual Object Net software
STEP X - Conclusions and evaluations

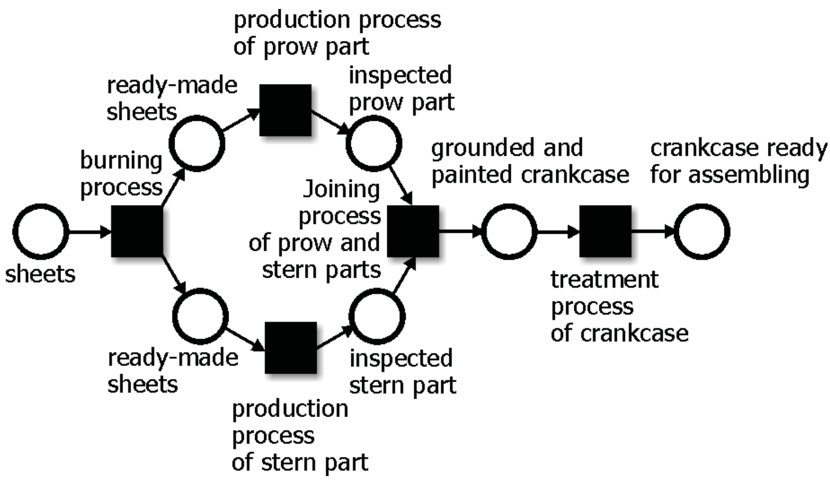

Fig. 6. Crankcase manufacturing process (source: HCP).

Figure 6 and figure 7 present models for main crankcase manufacturing and burning processes.

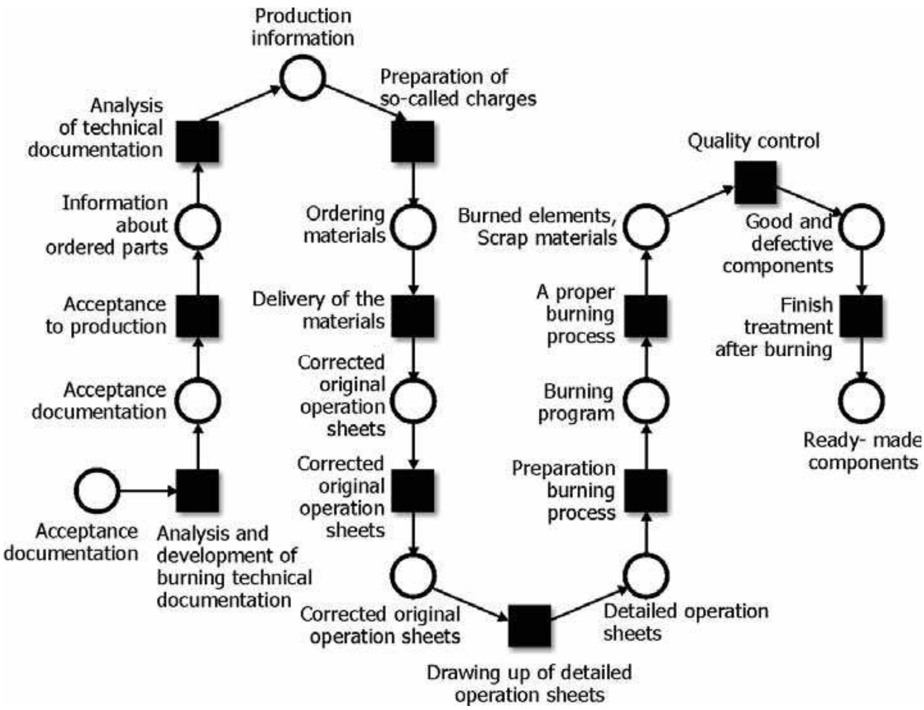

Fig. 7. Burning process (source: HCP).

The application of Petri Nets made it possible to collect valuable information about the structure of production process and provided suitable basis for the simulation. However, the obtained output was not sufficient to make a final decision about real process reengineering. Therefore, an additional analysis with the help of another reengineering methodology was required.

4. Discussion of approaches to reengineering

On the basis of literature study five different approaches to reengineering can be identified (Cempel, 2005), (Pacholski et al., 2009):

- M. Hammer and J. Champy approach (Hammer & Champy, 1993)
- R.L. Manganelli and M.M. Klein approach (Manganelli & Klein, 1998)
- N.M. Tichy and S. Sherman approach (Tichy & Sherman, 1993)
- T.H. Davenport approach (Davenport, 1993)
- J. Durlik approach (Durlik, 1998)

The first two approaches can be classified as of a consulting type, the third approach is purely managerial. The remaining two approaches can be classified as mainly academic (Cempel, 2005).

Hammer and Champy (Hammer & Champy, 1993). present an approach, according to which reengineering is rejecting procedures used before and looping at work needed to manufacture a product or perform a service customers require from a different point of view. In this approach information technology is crucial, as it is a factor enabling changes. According to Hammer and Champy their approach cannot be applied in reference to business processes that have already been performed. Therefore, instead of looking for an answer "how can we use technology to perform our processes faster or better?", it is more reasonable to answer the question "what can we do with new technology – what we never tried before?". The most difficult in this method is finding new possibilities and opportunities technology gives. Such approach requires changing deductive way of thinking into induction. In practice, it is simply finding a very good solution and then searching for problems that can be solved with methodology or tool already developed. Though the authors have never defined such methodology, analyzing their work, the following steps of reengineering project can be distinct (table 2).

Stage	Description
Introduction	Generate reasons for changes; define vision and goals and define and appoint a project team
Process identification	Map basic processes
Process selection for reengineering	Chose processes to be reengineered at first and define work teams to describe sub processes
Understanding of selected processes	At his stage, it is more important to understand how processes work than to analyze them in great detail, comparing processes actually are performed with their description in procedures
Clean state design of selected process	His stage requires creativeness, lateral thinking is used, imagination is employed, theoretical optimal processes are defined and then adjusted to fit reality
Implementation	Implementation of new solutions

Table 2. Stages of radical approach – Hammer/Champy (Pacholski et al., 2009).

R.L. Manganelli i M.M. Klein in Reengineering (Manganelli & Klein, 1998). introduced step by step organization improvement procedure. Their work presents unique systematic detailed approach to reengineering idea. The authors wanted to provide a practical tool that can be used in organization.

Rapid Re methodology consists of 54 tasks integrated into five stages (table 3). Finishing each stage is a milestone of a project. Each of the stages in the methodology is illustrated with an example of unreal company ABC Toy Company Ltd. The first results usually appear after six months, up to one year after implementation. It is a consequence of demotivative influence of time-consuming projects on employees, especially those lower levels, what is more managers generally want the results to come as soon as possible. The authors called their method Rapid Re. It is to improve processes of operational level, it is not supposed to be used for tactical or strategically processes such as market choice or New product development. To make the method complete software Rapid-Re: Reengineering Software for Microsoft Windows was developed.

Stage	Description
Preparation	At his stage goals to be achieved in reengineering process are generated by managers, scope of project is defined, schedule, risk and costs acceptable, members of reengineering team are appointed and trained
Identification	Customer-focused organization model is developed, strategic and value-adding processes are identified, models of processes are developed, organization and resources are mapped, processes to be reengineered (providing best results) are chosen
Developing a vision	Process vision is developed, developed vision is to provide radical change of effectiveness by identification of organization, systems, information flows, current problems, ratios to assess and compare effectiveness are developer, goals and improvement opportunities are identified, as well as changes necessary to achieve them
Solution design – technical aspect	During his stage technical aspects of changes are planned, preliminary plans are defined: procedures and systems developing, hardware, software and services purchases, technical changes, testing and modules allocation
Solution design – social aspect	Organization, personnel, workplaces, career and motivation system of reengineered process are described, preliminary plans of recruitment process, training, reorganization and personnel movement in organization are also defined
Transformation	His stage is simply pilot program and full implementation

Table 3. Stages of Rapid Re method - Manganelli/Klein (Pacholski et al., 2009)

GE based on leadership methodology was described by N.M. Tichy i S. Sherman in: Control Your Destiny or Someone Else Will (Tichy & Sherman, 1993). The stages of the methodology are presented in the table 4. The book mentioned describes the story of Jack Welch trying (successfully) to save General Electric from falling. The results of his ideas implementation was doubling income and tripling profits, while productivity zoom by 400%. The main idea of GE methodology is revolutionary changes implementation in a continuous way. N. Tichy gives five principles, which should be used when implementing changes in organization:

- Understanding business mechanisms,
- Understanding interpersonal relations,
- Rejecting compromises when striving for golas established,
- being open to changes,
- having a hard head and a kind heart.

Stage	Description
Awakening	At this stage awareness of changes necessity is defined, the next stage is creating urgent need for changes, technical, political and cultural barriers are diagnosed
Developing a Vision	During this stage motivating vision of future is created and employees are encouraged to be involved in a project
Design and reconstruction	At this stage creative destruction and redesign is performed, and then a new organization is built, it important to motivate people to create, after this stage changes are defined

Table 4. Stages of metod Tichy/Sherman (Pacholski et al., 2009)

Changing an organization requires defining an idea and vision. The authors suggest three aspects of ideas definition:

- technical – it describes how the company is going to earn money in market competition conditions with resources used,
- political – it describes how power, influence and prizes can be used to stimulate organization,
- cultural – it describes how commonly respected standards and values can keep people together.

The most important technical idea of this methodology is that each company being a part of GE was „the first or the second in the world". Cultural idea was mostly on destroying limitations, political on integrating.

T.H. Davenport (Davenport, 1993) suggests that reengineering teams should focus on several (no more than fifteen) most important processes. In contradiction to radical approach Davenport suggests studying chosen processes to avoid finding old solutions as new ones. The most important is implementation of innovation because it is very important for project success. This stage generally takes longer (minimum a year) than all the other stages. The stages of Davenport methodology are presented in the table 5. It seems that not only information technology is important but employees who are making the change. New work organization should motivate them and make them focused on value adding activities and continuous search for innovation. Innovation should be not a project but continuous process.

Stage	Description
Developing a Vision and objectives	Definition of vision and goals
Process Identification	Identification of processes to be redesigned
Understanding analysing processes	Testing processes functioning and benchmarking
Use of information Technologies	Analyzing opportunities of IT usage in redesigned processes
Creating process prototypes	Creating detailed process prototypes, personnel analyses the prototypes, develops further improvements and creates adaptation projects
Implementation	Implementation of prototypes tested

Table 5. Stages of Davenport method (Pacholski et al., 2009)

Davenport also suggests combining reengineering with less revolutionary process approaches f.ex. management through quality (Total Quality Management).

In dynamic business reengineering methodology, a controlling is stressed and (Durlik, 1998) proper steps in reengineering methodology can be performed only after a strategic and economic analysis of the company. After that some decisions concerning product positioning and company's structure are made. The steps of reengineering methodology proposed by Durlik (Durlik, 1998) are presented in the table 6. For each mega process and process goals accepted by managers and executors are defined. Company's departments to be changed are chosen and process to be improved are defined. The range of changes to be made is assessed and potential effects are analyzed. The criteria of projects selection should be profit by it does not have to be defined in traditional way. The profit can be preserving costs or increasing sales potential.

Stage	Description
Setting a Project task	At this stage goals for each process are defined, as well as criteria used to assess them.
Preparing a process map and setting the scope of further works	At this stage, except from creating a process map, the order of process solving, project range, executive team and budget are defined.
Radical re design of selected processes	At this stage general model of each subprocess, process and subprocess is defined. New solutions variants are developed and changes are designed. Organizational and management structure are adjusted to fit new processes.
Simulation and option assessment	At this stage detailed analysis of costs and benefits coming from implementation and use of each new process scenario is performed. The result is recommendation of a process to be implemented.

By selecting a Best option	Reengineering team chooses optimal variant by selecting options and presenting them to top managers.
Implementation	Based on project management methodology, includes: planning of project financing, organization of executive teams, negotiations, relations with partners, infrastructure, recruitment, training, mechanical and technological launching, controlling, implementation.
Controlling	Implementation of controlling to control execution and supervision on budget defined
Continuous improvement	Reengineering team and change manager are obliged to meet in a continous manner

Table 6. Stages of Durlik method (Durlik, 1998)

To describe processes in organizations process maps and relation diagrams are used. They are developed for each products and for the company as a whole as well. To model processes two types are used:

- technical – including physical parameters of a process (shop floor, machines, energy, resources)
- economic – including two most important parameters – time and money.

Durlik (Durlik, 1998) describes controlling as a tool used to control execution and supervision of a budget plan. Disregarding controlling, according to the author, used to be the reason of overfilling the plans in terms of cost or organizational issues. Changes in project, based on conclusions coming from controlling, are implemented only by reengineering team. The author introduces a term 'dynamic business reengineering' (DRB), which means continuous changes with respect to reengineering principles.

The analysis of these methodologies indicates a number of elements they have in common. A cycle of organized actions defined by Le Chatelier (Cempel, 2005) (Pacholski et al., 2009) was used as the base point for the analysis. This cycle is composed of the following phases:

- Goal choice
- Research of resources and conditions for goal realization
- Resources and conditions preparation
- Goal realization
- Inspection of results

Based on this reasoning, four phases can be distinguished:

- Qualification phase
- Research and optimal solution selection phase
- Realization phase
- Inspection and evaluation chase

Table 7 presents reengineering methods according to the defined phases. The presented order indicates a concentration of activities at the initial stages of the methods. It confirms that the initial stages are the sources of success in 80% of all cases (Vilfredo Pareto principle). However, this order reveals one more problem, i.e. in most methods, the inspection and evaluation phases are not clearly distinguished – only in Durlik's methodology this phase is defined, yet without determining tools or instructions.

	Qualification phase	Research and optimal solution selection phase	Realization phase	Inspection and evaluation phase
M. Hammer / J. Champy	Introduction Process identification Process selection for reengineering Understanding of selected processes	Clean slate design of selected process	Implementation	
R.L. Manganelli / M.M. Klein	Preparation Identification Developing a vision	Solution design: technical aspect social aspect	Transformation	
N.M. Tichy / S. Sherman	Awakening Developing a vision	Design and reconstruction	(Implementation is part of phase 3)	
T.H. Davenport	Developing a vision and objectives Process identification Understanding and analyzing processes	Use of information technologies Creating process prototypes	Implementation	
I. Durlik	Setting a project task Preparing a process map and setting the scope of further work	Radical redesign of selected processes Simulation and option assessment By selecting best option	Implementation	Controlling Continuous improveme nt

Table 7. Reengineering methods per individual as phases of an organized activity (Pawlewski et al., 2008b)

Only Durlik's method (Durlik, 1998) shows a need to use simulation to assess individual options; however, on closer analysis, the need for simulation is only indicated, without any hints given on how to proceed with it. There is no description of simulation tools or methodology. On the basis of this analysis, conclusion is that there is a gap in reengineering methodologies since they do not account for industry-based requirements for simulation.

5. Additional research based on methodology Rapid Re

In the case study presented, Rapid Re method was applied due to the fact that it has been described precisely and the literature on the subject provides many examples of detailed problem-solving solutions.

Rapid Re is the methodology which was developed by R.L. Manganelli and M.M. Klein in the beginning of the 90's, as a procedure which was described in „The Reengineering Handbook" (Manganelli & Klein, 1998).

The main arguments for this selection are:

- suitability for the improvement of the operation processes, yet not for the tactical or strategic ones
- the most methodological approach - described precisely
- the literature on the subject provides many examples of detailed problem-solving solutions.

This methodology consists of five stages:

- Arrangements – this stage concerns such matters as making the board accept the project, defining purposes of the project, composing the project team, determining skills of the team members, team training, changing the plan of development
- Identification - concerns mostly processes in an organization, their connections to supplier and customer processes, process modeling, preparation of the map of the organization and sources
- Creating a vision - the stage which is an estimation of the existing processes, their influence on general effectiveness, the strategy of the change implementation and the estimation method with the use of benchmarking
- Solution project – technical aspect – the use of technical sources and technology in modifications and – social aspect – the method of human resources transformations
- Transformation – methods of work progress inspection, success estimation, pilot tests

Investigations show that according to Rapid Re methodology, the correcting procedure of a crankcase manufacturing process was elaborated.

Stage 3 – creating a vision – this stage (Manganelli & Klein, 1998) identifies the actions which create added value; these are actions owing to which something is created or appreciated by customers, actions of inspection and others. These actions were compiled in tables for each main sub-process.

Example of a Burning process is presented in Table 8. Based on the tables with classified activities, the actions ratio which generates the added value was enumerated in relation to a general number of actions.

No	Activity	Type of activity		
		Value-adding	Inspection	Other
	Burning			
1	Acceptance to production			X
2	Technical documentation analysis		X	
3	Charge preparation			X
4	Order of materials			X
5	Preparation of detailed operation		X	

	sheets of details			
6	Developing the burning programme		X	
7	Burning process + transport	X		
8	Inspection		X	
	....			

Table 8. Classification of the activities in a burning process- an excerpt (Pawlewski & Fertsch, 2008)

In the following steps, the factors which influence the effectiveness of the process and potential sources of errors and problems were described. Based on the information collected before, the possibility of process modification was estimated. The modification was evaluated considering the range of modification and difficulties in execution. The expected costs of the modification were assessed as well as profits generated by them. The range of advancement was evaluated as well as the risk which arises from introducing the modification. The estimation of the possibility of reengineering is presented in Table 9.

Possibility of reengineering	Modification	Difficulty	Advantages	Risk
Faults elimination which occurs during order reception and technical documentation analysis	Electronic order reception current bringing up to date	Moderate	Accuracy, less work	Low
Fines sentencing for unpunctual orders completing	Modification in agreements signed with subcontractor	Moderate	No delays	May not succeed which results subcontractor change
Optimization of COBURG III utilization	Adequate time scale production preparation	High	Cost reduction of equipment operation	Well qualified production planners
Faults elimination which appear when appointing a date of executing actions included in the whole process	Making a proper time-scale production	High	Time reduction of crankcase production	Well qualified production planners
Quality inspection carried out adequately early after delivery annealed crankcase to subcontractor	Quality inspector checks up the delivered crankcase	Low	No possibility of receipt the wrong annealed crankcase	Low

Table 9. List of the possibilities of the ship crankcase production process rationalization – an excerpt (Pawlewski & Fertsch, 2008)

Accomplishment of the up-to-the-present works let to specifying the vision of the “ideal” process, i.e. describing performance of the process when all the parameters are optimal. The execution of basic actions which the process is composed of was defined in order to make them ideal.

Rapid Re methodology is appropriate mainly for business processes, that is why quite a few problems occurred when it was adjusted to reengineering of the production process of the ship crankcase. The method is very responsive to errors connected with compiling data. It is seen particularly in counting the ratio of the actions which bring added value to all actions. In the analyzed case, its high value is caused by time limitations. They resulted in compiled data based mainly on technological documentation instead of being based on direct observation. However, a compact and specified vision of the process was successfully suggested and enabled reengineering definition. It seems that further works should be directed to defining stricter requirements connected with the quality of the compiled data in order to have no doubt when calculating the factor which is the measure of the potential of redesigning the process. On the other hand, it seems to be impossible to build a formal model of the process so that it could be simulated and the results of the redesigning would be observed.

6. Hybrid solution based on Petri Net and Rapid Re

Investigations based on Petri Nets and Rapid Re methods presented in the previous sections has shown that none of them entirely fulfills the company requirements for the production process reengineering. The method based on Petri Nets is a suitable tool for identifying the process structure as well as an adequate framework for simulating the analyzed process before and after reengineering. Rapid Re method is not appropriate for simulation; it also lacks the possibility for time analyses of the operations and the classification of activities is not sufficient for a complex production process. The biggest advantage of Rapid Re methodology is the fact that it provides a framework for a reengineering process design and organization. Its procedure is very precisely described in the literature and many examples of detailed problem-solving solutions are given. Rapid Re provides tools and methods for making an assessment of the processes appropriateness, as well as a comparison of the activities in the process.

The research conducted in the analyzed company has shown that a hybrid solution is needed for reengineering a complex production process. The hybrid solution should combine the advantages of both methods. The Rapid Re methodology should be extended by the following elements:

- transition of a process map into a process model based on Petri Nets in order to gain the possibility of analyses and synchronization of parallel activities.
- supplementation of activity-based indicators used in Rapid Re, by the introduction of time-based indicators
- extension of Rapid Re activities classification (value adding, inspection, other) by the classification applied in ASME methodology developed by the American Society for Mechanical Engineers (Cempel 2005) :
    - value adding operations,
    - operations which do not add any value,
    - quality and / or quantity control,
    - transport, flows of people, materials, information, documents, etc.,
    - downtime, temporary storing, delay or –– idle time between operations,
    - storing which is not downtime.

Table 10 presents symbols used in ASME methodology completed by symbol of useless work an table 11 shows the scheme of typical chart of process flow.

Symbol	Description
ⓥ	Value adding operation
○	Operation which do not add any value
□	Quality and / or quantity control
→	Transport, flows of people, materials, information, documents
D	Down time, temporary storing, delay or – idle time between operations
▽	Storing which is not down time
⊗	Useless work (meetings, double operations, useless review, useless evaluatiuon)

Table 10. Symbols used in modified ASME methodology (Pacholski et al., 2009)

Index	Stages	ⓥ	○	□	→	D	▽	⊗	Time	Person	comments
1.	Stage A				●						
2.	Stage B	●									
3.	Stage C				●						
4.	Stage D		●								
5.	Stage E					●					
6.	Stage F						●				
7.	Stage G				●						
8.	Stage H							●			
9.	Stage I	●									
10.	Stage J			●							

Table 11. Scheme of chart process flow according to ASME methodology (Pacholski et al., 2009)

Simulation phase should be introduce into existing phase of Rapid Re methodology – "Solution design" according to fig.8.

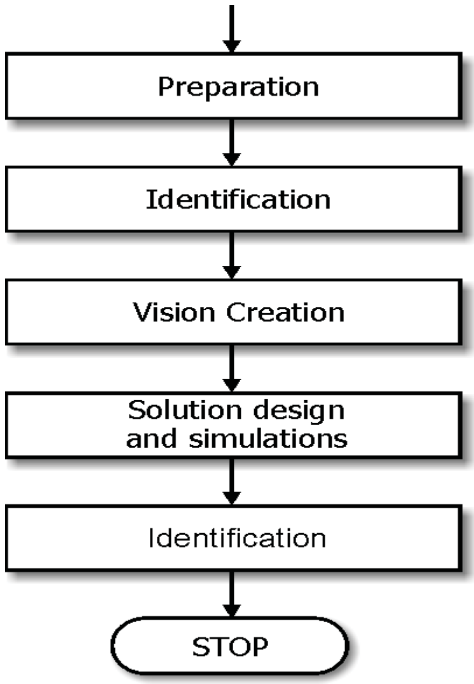

Fig. 8. Rapid Re methodology supplemented with „Simulations" phase.

The presented idea of a hybrid solution establishes the base of a new methodology which will be investigated and described. There are plans to continue this work in the collaboration with the ship engines factory where research was started.

7. References

van der Aalst, W.M.P. (1996) Three Good Reasons for Using a Petri-net-based Workflow Management System. In S. Navathe and T. Wakayama, editors, *Proceedings of the International Working Conference on Information and Process Integration in Enterprises (IPIC'96)*, pages 179–201, Camebridge, Massachusetts

van der Aalst, W.M.P. & van Hee, K.M. (1996) Business Process Redesign: A Petri-net based approach. *Computers in Industry*, 29(1-2):15–26

van der Aalst, W.M.P.; Desel, J. & Oberweis, A. (2000) *Business Process Management.* Springer-Verlag Berlin Heidelberg

Cassandras, C.G. & Lafortune, S. (1999) *Introduction to Discrete Event Sistems*. Kluwer Academic Publishers, MA

Cempel, W.A. (2005) *Metodologia reengineering w przedsiebiorstwach przemysłu maszynowego. [Reengineering methodology in engineering industry.]* Doctoral thesis, Poznan University of Technology, Poznan, Poland

Charbonnier, F.; Alla, H. & David, R. (1999) The supervised control of discrete-event dynamic systems. *IEEE Transactions on Control Systems Technology*, 7(2):175–187

Chen, S.M. (1990) Knowledge representation using fuzzy Petri nets. I*EEE Trans. on Knowledge and Data Engineering*

Davenport, T. H. (1993) *Process innovation: Reengineering work through information technology.* Boston, MA: Harvard Business School Press

Durlik, I. (1998) *Restructuring business processes: Reengineering theory and practice. Business process reengineering in High-Technology. [Restrukturyzacja procesów gospodarczych: Reengineering teoria i praktyka. Businesss Process Reengineering w warunkach High-Technology.]* Warsaw, Poland, Placet

Endsley, E.W. & Tilbury, D.M. (2004) Modular verification of modular finite state machines. *In Proceedings of the 43rd IEEE Conference on Decisionand Control*, volume 1-5, Nassau, Bahamas

Galan, J.C.; Marcos, M.; Reif, W.; Balser M. & Schmitt J. (2005) *New model of guideline process. Addendum. Specific Targeted Research Project Information Society Technology*, Universitat Jaume I, September 8, IST-FP6-508794

Genc, S. & Lafortune, S. (2003) Distributed diagnosis of discrete-event systems using petri nets. *In Proceedings of the 24th International Conference on Applications and Theory of Peti Nets*, pages 316–336, Oulu, Finland

Gollapudi, C. & Tilbury, D.M. (2001) Logic control design and implementation for achining line tested using Petri nets. *In Proceedings of the ASME-IMECE Dynamic Systems and Control Division*

Gruer, P.; Koukam, A. & Mazigh, B. (1998) Modeling and quantitative analysis of DES: A statecharts based approach. *Simulation Practice and Theory*, 6:397–411

Hammer, M. & Champy, J. (1993) *Reengineering the corporation*. New York, NY: Harper Business

Harel, D. & Naamad, A. (1996) The statemate semantics of statecharts. *ACM Transaction on Software Engineering and Methodology*, 5(4):239–333

Harel, D.; Pnueli, A.; Schmidt,J.P. & Sherman, R. (1987) On the formal semantics of statecharts. *In Proccedings of the Second Annual Symposium on Logic in Computer Science,* pages 54–64, Ithaca, NY, June, 22-25. Computer Society Press

Jansen-Vullers, H. & Netjes, M. (2006) Business Process Simulation - A Tool Survey. *Seventh Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools,* University of Aarhus, Danmark, October 24-26, ISSN 0105-8517

Johnson, D. (2002) Nano devices lead assault on traditional PLC applications. *Control Engineering*, 49(8):43–44, August

Kumar, R. & Garg, V.K. (1995) *Modeling and Control of Logical Discrete Event Systems*. Kluwer Academic Publishers, Norwell, MA

Lewis, R.W. (2001) *Modeling control systems using IEC 61499*. The Institution of Electrical Engineers

Lucas, P.; Hommerson, A.; Galan, J.C.; Marcos, M.; Coltell, O.; Mouzon, O.; Polo, C.; Rosenbrand, K.; Wittenberg, J. & van Croonenborg, J. (2005) New model of guideline process. *Specific Targeted Research Project Information Society Technology,* Universitat Jaume I, March 3, IST-FP6-508794

Manganelli, R. L. & Klein, M. M. (1998) *The Reengineering Handbook*. Warsaw, Poland: PWE (polish edition)

Pacholski, L.; Cempel, W. & Pawlewski, P. (2009) *Reengineering – reformowanie procesów biznesowych i produkcyjnych w przedsiebiorstwie. [Reengineering: Reforming business and production processes in company.]* Poznan, Poland: Publishing House of Poznan University of Technology

Park, E.; Tilbury, D.M. &, Khargonekar, P.P. (1999) Modular logic controller for machining systems: Formal representation and performance analysis using Petri nets. *IEEE Transactions on Robotics and Automation*, 15(6):1046–1061

Pawlewski, P. & Fertsch, M. (2008) Using Petri Net To Model Production Process Of Ships Engine Crankcase In Process Reengineering (case study). *Proceedings of 7e Conférence Internationale de MOdélisation et SIMulation* - MOSIM'08 – 31.03-2.04.2008 – Paris- France

Pawlewski P.; Trujillo J.A.; Golinska P.; Pasek Z.J. & Fertsch M. (2008) Process oriented approach versus description of technological routes - their role in production management, *Proceedings of the 18th International Conference on Flexible Automation And Intelligent Manufacturing* FAIM 2008 30.06-2.07.2008 Skovde Sweden

Pawlewski, P.; Golinska, P.; Fertsch, M.; Trujillo, J. & Pasek, Z. (2008) Supportive Role Of The Simulation In The process Of Ship Engine Crankcase Production Process of Reengineering (Case Study). *Proceedings of the 2008 Winter Simulation Conference* S. J. Mason, R. Hill, L. Moench, and O. Rose, eds.

Peterson, J.L. (1981) *Petri Net Theory and the Modeling of Systems*. Prentice-Hall

Processing Standard Publication 183 (1993) *Announcing the Standard for INTEGRATION DEFINITION FOR FUNCTION MODELING (IDEF0),* Draft Federal Information

Ramadge, P.J.G. & Wonham, W.M. (1987) Supervisory control of a class of discrete event processes. *SIAM Journal of Control and Optimization*, pages 206–230, January

Ramadge, P.J.G. & Wonham, W.M. (1989) The control of discrete event systems. *Proceedings of the IEEE*, 77(1):81–98, January 1989.

Romero, F. & Agost, M.J. (2008) Activity modeling in a collaborative ceramic tile design chain: an enhanced IDEF0 approach, *Res Eng Design*, Springer-Verlag, 19, pp.1-20

Tichy, N. M. & Sherman, S. (1993) *Control your destiny or someone else will.* New York: Doubleday

Trujillo, J.M. (2004) *Position Machine for Logic Control: Composition of Patterns in Reconfigurable Manufacturing System*. PhD thesis, University of Valladolid, Spain

U.S.Air Force. (1981) *Integrated Computer Aided Manufacturing (ICAM) Architecture Part II, Volume IV - Functional Modeling Manual (IDEF0),* Air Force Materials Laboratory,Wriht-Patterson, AFB, Ohio 45433, AFWAL-tr-81-4023

Zakarian, A. & Kusiak, A. (2001) Process analysis and re engineering, *Computers & Industrial Engineering* 41 pp.135-150