10.26411/83-1734-2015-2-55-8-23

# Evaluation and Analysis of the Implementation Process of the Use of Rail Transport in Military Transport Using Flexsim Software

Mieczysław Pawlisiak
*Military University of Technology, Poland*

Katarzyna Smalcuga
*Military University of Technology, Poland*

Tomasz Waśniewski
*Military University of Technology, Poland*

**Abstract**
In the realities of modern battlefield, training of soldiers is crucial, therefore it is so important to develop an optimal concept of moving troops by rail transport, for exercises and training in peacetime. Using the simulation of the implementation of rail and road transport, it is possible to analyse and meet the needs of the selected relationship of individual stages of the process studied. Simulation model allows to state that it serves as an illustrative, training element and an element showing some results with changeable situations, therefore it can be a solution for training and making critical decisions for competent commanders.

**Keywords:** rail transport, road transport, need, transport, military training ground, modelling, and simulation.

## 1. INTRODUCTION

Rail transportation is undoubtedly one of the important modes of transportation in the national economy, with its heyday in the second half of the 19th century and the first half of the 20th century. In Poland, railroads are relatively widely used in military transportation for operational, training and logistical needs, respectively.

In order to effectively conduct warfare, it is necessary to have the necessary forces and resources at the right place and time. The key issue, therefore, is to provide conditions suitable for moving supplies and military equipment from the place of permanent dislocation to the training ground. Transportation tasks should be carried out in accordance with the expectations of the place and time, so the idea of using the most accessible types of transportation possible while maintaining the highest efficiency of operation is so important. Taking this into account, it is reasonable to define the purpose of the article, which was adopted as a presentation of the possibility of using rail transport in military transportation, with an indication of optimization options using FlexSim modeling and simulation software. Based on the purpose of the article thus defined, the research problem can be defined in the form of the question of how to organize and plan the movement of troops by rail transport with the presentation of optimization options using FlexSim software? In order to solve such a research problem, it is necessary to use both theoretical and empirical methods. Based on the method of computer simulation and the method of individual cases, a visualization of the process of loading military equipment, transport by low-loader sets and transport by rail was developed. The obtained results of the research, based on the observation method and the diagnostic survey method, will allow to present in the article how to effectively organize and plan the movement of troops using FlexSim software.

## 2. THEORETICAL ASPECTS OF THE USE OF RAIL TRANSPORT FOR TROOP MOVEMENTS

In peacetime, rail transportation is mainly used to transport troops to training exercises and training grounds, as well as to realize the transportation of material resources and supplies. On the other hand, in times of crisis and war, rail transportation can be used to move forces and resources as part of an ongoing NATO or European Union allied operation. Training soldiers in conditions as realistic as possible to the intended conditions requires rendering the realities of possible scenarios of the modern battlefield, which is why it is so important to move for manoeuvres and trainings on the training ground using elements of the transport system that are available to the Armed Forces through cooperation with the state provider of such services. Following this line of thinking, it is necessary to establish an appropriate plan for the movement of troops[1].

[1] R. Kacperczyk, *Transport and forwarding, part I. Transport*, Warsaw 2009.

Transportation in the context of meeting the needs for the movement of troops, that is, the resulting transportation process as including movement from the point of origin to the destination and such activities as loading, unloading, reloading and additional handling activities[2]. An equally important element in the perception of the topic of transportation is the financial settlement of charges for the transportation of troops by rail, which is carried out on the basis of so-called: settlement agreements, concluded between the Military Economic Branches, which act as Economic Branches, and the contractor of the rail transport service, usually the state railroad carrier, namely PKP Cargo S.A. company. Transportation can be defined as the provision of a service for a fee, the purpose of which is to move people, equipment, as well as ancillary services, using dedicated forces and resources[3].

The question of the theoretical aspects of transportation use, is significantly related with the satisfaction of needs, so it is necessary to take into account transport parameters. Transport parameters are, as a rule, data on volume, time and distance. With these parameters, knowledge of transportation needs is crucial, for the effective and efficient operation of transportation by various modes of transport. When analysing the theoretical aspects related to the possibility of using rail transportation to transport troops, it is crucial to pay attention to the state of the rail infrastructure line network[4].

Summarizing the theoretical aspects presented, it is possible to accept the statement that there are opportunities to use rail transportation for military transportation. The key to indicate the quantitative, qualitative and temporal possibilities regarding the efficiency of military transportation, is to conduct research under real operating conditions. Undoubtedly, the movement process can be improved and adjusted accordingly by using computer simulation. Thanks to which, through the introduction of appropriate values, parameters and variables, the course of delays of such movement can be corrected, and ultimately this type of solution would serve as an illustrative, training and influencing element for making sensitive decisions for the relevant commanders.

2 Z. Kurasiński (et al.), *Compendium of military logistics*, Warsaw 2014.

3 *Doctrine DU-4.4.1(B) Rules. Transportation of troops by rail transport*, [in:] *General Command of The Armed Force Types*, Warsaw 2014.

4 M. Pawlisiak, *Logistics system determinant of the safety of the Armed Forces*, Warsaw 2016.

## 3. EVALUATION OF THE EFFECTIVENESS OF THE USE OF RAIL TRANSPORT AND LOW-LOADER SETS USING FLEXSIM SIMULATION ON THE EXAMPLE OF THE SELECTED ROUTE

In order to develop a simulation of the implementation of the transport of a subdivision, it was necessary to create the right conditions to analyse the execution time of the various stages of the process under study. Equally important to carry out the simulation, is the selection of appropriate software to consider the logistics process in terms of time, quantity and money. This makes it possible to analyse the process from a number of aspects, including those that are of most interest to subdivisions of both armoured forces - in this case, armoured troops - as well as logistics subdivisions or Military Transport Commands. The choice of the appropriate environment should be guided by the principles of simplicity, transparency, but also functionality.

FlexSim software version 2021 was chosen, which provides a clear user interface, facilitates programming by creating simulations not only in the classic version for programming environments - by typing code in the appropriate syntax - but also programming by designing algorithms for the relevant elements, which are graphically represented on the user model (Fig.1)[5].

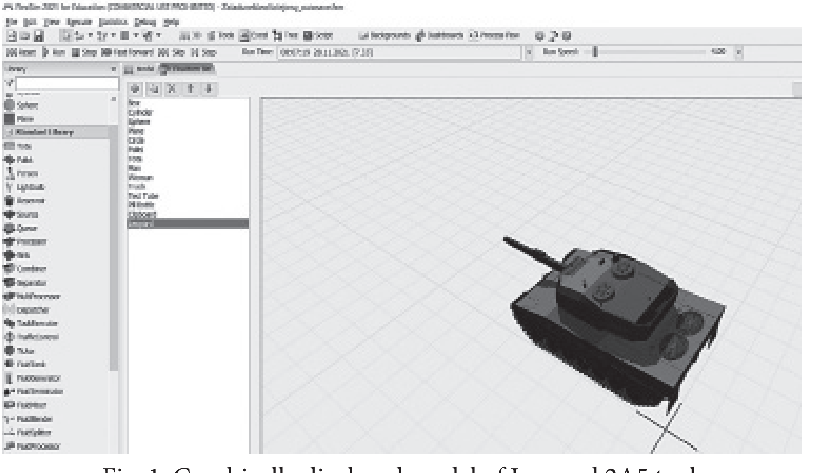

Fig. 1. Graphically displayed model of Leopard 2A5 tank
Source: own elaboration

[5] M. Beaverstock, A. Greenwood, W. Nordgren, *Applied simulation. Modeling and analysis using FlexSim*, Kraków 2019.

FlexSim software provides the user with the implementation of the simulation by adding elements to the model under consideration, in other words, the “workspace”, which in the form of graphic objects (both two- and three-dimensional), have their parameters, which the user can change before running the simulation. In this way, the simulation is personalized for the user 5 considering the process under study, and this allows it to be even more representative of the real situation. This, in turn, makes it possible to search for a solution not only to a general situation, such as the consideration of the choice of the type of transport, but also to modify the chosen realization of the process in terms of introducing variables - for example, the change of maximum speed reached by the considered vehicle - having a dramatic influence on the analysis of the examined process.

In addition, the FlexSim software also has two built-in modules for the described work components:
- Process Flow
- Dashboard

The first one allows the user to program in an algorithmic way the logic of the process execution. Process Flow allows the user (Figure 2) to:
- Decide the way in which the observed simulation will begin.
- Adding additional logic by introducing an algorithmic decision-making process (similar to the classic programming languages “if” or “switch case” or “when”).
- Creation of the so-called tokens, i.e. elements of the considered model. Generating instances of objects in the considered model. In the case of described simulation these are tanks Leopard 2A5.
- The SubFlow creation process, which is the starting algorithm executed in parallel with the main algorithm, is based on a similar principle - its operation can be compared to the execution of concurrent instructions, but in a simplified way. SubFlow is a co-program executed asynchronously with the main code from the Process Flow, in order to execute the corresponding instructions, such as loading and unloading objects from the order list generated earlier.
- Changing the graphical aspect of the model or model elements by programmatically changing the size, location or rotation of the object, as well as introducing animation.
- Create new objects relative to other existing objects.
- Create sequences of operator actions such as loading an object, moving it from a start point to an end point, or unloading it.

- Create lists and retrieve tokens from the list created by the Process Flow logic or model element.
- Creating relationships between 'people-operators' who must have many specific relationships with each other.
- Adding objects using a procedural algorithm that translates visually into quantity and time.

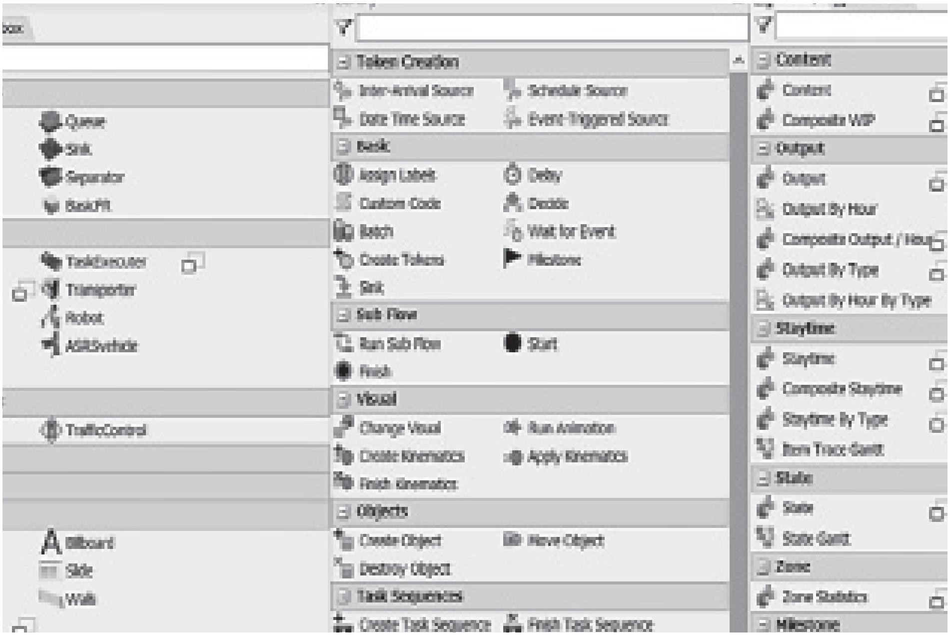


Fig. 2. An example of programming in an algorithmic way the logic of process implementation

Source: own elaboration

The above-mentioned elements of logic, allow the user to create both a simple, basic algorithm of conduct in the case of appearance of an object on the waiting place (queue, buffer), as well as the process consisting of a complex logic, for example, deciding on the transport of items in accordance with their parameters such as weight, dimensions, purpose defined by adding "identification labels" (label) by various operators performing advanced animations, or during the implementation of other equivalent processes. FlexSim software is, therefore, an intuitive solution for the simulation of the implementation of land transport, and the second update of the version 2021 also allows the implementation of other forms of transport by air using map elements.

The prepared model before commissioning contains elements, with appropriate parameters. In this case, attention should be paid to:

- Queue (buffer), which, as objects appear on it, adds them to the order list, from which they are then retrieved when executing the algorithm described in Process Flow.
- Queue objects, to which a 3D model of the railroad ramp has been introduced, in order to represent as close as possible to the real process under study. These queues have an introduced parameter for the maximum number of things stored in it of 1, since and in real conditions only one Leopard 2A5 tank can be accommodated per rail ramp.
- Sources generating at time instant t=0 the appropriate number of objects, which are assigned the Leopard 2A5 model. This allows, to start the simulation with a top-down limited number of equipment needed for the analysis of the logistics process.
- The processor to which the working time is defined, which will be called the averaged execution time of loading a single object on the rail ramp. In the case of the simulation, it is 15 minutes. This is the value taken from the environmental interview and divided by the amount of equipment.

A loading simulation was created which has (Fig. 3):

- Algorithm starting event - “Event-Triggered Source” has been selected, which allows to start the algorithm when 18 vehicles (tanks) appear on the queue station (in the model it is “Queue1”).
- The appropriate number of tanks that have been entered into the object list. Thus, only those objects are used in the simulation which were generated at the beginning of the algorithm.
- Assignments to operators to perform actions described in later Process Flow instructions.
- Loading process.

The loading process (Fig. 3), in this case, is the most elaborate part of the algorithm. It stipulates that the operator executes the movement from location A to location B, where the appropriate amount of transportation means has been generated, and then the operator picks up one of them and transports it to the designated location in the time taken into account. This process, compared to the execution time of the processor, is not large, and it does not significantly affect the loading time or the duration of the simulation, as it takes less than 3 seconds (which generates a delay of less than a minute in the total execution of the simulation). In the actual loading process, the loading time of a single tank is not a constant value, but a fluctuating one, which makes the assumption of a one-minute delay on the loading of the entire transport not a gross error, since according to the DU-4.4.1(B) standard, a total loading time of 4 hours and 30 minutes for tank subdivisions is considered. Once the processor completes its work, it transports the object to the rail ramp.

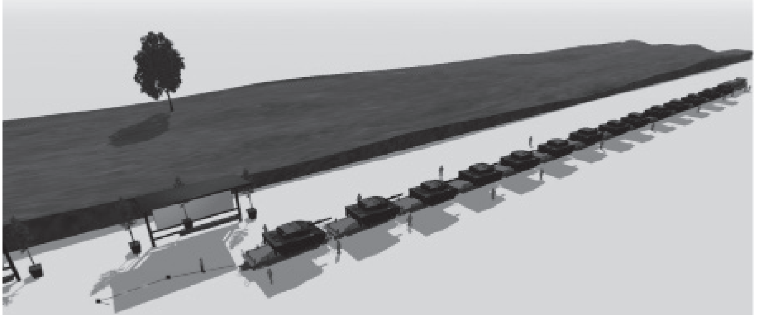

Fig. 3. Simulation of the loading process
Source: own elaboration

Thanks to the assumption that there can only be one tank on the ramp, the combined 18 cars with the processor create a good representation of the rolling stock, which is loaded from the car closest to the locomotive to the last car. When this process is executed, another number of object will be taken from the order and the process will be executed until the list is not empty, that is, all tanks are taken and transferred to the processor.

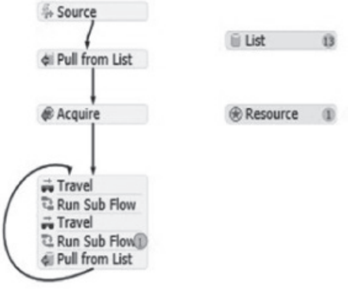


Fig. 4. Loading algorithm using Process Flow module
Source: own elaboration

As mentioned before, this process should, according to the norm, take no more than 4 hours and 30 minutes. In the option under consideration, loading takes exactly that amount of time including the delay due to the timetable.

Analysing this process, the following conclusions should be made:

1. Time of realization of loading largely depends on the time of loading a single tank on the ramp. Increasing the number of exercises and at the same time the experience of soldiers in the implementation of loading, familiarization with the driven vehicle, you can effectively reduce the time required for loading the entire transport.
2. Another factor that would help increase the speed of vehicle loading is the expansion of infrastructure. In this example, it is assumed that the military railway siding has one track per direction. If the number of tracks is increased, the number of tanks loaded at the ramps can be increased.

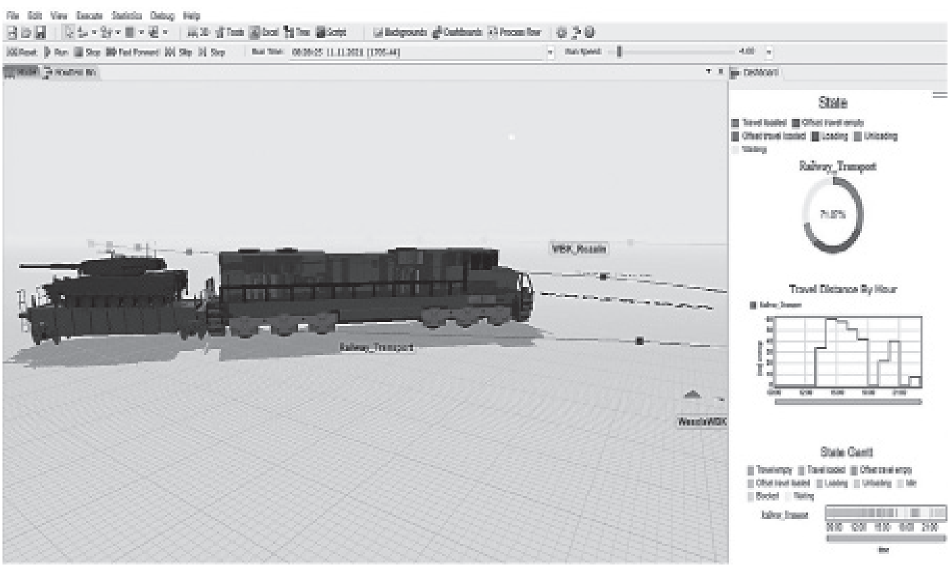


Fig. 5. Visualisation of rail transport with Dashboards
Source: own elaboration

After analysing the loading of military equipment on ramps, the process of rail transport of a subdivision of Leopard 2A5 tanks from the place of permanent dislocation to the training ground is presented.

The next element subjected to computer simulation is the whole logistic process of railway transport, which time includes loading, moving the subdivision and unloading. The loading time has been assumed according to the standard and included in the simulation process (Fig. 5).

An algorithm for the operation of the transport simulation (Figure 6) was developed:

1. In an analogous way to loading, 18 objects were generated on the queue described as "WBK Wesoła", which represent wagons in the rolling stock.
2. The loading process was simulated by attaching a ramp with a loaded tank to the locomotive. In this case, the tanks are generated by inserting the appropriate block in the Process Flow algorithm. The military equipment is generated on the ramp model according to the loading direction.

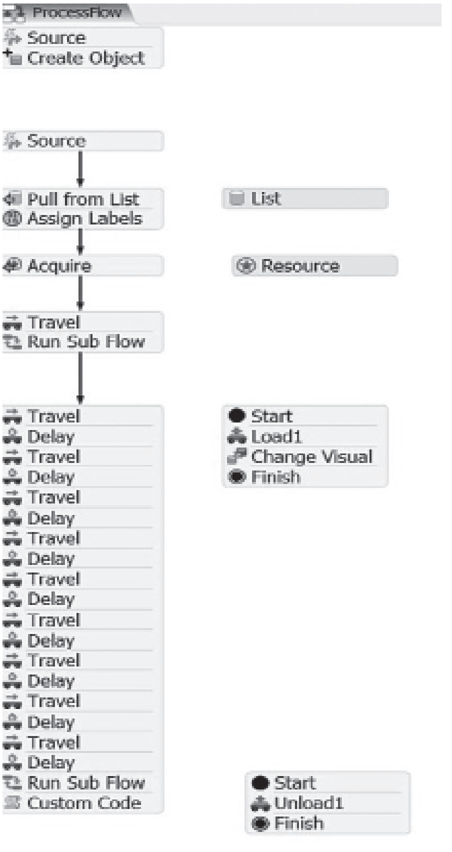


Fig. 6. Algorithm of rail transport using Process Flow module.
Source: own elaboration

3. After loading the military equipment, the train - which is the operator that performs the movement of the object (in this case, 18 wagons, according to an individual timetable) - performs its task moving through objects that the software defines as a network of connections - “Network Node”. The logic of these objects makes it possible to set the appropriate parameters of the journey, such as the change of virtual distance value, the introduction of the maximum speed developed on a given section and traffic intensity in a given direction of the route. This allows to increase the real representation of the considered process and its analysis.
4. Rail transportation of military equipment is subject to many variables, resulting in the need to introduce delays that affect the overall process time.
5. When the train reaches point B, unloading takes place. The unloading time according to the standard is a maximum of 2 hours and 30 minutes, which is also assumed in the simulation.

After the simulation, the user receives data in the form of a graph (operator occupancy), which in this case is the locomotive (Fig. 7).

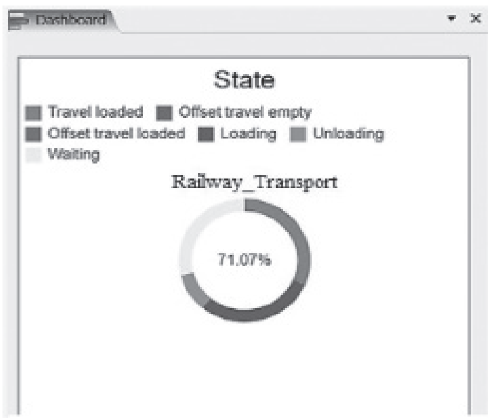


Fig. 7. The diagram describing the dependence of operator (locomotive) occupancy.
Source: own elaboration

The diagram describing the dependence of the occupancy of the operator (locomotive), allows for the analysis of the time required for the implementation of the various elements of the process considered (Fig. 7), and thanks to it the following conclusions can be drawn:

1. The most time-consuming part of the entire process is not only moving the subunit from its permanent dislocation to the training ground, but

also loading the military equipment. This was pointed out when describing the previous simulation, however, within the overall process, it further emphasizes how important it is to work with soldiers to minimize loading time, increase familiarity with the equipment being operated, and get them accustomed to executing procedures that require a high degree of precision.
2. The movement is always associated with the introduction of delays, which are due to the occupation of railway tracks in a given direction.
3. Delays beyond PKP Cargo's control, such as track damage or accidents on the route, cause additional delays that require the Military Transport Commands to draw up another individual timetable and resume transport.

Another type of Dashboard object that was used in this work was the relationship of the distance travelled by the operator in hours (Figure 8). From this relationship, the average speed of the vehicle in time windows can be determined, and this allows to analyse how the transport was performed. The area under the graph indicates the total distance, i.e. the distance from the place of permanent dislocation to the ground forces training centre. In the case of the studied relation, the graph indicates two time intervals where the journey is interrupted: from 6 p.m. and from 9 p.m. In these time intervals, the operator (low-loader set) respectively has a scheduled stop or realizes the unloading of military equipment (Fig. 8).

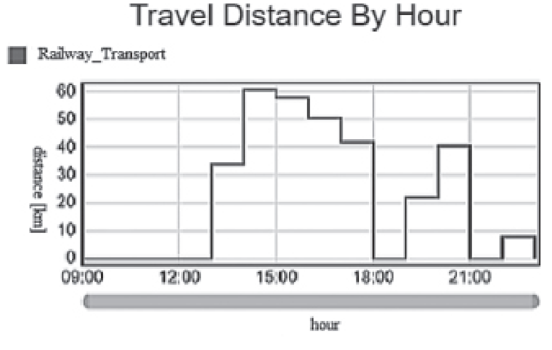


Fig. 8. Travel distance by hour
Source: own elaboration

The last chart discussed is the Gantt chart (Fig. 9). It is a type of bar chart, whose purpose is to depict the simulation time (in an hourly window). It describes the status of the operator, which he achieved by executing the appropriate instructions contained in the algorithm of conduct, i.e., in the Process Flow described earlier. Thanks to this, the user is enabled to analyze in real time, (time window) how the simulation process is progressing, and this allows further considerations for the optimization of the studied simulation case.

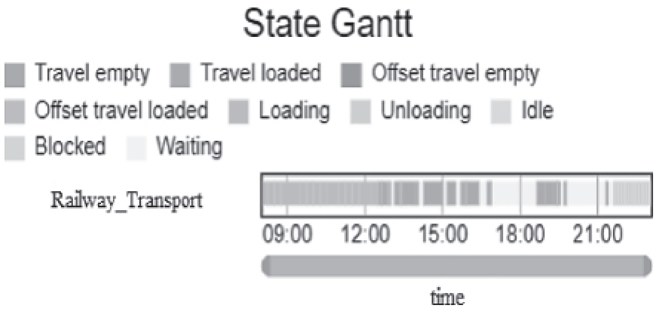


Fig. 9. State Gantt chart for railway transport - Dashboard object in FlexSim software
Source: own elaboration

In order to compare the methods of realization of the process of transportation of troops, simulations of transportation of a subdivision of troops by road transport were also considered (Fig. 10).

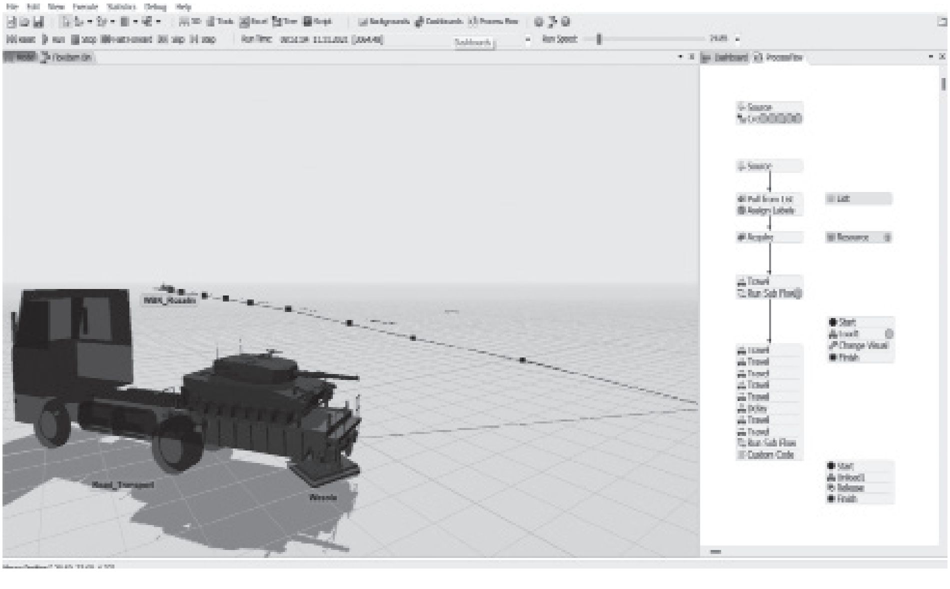

Fig. 10. Visualization of Road Transport with Process Flow Algorithm
Source: own elaboration

Transport using low-loader sets for the same relation as rail transport, in order to analyse this transport option in terms of time. A corresponding simulation was developed for this purpose, which showed a lower operation time, however, the financial analysis for longer distances makes this transport less efficient than the previously described mode of transport. The simulation of road transport has an analogous algorithm to that of rail transport, with the difference in loading time, route, and unloading time, which was developed according to the time standard for loading and unloading operational road transport for tank subdivisions. Describing the time of loading and unloading were monitored using the Dashboard module in FlexSim software, and then were exported to a file with the extension csv[6]. Thanks to such a record of data, the user of the software can select the data and give them further analysis in programs more suitable for this purpose such as Microsoft Excel.

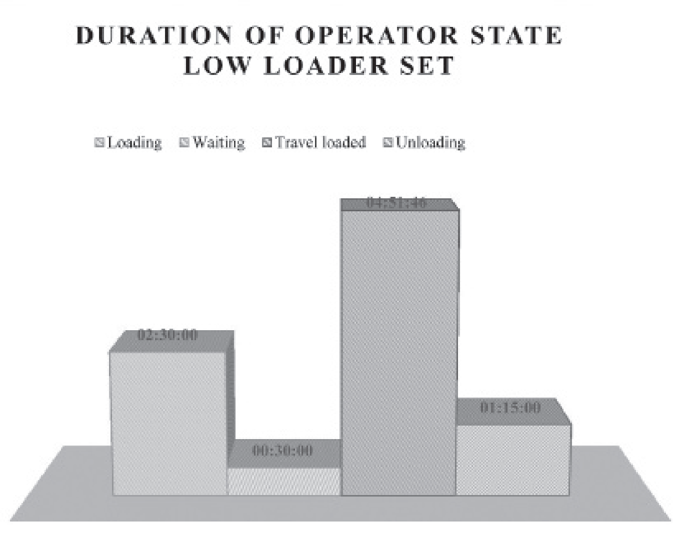


Fig. 11. Duration of the operator's state for the simulation of the realization of transport with the use of low-loader sets

Source: own elaboration

In conclusion, with the use of FlexSim software in the field of transportation by performing a detailed analysis of the different modes of transportation, the structure of the models can be considered and improved using visualization with visualization of the process, which allows the commander to make the right decision.

6 CSV (ang. comma-separated values).

## 4. SUMMARY

The purpose of the article, as noted in the introduction, was to present information resulting from the possibility of using rail transport in military transport, and then to indicate the appropriate variants, using FlexSim software. On the basis of the developed model, it can be clearly stated that the process of movement of troops in peacetime by rail and road transport is possible to implement, however, one should consider the relevant issues related to time, cost and distance of the chosen relation of movement. In addition, choosing a particular mode of transport, one should consider the most economical and effective means of transport during movement of forces and means of subunits.

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**Mieczysław Pawlisiak**
**Military University of Technology, Poland**
**mieczyslaw.pawlisiak@wat.edu.pl**
**https://orcid.org/0000-0003-2501-8779**

**Katarzyna Smalcuga**
**Military University of Technology, Poland**
**katarzyna.smalcuga@student.wat.edu.pl**
**https://orcid.org/ 0000-0002-5768-7793**

**Tomasz Waśniewski**
**Military University of Technology, Poland**
**tomasz.wasniewski@wat.edu.pl**
**https://orcid.org/0000-0002-9424-377X**