MODELING AND SIMULATION IN THE FRAMEWORK OF CIVIL AND MILITARY LOGISTICS

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Abstract

The article briefly explains the concepts of modeling and simulation. It gives examples of the use of modeling and simulation in civil logistics - simulation of a beer can production line and also in military logistics - simulation of deployment process of military unit. It also describes the differences between civil and military logistics and the advantages of using modeling and simulation. The use of Simio software for supply chain modeling and simulation is illustrated with a model example. The result is a description of the outputs from the simulation software and the selection of the best option based on the given criteria. The topic of modeling and simulation, especially in the military domain, deserves deeper exploration and the use of complex models to capture real-world situations, which can be used to improve logistic processes not only during military operations but also during peacetime.

Key words: modeling, simulation, logistic process, military, Simio

1. INTRODUCTION

The main goal of this paper is to introduce modeling and simulation, their possible use in civil logistics and subsequently also in military logistics.

The supply chain in civil logistics can be an absolutely critical factor in product design. Various factors influence the design and operation of the supply chain itself, such as concerns about contingencies, economic security, uncertain input and energy costs, and others.

Thiers and Mcginnis (2011) suggest that for a sustainable practice of simulation in logistics, the current practice of using an analytical model as the first formal model of a logistics system cannot be continued; rather, a model-based approach is needed that begins with a formal language to capture a definitional description of the logistics system itself.

With the development of computer technology and therefore computing power, not only are the possibilities for more complex simulations opening up, but simulation software is nowadays no problem to run on a regular personal computer, making simulations accessible to a wider range of users

Producers of goods, companies involved in the transport of inputs for the production of the goods, and subsequently in the transport of the final product. Other companies that store the goods and, last but not least, the customers. All these entities are part of the global supply chain. These chains are complex systems made up of often a large number of companies, locations and transport hubs. The result of these chains is often the satisfaction of demand for millions of units of the final product.

Research on global supply chains is mainly concerned with optimisation models. These models, as the name implies, try to optimise various factors of the supply chain, on the basis that we know all the necessary facts. Typically, these models can be used to optimize, for example, the ideal location for production or warehousing, how much inventory we should optimally have in these warehouses, which supplier will be most efficient to take the necessary inputs from, and how to transport the goods. All this for the sole purpose of minimizing logistics costs.

The second approach is simulation models, the fundamental difference from optimization models is that the things we were trying to find out with the optimization model are known or given in this case. An important factor here is the uncertainty about factors such as costs. So these models are trying to build a picture of actual performance based on these variable parameters.

Military logistics is quite different from civil logistics. There is neither competition nor a requirement to make an economic profit. The essence of military logistics is mainly to secure the required amount of material in required quality at a given time in a given place for given military unit. A fundamental aspect of operational logistics, for which simulation tools are of key importance, is its ad hoc nature and the process of deploying military units (contingents) and their operations in a multinational operation is always, at least partially, unique. Nevertheless, it is highly advantageous to have a predeveloped model (model core for the respective SW interface) that will ensure, even with limited a priori information, basic decision support for the respective commander. In the context of the actual operation, it is then possible to model and simulate basically any logistics process with sufficient time and information. In contrast to civil logistics, problems in the logistics chain in such an operation can be fatal, e.g. due to shortages of water, ammunition and other vital supplies of a bulk nature.

2. MODELING AND SIMULATION

The use of modeling and simulation can be seen not only in supporting the planning, design and subsequent evaluation of dynamic systems, but also in evaluating strategies for system transformation. According to (Birta & Arbez, 2013), their importance is growing at a remarkable rate because their use is not limited by the boundaries of the disciplines.

However, the growth is also due to the opportunities provided by the availability of computational resources and the growing portfolio of human skills that can make use of this computational power effective.

2.1. Modeling

The model plays the role of a surrogate for the system it represents and its purpose is to replace the system in experimental studies. If the underlying system does not exist (e.g., it may only be an idea, concept, or design), the model is the only option for experimentation. But even if it does exist, there are a number of reasons why experimenting directly with it might be inappropriate. Such experimentation might be, for example:

- too costly (determining the performance benefit that would likely be achieved by upgrading the hardware at all switching nodes in a large data communications network),
- too dangerous (exploring alternative control strategies for a nuclear reactor),
- too intrusive (assessing the effectiveness of the proposed network of one-way streets in the centre of an urban area),
- irreversible (examining the impact of a change in tax policy on the country's economy), (Birta & Arbez, 2013)
-too time-consuming (investigating the spread of an invasive plant species),
- morally/ethically unacceptable (testing the spread of toxic substances from the factory through the river system).

2.2. Simulation

A computer simulation is, in a narrower sense, a program that is run on a computer. This program uses sequential methods to investigate the behaviour of a mathematical model. Usually this model is an image of a real system, but it can also be just an imaginary system. One run of the program on a computer is a simulation of the system. The algorithm takes as input the values of the system variables at a certain time. It then calculates the state of the system at time +1. From these values, it then calculates the values at time +2, and so on. The computer produces a numerical picture of the evolution of the system, based on the model.

According to Winsberg (2019): the sequence of model variable values can be stored as a large collection of "data" and is often viewed on a computer screen using visualization methods. Often, but certainly not always, visualization methods are designed to mimic the output of a scientific instrument - to make the simulation appear to measure the system of interest.

3. CIVIL USE OF MODELING AND SIMULATION

Simulation is a modern tool for the analysis of complex production, supply, service, communication and other business processes (systems). A significant advantage of simulation is the fact that everything happens only in the model, without any necessary intervention in the operation of the enterprise. Using simulation, it is possible to explore different alternatives for changes in the system, verify the impacts and consequences of these changes, and select the solution that is most appropriate for the situation. Thanks to simulation modeling, the risk of wrong decisions is reduced to a minimum, as an error discovered during experiments with the model is always cheaper than an error that is discovered only during the implementation of a specific, unexamined solution proposal (Tvrdoň & Bazala, 2019).

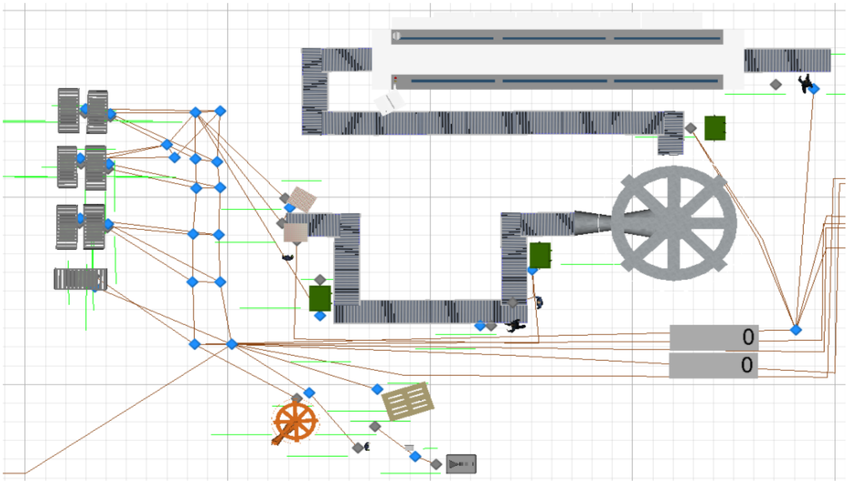
Civil logistics is a very broad concept, so there is a plethora of possible applications of modeling and simulation in this area.

3.1. Use for the support of decision-making in logistics design of a cans packaging line

Strategic decisions concerning production systems usually concern the design and allocation of resources in the medium/long term. Problems at this level may typically involve conflicting objectives and therefore require strong expertise as well as advanced decision support tools (Bruzzone & Longo, 2013). They also have a strong impact related to financial issues.

This example shown in the figure 1 focuses on the design of a new can packaging line. It aims to support decision making to ensure the best configuration of internal logistics, including storage and material handling, to avoid additional costs. In this paper, discrete event simulation is used to support decision making in the design of the internal logistics of a can packing line. The proposed simulation model allows to evaluate and define the best strategy to minimize the costs associated with production and distribution. With the impact of introducing a new packaging line within the logistics operation. The main attraction of this tool for the customer is that it can emulate future operational policies and analyse the behaviour of a system that is currently only in design. It also allows experimentation with new equipment layouts, conveying systems, hardware systems, etc. without having to invest money to acquire or purchase them, interrupting the normal operation of other lines that will be used to interact with the new line (Achkar et al., 2020).

Figure 1. Model of can packaging line made in Simio



Source: (Achkar et al., 2020)

4. MILITARY USE OF MODELING AND SIMULATION

Military logistics is somewhat narrower than civil logistics. However, the use of modeling and simulation can be seen in particular in areas such as training of military professionals, during planning and during military operations, to support the decision-making process of the commander, but also in peacetime conditions, when the requirements for military logistics approach the requirements for civil logistics (e.g. rationalisation of stock flow, etc.).

Modeling and simulation provide a comprehensive overview of the planned operation, can help to identify weaknesses in a given system or predict the amount of inventory and human resources needed to successfully complete the task. Another possibility is to use them in specific training of military professionals without the need to organise a military exercise, i.e., using only simulation. A combination of live simulation with computer simulation is also possible.

When we talk about simulations in the military environment, it is mainly about live simulation. This simulation usually takes the form of a military exercise, where manoeuvres are carried out to simulate possible real combat activity. These exercises are most relevant to combat units training combat skills. They are usually personnel and financially demanding, and the simulation of logistical activities is usually neglected. As a rule, it is considered that the units are automatically resupplied and the vehicles are repaired or no damage is envisaged.

In recent years, with the development of modern technologies, even in the military environment, there are opportunities to perform modeling and simulation of complex situations using software tools in military logistics, these are mainly supply chain simulation and stockpile management. As all activities can be divided into processes and sub-processes, it is also possible to model and simulate processes related to the consumption of spare parts or ammunition. The future use has great potential with many advantages.

The main advantages of using modeling and simulation tools are:

- Simplicity, variability and modularity: Different factors can be included if needed, so it is possible to create a similar model or test one model in different scenarios. Simulation tools generally allow for rapid modification by adding additional factors, changing unit parameters, as well as changing the quantity and structure of supplies or changing the type of military equipment. (Foltin et al., 2018)

-Speed: Model building and subsequent simulations are relatively fast and accessible using the available software. There are many different programs available that allow many different approaches.

-Low cost: Compared to the implementation of a military exercise, where a large number of personnel, equipment and related additional resources are required, simulation can be carried out on a military base.

The main disadvantages are:

- High abstraction of the simulation model: If the model is poorly constructed, there is a risk that it is too far from reality

-Complexity: Advanced software with too many controls can be quite difficult to use for a person who is not experienced with this approach

-Creating the model: Creating a complex model can be very time consuming and requires considerable knowledge and experience.

The integration of digital technologies and industrial automation in military installations and operations requires careful planning to eliminate waste of resources while reducing operational costs. One of the advanced simulation software is Simio. Simio provides extensive simulation modeling and planning support. Departments of Defense or military installations can use Simio to implement an automated transportation or material handling system at the installation. The program can be used to evaluate the success of various processes such as supply strategies, transportation reconnaissance activities, and more. Detailed 3D visualizations and statistics from simulated models provide the insight needed to optimize decision-making processes and implement new strategies (Simio, 2021).

Simio can be used to improve defence-related processes within:

- repair facilities,
- military hospitals,
- supply chains and logistics plans,
- environments with complex interactions and workflows,
- modernization projects (Simio, 2021).

4.1. Use for the simulation of the deployment process of military operation

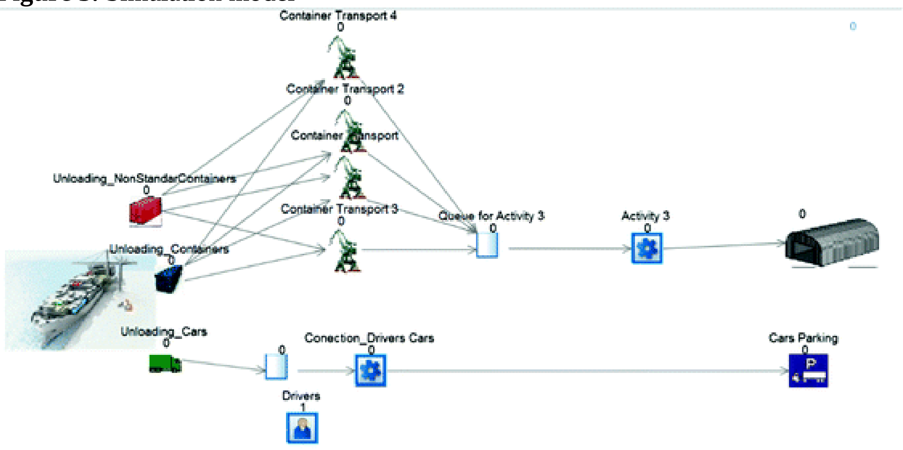
As part of the process of deploying forces to a multinational operation, the so-called RSOM/I (Reception, Staging and Onward Movement and Integration). The objective of this process is to ensure the smooth progression of strategic force deployment and the initiation of operations in the joint area of operations in the same phases (Joint Operation Area).

In the RSOM/I process, as in the civil sector, it is appropriate to simulate simpler process activities with a higher degree of repetition that may allow for variability in time, capacity, or number of indicators. A typical example would be the simulation of operations associated with unloading or loading cargo at ports, where the handling and unloading of container units needs to be coordinated with the departure of military vehicles, plus the scheduling of driver turnover for the respective vehicles. (Foltin et al., 2018)

The object of such a simulation model is to select and subsequently verify a variant that minimizes the time of each handling operation while making more efficient use of the available capacities (personnel, handling and transport vehicles). Finding the optimal unloading or loading method allows for optimal use of available capacities while optimising the financial resources spent. For the needs of the armed forces, it is possible to use the modular principle and to verify different scenarios depending, for example, on different unit size (stock volume) and unit type (stock type). The situation is more complex when it is necessary to simulate the operation of not only one unit, but multiple units in a multinational context, where multiple North Atlantic Treaty Organisation (NATO) armies are unloading supplies and vehicles and at the same time implementing the time schedule of the commander of a multinational operation. (Foltin et al., 2018)

For these purposes, a model of port of debarkation handling and transport operations was developed, based on the formulated assumptions and a simulation of these operations was conducted. It presents the logistics simulation as a tool that can be used to gain insight into the potential outcomes of deployment plans. The research focuses primarily on alternative scenarios for the RSOM/I process. Outputs for the logistics analysis formulated can be used in the training phase of experts in the logistics implementation of the RSOM/I process. (Foltin et al., 2018)

Figure 3. Simulation model



Source: (Foltin et al., 2018)

The output of the simulation model is a transparent overview of the entire process of the receiving phase – unloading of container units and military equipment and ensuring standardization of the activities performed. The contribution of the simulation model is the determination of the maximum waiting time of the ship depending on the defined variable – the number of drivers. The created model can be easily modified by determining other variables and observing differences in the model output characteristics (Foltin et al., 2018).

The simulation software used in this example is Simul8. It is a program similar to the Simio software used below. It offers similar capabilities, but is slightly simpler, which in turn offers simpler user control.

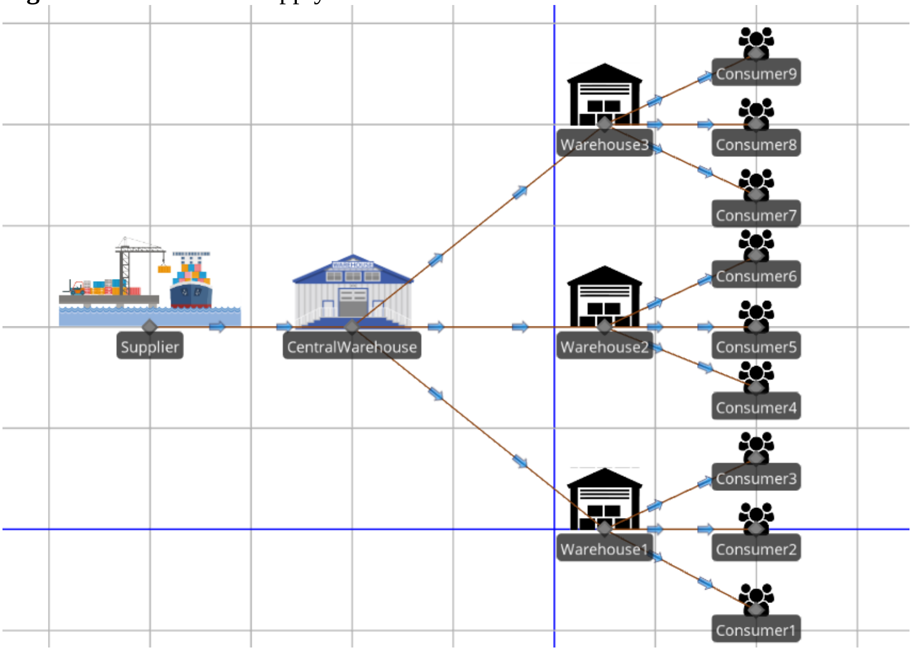
5. SUPPLY CHAIN MODEL

To demonstrate the use of simulation software tools, specifically Simio, a model example of a supply chain is created in the following chapter. The use of simulation software in this example can be seen mainly as a support for possible decision making on the specific composition of the supply chain, the dimensioning of warehouse space, the utilisation and amount of transport capacity needed and the intervals between ressupplies of warehouses.

5.1. Model

The model created in Simio can be seen in the figure 4. It consists of a Supplier, which has a picture of a port, this element has an unlimited amount of resources. From the Supplier the product is transported to a central warehouse, from where they are further distributed according to the needs to three individual warehouses from where they are further distributed to individual Consumers, which are 9 in total. The product is always delivered from one warehouse to three Consumers.

Figure 4. Model of the supply chain



Source: Own

Timepaths are used to represent the transport between the individual elements of the model. These are representations of the time required for transport between the elements of the model. The specific parameters used can be seen in the table 1.

Table 1. Timepaths

Supplier to Central warehouse (min, mean, max) [hours]	Central Warehouse to Warehouse 1, 2, 3 (min, mean, max) [hours]	Warehouse 1, 2, 3 to Consumer 1-9 (min, mean, max) [hours]
(42, 48, 54)	(26, 30, 34)	(4, 6, 8)

Source: Own

The values in the table show the time from the creation of the request to the delivery of the product to the requested location. Triangular distribution is used to show the possible differences in the times needed to deliver the requested quantity of product. In a real situation, differences in times may be caused by e.g. loading and unloading problems, heavy traffic, etc.

5.2. Assumptions and limitations

The assumptions and limitations of the model are:
- the model does not assume that a failure could occur (e.g. vehicle failure during transport between warehouses),
- it is assumed that the necessary equipment and people needed to carry out all processes are always available,
- an unlimited quantity of the required product is always available at Supplier
- the model assumes the use of only one type of product,
- it is assumed that all processes can be started at any time of the day (no rest, shift, day and night are considered).

5.3. Simulation

The model is fully customisable and by adjusting its parameters it can be used in a wide range of possible real-world situations. Different scenarios showing different variables and their combinations are selected to demonstrate these possibilities. These scenarios are simulated in Simio and then the most suitable option is selected.

5.3.1. Fixed model parameters

The fixed parameters entered into the model during the experiment are displayed in the table 2, these are the Initial quantity, for the Warehouses and for the consumers. This value shows the quantity of product available at the locations at the beginning of the simulation. Reorder point at Consumer 1-9, shows the stock level at Consumer at which resupply will be requested. Time of Consumption shows the time during which the product is consumed in the quantity shown in the Quantity consumed column. The last two values are triangularly distributed.

Table 2. Fixed model parameters

Initial quantity [pcs]			Reorder Point [pcs]	Time of consumption (min, mean, max) [hours]	Quantity consumed (min, mean, max) [pcs]
Central warehouse	Warehouse 1, 2, 3	Consumer 1-9	Consumer 1-9	Consumer 1-9	Consumer 1-9
88 200	29 400	1 400	700	(23, 24, 25)	(400, 600, 700)

Source: Own

5.3.2. Variable parameters

The variable parameters entered into the model are shown in the table3, these parameters are the reorder point for Central warehouse and individual Warehouses and the Reorder quantity, showing the quantity of product ordered, which is additional for Consumers 1-9. The second row shows the base values, the first row the half values and the third row the double values. By creating variations of all of these values, 162 scenarios were created and then subjected to simulation to determine the most appropriate variation.

Table 3. Variable parameters

CentralWarehouse		Warehouse 1, 2, 3		Consumer 1-9
Reorder point	Reorder quantity	Reorder point	Reorder quantity	Reorder quantity
33 075	14 700	9 450	7 350	700
66 150	29 400	18 900	14 700	1 050
99 225	44 100	28 350	22 050	

Source: Own

5.3.3. Defining the research question, limit criteria and simulation parameters

The basic question is in which scenario the smallest total number of trucks will be needed to transport the product, taking into account the initial filling of stocks and then the subsequent operation of the whole system for 30 days.

The truck capacity is set to 700 pcs of product.

The basic constraints are the minimum required stock level in Warehouse 1-3 – 14 700 pcs (7 days' supply for Consumers) and the minimum required quantity in Central warehouse – 44 100 pcs (3 days' supply for Warehouse 1-3)

The simulation period is set to 30 days. Each scenario is repeated 200 times to achieve relevant results

5.3.4. Simulation

The first step is to discard scenarios that do not meet the threshold criteria in the selected parameters. The determined values of the minimum required stock levels for Warehouse 1 for the first 50 scenarios are shown in Figure 5. Stock levels that no longer meet the criteria are highlighted in red, the values for a given scenario are shown as dots or as a box plot.

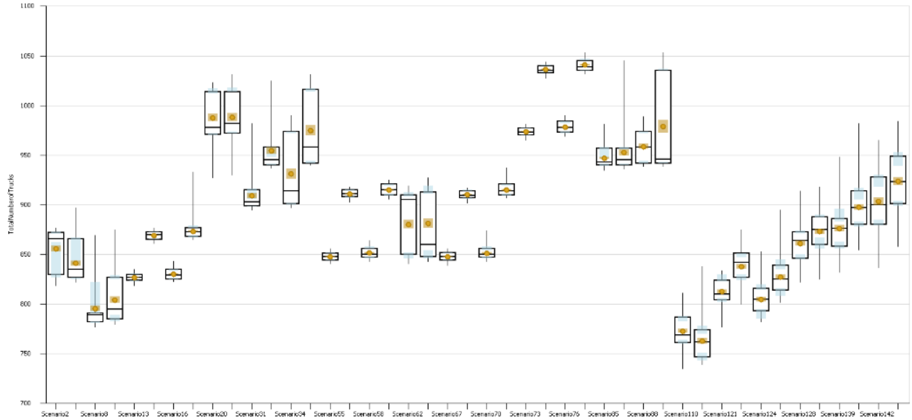
Figure 5. Minimum required stock level limiting criteria

Source: Own

The above example shows that certain scenarios do not meet the requirements. After analysing all the scenarios, it was found that 44 scenarios out of the original 162 scenarios met all the threshold criteria.

Crucial for the evaluation is the figure 6, showing on the x-axis the individual scenarios and on the y-axis the number of trucks needed for the initial stocking and then the subsequent operation of the whole system for 30 days. The values are shown as box-plots due to several triangularly distributed parameters. The best scenario will be selected based on the average values in the plot shown as yellow dots. We aim to minimize the number of trucks, therefore the best solution is Scenario 113 with an average of 762,995 trucks.

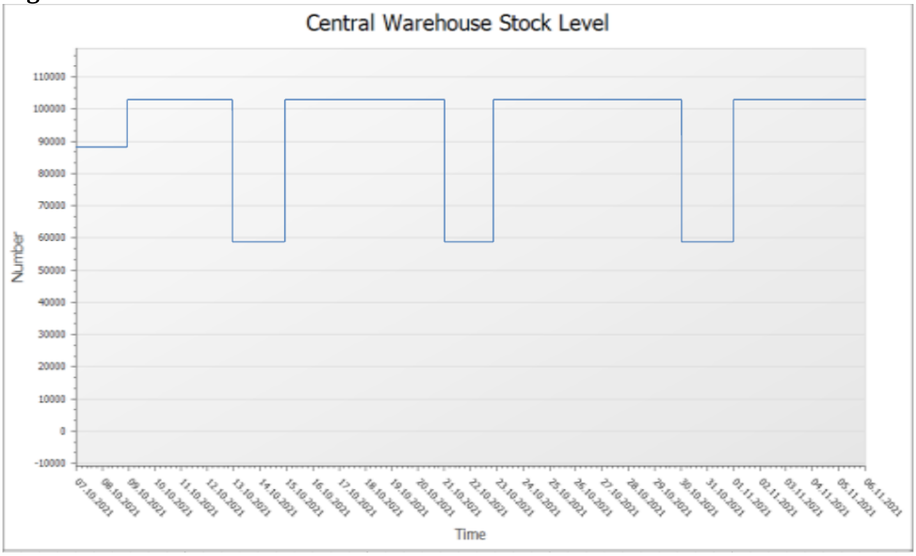
Figure 6. Number of trucks used for every scenario



Source: Own

For a better understanding of the scenario, a figure 7 showing the stock level in the Central warehouse, is added. In the figure, we can see how the volume of product in stock decreases by leaps and bounds over the course of 30 days based on the demand from Warehouse 1-3. Subsequently, the stock is replenished. It can also be seen from this figure that the minimum quantity in stock does not fall below the specified 44,100 pcs, falling to a low of just under 60,000 pcs. Conversely, the maximum quantity of product in stock exceeds 100 000 pcs after replenishment.

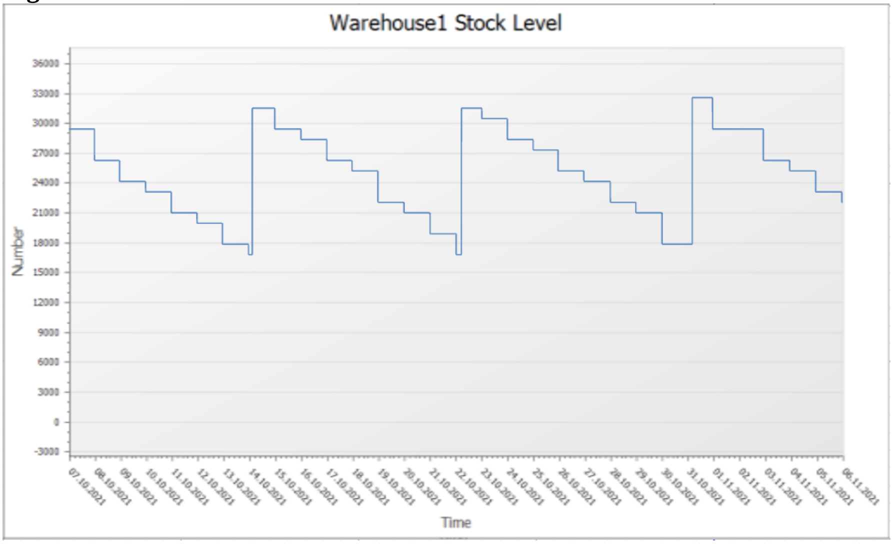
Figure 7. Central warehouse stock level



Source: Own

The stock level over 30 days in Warehouse 1 is shown in the figure 8. It shows a gradual decrease in the stock as product is taken by individual Consumers and a subsequent leap in resupply. The minimum quantity in stock does not fall below 17 000 pcs. The maximum is slightly below 33 000 pcs.

Figure 8. Warehouse 1 stock level



Source: Own

5.4. Partial conclusion

Based on the given criteria, the best scenario was selected from among all those created. This scenario was selected based on simulation for 30 days. The main selection criterion was the number of trucks needed to initially fill the warehouses and then run the system for 30 days. As the parameters were chosen randomly and do not correspond to any real situation, it can be assumed that this particular scenario (if it were a real situation) would not have been selected, e.g., because of a preference for a variant with lower stock fluctuations.

The advantage of the simulation software shown in the example is in particular the possibility to choose one of a huge number of variants. In practice, this can mean a significant reduction in costs. Graphs showing the outputs selected by the user allow important data to be easily understood.

Although the creation of the model is quite complex, the subsequent outputs are an invaluable source of information.

6. CONCLUSION

Modeling and simulation is a commonly used modern tool for analysing complex systems, especially in business processes. Simulation can capture complex and changing processes and help to improve them. However, the use of simulation and modeling is not limited to the civil domain. A wide range of applications can also be found in the military environment

The use of modeling and simulation can be observed in both the civil and military domains. The sizing of warehouses, decisions on the location of warehouses, the number and volume of replenishment of products needed, transport requirements, all can be determined with the correct setting of the model parameters. Potential applications can be seen in supply planning within humanitarian logistics. Military use can be envisaged e.g. in planning a military operation.

Example of modeling and subsequent simulation of a supply chain used shows the possibilities of using a model to solve the supply for a certain period of time - in this case 30 days. Using the model data and combinations of the given variables, the best scenario for the given criteria was identified. The main advantage of the developed model is its variability - by simply changing the parameters it can be applied to relevant real-life situations within civil and military logistics. The resulting outputs from the simulation software, showing the level of inventory over time, can be an important basis for logistics management decision-making.

In the field of civilian logistics, it can be stated that the subject is quite intensively researched and a considerable number of scientific publications are available. Further research needs to focus in particular on the possible military applications of computer modelling and simulation Military operations bring many unexplored topics that civilian logistics does not research and many factors that need to be taken into account when creating a simulation model. Specific topics worthy of exploration are simulations of ammunition supply in military operation planning, useful for predicting the amount of ammunition needed in a particular situation, or for streamlining the supply chain. Another area of research should be a simulation model of the maintenance system of military equipment in a military operation, which would be used to predict spare parts consumption and repair capacity. Both given examples can be seen as a possibility to optimize and streamline military logistics processes. Generalizing the models, their use can also be seen in the civilian area, possibly in humanitarian operations.

In particular, the lack of information on storage options, transport routes and infrastructure are major limitations for future research. Other factors are the political and security situation in the country. All of these factors can change dynamically and can fundamentally affect the development of the simulation model and the outputs obtained

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