Using DES/ABS Approach to Model and Simulate Bus Assembling Process

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Abstract. This paper presents the results of the project, which goal is to analyze the production process capability after reengineering the assembly process due to expansion of a bus production plant. The verification of the designed work organization for the new configuration of workstations on new production hall is necessary. The simulation model is the best tool for visualization and verification of the work organization based on individual workteams which are supporting particular workstations. Owing to the simulation it is possible to define the imperfections of this conception and elaborate improvements which will minimize the idleness of workers and downtime occurring in the assembly process. The objective of performed activities is to provide assurance that the new organization of assembly process will lead to maximum utilization of production capacity in the company. To solve described problems authors propose a method based on mixing DES (Discrete Event Simulation) and ABS (Agent Based Simulation) approach. DES was used to model the main process – material flow (buses), ABS was used to model assembling operations of teams of workers.

Keywords: Agent based modeling · Simulation · Assembling · Production plant

1 Introduction

The authors of the article conducted research in a bus production plant. Due to the increasing number of orders and the diversity of bus types, the assembly organization which has been applied so far does no longer meet the new requirements. Therefore, the reorganization of the assembly process is necessary. The factory employees have a radical idea for changing the organization of the assembly process. Their idea is to transition from one assembly line to three parallel assembly lines. As a result, such a change can be considered as the reengineering of the assembly process [6].

The main goals, which the enterprise wants to achieve, are the elimination of "bottle necks" and the increase in the production process efficiency. In the reengineering project the company staff designed the arrangement of workstations in the new production hall and the work organization of workteams, which perform various operations for many different types of buses. Then the simulation model was made to verify the described concept. The scope of the project includes:

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- building a simulation model, which presents the new assembly line in the factory, taking into account the arrangement of workstations and workteams in the new production hall as well as the transport between workstations,
- presenting work organization of workteams and division of individual workers' labour (who belongs to a particular workteam and performs operations on buses in a particular workstation) in order to determine the best allocation of tasks and the optimum size of individual workteams,
- determining the effect of assembly interferences on the work of particular workteams and the efficiency of the whole production system,
- defining the efficiency of the designed assembly lines and proposing changes aimed at the quality improvement of the created conception.

Another problem, which we needed to analyse simultaneously, was the question of verifying the efficiency of the designed workstations system, especially when the factory produces such types of buses which are the most labour-intensive for employees.

In the course of research and creation of the simulation model there were a lot of difficulties. They were mostly related with the need to understand the specific vision of the company's employees, as well as with the visualization and verification of the new work organization and the appropriate use of data about operations in the simulation model. After the selection of data, separate lists of operations for each workteam were created. These lists determined, among other things, sequences and execution times of operations for different types of buses. The lists of operations were organized in a such way that operations were carried out in accordance with the technological route (used in the factory) and the actual state of affairs in the production plant. A big challenge was to present the work organization of various workteams in individual workstations.

The model was created with use of LogABS technology [10] and FlexSim Simulation Software.

The main goal of the paper is to present a method based on mixing DES (Discrete Event Simulation) and ABS (Agent Based Simulation) approach where DES was used to model the main process – material flow (buses) and ABS was used to model assembling operations of teams of workers.

The article consists of 6 sections. The first section provides an introduction. Literature review is the subject of the second section. The third section defines the problem. The fourth section discusses the DES and ABS approaches. Implementation of Agent Base Simulation, structure of agents and possible analysis are described in section five. Conclusions and plans for further work are the subject of the sixth section.

2 The Literature Review

The problem described in the previous section refers to balancing the production line. It is a technique applied in factories which use production lines or group technologies by elaborate objective systems [4]. It depends on assigning work to workstations, which are connected in a series, while we should focus on minimizing the number of workstations and reduce the total idle time for all workstations (e.g. changeovers, unplanned maintenance activities [7]) for a given level of production [5]. In theory, when all workstations have the same amount of work which must be done, the production line is perfectly balanced. In reality, however, most of production lines are unbalanced, because the actual amount of work done by individual workstations is different. The problem of proper balance of production lines is one of the most common issues raised by engineers – production organizers. It is a multi-step decision-making process, which is related to allocation of a specific permissible group of operations to workstations on an assembly line, at particular discrete points in time called the assembly cycles. Due to the criterion of optimization, the problem concerns two types of tasks: minimizing the quantity of assembly positions with a constant cycle, or minimizing the duration of the production cycle with a constant quantity of workstations. According to the classical method of balancing the production line for a set cycle time, tasks should be assigned to workstations in such a way so that the time losses (idle time of machines) are as short as possible [2]. The balance problem is related to a much wider group of production lines. However, taking the constraints into account, the solution in each case is supposed to minimize the idleness of workstations. The applied methods can be classified into two groups [11]:

– exact methods, discrete linear programming, dynamic programming, division and restrictions,
– heuristic methods, serialization and division algorithms, approximation methods (one and many heuristics, relapse, limited time to obtain an optimal solution).

The examples of heuristic methods are as follows [13]:

– RPW- Ranked Positional Weight,
– RRPW- Reversed Ranked Positional Weight,
– Kilbridge’s and Wester’s,
– Hoffman’s Sequence Array Method,
– IUFF – Immediate Update First Fit.

In the industrial environment, the most commonly used solutions are the very simple ones. Employees create graphs on boards, in the form of magnetic panels or sheets (the size of a sheet is proportional to the time it takes to perform an individual activity), which show Gantt charts. In this case, Excel Spreadsheets are the most commonly used IT support. Usually, such solutions are sufficient to organize work in one workstation for several workteams.

However, simple solutions like, for example, magnetic boards with Gantt charts cannot solve complex problems and take into account uncertain execution times of operations which are extremely important in this case (usually execution times are changeable, they oscillates around particular values). It is also necessary to take into account the distance travelled by workers during the passing between several workstations - it is important factor in case of the assembly of large objects such buses. Considering issues listed above we decided to use simulation technology for modeling work organization of workteams. The available simulation software allows building complex models [3] in a relatively easy way. Moreover many simulation programs offers tools, which supports the preparation of schedules.

The most commonly used software is DES (Discrete Event System). DES has been the main way for the process simulation of manufacturing and logistics for about four decades.

This is adequate for problems that consist of queuing simulations and a variability is represented through stochastic distributions [12]. This approach is applicable in simulating the manufacturing and supply chain processes. DES models are characterized by a process oriented approach (the focus is on modeling the system in detail, not the entities) [8]. They are based on a top-down modeling 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 modeled as part of the system. In DES, queues are the crucial element; a flow of entities through a system is defined; macro behavior is modeled and input distributions are often based on collected/measured (objective) data.

In case of assembling operations we think that the process approach is insufficient. Workers are task executers. It means that they have the list of tasks to do. The worker decides what he will do next based on this list. So we think about worker as an agent. To do it we use approach based on ABS (Agent Based Systems). ABS modeling seems to be useful for modeling operators and forklifts, which have their own “intelligence”, where the intelligence means the ability to complete changeable task lists (in our case – the picking list). In this case, an operator must have the ability to receive and send messages to the adoption of a task list, and to send a message about the execution or termination of the implementation of the task list. In the literature this approach is also referred to as Task Driven [3]. In some papers can find different opinion about using agent based simulation for manufacturing:

– Not recommended for example in [1],
– Recommended in [1].

Authors based on their research propose to mix DES and ABS approaches.

3 Problem Definition

The topic of the project is reengineering of the assembly process and the analysis of assembly process efficiency in an expanded production hall, in one of the biggest bus production plants in Poland. Due to the rapid development of the company there is a need for investment. In recent years the number of contracts won by the company has been steadily growing and their products have been conquering the European market. The assembly line must be more efficient, because imperfections of the current work organization are becoming a problem for the company employees and directly affects financial results of the company. The current work organization does not allow to take full advantage of labour force and it is impossible to realize the necessary number of procurements.

Currently, work is performed spontaneously. Data about the time and sequence of performing operations are not standardized. Employees are often not able to perform all operations in one cycle of work. Workers perform them in the next workstation or continue operations when other workteams have already finished working on a bus. The potential of many workers is not used in the right way, while others are overworked. That is why, the company management have decided to expand the production plant by building a new production hall and changing the work organization. The purpose of these actions is to reduce the time and distance travelled by workers during the assembly process and, therefore, help the company save both time and money.

The defined task is to visualize and verify the work organization so that we can design precise arrangement of workstations and workteams. The aim of the analysis performed with the simulation model is to confirm or reject the designed organization of the production process and identify imperfections of the created conception. These activities will help the company to improve the project before it is put into practice and also avoid time-consuming and expensive verification or solving problems which may appear.

The main change is to transition from a single assembly line to three parallel assembly lines, which work with a delay, but their work is synchronized. This is a complex problem because it is necessary to describe each phase of the process, which involves completion of more than 2700 operations for many types of buses by over 200 workers, who work in 20 workstations.

The model presents groups of workstations called: ST0, ST1, ST2, ST3, ST4, ST5, ST6. These workstations support three parallel production lines (Fig. 1).

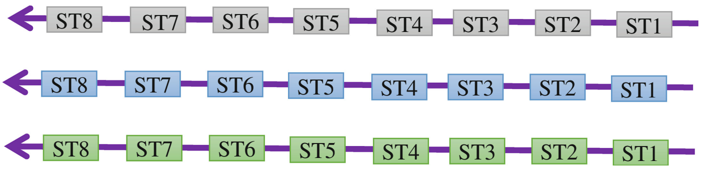

Fig. 1. Material flow by three parallel production lines

The workstations are supported by many workteams, which have different names, different sizes and various lists of operations which must be performed in consecutive cycles of work. Information about individual workteams is presented in Table 1. The work organization in workstations St1–St6 differs significantly from the work organization in St0 workstation. St0 workstation is supported only by B1 workteam, which performs operations on a bus continuously over the period of 300 min. Other workstations are supported by at least three workteams. Every workteam works in a workstation for 150 min and then passes to the next production line within a given workstation. The way of changing workstations by B2, B3 and B4 workteams in time is shown in the Fig. 2.

Table 1. Summary of the information about the workteams.

Workteams name.	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
The number of members.	15	12	12	11	11	11	11	13	12	10	11	12	12	14	10	13
Supported workstations	ST0	ST1	ST1	ST1	ST2	ST2	ST3	ST3	ST2, ST3, ST4	ST4, ST5	ST2, ST3, ST4	ST4	ST5	ST6, ST7, ST8	ST6	ST5, ST6

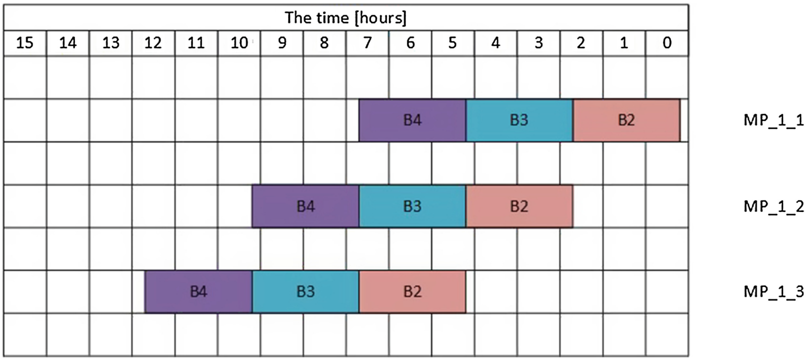

Fig. 2. Work organization of a workteam.

Buses pass through several workstations within the same assembly line. In the consecutive workstations buses are operated by other workteams. Employees from several workteams perform operations on buses in a sequence and time defined by global tables. Therefore, it is possible to carry out activities in accordance with the technological route and the work reality in the factory.

The data obtained from the company:

- information about the number of staff in each workteam, with their assigned workstations, supported by a several workteams,
- the list of all operations carried out during the production process,
- the duration of each operation, depending on the bus type,
- the project of the new production hall,
- the locations and names of workstations,
- the layout of operator workplaces in a workstation.

The assumptions of the project:

- The speed of workers is 37 m/min.

Each workteam consists of a specified number of employees. Each workteam is assigned a list of operations and workstations, which is necessary for the work. B1 workteam works in accordance with a specific algorithm, which is different than work organization of the other workteams. B9, B10, B11 and B16 workteams work in many workstations at the same time. Takt time of the production line for St0 workstation is 300 min, while for St1, St2, St3, St4, St5 and St6 workstations it is 450 min. After 300 min (which each bus spends at the St0 workstation) or 450 min (in case of others workstations) a bus is moved to the next workstation within a given production line.

Six major zones are designated in each workstation, depending on the stage of production. These zones are the destinations for workers, who have to execute their assembling operations. The division of the workplace into zones is shown in Fig. 3. Zones are marked with the numbers 1 to 6, which means respectively: 1- front, 2- interior, 3- back, 4- side, 5- roof, 6- chassis of the bus. The employees also carry out the subassembling operations in the dedicated zone of the production hall.

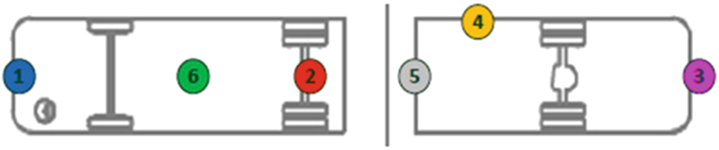

Fig. 3. The division of a workplace into various zones.

4 DES/ABS Concept to Model Work of Workteams

As mentioned earlier – Sect. 2, authors propose to mix DES and ABS approach to model work of workteams. Typically simulation tools use a process driven approach where the flow of the parts between processes cause the demands on resources, i.e. a part moves to a machine and demands a resource to complete the operation. Whilst this methodology is fine for some applications it does not allow for situations where the resources have tasks to complete which are not flow related – in. In these situations a 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 jobs to do and when.

Many discrete events simulation programs available on market offer these possibilities. For the performed projected we choose FlexSim due to the following features [3]:

- ease of use in a real size with drag and drop technology,
- loading an .dwg file from the layout directly to a model,
- objects ASRS vehicle, Crane, Robot, Elevator,
- extended possibilities to model conveyors,
- fitting the shape of trucks and their parameters – in real values,
- integrating built-in experimenter tool with OptQuest,
- **including task sequence technology**.

Flexsim Simulation Software is a powerful analytical tool, which allows building three-dimensional computer models of systems as well as studying and analyzing their performance at a significantly lower cost than in case of real-time simulations. Moreover constructed model must be easy to use and understandable for its future users, because it takes into account all their requirements for the verification of the designed process and also helps them to understand it.

The bus assembling process is characterized by this feature that the bus is moving from station to station every cycle time (450 min) and on the station some workteams of operators work. Their work depend on task lists not on flow. So natural way is to model flow of buses using standard process approach (offered by DES program – in this case by FlexSim) and to model work of operators grouped in workteams using task driven approach. FlexSim offers one of more developed task driven approach on the market, but it is still not enough for complex model of human works. We need more general concept/idea, more “smarter” object which break the restrictions of FlexSim’s tasksequence concept. Approach based on ABS offers it.

5 Implementation

This section presents the main idea to implement ABS in discrete event simulation program. We prepared the solution in environment of FlexSim. This program offers the tasksequence mechanism to model mobile resources. The modeler 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. We extended this concept. We define agents based on taskexecuters from FlexSim – we add intelligence it means that our agent (extended FlexSim taskexecuter object) can make decision and he prepares based on order for him, his own list of tasks to do with possibilities to change this list. The defined agent has following characteristics according to [9]:

- is identifiable, a discrete individual with set of characteristics and rules governing its behaviors and decision-making capabilities,
- is autonomous and self-directed,
- is situated, living in environment with it interacts with other agents – has protocols for interaction with other agents,
- is goal directed – having goals to achieve,
- is flexible – having the ability to learn and adapt its behaviors based on experiences.

To solve problem of modeling and simulation work of many workteams for assembling, we defined two special agents:

- base agent – contractor,
- team agent.

Contractor is agent build based on taskexecuters from FlexSim, but his set of skills is extended in comparison with original taskexecuter from FlexSim – Table 2.

Team agent is the agent which has following rules:

- to prepare the goals for agents from team based on order (main task list),
- to control – it means to select, prepare and activate agents in team,
- to control time.

The protocols for communications between agents and team agents are defined – Fig. 4.

Table 2. Summary of the information about the workteams.

Feature	FlexSim taskexecuter	Agent contractor
Making decision	No	Yes
Possibility to check and evaluate the situation	No	Yes
Base skills	Travel, load, unload, utilize	Travel, load, unload, park, ready, check, check and load, call (other agent), free, reorganize, work
Where is represented intelligence?	Outside taskexecuter	Inside - Intelligence is represented within each individual entity

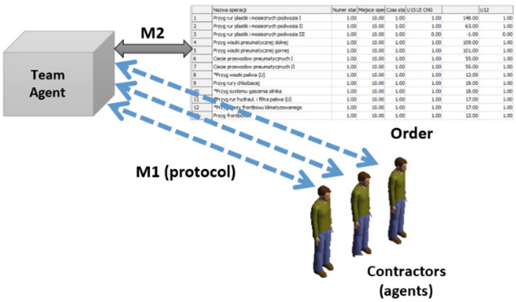

Fig. 4. Information flow between agents

Orders (list of activities to perform) are built based on an excel file obtained from bus company. The structure of this file is as follow:

- a row in a table – one activity from the location indicated by columns,
- columns contain the name of the activity, number of station (Fig. 1), number of zone (Fig. 3), time of activity depend on type of bus – if time is 0 it means that this activity is not valid for this type of bus.

The Team Agent prepares the list of tasks based on the set of rows from Order table (M2 arrow from Fig. 4) and sends this list to Contractors (M1 arrows from Fig. 4). The Team Agent works as an answer to a request from the assembling line Fig. 5 – big arrows with "Requests" starting from ST1. When the bus enter to station the requests are sent to Team Agents which are assigned to this station. Team Agent has to perform the list of all activities in cycle time (150 min) using all Contractors assigned to team.

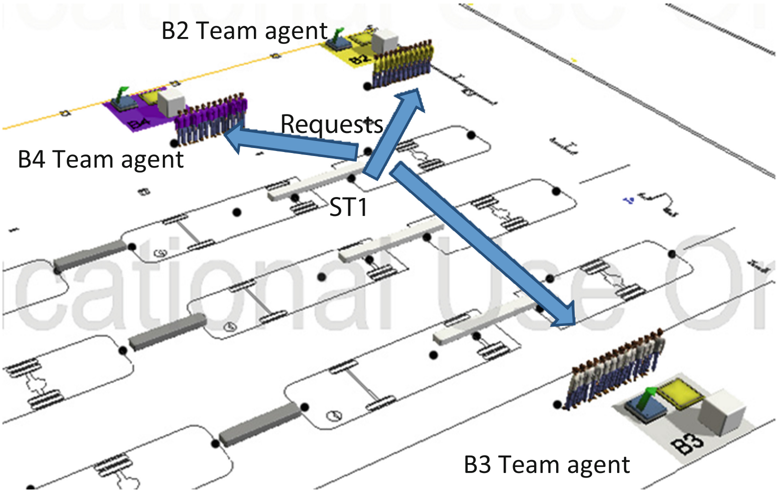

Fig. 5. Requests for work from assembling line to team agents

Described mechanism was implemented in FlexSim (Fig. 6). The model includes 20 stations – 2 special stations in the beginning of process and 18 stations in three parallel lines (Fig. 1). The work of 23 workteams was modeled. It is possible to change the number of members of workteams and to define new type of bus. The model enables to perform experiments with following reports:

– workteam conflicts – situation when the workteam finish his work after end of the cycle time,
– list of operations which cannot be performed because the time to the end of cycle is shorter than time of operation,
– list of idle time by workteam at the end of cycle – to evaluate the team work.

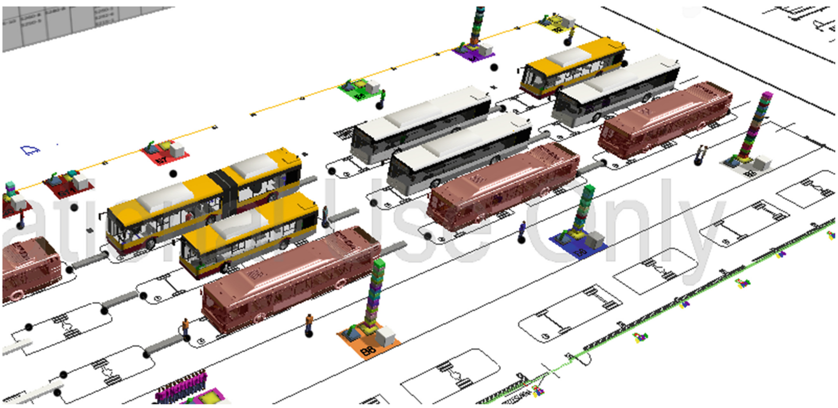

Fig. 6. View of bus assembling line in FlexSim

6 Conclusions

The paper presents the research results performed for bus company. The research focus on building the simulation model of workteams work in finish assembling line. To build the model we use mixt DES/ABS approach. As base the DES simulation program FlexSim was used and in this environment we developed our own agent base simulation tool. To do it we extended standard FlexSim taskexecuters and tasksequence mechanism. The model and prepared tools were implemented in bus company to analyse new assembling process. Thanks it company can short the time to make decision about workteam work organization. This tool can be used in two levels:

– design level – when new layout and new organization of works are designed,
– operational level – where finding the best solution is needed because of absence of workers or sudden disturbances in assembling process.

The paper presents first build model. Model was accepted by bus company so we define the possibilities to extended it by:

– skills matrix of workers – Team agent assign workers to activity based on skills of workers which are saved in this matrix,
– introducing special Contractor Agent – Jumpers – workers which can be shared by many workteams,
– introducing tools which will enable to define optimization task to find the best assigning.

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