COMPUTER MODELLING AND SIMULATION OF THE SUPPLY CHAIN IN MILITARY OPERATION

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Abstract

Success of any current military operation is strongly related to the level of its logistic support and supply of all crucial resources such as water, food, spare parts, fuel etc. Some of these resources can be obtained from the local market, some from neighboring countries or just from the homeland. Increasing computing capacity and speed of CPU allow us to develop very sophisticated software for modelling and simulation of these logistics supply chains in order to find the best possible solution up to our own assumptions and criteria. The aim of this paper is to show the possibility of modelling and simulation as a suitable tool for the military supply chain. The article deals with the application of the computing modelling and simulation theory, statistical methods for data estimation and verification and validation of the model. There is also the final experiment with received data analysis to bring possible scenarios to the decision makers about the structure of the logistics chain.

Key words: computing modelling and simulation, verification and validation of mode, military logistics chain

1. INTRODUCTION

We can meet with simulations and models around us every day, so it is a concept that is not strange to as at all. Somebody spent his or her time relaxing with computer or console games that simulates some strategies like farming, city development, driving skills or sport activities. Otherwise, models or simulation have not to be just computer conducted. Architectonical models of future skyscraper, remote control cars are quite common type of physical model used in practice. In this paper we will concern on the dynamic simulation of designed physical system rather than the physical model of elements of model.

Modeling and simulation is widely used within some main domains of man's activities:

- Supply chain management,
- Transport,
- Industry,
- Engineering,
- Health systems,
- Military Command and Control Systems
- Biological systems etc.

Simulation allows user to forecast things that have never happened before and to run some scenarios. The problem is, that one needs a good knowledge about how the system works to implement correct data in the model. Another advantage of simulation is its flexibility. It can be used for wide range of topics. On the other hand, it also requires the researcher to have access to background information about the process. For example, unformal rules, best practise etc. This information has also huge influence on the result of simulation.

Building a model and simulation in itself doesn't require knowledge of many data. The problem is when it comes to validation of model. The more and the more accurate data we provide in the model, the more precise results we get. Compared to the real-world experimenting, simulation doesn't consume so many resources. Still it requires time to build a model and also financial resources.

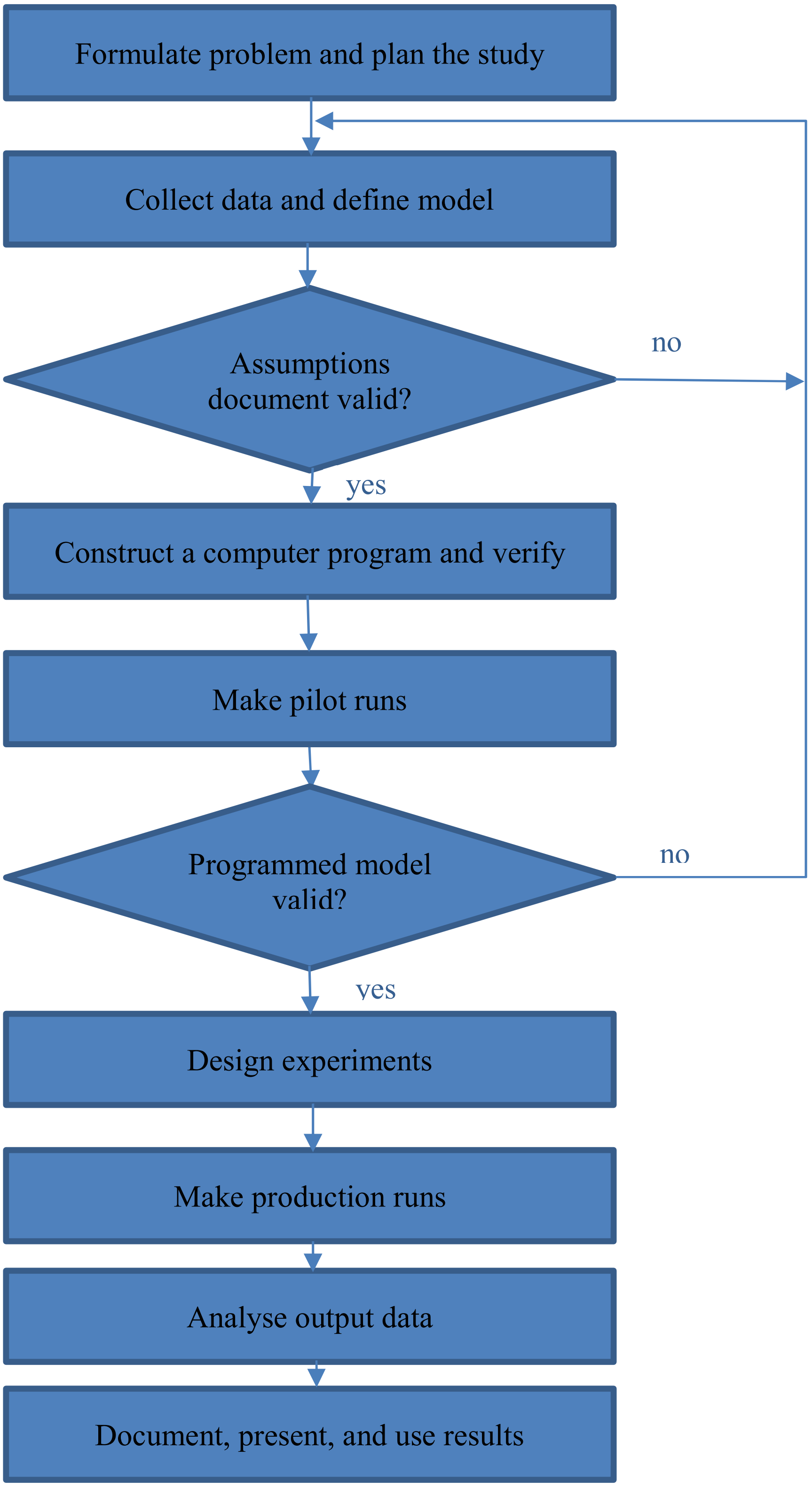
2. CREATING POTABLE WATER SUPPLY MODEL

One of the most important task for the logistics within the military operations is supply troops and other personnel by wide spectrum of resources such as water, food, accommodation, ammunition, fuel, spare parts and clothes etc. which provide them necessary condition in order to be able to successfully finish the operational tasks. From the medical and physiological perspective, lack of adequate water results in dehydration, which increases risk of serious heat illness and performance impairment. In these terms we can consider potable water as the crucial good, especially in hostile or arid environment or places with low level of sanitation or poor water supply network.

Potable water supply is usually one of the main responsibility of unit commanders and is organize by the standardized rules or national directives. These documents content the complex instructions regarding the potable water supply, chemical and bacteriological norms for potable water, available means for water drawing, purification, sanitary protection, treatment, storage etc. For this reason, pre-deployment planning and preparation is very important. And there we see the place for modelling and simulation of the potable water supply up to different input conditions for the decision makers.

In this paper, the process of designing the water supply model is shown on the figure 1 – steps in a simulations study.

Figure 1. Steps in a simulation study



Source: Law 2015

2.1 Model Objective

After reviewing open source documents concerning water supply is elemental to set project objectives, assumptions, limits and the level of comprehensiveness. Therefore, the objectives of our model is to prove the value of this method for decision makers. Further to show the results of the run of this model under different conditions – variants of possible solution.

2.2 Model Assumptions

For this purpose, we set several assumption, which help to create simplified model close to the real logistic chain, without unnecessary details, such as some kind of technical detail of military equipment or technical characteristics of construction material. This approach enables avoid the usage of confidential or secret data and it makes this model transparent, and appropriate to objective set above. We want to create understandable and flexible model, not the huge complex model full of details difficult to check, validate or update when some kind of component changes.

- Elements of the model are described as general items, e.g. tanker truck, potable water tank – no place for advertisement;
- Potable water should be storage max. 48 hrs. respective 72 hrs. when running out of fresh water supply;
- Manpower give the volume of the demanded water;
- Purification, disinfection and other kind of the water treatment is done;
- Potable water is used for personal consumption (drinks and cooking) and hygiene; when running out of potable water, the hygiene is restricted until the storage is replenished;
- There is limited storage capacity and limited number of tanker truck available;
- Military base operates 24 h., but the working time out of the base is restricted;
- Dry out of water is unacceptable, rather the disposal of the rest water from the Tank before replenishing is justified,
- Fresh water cannot be mixed with the storage water, Tank has to be emptied before refilling starts.

2.3 Elements of the model

Proposed potable water supply model consists of a storage capacity tank, tanker truck, filler and paths or pipes between these elements. Necessary information about all of them are set in tables. That allow the user to change some value of model's elements without knowledge of programing all the system links and programing language or variables syntax, structure and conditions, for example user can change the maximum capacity of the tank, capacity of the tanker truck, number of personnel on the base etc.

However, user has to be aware that several changes implicates changes in numbers of elements generated during the run of the model up to the current situation. It means that certain level of understanding of the modelled process and it logic is appreciated. For example, change of the maximum capacity of the potable water tank implicates higher number of container truck for refilling in case of the number of travel kept and vice versa when number of container remains the same the number of travel round has to be increased. This model is initially set regarding the “priority of security” so it prefers to keep number of travel round as less as possible and take as big transporting capacity as necessary.

Potable Water Storage
Storage capacity of the Potable water tank (what exactly represents the Potable Water Storage) is chosen according to the current market possibilities, therefore, in case of specific army forces requirements it should be edited. The only set condition is that it must be able to contain water at least for two days regard to the NATO regulations integrated in Czech army forces (Vševojsk-16-2, 2013). Water tank has ability to indicate the current state of the water level. In case that it drops down below the certain point tanker truck is send from military base to the filler for fresh potable water. The setting of appropriate level of storage in order to start the delivery water process is one of the important decision for management.

Filler Base
Filler Base in this model represents the source of the potable water other than public potable water network. It can be natural source of water which is dwell there by the specific means. Thereafter, that water has to be treated specific way (cleaning, purified etc.) to gain a potable water for further usage. However, in this case we consider this “base” as the source of potable water with infinity capacity. There is schedule of the processing time created to get closer to the real situation, so the Filler Base does not work continuously.

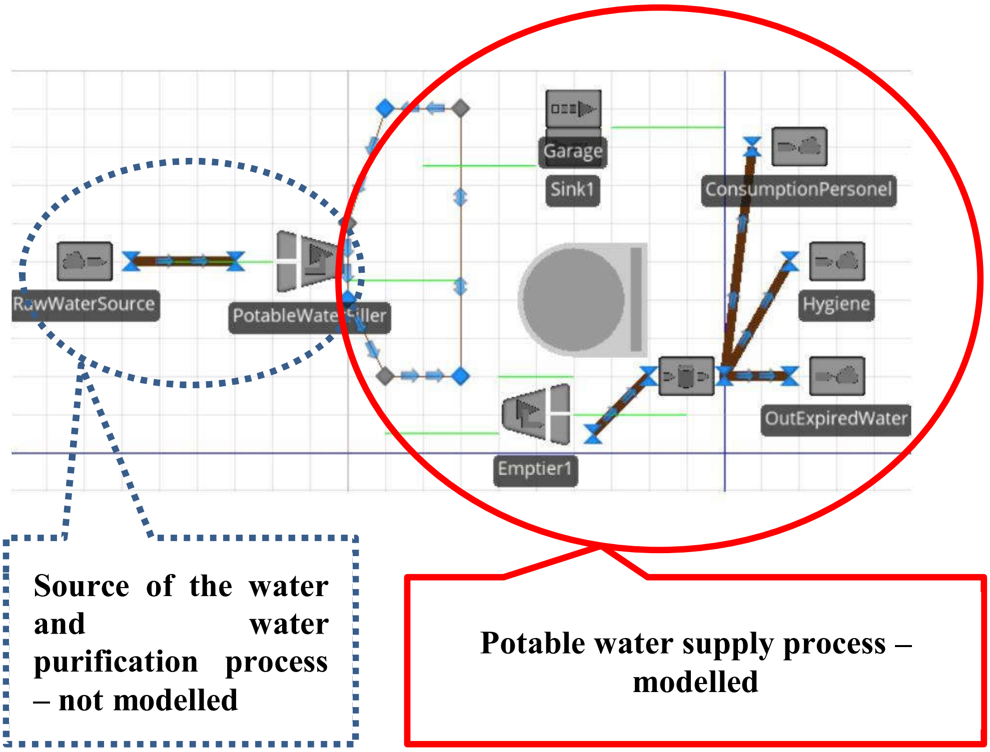
Travel path
All path between main elements of this model have a specific length and its own speed limit, so it allows us to count the transporting time when truck on their way. In our case we set the distance between our base and the Filler Base to 100 km, but it can be easily change without impact on the system’s logic.

Tanker Truck
Tanker truck is in this case the designation of truck convoy limited with its speed to 80 km/h when empty and travel speed of 60 km/h when full. Again, it does not concern any specific army forces requirements, so the capacity and number of trucks in system is chosen with simple rule. It must be able to fill the water tank on the base and it is desirable to have the least possible number of trucks in the system. Another variable to be set, concerning Tanker truck, is drivers working hours. In this case driver are on duty 7 days a week 12 hour per day with one our break.

Pipes and water consumptions
There is several output from the Potable Water Tank, whose represents different water usage. The Personal Consumption and Hygiene are the most important variables because Total daily water consumption creates the Demand for fresh water from the source. For setting parameters of the model, Daily water consumption on the base is

related to the number of present staff and is also regulated by integrated NATO standard (Ševojsk-16-2, 2013). In general, the consumption is set as the multiple of number of personnel and the volume of water per person per hour.

Figure 2. Supply potable water design



Source: Author's own

There is the final design of the exanimated model of potable water supply on the Figure 2, whose parameters are set up to all assumption and specific condition discussed above.

3. RUNNING THE SIMMULATION

When desired model is designed and all parameters are set, the Pilot run of the model was launched and the first results came out. These data were crucial for the process of validation of the model functionality and validity. Up to these results the model was checked and tuned and some mistakes and logical failure have been replaced. This part of check and validation was the second most significant moment of this model's design.

When validation phase was successfully finished, the preparation of the Experiments show up. There is the moment, when we have to be sure, what variables of the model are important for us, and which variables leading ones, it means variables, whose are changed during the simulation's run up to our request to create different scenarios. So, in our model, we run several scenarios, where the level of current potable water storage gets lower then "Low Mark".

This moment strikes several procedures, set behind the model. The first step gives the order to Tanker Truck to be ready on the output of Garage. After that the travel mission starts – the Tanker track follow designed path to Filler Base and back to Base when filled with fresh potable water. When Tanker Truck arrives to Base, it goes to Emptier to fill up the Potable Water Tank, this moment triggers another processes:

- Emptying the Potable Water Tank if not empty yet,
- Closing output from the Potable Water Tank
- Emptying Tanker Truck
- Filling the Potable Water Tank,
- Close the Expired Water Input and set the Personal Consumption and Hygiene to average consumption.
- Sending truck out of route (waiting for new orders).

There is several supporting processes also defined in the model, such as quite important trigger for managing the potable water consumption when the level of water in the storage is running down (in this case it is Low Low Mark) very low and new supply does not arrive yet. There is, for this particular situation, process when water consumption is strictly redirected jut for the personal usage (drink, cooking) but no water service for Hygiene (mainly baths or showers).

So, regarding these condition, the most important values of the model were set as show in Table 1 – Model settings overview (note that this is really very brief list of important ones). Therefore, all of this attributes, are set within the model (attributes of entities and links between them), and they creates the system and its characteristic itself. So, for making scenarios in order to get reports for decision about the right moment for new water delivery, we set the Low Mark as the changing variable.

Table 1. Model setting overview

Potable Water Tank	liters
Max. Capacity	15000
Low Mark	variable 4 – 8
Low Low Mark	2500
Water consumption	liters / hours
Personal Consumption	104
Hygiene	208

Source: Author's own

This way of experiment setting is very useful tool when lot of variation or experiments required, because they run simultaneously without animations and propose well organized results in format readable in different software for further analysis.

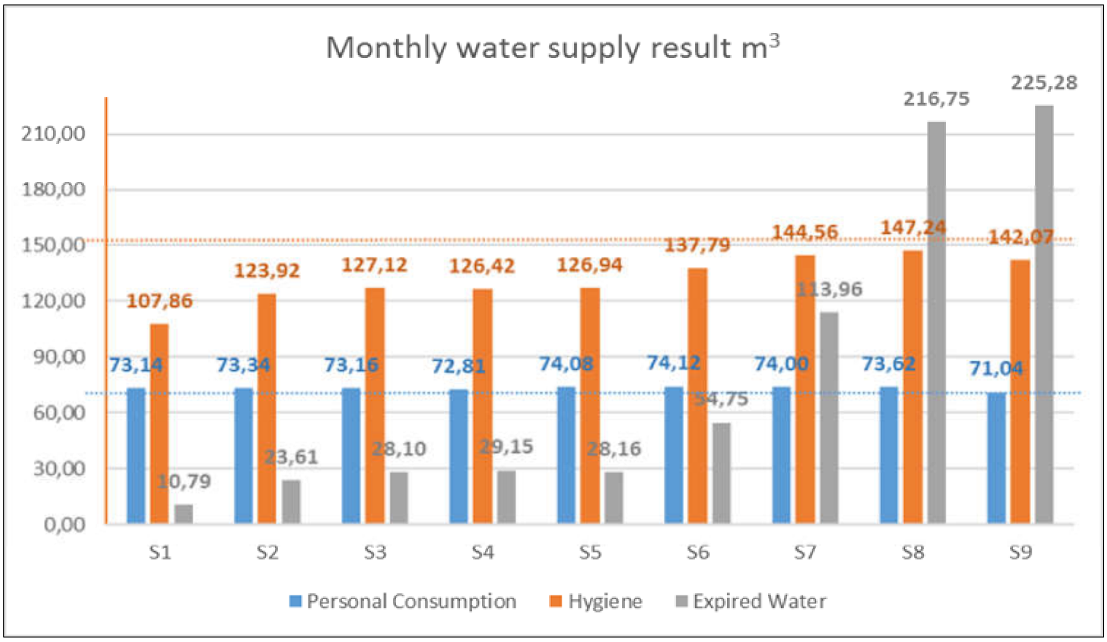
When we ran out model we received these results:

Table 2. Model results

Scenarion	S1	S2	S3	S4	S5	S6	S7	S8	S9
Low Mark	2	3	4	5	6	7	8	9	10
Personal Consumption	73,14	73,34	73,16	72,81	74,08	74,12	74,00	73,62	71,04
Hygiene	107,86	123,92	127,12	126,42	126,94	137,79	144,56	147,24	142,07
Expired Water	10,79	23,61	28,10	29,15	28,16	54,75	113,96	216,75	225,28
PC norm	75,00	75,00	75,00	75,00	75,00	75,00	75,00	75,00	75,00
Hygiene norm	150,00	150,00	150,00	150,00	150,00	150,00	150,00	150,00	150,00
Water tank empty (time)	1:14	0:53	0:57	0:57	0:04	0:00	0:00	0:00	0:52

Resource: Author's own

Graph 1. Model results



Source: Author's own

4. RESULTS DISCUSSION

We run the experiment of potable water supply on the designed base for 100 people with average daily potable water consumption of 312 liters per hour without the public potable water network for testing period of 30 days. During the experiment we search for the right moment for the new water delivery in order do minimalize the waste of water but avoid the situation, where there is no water on the Base. Also, we try to consider the level of personal and hygienic comfort of personnel.

Considering the Personal Consumption, there is no important discrepancy within all scenarios except the last one, when the water consumption varies from 71.04 to 74.12 liters per hour. This is quite understandable according to the model assumption and flexibility in case of running out of water, because the Total consumption is restricted just in favor to the Personal Consumption. Otherwise, the Personal consumption in this model never reach the maximum, due to off service time when emptying and filling Potable Water Tank.

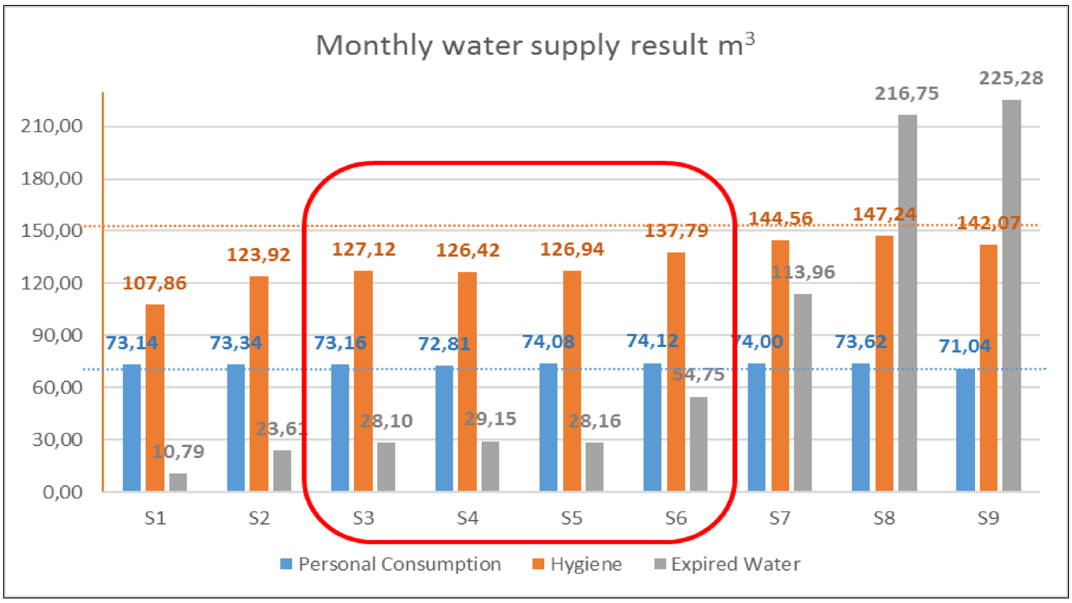
The Hygiene Consumption is other case. When the order for the new water is too late (it means the level of storage water is too low) its consumption does not reach high level too, on the contrary, it does not reach the standard quota set by the directives, because the restriction mentioned above. Thus, the amount of water in the Hygiene system varies between 107.86 – 142.07 liters per hour. It reaches it maximum values in the scenario 8 and scenario 7, when the order for water starts very early (when the level of water storage is high) and when the restriction of water consumption is not applied. Unfortunately, that brings a huge amount of the water to be wasted due to the mixture restriction (storage water cannot be mixed with the old one).

Regarding the Expired Water this simulation brings very interesting results too. The amount of Expired Water (note: here it is water to be wasted due to mixer restriction) grows with the level of water storage for the new water delivery, respectively when the Low Mark raises, the amount of Expired Water raises too. The Scenario 9, where the Low Mark is set to 10 000 liters, brings very interesting moment too. It shows that very early new water order will cause decrease of the Personnel Consumption, hygiene consumption and rise of wasted water. This is caused by the moment of emptying and filling the Potable water tank, when Tanker Truck arrive on the Base and the output from the Potable Water Tank is off.

Choosing adequate scenario

According our mission to supply the personal with adequate quantity potable water (drinking + cooking + hygiene) within several limitations due to some internal directives several scenarios are available as shown on Graph 2 within red rectangle.

Graph 2. Choosing scenario



Source: Author’s own

What is the final rank of these scenarios? For the correct decision we should check the results from the experiment again and pay attention of the time when the Potable Water Tank is empty. There are two of these scenarios where the time is 57 minutes. So we can consider their rank 3 and 4 respectively. Two last scenario remains to compare. Scenario 5 with 4 minutes per month of time out of water and waste of water approx. 28 160 liters per month, or Scenario 6 with 0 time out of water, but with waste of 54 750 liter of water.

This is the moment when the modeling and simulation cannot help itself. This is the moment for decision makers to take this output data from a simulation software after model validation and finished experiments and analyze them and choose optimal scenario.

Table 3. Final rank of experimented scenarios

Rank	1	2	3	4
Scenarion	S6	S5	S3	S4
Low Mark m^3	7	6	4	5
Personal Consumption m^3	74,12	74,08	73,16	72,81
Hygiene m^3	137,79	126,94	127,12	126,42
Expired Water m^3	54,75	28,16	28,10	29,15
Water tank empty (time)	0:00	0:04	0:57	0:57

Source: Author's own

Possible final rank is in the Table 3 – Final rank of experimented scenarios what shows the order of chosen scenarios for the further decision making. Final decision depends on personal attitude of the decision makers, their own experience from solved system, risk sensitivity and cost sensitivity.

In this case of military supply chain design, when the life of personnel has higher price than a water and when their level of psychical and physical condition is very important in order to finish their tasks, the scenario 6 is the correct choice. Otherwise, this wasted water in our model does not have to be completely wasted, it can be use for cleaning the military equipment such as Trucks, cars etc. if necessary.

5. CONCLUSIONS

Based on the performed model runs, it can be stated that the approach is suitable for planning and evaluating military logistic chain even without confidential or secret information. This approach allows further development of this model adding more detailed information such as running costs, water costs, personal cost to show possible total cost eventually possible savings if occurs.

There are other ways how to enlarge this model of another processes, such water dwelling, treatment even adding dynamics of water consumption regarding weather condition (higher consumption in warm and hot weather) or operating time of trucks or filling station, when applicable or requested.

Therefore, this approach gives us the opportunity to design the diagram of logistic chain, describe every element within the system with necessary characteristics, their place and behavior. When some changes occures, new model has not to be designed from the beginning. Changed item or data or condition could be just replaced or updated, and validated.

Another advantage of this approach is continuous designing, we can go back to previous version or setting without huge investment to parts of the system. Also, the ability of visualization of the results or of the model's run itself mean better understanding of the solved problem for wide public and management.

The last but very interesting area of modelling and simulation is to bring unpredictable situations into the model (risks) to make designed model close to the real system with its possible failure or delays etc.

6. REFERENCES

Anu, M. (1997). Introduction to medeling and Simulation. In. S. Antradóttir, K. S. Healy, D. H. Whiters and B .L. Nelson (ed.), Proceedings of the 1997 Winter Simulation Conference, Atlanta, Georgia, pp. 7 – 13, ISBN: 0780342801.

Vitoriano, B. & Ruan, D. (Eds.), Decision Aid Models for Disaster Management and Emergencies, Atlantis Press 2013, Paris, ISBN 978-94-91216-73-2

Bonabeu, E. (2011). Agent-based modeling: methods and techniques for simulating human systems. In. Proc. National Academy of Sciences 99(3): IEEE.

Brooks, R. & Robinson, S. (2010). Conceptual Modeling for Descrete-Event Simulation, CRC Press. Boca Raton, ISBN 978-1-4398-1038

Flood, F.L & Carson, E.R. (1988). Dealing with Complexity: An Introdution to the Theory and Application of System Science. New York. Plenum Press. ISBN 978-1-4757-2235-2

Law, A.M. (2015). Simulation modeling and analysis. Fifth edition. New York: McGraw-Hill Education. ISBN 9781259254383.

Macal, C.M. & North, M.J. (2005). Tutorial on Agent based modeling and simulation, In. Proceedings of the 2005 Winter Simulation Conference. Orlando, Florida, IEEE, strana 2-14, ISBN 0-7803-9520-4.

Merkuryev Y., Merkuryeva, G., Piera, M.A. & Guasch, A. (2009). Simulation-Based Case Studies in Logistics, Springer-Verlag, ISBN: 978-1-84882-186-6

Robinson, S. (2004). Simulation: the practice of model development and use. Chichester, West Sussex, England; Hoboken, NJ: John Wiley & Sons. ISBN 0470847727.

Rogers, R.V. (1997). What makes a modeling and Simulation Professional?: The Consensus view from one workshop. In. S. Antradóttir, K. S. Healy, D. H. Whiters and B .L. Nelson (ed.), Proceedings of the 1997 Winter Simulation Conference, Atlanta, Georgia, pp. 1375 – 1382, ISBN: 0780342801.

Sanag (2014). 2136, NATO Standard AMedP-4.9: Requirements for Water portability during field operations and in emergency situations, NATO Standartization Agency.

Singh, V.P. (2009). System modeling and simulation. New Delhi: New Age International (P) Ltd., Publishers, ISBN 9788122429244.

Sokolowski J. A. & Banks, C.M. (2014). Principles of Modeling and Simulations: A Multidisciplinary Approach, Wiley India, ISBN 978-8126551538

Sturrock, D.T. (2011). Tips for successful practice of simulation, In. Proceedings of the 2010 Winter Simulation Conference. Baltimore, Maryland, IEEE, pp. 87 – 94, ISBN 978-1-4244-9866-6.

Vševojsk16-2 (2013). Zabezpečení Armády České republiky pitou vodou, Věstník MO, Praha.