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Dear readers,

In your hands, you are holding this year's first issue of the Science & Military journal. As usual, the journal is characterised by openness that allows a wide range of topics and results from its concept and efforts of the editorial board to make the Science & Military open to all kinds of cooperation. Bearing this goal in mind, we keep on encouraging our readers to submit their articles and proposals for improvement since we want the Science & Military journal to be open to all its readers and we hope their number will continuously increase.

In the journal archive, which is available at http://sm.aos.sk/index.php/en/archive-of-journal.html, you can find all its issues, which even after several years still appeal to readers by their thematic originality and interdisciplinary approach. They contain valuable sources of information that help educate young scientific staff and doctoral students. We are pleased to provide our readers with the latest trends and research in military science and an opportunity to engage in an active dialogue.

This issue contains high quality and interesting articles, which have successfully passed the peer review process. I firmly believe that they will inspire their readers and make them think about and discuss the presented issues.

*The first among the reviewed articles, which was written by Ján Kollár and Vojtech Florko titled **Solution of Selected Problems Using IBM QX**, presents a set of works that were chosen to be decomposed to individual algorithms and solved using a quantum computer, which is available publicly through the IBM QX platform. The objective was to demonstrate a fundamental change in the way of thinking about problems when working with a quantum computer as opposed to solving a computational problem on a classical computer.*

*Another article titled **Target Tracking by Adaptive Filtering** was written by Peter Rohaľ and Ján Ochodnický. In this paper, we approach the structure and key features of the proposed adaptive targeting radar and the algorithm of the particle filtering (PF), the Elman NN (neural network) and the Group Methods for Data Processing (GMDP). The proposed algorithm was used in adaptive radar especially for monitoring problems with emphasis on backpropagation learning, selection of correct algorithm, decision making based on the situation and storage of information.*

*Among the articles in this issue, you can find the article written by Pavel Žižka titled **The Current Command and Control System of Realization of Engineer Support Tasks of Task Force Operation.** The article deals with the current command and control system of completing engineer support tasks of task force operation depending on the realized steps within the army of the Czech Republic transformation in recent years. The aim of the paper is to evaluate the current state of command and control system and identity possible causes contributing to the current situation in this area.*

*The author Peter Mako wrote the article titled **FEM Analysis of Mobile Bridge AM-50 as Per Needs of Slovak Armed Forces.** This article is showing detailed description of FEM analysis of AM-50 bridge load capacity in accordance with standard STANAG 2021 and their results.*

*The article written by Serhiy Orel titled **Sensitivity Analysis in Risk Assessment of Drinking Water Chemical Pollution Caused by Military Activities** presents the sensitivity analysis of environmental pollution risk assessment caused by military activities. The role of the sensitivity analysis for environmental decision-making is shown. Sensitivity analysis is a valuable tool in quantitative risk assessment by determining critical aspects and effects of variations.*

*The series of articles is closed with the paper titled **Tasks and Activities Executed in the Field of the Support of the State Defence** written by Ján Brezula. This paper deals with the tasks and activities executed in the field of the support of the state defense. The defence infrastructure is a necessary element of supporting the state defense and it is formed by the services and activities provided to the Slovak Armed Forces for ensuring effective protection and defense of the state.*

Dear readers,

on behalf of myself and the entire editorial board, I would like to thank you for your interest and support. My gratitude also goes to the authors submitting their high quality papers, without which our journal could not exist. In conclusion, I would like to express my sincere appreciation to our reviewers, who contributed to professional and scientific quality of the Science & Military journal by their systematic approach, expert knowledge and constructive criticism.

Col. (ret.) Prof. Eng. Marcel HARAKAĽ, PhD.
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SOLUTION OF SELECTED PROBLEMS USING IBM QX

Ján KOLLÁR, Vojtech FLORKO

Abstract: This paper presents a set of works that were chosen to be decomposed to individual algorithms and solved using a quantum computer, which is available publicly through the IBM QX platform. The objective was to demonstrate a fundamental change in the way of thinking about problems when working with a quantum computer as opposed to solving a computational problem on a classical computer. Although a novelty for most people today, the way of approach that is explored in this paper might become a valuable skill one day, when quantum computers become more wide-spread.

Keywords: Quantum Computer; Qubit; IBM QX; Quantum Circuit; Quantum Gate.

1 INTRODUCTION

Quantum computer is surprisingly old as a concept, more specifically it comes from 1959, when the underlying idea was presented as a concept of computational machine for physicists.

Recent developments and headlines have launched it as a popular subject in the realm of information technologies, but in reality it is principles and fundamental ways of operating it are mostly unknown to the mainstream software development community.

As of today, there is a number of public application programming interfaces available on the internet, which offer access to a quantum computer, so at the moment there is a huge opportunity to broaden the horizons of what can be done using this technology in the future, once it becomes more ubiquitous. There are a few well known algorithms available today which demonstrate the advantages of quantum computers. A lot of these algorithms show promise of quantum computers based on certain criteria, such as performance gains we receive during the program execution, but the advancement of development of these machines is based very much on how the quality of the software catches up with the limited hardware we have available today.

To this end, we have prepared a set of algorithms that show a potential way of choosing certain types of problems and developing their solutions on quantum computers. To amend the broad lack of simple practical examples, we have chosen to experiment on the most advanced way of accessing a quantum computer at the moment, the IBM QX platform. This platform offers a set of public quantum computers, where anyone with an internet connection is capable of running their own quantum programs [1].

All of the algorithms were executed on a 5 qubit ibmqx4 quantum computer. These were developed and tested on a web graphical interface that allows composition of quantum circuits and executed as a part of desktop programs with a quantum component.

2 MOTIVATION

As with all emerging technologies, to empower it is use, there have to exist more applications that can be incorporated in a practical manner into our daily world. Since the types of algorithms and the way quantum computers work are notably different from a classical computer, there is a need to invent ways of how to leap from a well established way of algorithmic thinking to this new mindset.

This paper above all else aims to present a select few results that show various techniques of thinking when approaching a development of new algorithms for a quantum computer, as opposed to algorithms on a classical von neumann computer.

3 RELEVANT WORKS

The most important notion that needs to be considered when exploring the potential for a new quantum algorithm is whether the quantum computer offers a significant advantage over abundantly more cost effective classical computer implementation.

There are several of well known and established algorithms that leverage the quantum computers in varous ways. One such algorithm for example is Grover's algorithm, which Coles et al. describe in their paper about quantum algorithms implementation. As a matter of fact, Grover's search algorithm, which enables to find a spefic item in a randomly ordered database, provides a notable speedup over a classical computer. The quantum implementation would require $O(\sqrt{N})$ operations, while the classical computer would do this in $O(N)$ operations [2][3]. The speedup provided in factorization incorporated in the famous Shor's algorithm is also a similar type of application [4].

As Valiron mentions in his work, the real advantage and gain we strive for with quantum algorithms is for example when it leverages the quantum phenomena, namely entanglement [5], which Horodecki et al. describe in how important role it has played in development of quantum computing, including measurement based schemes [6] as well as superposition, with Sarma noting that these phenomena can be used to process data [7]. When implementing a mapping for a boolean truth table on a quantum circuit, he mentions two ways one can go about implementing a tangible logical state on a set of quantum bits, the naïve one using a direct mapping, where we map subparts of the object correspondingly to the number of quantum bits we have, or a compositional implementation, where the efficiency is taken into account. There are of course, some limitations as well in the current IBM QX hardware offering, which makes the creation of new algorithms more complicated. In the works of Zulehner and DiVincenzo we can see how the two-qubit CNOT gates cannot be arbitrarily placed in the architecture but are restricted to dedicated pairs of qubits only [8] [9]. In addition, Wooton et al. describe in their paper how there is a need not only for devices with more quantum bits, but also the ability to achieve fault-tolerance as well. To this end, there is a need for algorithms that have been specifically designed to work on small and noisy devices [10]. The way of assembling an algorithm to be executed on IBM QX was mentioned to be a quantum circuit, which is a timeline of quantum gates (general types of quantum operations) by Nielsen et al. [11].

The path to invention of new practical quantum algorithms is definitely rooted in experimenting and this can be seen in a work of Pathak, where he describes the development of their implementation of a quantum random number generator and what it means for cryptographic purposes [12]. Like Pathak, we have been tinkering with random number generators independently ourselves. Laforest provides evidence of this noting existing stable quantum cryptography systems which are already to some extent used by government and banks [13]. Biamonte et al. describe how the search for quantum machine learning algorithms strive to gain a speedup compared to their classical couterparts [14]. In the paper of Avaliani, another topic related to true randomness is simulations, which are important for developing applications for chemistry and biology [15]. This further confirms what Valiron mentions, that the search for quantum optimizations over classical algorithms is a vibrant area [4].

4 RESULTS

Quantum computers are not oriented to evaluate and present the results to an end user in a user friendly fashion at this moment. Therefore, when striving to create quantum programs as practical applications, the quantum algorithm should form a component of a larger program running and evaluating the results on a classical computer.

As previously mentioned, the big challenge with using quantum computers is choosing an appropriate problem or a part of a problem that fits the way quantum calculations work. Rather than focusing on well documented types of problems, we have chosen at first to attempt to assemble a set of simple and very common operations. One such type are operations with strings of characters. Attempting to perform these on a quantum computer shows the type of problems a quantum computer is not good at.

The first operation has a task of reverting a string at the input. Each letter is encoded by a numerical index value before being sent to a quantum circuit and thus is reverted purely numerically. A sample four letter word is encoded by a sequence of indices 0123. Since quantum computers return individual result values within an interval of <0; 1>, each number must be modified by a factor of string length:

$$factor = \frac{length}{10}, \quad index^* = \frac{index}{factor} .$$

If we have a string with a length of 5 characters and we invert a letter under index 3, we have a factor of *0.5* and index* of *6*. We then execute a quantum circuit with the following results:

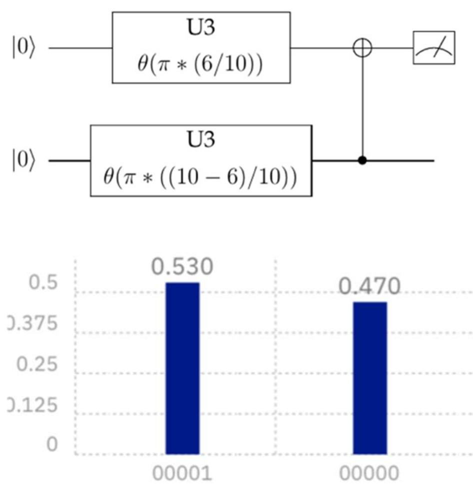

Fig. 1 Quantum circuit performing a revertion process using a modified index
Source: authors.

If our value index* is higher than 5, we are interested in the lower result of the two and vice versa. Since we have a bit of imprecision going on, we round the values by ceiling the value which is higher than *0.5* and flooring the lower value. We then multiply the result with our factor and get the reverted index, in our case it is *2*. We do one quantum operation per index and assemble the word on a classical computer.

The second experiment we have decided to perform is also a common string operation, which is getting a character from a string using a specific index or a list of indices at the input. In this case, the task was to encode each letter on one quantum bit. Since we receive the results as individual numerical values per quantum bit, we need to assign a unique number to each letter of the word.

Here, an interesting experimental phenomena occurred when choosing numbers for the characters. When we set a quantum bit by rotating it is theta angle, we expect that exact particular number at the results, which is how we identify the chosen character. In the higher range of numbers, e.g. higher than 0.8, we receive relatively precise results with minimal variation. The lower we go, the higher the spread of possible values we get, which is not what we are looking to leverage for this experiment.

Again, we are using the 5 qubit quantum computer, and bearing in mind the aforementioned manifestation, we encode the sample four character string ABCD using the following values:

A = 0.95, B = 0.9, C = 0.85, D = 0.8. We map the values by encoding the first four quantum bits by a theta rotation using the U3 quantum gate available at the IBM QX. Each quantum bit performs a CNOT operation with the controlling quantum bit, which uses the X gate to determine the chosen characters at the output. While the mapping at the first four quantum bits is the same for any four character string, the distribution of X gates in between the CNOT operations determines the input of the chatacter indices. We then rotate each theta backwards tonullify the values of uncaptured quantum states.

Fig. 2 shows us the circuit in place when choosing the first three letters at the output. Had we set the second X gate one CNOT operation backwards, we would have received only the first two letters at the output. If we had set it at the very end of the quantum bit (or not at all), we would have received the result comprising of all four letters. There is a possibility to add multiple X gates as well, if we had set the first two gates around the first CNOT operation and the second pair of X gates around the last operation, we would have received only the first and the last character codes at the output.

When we run the circuit illustrated in Fig. 2, we receive the in Fig. 3.

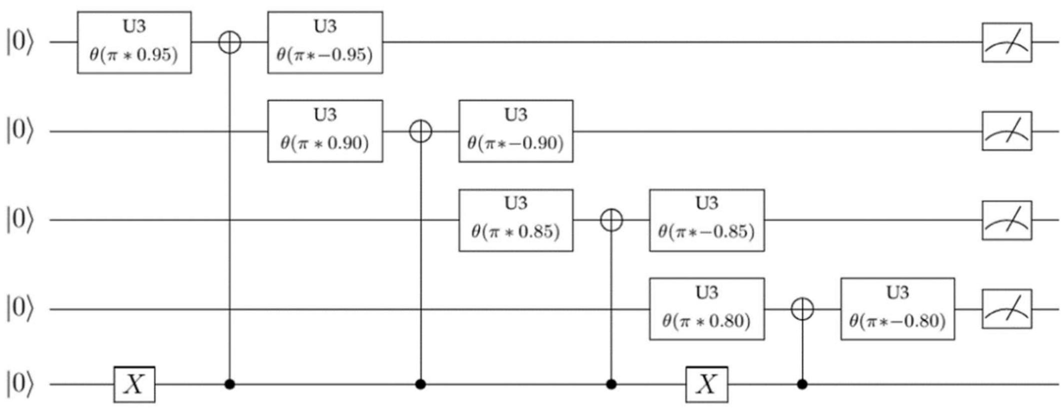

Fig. 2 Quantum circuit performing a mapping of a four character string, while choosing the first three characters at the output. Note: the phi and lambda rotation angles are set to 0, only the relevant first parameter theta is shown to make the circuit more concise
Source: authors.

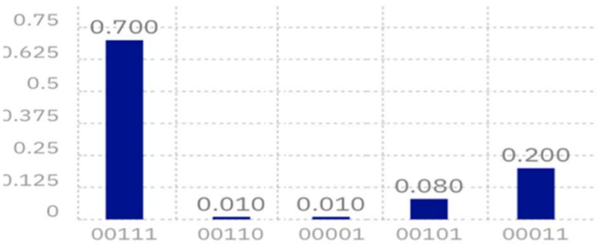

Fig. 3 Results from running a quantum circuit
Source: authors.

Right away we can see that the fourth quantum bit is not contained in the results, which is exactly how this circuit was supposed to run. We then proceed with adding the results up for each represented quantum bit:

$$q[0] = 0.7 + 0.01 + 0.08 + 0.2 = 0.99$$
$$q[1] = 0.7 + 0.01 + 0.2 = 0.91$$
$$q[2] = 0.7 + 0.01 + 0.08 = 0.79$$

The results come from a quantum simulation, where we can see that while the value 0.95 was received as 0.99 and the value 0.95 was received as 0.91, the 0.85 expected at the output turned into 0.79. Running the circuit on a quantum computer would provide more precise results, but at the moment there is not an available quantum chip at IBM QX, where four quantum bits can perform a CNOT to a particular designated controlling bit. Performing this operation with two quantum bits, ergo two character string, shows that this algorithm works properly.

Another type of algorithm that has shown potential for using a quantum computer, is optimizing a route through a graph/map, for example, looking for the shortest route. Operations of this kind have a number of real world applications, from logistics to biology. If we successfully map a particular graph onto the circuit, we can leverage the significant parallelism quantum computers provide. A classical computer algorithm would recursively search all the different variations of possible subroutes between two chosen points. The challenge that presents itself is how do we represent the different subroutes that can occur in the search by encoding them on the quantum bits.

The natural choice might of course be the simplest one, by attempting to map the graph in a naïve manner, in other words, imprinting the whole graph onto a circuit. It of course depends how we can encode the individual routes. The mapping in Fig. 2 is one of the ways we have tried, because each quantum bit rotation is essentially a graph node, where the CNOT operations are the subroutes. The values encoded by the rotations are lengths of the route coming from the node. This mapping is of course very ineffective and sluggish, because we waste quantum bits with each node and the method does not capture any branching situations from nodes.

A better solution would be to map the routes directly in a way that the circuit would encompass crossroads on the way. Let us consider the following simple graph:

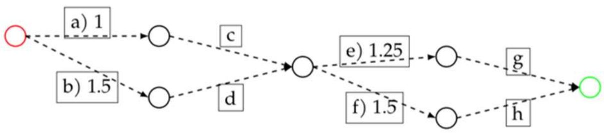

Fig. 4 A simple graph with two crossroads, routes c), d), g) and h) are of same lengths
Source: authors.

Naturally, this particular graph is easy to solve on a classical computer, but we are trying to construct a method on how we can solve any graph with a reasonable size on quantum computer. The way of how we resolve individual crossroads is more effective compared to the previous attempt, because we solve one crossroad on one quantum bit, provided the crossroad has two outbound pathways. The way this is done is we chain two theta rotations to effectively perform a comparison of individual values, which represent the lengths of the compared routes.

The first rotation is by $\pi * (2 - route1)$ and the second rotation by $\pi * route2$, where route1 and route2 are the respective lengths of the outbound paths. If the first value is higher, the rotation shifts into the third quadrant so much, that a lower second value cannot rotate it backwards to revert to the second quadrant and vice versa. After the rotations, we need to apply Hadamard's gate to shift the perspective from the X-axis to the Z-axis, to be able to read the results. For the first crossroad, the solution is as follows:

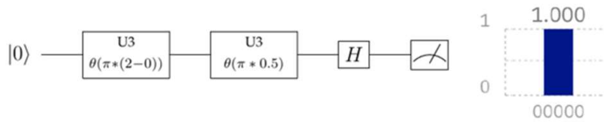

Fig. 5 Results from the circuit solving the first crossroad from the graph Fig. 4
Source: authors.

We have subtracted 1 from both values to prevent unnecessary rotation. The first value is zero, thus we receive 0 at the result. We can then solve both crossroads in a parallel way, where we can see that the second solution is readable from the overall combined result:

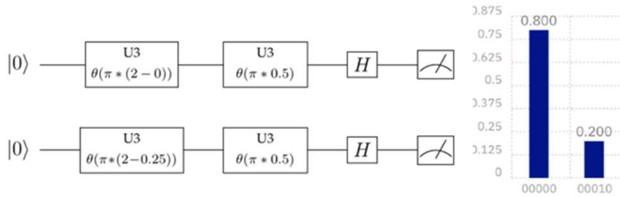

Fig. 6 Results from the circuit solving both crossroads from the graph Fig. 4
Source: authors.

This approach is fine for solving the routes on a per crossroad basis, but since we are not leveraging the remaining quantum bits, we can try a more complete approach where we choose the shortest route with one calculation. Since have four overall routes in this particular graph, we can compare individual subroutes in a total of 6 operations. It is important to note that when assembling this circuit, the lengths of the routes might seem to be are already known. In a practical implementation, the circuit would be assembled dynamically, meaning that the classical computer would only have to assemble all of the combinations of the available subroutes, which would be then fed as a calculation to the interface of the IBM QX.

After evaluation of the results, this circuit identifies the shortest route of all possible routes in the graph. With the currently limited selection and number of quantum bits in quantum computers, an application utilizing this operation can be created in a way that a large graph is broken down to a set of key subgraphs which need to be resolved as a chain in order to determine the optimal route.

To create applications with a quantum component, there is a need for a library that interacts with the IBM QX application programming interface. The official solution is called Qiskit, which provides access to applications developed in the Python programming language. Since we wanted to create a mobile implementation of quantum applications, we have created a port of the library for the iOS platform called QuantumSwift for the Swift programming language.

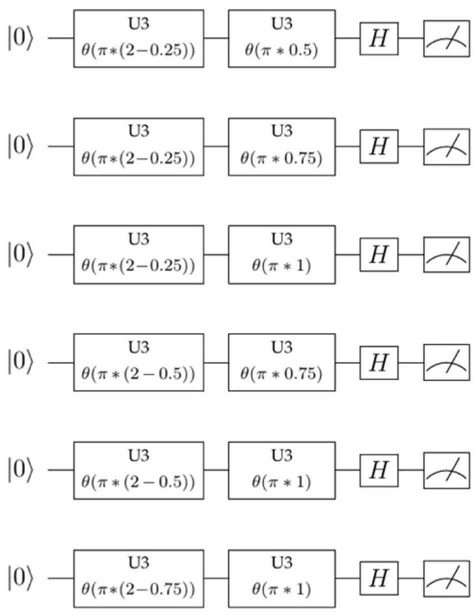

Fig. 7 Circuit which compares individual routes of the graph Fig. 4
Source: authors.

The resulting program is an application of the experiments that is used to determine the shortest path between a choice of two cities in Slovakia on the map (Fig. 8).

5 EVALUATION OF RESULTS

This paper has provided a set of algorithms executed on public IBM QX quantum computers. We have demonstrated that quantum computer can be used in some manner for ordinary operations, such as working with strings. Using quantum computers for string operations is obviously an overkill in terms of cost-benefits perspective, however it is a good practice in terms of evolving one's thinking when developing quantum circuits.

The graph representative algorithms further expanded the ways of approaching a quantum mapping problem from different perspectives. The naïve approach was described but rejected because of it is inefficiency and the granular crossroads and route circuits showed how to extract the key points from a particular problem with relation to encoding them on quantum bits and reading the results.

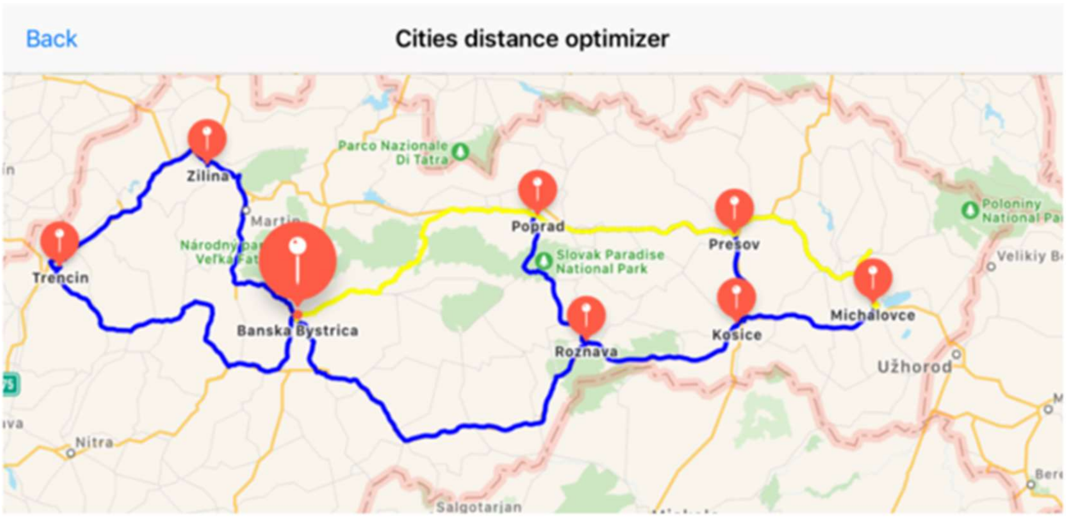

Fig. 8 Mobile application of the optimal route algorithm on a set of major cities in Slovakia
Source: authors.

6 CONCLUSION

The algorithms provided in this paper are by no means aimed for production grade software, however they might be expanded upon in the future to provide real quantum applications of some value, such as some evolved version of the example application in Fig. 8.

Although the search for viable quantum algorithms has been ongoing for decades, the important works are yet to come thanks to unprecedented availability of quantum computers such as IBM QX platform and the popularity of the subject which might potentially provide solutions to important problems using the advantages the quantum computers might provide.

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Prof. Dipl. Eng. Ján **KOLLÁR**, PhD.
Department of Computers and Informatics
Technical University of Košice
Letná 9
042 00 Košice
Slovak Republic
E-mail: jan.kollar@tuke.sk

Bc. Vojtech **FLORKO**
IBM Slovensko spol. s. r. o.
Krasovského 14
851 01 Bratislava
Slovak Republic
E-mail: Vojtech.Florko1@ibm.com

Ján Kollár – He is Full Professor of Informatics at Department of Computers and Informatics, Technical university of Košice, Slovakia. He received his M.Sc. summa cum laude in 1978 and his Ph.D. in Computer Science in 1991. In 1978-1981 he was with the Institute of Electrical Machines in Košice. In 1982-1991 he was with Institute of Computer Science at the P.J. Šafárik University in Košice. Since 1992 he is with the Department of Computer and Informatics at the Technical University of Košice. In 1985 he spent 3 months in the Joint Institute of Nuclear Research in Dubna, USSR. In 1990 he spent 2 months at the Department of Computer Science at Reading University, UK. He was involved in research projects dealing with realtime systems, the design of microprogramming languages, image processing and remote sensing, dataflow systems, implementation of programming languages, and high performance computing. His research area covers formal languages and automata, functional programming, implementation of programming languages, grammatical language evolution, natural language analysis, adaptive software and language evolution and reflection of languages in quantum systems.

Vojtech Florko – He received his Bachelor‘s degree in Informatics at Department of Computers and Informatics, Technical university of Košice, Slovakia in 2017. He is a student of Master‘s degree in Informatics in the same university. His thesis is based on exploring ways on how to construct algorithms for quantum computers and how to integrate them into tangible computer applications. He is also working as application developer for the IBM company in Košice, Slovakia, being responsible for mobile development practice, frontend and backend technologies as well as cloud and DevOps integration.

TARGET TRACKING BY ADAPTIVE FILTERING

Peter ROHAĽ, Ján OCHODNICKÝ

Abstract: In the field of adaptive radar (tracking) under conditions of interference, techniques such as the extended Kalman filter, particle filtering algorithms, etc., are usually used for state estimate. Many techniques have been developed for more effective target tracking. In this paper, we approach the structure and key features of the proposed adaptive targeting radar and the algorithm of the particle filtering (PF), the Elman NN (neural network) and the Group Methods for Data Processing (GMDP). The adaptive tracking algorithm can solve the question about the accuracy of estimates around probable points. The proposed algorithm was used in adaptive radar especially for monitoring problems with emphasis on backpropagation learning, selection of correct algorithm, decision making based on the situation and storage of information. The simulation results showed that adaptive tracking had a great impact on the accuracy and smartness of tracking compared to common approaches.

Keywords: Target Tracking; Adaptive Radar Data Processing; Kalman filter; Particle filter; Neural Network.

1 INTRODUCTION

Radar is a remote measuring system that is used for observation, tracking and display applications, whether for civil or military purposes. It is possible to build an adaptive radar system (ARS) with today´s technology. The trend in new generation of adaptive radar development is wireless adaptive technology. The first adaptive radar architecture based on knowledge-aided (KA) in real-time (RT) was developed by the Defense Advanced Research Projects Agency (DARPA). The development was focused on the future possibilities of ARS software processing with an emphasis on the area of learning. Learning is a primary part of adaptive radar. In general, the learning process can take place in two different modes: offline or online. Backpropagation learning is the best approach for adaptive radar among many online learning approaches [1]. In modern approaches of backpropagation learning, also known as neurodynamic programming, Bellman´s dynamic programming provides a theoretical basis to approach [2]. However, Bellman´s dynamic programming has a disadvantage in dimensionality, which limits its practical applicability. Neurodynamic programming overcomes this limitation by neural network that approximates dynamic programming to a feasible form. Neurodynamic programming allows the learning system to do two things [1], [2]:

- To make the right decisions by following its own system behaviour using Monte Carlo simulations in offline mode;
- To improve system operations by built-in support using iterative optimization in online mode.

The result is a learning process that allows adaptive radar to learn continuously by interactions with the environment. It works in the same way the bats know their surrounding environment due to echo-location. As illustrative case in this study, the issue of target tracking with backpropagation learning and the design of adaptive radar applied for tracking in the environment with interference is described.

The target of this work is to compare the efficiency of individual methods used for adaptive processing of radar data. In this article, simulated and practical experiment will be performed with the real data to verify the effectiveness of the method of Kalman filtering, extended Kalman filtering, particle filtering, unscented Kalman filtering and Kalman filtering using neural networks for adaptive processing of radar data in a data processor. In implementing these methods, we will focus mainly on the deviation between the predicted and the actual position of the target in the form of an absolute error. The main mission of this practical experiment is to track the target with these five methods in order to get rid of this error, to make this error as small as possible, and to determine by comparison what procedure is more effective.

2 SYSTEM OF TRACKING

The radar in this paper is a cascade which consists of the signal processor, the data extractor and the data processor. The data processor is the ultimate broadband compressor. It receives data at high speed (e.g.: bandwidth of the radar signal that is in the order of even tens of MHz) and processes the signal in such a way that a relatively low data rate (several Hz) is achieved. At the same time, there is progressive discrimination between useful and interference data by a step-by-step decision-making process. The information processed by the process chain is gradually modified to a form that makes it easier for users to make decisions. In fact, the raw video signal contains many false alarms. The data extractor isolates a useful target, and the data processor identifies the target (indicated by a code), determines the target speed and other parameters that are displayed on the display in the form of a table with data (tabular display). Furthermore, it´s possible to observe an increase in the time span in which processing is carried out over a cascade. The signal processor includes only a few pulses and the extractor gives some adjacent pulse groups and sequential radar scans of the data processor. Processing memory increases only when the processing cascade works like it´s depicted on the Fig. 1 [3].

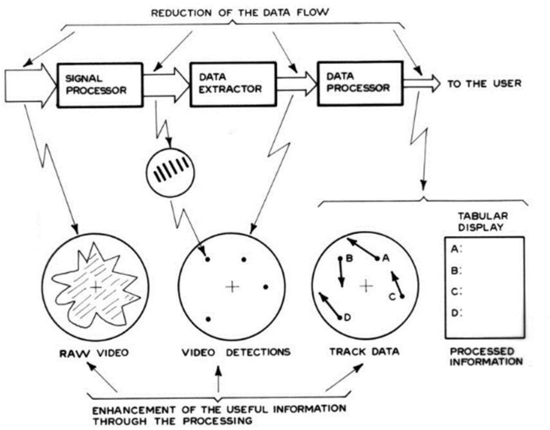

Fig. 1 Functions performed during the radar receiving phase
Source: [3].

In this paper, we´ll focus on tracking the targets which is implemented in the block of data processor Fig. 1 as data processing of track data for individual targets. Tracking can be defined as a set of algorithms that through applying on radar detections obtained during sequential checks allow:

- Recognizing a pattern of sequential detections that relates to the same target;
- Estimation of the target kinematics parameters (position, speed and acceleration), thereby is created so-called "target track";
- Extrapolation of the track parameters;
- Distinguishing of other targets, including other attributes (e.g.: IFF: Identification Friend or Foe, shape, electromagnetic signature / finger printing) and base on this creating a different track for each target;
- Resolving false alarms (cause by intentional or natural interference);
- Adaptive adjusting of signal processor threshold to make the radar more/less sensitive in different directions of receiving, depending on the false alarm detection map refreshed by scan-to-scan (cycle-cycle/period-period of processing the information);
- Tracking by radar with a phase-controlled system (The radar can track a manoeuvring target with minimal absolute error and optimally overlap the phase of tracking with searching and other radar functions.);
- Effective controlling of detections and/or tracks obtained from sets of cross-linked systems of different radars that track the same searching area to provide better detection and final target track.

I´d like to note the difference between the classic adaptive radar and the cognitive radar. The adaptive radar is capable to extract and utilize information about the target and interfering signals to improve its efficiency by appropriate signal processing algorithms that adapt the signal at the receive level. On the other hand, the cognitive radar can use all extracted information not only at the receive level but also at the transmit level by changing the transmit frequency channel, waveform shape, time-on-target (it means that the target will arrive at a certain location at the same time with just another path – the military standard for the estimated time of impact is ±3 seconds), pulse repetition frequency (PRF), power, number of pulses, polarization, etc. In adaptive radar, all these parameters are pre-set and cannot be changed.

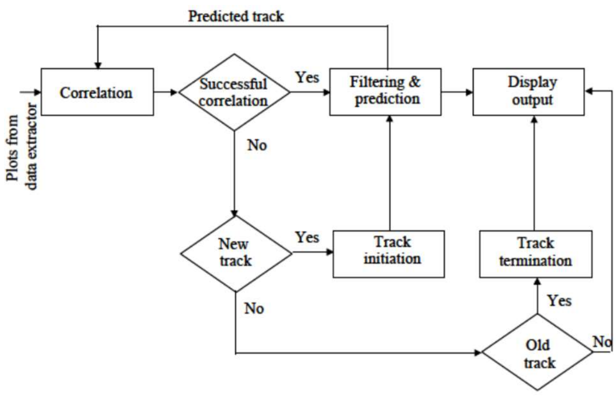

Fig. 2 Basic tracking features
Source: [3].

The principle of tracking can be explained by following logical steps: track initialization, correlation with track plotting, track prediction, track filtration and final track. Connections between these basic tracking functions are shown on the Fig. 2 [3]. At first, the track (track initialization) must be created. The initial kinematic state estimation of the target (position and speed) can usually be obtained from two consecutive reflected signals from the target. The speed of target is achieved by the ratio of the position shift to the period of radar scan. This simple procedure is not reliable if false alarms/plots are present. The track is then distorted. Then, it is necessary for the track initialization to use a longer string of plots as only a few sequences that are consistent with the expected behaviour of the target. In the next scan, it´s desirable to capture the reflected signal from the same target and assign it to its track if it´s possible (logic of the plot-track correlation). Assume that the target is moving at a constant speed; the position of the target can be predicted in the next scan (logic of the track prediction) by current estimates of its position and speed. In these estimates can be inaccuracies and random element exists due to the presence of noise at the location where the plot was expected in a next scan. It´s expected from the random element that it appears on the target plot in the next scan. Therefore, in order to find a further reflection from the target, it´s necessary to correct these errors. This can be achieved by deploying a scan area with focusing on predicted position of the target;

found plot in scan area is associated with detected track. The size of the radar search area is determined by error estimates in position and velocity, and by the number of random locations (plot noise). The search area must be large enough to ensure a high probability that another reflection from the target will be there. But at the same time its size should be as small as possible in the presence of false plots, the large search area will capture statistically more false plots. This getting worse the association problems in case that more than one plot will be in search area, it´s not known which plot represents the target. The process mentioned above is applicable only to target which is not manoeuvring. In principle, this approach is simply extended about manoeuvring targets. Certain restrictions on target manoeuvre are assumed; in the simplest case it can only be its maximum acceleration. The target manoeuvrability can be expressed as a manoeuvre area that surrounds predicted target positions, so that by ignoring the effect of estimating and noise error plotting, the target must be found at a certain point within that area in the next scan. But there are two sources of difference between the predicted position and the current position of the next target plot, namely: estimation errors and noises, and possible target manoeuvres. The overall search area should be created to allow for the worst differences from each of these sources. In other words, the area of noise (i.e. search area used for the non-manoeuvring target) and the area of manoeuvre are "added" to obtain the final search area. Assume that the next target plot is identical with predicted flight track. Now, it remains to update and improve estimates of target position and velocity by a newly-acquired plot (logic of the track filtration). This operation is performed by a digital filter that determines an error between the measured and predicted position of the plot, and also represents in ultimate consequence the smoothed target position and velocity at the output (the most probable nearest future target position). Development in the field of smoothing and correlation logic goes hand in hand with the steady increase in processing speed available in increasingly powerful computers.

3 TRACKING, ASSOCIATION AND DATA FUSION

This section illustrates new recent findings in the theory of nonlinear stochastic filtering, which are outside the classical Kalman filter theory. Here are summarized the recent findings in the theory of nonlinear stochastic filtering that goes beyond the classic Kalman filtration; these results enable us to solve filtering problems characterized by nonlinear dynamic state equations, such as ballistic missile tracking to the point of impact and solving nonlinear measuring equations (for example, equations only for tracking problem) [4]. The general problem of the non-linear non-Gaussian equation is that it has an optimal estimate requiring calculating the whole probability density function (pdf) of the dynamic state x_k adjusted to the entire set of available measurements $Z_k = \{z_1, z_2, \ldots, z_k\}$. For the same purpose, it should be solved by the non-linear stochastic partial differential equation (Fokker-Plank-Kushner equation); this task is practically impossible, except for a few cases when the linear Gaussian equation brought by the Kalman filter and the Benes filter [5], which really represents a nonlinear case (Fig. 3 and 5). In general, it´s necessary to resort to analytical approximation; the most widely used is the Extended Kalman filter (EKF), which may work wrong in some cases (Fig. 6). Nowadays, the approximation method is more efficiently used in the Unscented Kalman filter (UKF); another approach that is close to optimal is particle filtering (PF).

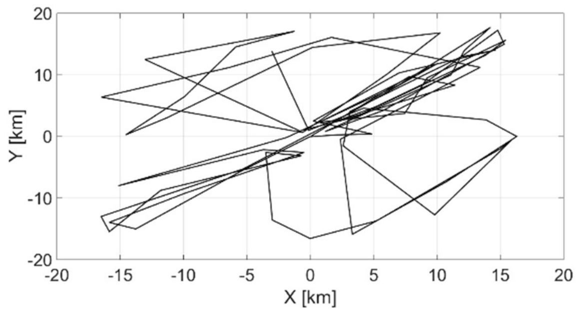

Fig. 3 Simulated object´s flight track (True flight track)
Source: author.

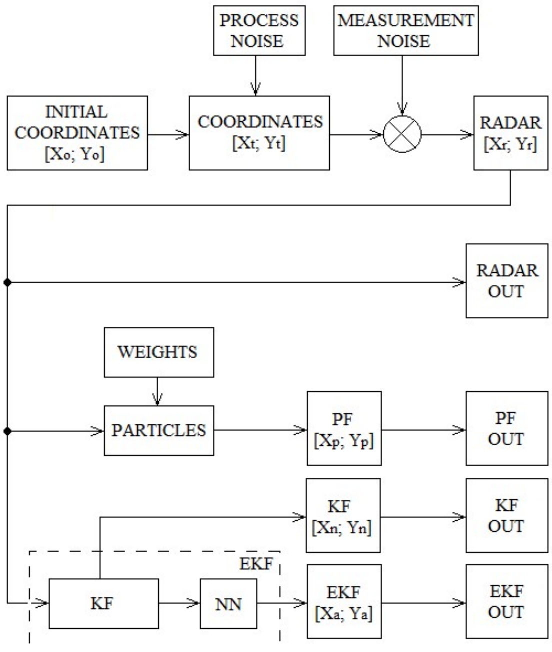

Fig. 4 Target tracking system model
Source: author.

Considered model of target tracking system is shown on Fig. 4. Coordinates for target were generated randomly by equation for coordinate X and Y. In these equations were set initial coordinates and process noise with random process was added. To receive coordinates from the target tracked by the radar additional random measurement noise needs to be included. All chosen filters (particle filter, Kalman filter and Extended Kalman filter) for data processing were parallely created and inserted after target coordinates obtained from the radar. Particles were affected by their weights in particle filter. Extended Kalman filter was created with help of additional neural network.

On Fig. 5 is simulated object´s flight track or true flight track generated by generator of random track and radar tracking or radar flight tracking. The generator consists of random equation with additive random process noise (PN) and the radar tracking has extra additive random measurement noise (MN). In this case, it was for coordinate:

$$x_t = 0.5*x_{t-1} + 25*x_{t-1}\text{^}2 + 8*cos(t-1) + PN*randn;$$

$$y_t = 0.5*y_{t-1} + 25*y_{t-1}\text{^}2 + 8*cos(t-1) + PN*randn;$$

and the radar tracking was defined as:

$$x_r = x_t + MN*randn;$$

$$y_r = y_t + MN*randn;$$

where $t = 1, \ldots, 73; r = 0, \ldots, 73; x_0 = y_0 = 0.1; PN = 1; MN = 1$ and *"randn"* is random scalar drawn from the standard normal distribution.

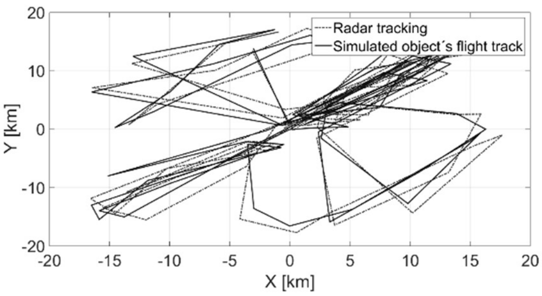

Fig. 5 Rendering of Radar tracking (Radar flight tracking) and Simulated object´s flight track (True flight track)
Source: author.

As in the case of the EKF, the UKF works on the recursive estimate of the minimum mean square error (MMSE). But unlike EKF, the UKF doesn´t approximate nonlinear equations (dynamic and/or measuring). Instead of it, the UKF uses a true nonlinear model and approximates PDF (probability density function) of the state vector [6]. However, this density is still considered as the Gaussian equation (in fact it´s not due to nonlinear dynamic equations of measurement) and is specified by $2n_x+1$ deterministically selected samples or sigma points (n_x represents the size of state vector). The choice of sigma points guarantees accurate prediction of the diameter and covariance up to the third order for given Gaussian equations. The UKF prediction step is described as follows. At first, the unscented transformation [6] calculates the sigma points based on the values of the filtered state vector and the corresponding covariance matrix: $\hat{x}_{k/k}$, $P_{k/k}$. Then, sigma points are propagated by nonlinear functions, and from them the predicted state and its covariance are calculated. An example of application UKF is ballistic target tracking to its point of impact, where the dynamic equation is used and it´s nonlinear [7].

On Fig. 6 is comparison of KF and EKF absolute error. Standard KF has bigger absolute error, because it´s linear filter and simulated track was with high dynamics of object. The adaptive KF has better performance in this case, because of neural system which behaves as nonlinear filter.

The particle filter error on Fig. 7 is also nonlinear and has comparable performance to adaptive KF with neural network.

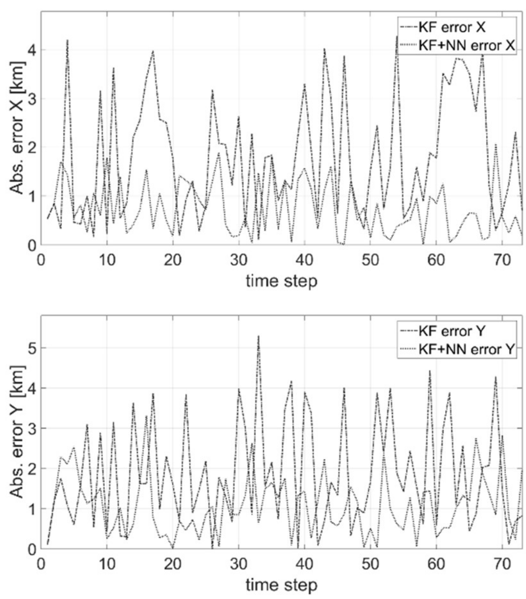

Fig. 6 Kalman filtering and Extended Kalman filtering absolute error (separately axis X and Y)
Source: author.

Particle filtering (PF) is a recursive Bayesian filter based on the Monte Carlo method, also called the Sequential Monte Carlo (SMC). In this method, the probability density is realized by the set of samples whose distribution in the state space and the weight determine the probability of each position of the object. PF is capable to process nonlinear data acquired from sensor measurements (Fig. 7) and non-Gaussian noise is gained by distribution represented by a set of samples (particles). The complexity of calculation increases with the growing number of points of interest [8]. That's why is this filtering used for localization tasks solving and for object tracking, and it used to combine itself with other methods or by using so-called filter bank. Each sample (particle) is represented by the hypothesis about association its data with a certain probability. The algorithm consists of the process of generation particles (samples) and resampling process. Its complexity is algorithmic. The more samples (particles) is used, the more time is needed for a more complicated calculation, while it´s difficult to define the time because it´s difficult to define the enough particles (samples) for sufficiently correct calculation.

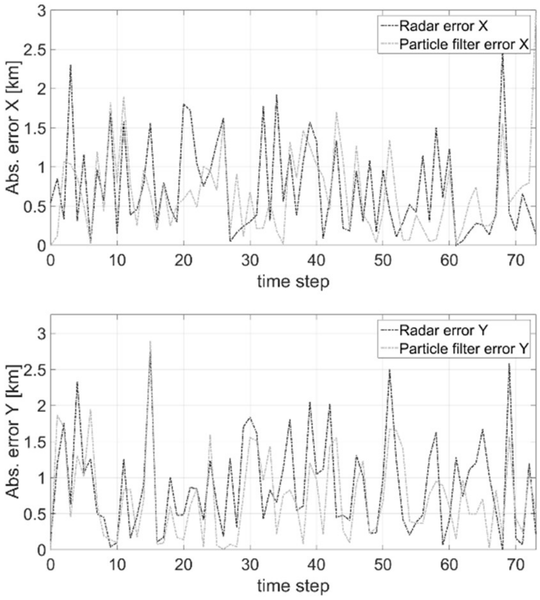

Fig. 7 Comparison of Particle filtering and Radar absolute error (separately axis X and Y)
Source: author.

Basics of PF consist of two steps: prediction and update. Prediction is the way, the previous PDF is given by the Chapman-Kolmogor equation, while the update is an operation that modifies the previous PDF using Bayes formula by new observations. Recurrent predictions and updates recursively estimate posterior PDF.

$$p\left(X_k \middle| Z_{1:k-1}, \theta_{1:k-1}\right) = \int p\left(X_k \middle| X_{k-1}\right) p\left(X_{k-1} \middle| Z_{1:k-1}, \theta_{1:k-1}\right) dX_{k-1} \quad (1)$$

$$p\left(X_k \middle| Z_{1:k}, \theta_{1:k}\right) = \frac{p\left(Z_k \middle| X_k, \theta_k\right) p\left(X_k \middle| Z_{1:k-1}, \theta_{1:k-1}\right)}{\int p\left(Z_k \middle| X_k, \theta_k\right) p\left(X_k \middle| Z_{1:k-1}, \theta_{1:k-1}\right) dX_k} \quad (2)$$

The particle filter is also used in this case, when the spatial-state model also includes non-linearity, as it´s often in the case with the practical method for performing the repetitive relations mentioned above. PF begins with a set of *N* particles selection from a known distribution. The weights of these samples are first labelled as *1/N*. In the predictive step, PF propagates each particle by (the second mentioned above) equation to obtain samples at time step *k* from the previous PDF, i.e., where the sample X_k^i taken from the PDF is process noise. During the update step, PF is revaluating the weights for each sample using the following equation:

$$\omega_k^i = p\left(Z_k \middle| X_k^i\right) / \sum_{i=1}^{N} P\left(Z_k \middle| X_k^i\right) \quad (3)$$

The posterior probability density function $p\left(X_k \middle| Z_{1:k}, \theta_{1:k}\right)$ is in the particle filter represented by a set of *N* random samples and related weights

$$p\left(X_k \middle| Z_{1:k}, \theta_{1:k}\right) \approx \sum_{j=1}^{N} \omega_k^j \delta\left(X_k - X_k^j\right) \quad (4)$$

where X_k^j are particles (samples) and ω_k^j are the corresponding weights. If the number of particles increases asymptotically, this representation almost converges to the usual functional description of posteriori probability density function.

If it´s not possible to sample from this density, it needs to be established the significance of density *q(.)*, from which it´s possible to sample easily. With the independent selection of the samples as $X_k^j \sim q\left(X_k \middle| X_{k-1}^j, Z_k, \theta_k\right)$, the weights ω_k^j are given:

$$\omega_k^j \propto \omega_{k-1}^j \frac{p\left(Z_k \middle| X_k^j, \theta_k\right) p\left(X_k^j \middle| X_{k-1}^j\right)}{q\left(X_k^j \middle| X_{k-1}^j, Z_k, \theta_k\right)} \quad (5)$$

Sequential Monte Carlo (SMC) methods lead to the estimation of a complete PDF (probability density function). Approximation is focused more likely on a set of PDF than on a compromise with the state space model. They are known as particle filters, SIR (sequential importance re-sampling), bootstrap filters, Monte Carlo filters, condensation, etc. PF estimates the entire density of the state vector on the background during its development. PF has the advantage of being able to handle any functional nonlinearity, and system or measurement noise of any distribution. They effectively provide an accurate and equivalent view of the desired PDF, because the number of random samples used in the filters is sometimes very large. Moment estimates (such as diameter and covariance) or percentiles of the PDF state vector can be obtained directly from the samples. The MMSE estimate is then calculated as the average of the following density. The main idea is to represent the required density by the set of random samples (particles) [9], [10]. When the number of particles grows to infinite, the expression of the required density becomes accurate. In practice, the work with the finite or small number of particles is the most often and that´s why the optimality of PF is sometimes lost. However, PF has shown excellent efficiency in many practical applications compared to other nonlinear filters. Let the following density $p(x_k, Z_k)$ be represented by a set of random samples (particles) $X_k=\{x_k(i):i=1, 2, ..., N\}$. PF is an algorithm that propagates and updates the set X_k to a new set of random samples X_{k+1} which is approximately decomposed as the following density $p(x_{k+1}, Z_{k+1})$. A specific PF scheme that has been tested as an example is based on a sequential importance re-sampling scheme [9] with a regularization step to avoid the problem of "impoverishment". All particles N from X_k go through the state equation in the prediction step. The weights associated with each predicted particle are calculated as the normalized probability based on the observation of the z_{k+1}. The predicted particles are sorted by Epanechnikov kernel and selected based on a probability equal to their weight in the resampling step. In the case of non-linear dynamics and linear measurements (as in the case of ballistic target tracking), a more effective PF based on density of optimal importance could be proposed [10]. The KF corresponds to each particle filter.

Other examples of PF applications (Fig. 8) are tracking in clutter, tracking with interrupted target tracks, tracking a target group, and tracking based only on the target relevance, multiple target tracking, and data fusion, etc. Some features of the PF are: the algorithm can be parallelized, it combines realistic models, and it combines prior and context information (terrain shadowing, manoeuvrability) integrates with decision-making processes.

One problem that PF has is a much more complicated calculation than for EKF and UKF. For the purpose of comparing the complexity of the PF calculation with respect to the calculation of the EKF and UKF in terms of ballistic target tracking, the calculations are presented in [7].

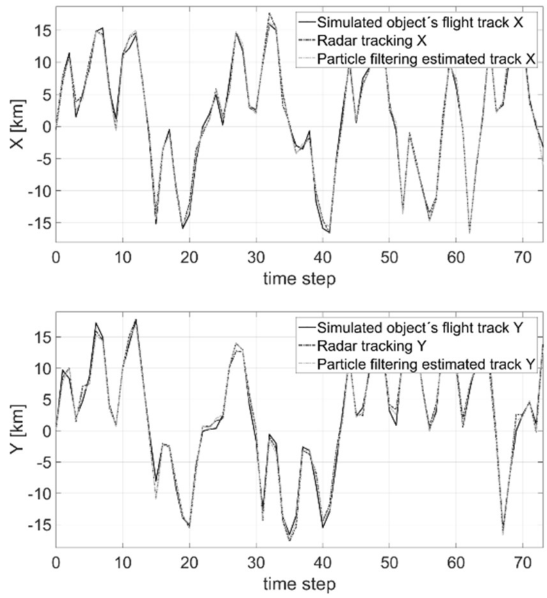

Fig. 8 Rendering of Simulated object´s flight track, Radar tracking and Particle filtering estimated track (separately axis X and Y)
Source: author.

The performance of simulated filters is clear from Fig. 10. The highest absolute error had standard KF, because object track was simulated with high dynamics Fig. 3 and KF is well known by its linearity. Very good performance was reached (in MSE less than 900 meters) by particle filtering (also Fig. 7) and adaptive KF with neural network (also Fig. 6).

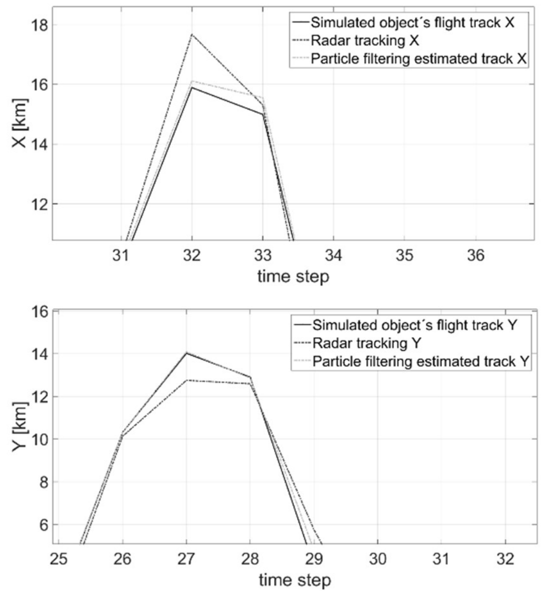

Fig. 9 Detailed view of Simulated object´s track, Radar tracking and Particle filtering estimated track
Source: author.

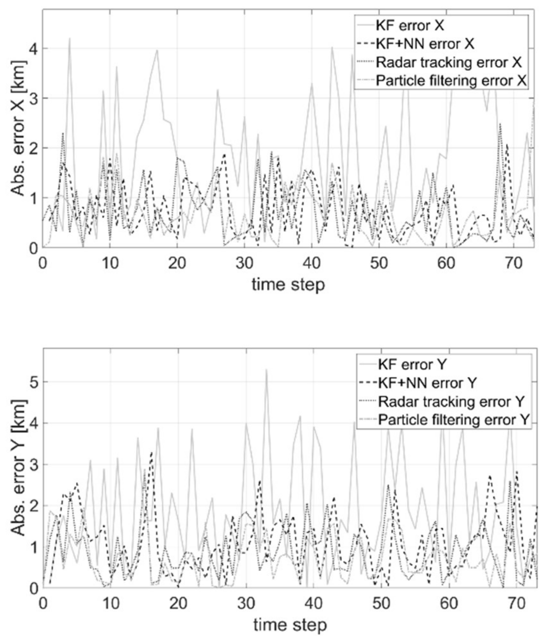

Fig. 10 Comparison of KF, KF+NN, Particle filtering and Radar tracking absolute error (separately axis X and Y)
Source: author.

An association is a process which results is redistribution in data acquired from multiple sources into the groups created for individual targets. Integration of these data about the target into the given group of this target is called data fusion. Refined and summary information about the target that characterizes its state is obtained by the data fusion process.

It´s possible to distinguish so-called lower and higher level of data processing in the data fusion model. Target detection by sensors, data association, state estimate and target classification can be included in the lower level. These data do not more accurately specify the target. The higher level of processing includes data evaluation considering of the way the targets behave and the way of their prediction, the targets and their features association, and the classification of the situation. This is a qualitatively higher level of data that contains target identity data. The system can continuously track the track of the detected target, and it can determine which target is new, or whether it´s a false alarm. In this case, an iterative association process is used with a state estimation in the next measurement cycle (with the state prediction) of already known targets to ensure continuous tracking and to detect new targets. In this way, the system can track and predict moving targets by time-discrete or continuous measuring of their position. The target position prediction is ensured by so-called Probabilistic Data Association (PDA) or Joint PDA (JPDA). To estimate the state of multiple targets whose tracks overlap and cross each other is used JPDAF, the extended PDA filter. All reports of the JPDA algorithm correspond to common associative hypotheses, which give these messages redistributed to individual targets and interferences, the associative probabilities in the algorithm are represented by weights.

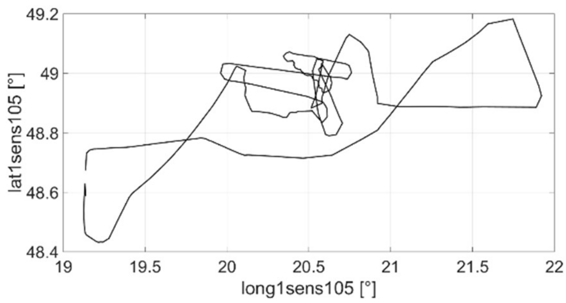

Fig. 11 Target tracking by one tracker with 343 samples during trial flight in WGS 84
Source: author.

The issue of association and data fusion is not systematically elaborated, but only individually in relation to the concretely solved situation. Nowadays, research focuses on the application of neural networks, their advantages and disadvantages, and new optimization criteria suitable for implementation into the field of association and data fusion.

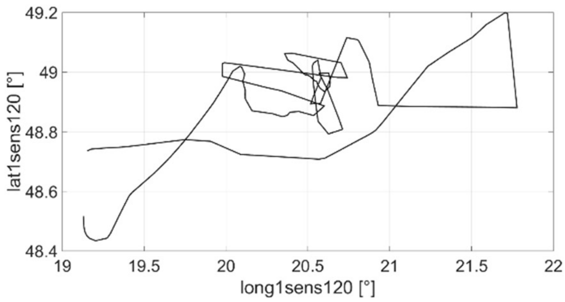

Fig. 12 Target tracking by another tracker with 216 samples during trial flight in WGS 84
Source: author.

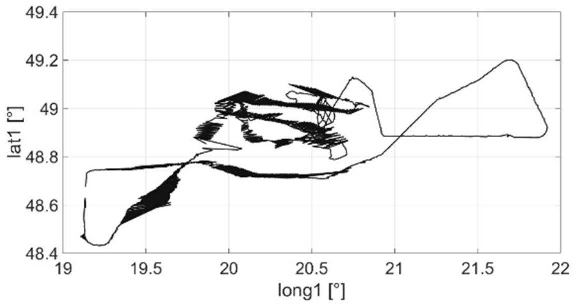

Fig. 13 Target tracking by five trackers with all 1697 samples during trial flight in WGS 84
Source: author.

According to association and data fusion, it´s clear from Fig. 11, 12 and 13. The more samples and sensors are used, the more precise track is, but there is a risk that the track will be much noisy as it´s visible on Fig. 13. The track is still recognizable (it´s not so clear), but uncertainties in target tracking were occurred. On the other hand, the track was much more distorted when less or few samples were used.

4 CONCLUSION

Association and data fusion, and different algorithms for data processing have been described in the paper. The disadvantage of particle filtering is the high demand on computational performance (the more particles are used, the more time is needed for calculations, and the more accurate is estimated track). It´s important to find a compromise between times spent by calculations and estimated track accuracy. It´s worth to mention that some adaptive filters exist with applied adaptive part represented by for example neural network. It´s possible to use classical filter less dependent on computing performance with adaptive element to meet relative similar performance as PF has. It´s highly recommended to use all above-mentioned filters in so-called “filter bank”.

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Dipl. Eng. Peter **ROHAĽ**
Armed Forces Academy of General M. R. Štefánik
Department of Electronics
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: ing.peter.rohal@gmail.com

Assoc. Prof. Dipl. Eng. Ján **OCHODNICKÝ**, PhD.
Armed Forces Academy of General M. R. Štefánik
Department of Electronics
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: jan.ochodnicky@aos.sk

Peter Rohaľ – was born in Košice, Slovakia in 1988. He received his M.Sc. (Eng.) at the Technical University in Košice. He started his dissertation studies at the Armed Forces Academy of general Milan Rastislav Štefánik in Liptovský Mikuláš in 2013, his research interests are focused on adaptive radar data processing in data processor. Currently he is working as a System Engineer at the Development Department, IEE Sensing Slovakia in Veľká Ida.

Ján Ochodnický – received a M.Sc. (Eng.) from the Military Radioengineering Institute in Kiev, Ukraine in 1986, in C2 systems. In 2000 he successfully finished his PhD. studies in air defence electronics at the Military Academy in Liptovský Mikuláš, Slovakia. From 1979 to 2004 he served for army as Engineer, Staff Technical Officer and Lecturer. Since 2004 he is with the Armed Forces Academy of general Milan Rastislav Štefánik in Liptovský Mikuláš. Currently he is working as an Associate Professor at the Electronics Department and his areas of research are radar technology, EW technology, neural networks and signal processing.

THE CURRENT COMMAND AND CONTROL SYSTEM OF REALIZATION OF ENGINEER SUPPORT TASKS OF TASK FORCE OPERATION

Pavel ŽIŽKA

Abstract: The article deals with the current command and control system of realization of engineer support tasks of task force operation depending on the realized steps within the Army of the Czech Republic transformation in recent years. The aim of the paper is to evaluate the current state of command and control system and identify possible causes contributing to the current situation in this area. To identify crucial causes which have a significant impact on the command and control system of realization of engineer support of operation was used so-called problem tree method.

Keywords: Command and control; System C2; Engineer support.

1 INTRODUCTION

The role of military forces in the military operation must be carefully considered and understood. With regard to difficult and unpredictable changes in the strategic environment, new ways of thinking, planning and negotiating will be required. Today's dynamic process of the growth of modern technology has a major impact on areas such as the construction and development of command and control systems. All this is happening beneath constant by changing conditions and under the influence of a number of active factors stemming from the military research carried out and the deployment of forces and resources in operations. Not only these active factors, but also other general factors, emphasize how important it is to constantly check and improve command and control systems in operations.

The field of engineer support plays an irreplaceable role in performing various military operations. In view of the requirements for effective realization of engineer support, it is necessary to continuously verify the functionality of the organization structures, the number of engineer units and the effectiveness of the command and control system in the operation.

2 OBJECTIVE AND METHODS USED

The main goal of the author is to make an analysis of the command and control system in performing the tasks of the engineer support of the task force operation and, on the basis of the findings, to propose measures that will optimize the problem.

In order to achieve the main goal of the work, the following partial objectives were set:

Goal 1: Analyze the current status of the command and control system in performing the tasks of engineer support for the task operation.

Goal 2: Formulate a key issue.

Goal 3: Define recommendations for optimizing the command and control system to perform the tasks of the engineer support task of force operation.

3 THE INITIAL DEFINITION OF THE PROBLEM

Until 1999, the Czech Army developed the capabilities to ensure the individual defense of the Czech Republic. After joining NATO, capabilities were developed in line with the needs of collective defense. After 2004, the necessary skills were strengthened for deployment in foreign operations, which has in many respects increased professional readiness and enhanced interoperability with allies. However, the military action in military operations had negative impacts, which reflected in the limitations of the training of troops, commanders and staff for the main types of combat activities. In the years 2009–2013, due to the decrease of the source framework allocated to the ACR, there was a slowdown in the transformation, which was significantly reflected in staffing and replenishment of machinery according to the number of soldiers and especially the achievement of the required capabilities of the Czech Army. Command and control systems have been unified both in terms of composition and staffing, as well as technical equipment [1].

Nevertheless, even under limited conditions, the capabilities of individual troops have been developed, notably in the unification of planning procedures and the actual execution of operations. Most attention, however, was focused on manoeuvre forces.

4 VALID DOCUMENTS DEFINING THE CURRENT STATUS OF COMMAND AND CONTROL SYSTÉM OF REALIZATION OF ENGINEER SUPPORT TASKS OF TASK FORCE OPERATION

At present, we can find a wide range of documents that are partly or fully engaged in the command and control system of military operations. Doctrines provide general framework for the planning and preparation of army forces to conduct operations in peace, in crisis situations during the war. The importance of doctrines is to ensure a consistent understanding of the principles of preparation, operations management and the achievement of an optimal level of interoperability by NATO member states. The doctrines are based on the "Security Strategy of the Czech Republic", on the "Military Strategy of the Czech Republic" and on NATO's basic military and political and operational standards. It deals with the current issues of the Czech Army concept and development and the level of contemporary military thinking and cognition. For the needs of engineers "Allied Tactical Doctrine for Military Engineering" ATP 3.2.1" is of paramount importance.

Within the Czech Army Doctrine of the Command and Control System in Operations there exists the publication of "Ground Forces in Operations" (2011), whose aim is to clarify sharing ground forces in the conduct of joint Allied operations, to clarify the way and the principles of ground operations and the way in which the Czech Army ground forces are involved in these operations [2]. In 2007, the publication of the "Staff work in operations, part I" was published, describing the authorities of the command and their main tasks, which will usually be fulfilled in the operation, command positions of the individual organizational elements of the Czech Army following the strategic command posts, their composition and tasks with the concept of command posts and the current organizational structure of the professional the Czech Armed Forces [3].

The system of command and control of engineer support in operations is not a new area, however the proper elaboration and description of this area in the documents that clearly define the required state of the Czech Army in 2025 is done only partially and mainly for strategic or operational level.

For a tactical level, the command and control system is also developed only partially, especially from the point of view of infantry units. Also, these documents are not responding to current developments and their content often does not correspond to the actual or required status according to the approved army development documents.

5 DIFFERENCES AFFECTING THE SYSTEM OF COMMAND AND CONTROL SYSTEM OF REALIZATION OF ENGINEER SUPPORT TASKS OF TASK FORCE OPERATION

Engineer support is a multi-branch activity that is carried out by all types of troops and multiplies the capabilities of troops across the whole spectrum of operations. Engineer support is a part of the combat support provided to commanders, crews and task forces troops. It includes a whole range of activities from providing engineering recommendations to the implementation of the most complex engineering measures for the benefit of troops [2].

With regard to the specific use of engineer units for combat activities the intensity of use of these units during the entire conflict is affected not only in the period before or during the conflict, but also in the post-conflict period. This effort then changes in the different phases of the operation.

Fig. 1 shows the intensity of effort of engineer units. In support of operation, the intensity of effort of engineer roles useable for general support is greatest at the beginning and end of operations. On the contrary, for the effort of engineer roles useable for combat support are intensity the highest during operation, while the total effort is constant throughout the military operation.

From the point of view of the activities of manoeuvre and engineer units, we are led by facts that are reflected in the scope and content of each period of the military decision-making process of the commander and the staff at all stages of the operation.

The following points describe the most important facts:

- The structure of the command post of the engineer battalion from the point of view of occupying positions is similar to manoeuvre units. The main difference lies in the fact that the emphasis is put on the staff members with engineer specialization. Another, no less important, difference is that engineers do not have expert of manoeuvre units. From the above, it is clear that in most cases it is not possible to create the same command post from the point of view of the structure of function position as the command post of manoeuvre units;
- Engineers have usually defined very specific tasks in the operation order, characterized by time, synergy and volume of work, including limitations. Tasks that are specifically set out clearly show the follow-up in preparation, planning and execution itself. For this reason, members of the engineer battalion perform a variant solution rather than the actual creation of options of realization of engineer support tasks in favor of all arms commanders;
- Different planning activity at the level of the brigade task force and engineer battalion. The brigade task force staff carries out the planning of engineer support tasks and the engineering battalion staff is planning realization of engineer support tasks, see Fig. 2;
- The necessity to ensure synergy between manoeuvre and engineer units in the realization of the engineer support tasks. Implementation of engineer support tasks is usually coordinated and tailored according to specific details directly at a designated location in the field - for example, location and orientation of protective structures;

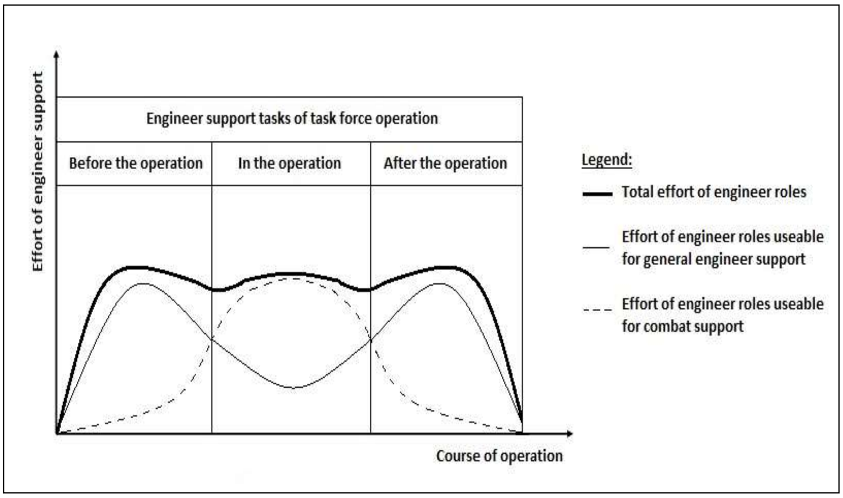

Fig. 1 Division of efforts of engineer support during the military operation
Source: [4].

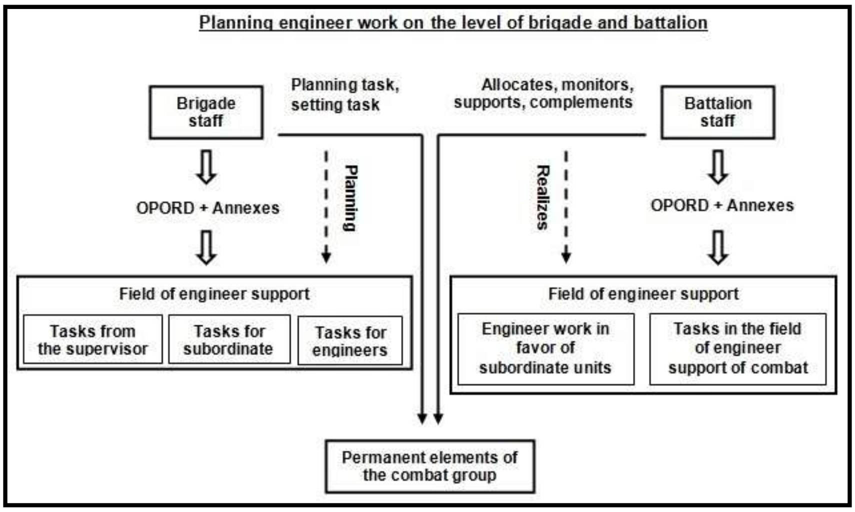

Fig. 2 Planning of the Engineer's Work
Source: author.

- The high complexity of the planning process imposed on the engineer battalion commander due to the simultaneous fulfillment of more engineer support tasks for the benefit of ground units in the operation area. The commander of engineer battalion must be able to create, manage and coordinate a variety of groups and teams in the most effective way to fulfill engineer support tasks at one moment;
- Allotment (transfer, takeover) of engineer units to the benefit of manoeuvre units. According to the established principles of warfare, one commander is usually responsible for the area of responsibility. In the case of realization of the tasks of engineer support it is necessary to transfer the units of the engineer troops to the subordination of manoeuvre commander so that he can make the best use of them for his benefit. Within the framework of engineering combat forces are created permanent and unstable components of the combat group. For example, between permanent components of the combat group are included a movement detachment or blocking detachment. These permanent components are usually transfered to the subordinate of the manoeuvre commander, and are controlled by the task force engineer;
- The use of engineer units resulting from their organic structures. Units of the engineer battalion are usually divided into special units according to the tasks of the engineer support in order to achieve the most efficient tasks of the engineer support. For this reason, the purposeful use of engineer troops is more effective than strict adherence to the organic structure;
- As part of a warfare, the engineer commander is usually commanding only engineer battalion members included in the engineer reserve. As

described above, the commander of the engineer battalion creates from its own forces the permanent component of the combat group. Units that are not a part of the permanent comonents of the combat group create engineer reserve that remains under the command of the engineer battalion commander. As a part of the warfare, the battalion commander is in charge of this engineer reserve, which is predetermined to perform unplanned or unforeseen tasks based on the development of operation. Engineer reserve also serves to strengthen or compensate for the loss of permanent components of the combat group.

6 IDENTIFYING A KEY PROBLEM USING THE "TREE OF PROBLEMS" METHOD

To identify the key issue, I used the "Tree of Problems" method, the output of which is the graphical visualization of the detected problem. The aim is to provide a comprehensive view of the problem and identify its main causes and implications [5].

6.1 Identified causes

- The creation of an ever-new state of public finances influenced by the Czech Armed Forces concept leads to the unsystematic development of the military capabilities of the Czech Army;
- Creation of engineer structures regardless of the fulfillment of obligations and needs arising from NATO standards and national requirements;
- The absence of a scientific reserch of the issue, where at present the issue is not solved and further developed with respect to the needs of the engineers;
- Various activities of manoeuvre units in relation to the activities of the engineer units - composition of the engineer units, the use of engineer specialists and the time-consuming requirements for planning, preparation and fulfillment of tasks;
- Obsolete technical and material equipment with regard to the financial demands of a wide range of techniques and material for the needs of engineers – inadequate response to development trends in command and control system, the necessity of introducing mutually compatible material and technical means;
- Documentation addressing the area of the system of command and control of the engineer support of the operation - general elaboration of doctrinal documents, dealing in most cases only with all deployment units. Obsolete or even unprocessed regulations within branch of engineers. Unprocessed regulations dealing with the issue of the system of command and management of the operation support;
- Low soldiers resources for military engineers - limited opportunity to gain new experience and verify current knowledge in combat operations or at foreign workplaces, and then use them for the benefit of engineers.

6.2 Identified consequences

- Failure to meet the objective of the operation that is failure to complete the task. To successfully accomplish the task, it is necessary to maximize the capability of all the components involved in achieving the main objective of the operation, and to do so in the most optimal way;
- The non-use of the positives provided by the system of command and control of the engineer support of the operation, especially when entering the requirements for the engineer support;
- Insufficient coordination of units which are providing engineer support;
- Requirement of tasks performed by engineers not related to their task;
- Inaccurate determination of the responsibility of officers on the command post in the planning and implementation of the engineer support;
- The administrative burden placed on the command post due to the non-use of the possibilities resulting from the system of command and control of the engineer support;
- The time-consuming fulfillment of the resulting tasks arising from the requirements of commander of manoeuvre units to engineers with regard to the organization of individual workplaces and their tasks;
- The flow of information, scope and content of the processed documentation does not occur in the plan and realization of the engineer support tasks in the staff of engineer unit.

6.3 Modeling the "Tree of Problems"

The problem tree modeling and its subsequent depiction is a central problem in the trunk of a tree, when I assume that there is no command and control system of realization of engineer support tasks of task force operation and its parameters are not defined.

The overall image of the "Tree of Problems" illustrates the individual links between the causes and the central problem, as well as the central problem and the consequences. "Tree of Problems" shows a comprehensive view of the issue, see Fig. 3.

The bottom of the "Tree of Problems" shows the general causes of the problem, which are further branched into specific causes that define our central problem.

The top of the "Tree of Problems" illustrates a set of consequences that are arranged and graded from the least impact to the effects with the greatest impact.

An important root cause of the problem is the absence of an overall concept of building a command and control system of realization of engineer support that would clearly define the different areas of developing a command and control system of realization of engineer support on a tactical level.

6.4 The following key causes need to be eliminated to remedy the problem

- Creating new concepts based on budget resources for the needs of the Czech Armed Forces - this fact affects other specific causes, which negatively affect the functioning of the command and control system of realization of engineer support;
- Engineers are not a priority type of troop - the result is the overall lack of engineers within the Czech Army with impact on the technical-material and human resources;
- Missing or insufficiently elaborated documentation dealing with the use of engineer units - it is appropriate to create a basic model of the task force of the engineers and propose an optimal variant of the command and control system of realization of engineer support;
- Lack of specialists of engineer branch with expertise - without experienced experts, conceptual documents and basic requirements for the command and control system can not be drawn up;
- Obsolete technical equipment - the need to modernize the technical equipment of the command and control system of the engineer units fully compatible with the command and control systems of the other units.

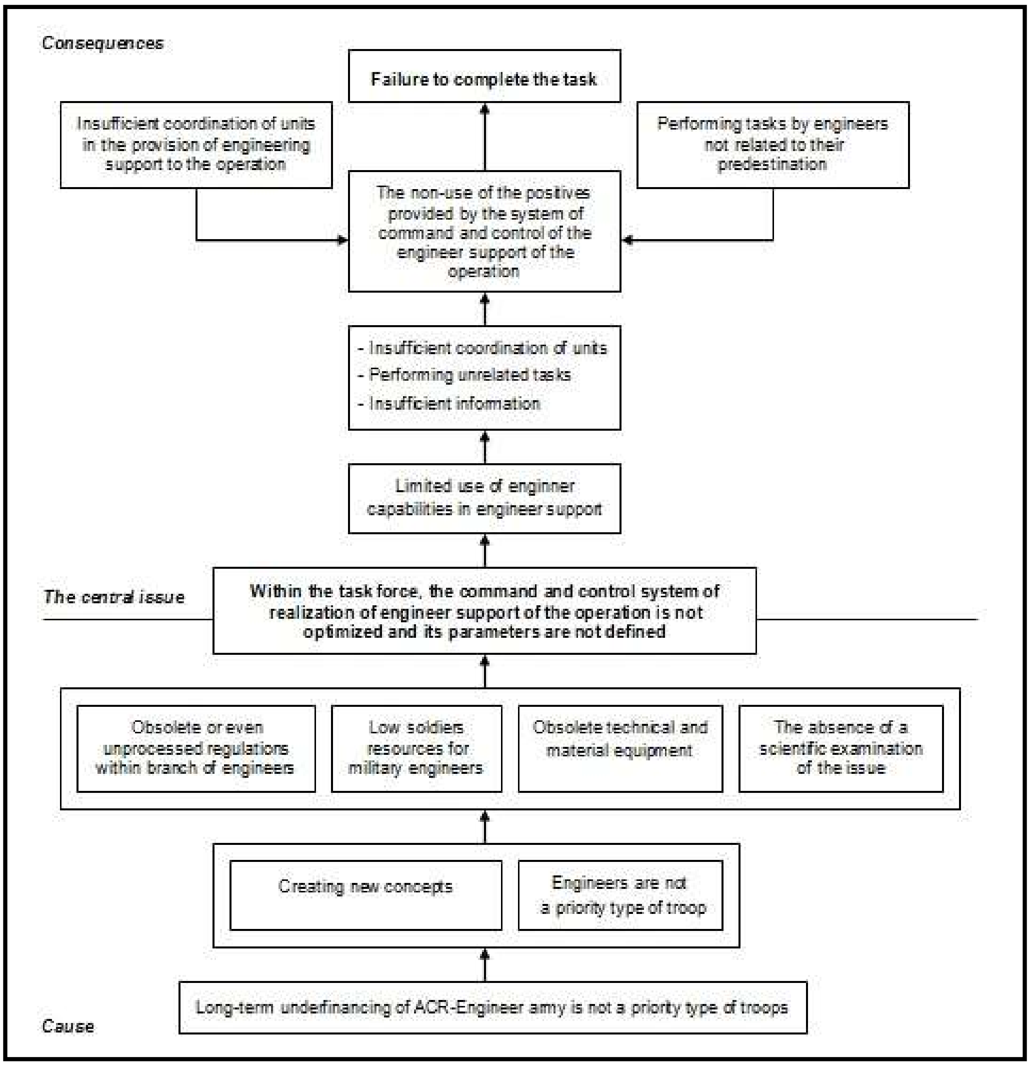

Fig. 3 Planning of the engineer's work
Source: author.

As a result of the root cause of problem,it is clear that the system of the command and control system of realization of engineer support is not optimized and its parameters are not defined. This has resulted in a major consequence, which is, in the extreme case failure to perform the operation.

Apart from the above-mentioned main result in the solution of this problem, we observe other consequences that need to be mentioned:

- Insufficient use of the command and control system of realization of engineer support outputs;
- Insufficient co-ordination between manoeuvre and engineer units in the provision of engineering support;
- Performing tasks by engineers not related to their specialization;
- Partial use of engineer capabilities in engineer support.

6.5 Problem determination

Based on the outcome of modeling the problem, the problem found in this work can be defined as follows: „Within the task force, the command and control system of realization of engineer support of the operation is not optimized and its parameters are not defined".

From the „Tree of the Problem" these six causes have emerged:

- Creation of new concepts of the Czech Army;
- Absence of scientific research;
- Engineer army is not a priority type of troop;
- Insufficient processing of documentation for the creation and use of engineers;
- Lack of specialists of engineer branch with expertise;
- Obsolete technical equipment.

The creation of the new concepts of the Czech Army and the absence of scientific research can be identified as key causes, which are influenced by the amount of budgetary resources allocated to the Czech Army.

7 CONCLUSION

The work is focused on determining the current state of the command and control system of realization of engineer support. This text describes the current state of the command and control system of realization of engineer support at the tactical level and defines the key issues in the field. The thesis defines the central problem.

In the next step is necessary to carry out a detailed analysis of the command and control system of realization of engineer support. To consider the requirements for the system of engineer support of operatin. Subsequently, in accordance with the concept of development, propose steps to optimalize the system of command and control of engineer support.

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Dipl. Eng. Pavel **ŽIŽKA**
153. Eng. Battalion
Libušina 648/111
779 00 Olomouc
Czech Republic
E-mail: zizkap@unob.cz

Pavel Žižka - serves as Deputy Commander of the 153rd Engineer Battalion Currently he is a PhD candidate at the Military University in Brno. His research topic is focused on the implementation of tasks of the engineer support of the task group operation.

FEM ANALYSIS OF MOBILE BRIDGE AM-50 AS PER NEEDS OF SLOVAK ARMED FORCES

Peter MAKO

Abstract: Mobile bridge AM-50 is most common bridging equipment in Slovak Armed Forces. The main purpose of vehicle like AM-50 is to ensure mobility of heavy equipment over different types of barriers. Main tactical parameter is load capacity expressed in MLC classification of the bridge. Because of these facts, FEM analysis of AM-50 load capacity as per NATO standard is essential. This article is showing detailed description of FEM analysis of AM-50 bridge load capacity in accordance of standard STNAG 2021 and their results.

Keywords: FEM Analysis; AM-50; STANAG 2021; Load capacity; Simulation.

1 INTRODUCTION

Slovak republic became a part of NATO in 2004. This membership is bringing benefits as advanced protection by other member states but on other hand duties to fulfil requirements of cooperability with armed forces of member states in case of emergency. One of the most important field of cooperation is interoperability of heavy battle equipment and bridging equipment. Slovak Armed Forces are equipped with tank T72 which fighting weight is much less than weight of main battle tanks and heavy technique of western armed forces. This fact is giving task to Slovak Armed Forces to ensure cooperation with heavy technique of Slovak allies and enginery bridging equipment which is in using of Slovak Armed Forces. Bridging system AM-50 is one of the most common bridging equipment in the Slovak Armed Forces so its FEM load capacity analysis as per NATO Standard STANAG 2021 is essential.

2 AM-50 TACTICAL PARAMETERS

The AM-50 vehicle became part of the Czechoslovakian Army in the beginning of 70-ties of 20th century. Nowadays it is possible to find this equipment in armed forces of Slovak Republic, Czech Republic, India or Pakistan. The AM-50 is a vehicle built on the Tatra 813 8x8 or Tatra 815 8x8 chassis with a bridging superstructure consisting of hydraulically powered laying equipment, a full bridge and a telescopic pull-out trestle. The bridge is a scissor type. Trestle is connected with two pins to the bridge and two rods are connected with body of the bridge as well. Trestle allows telescopic extension which is giving to the equipment opportunity to overcome obstacles with depth of 5.15 m. Bridge own weight as well as a load on the bridge is transmitted to the trestle pads which are contacting the surface with three nuts and bolts with ball thread inside of the trestle. [1, 2, 4]

There are two options for using of the AM-50. First is overcoming of the barrier with width of 12,5 meters without trestle. Second option is using connection of more bridge fields, from 2 up to 8 with using of the trestle in between of them. Based on facts above is clear that for exact designation of the bridge load capacity is necessary to check load capacity of the bridge and trestle also. [1, 2, 4]

Tab. 1 Basic tactical parameters of AM-50 bridge vehicle

Parameter	Value
Bridge width	4000 mm
Bridge length	13 500 mm
Max. load capacity for tracked vehicles	50 000 kg
Maximum load capacity for wheeled vehicle (truck with trailer)	70 000 kg

Source: [2].

AM-50 Bridge vehicle is used by Slovak Armed Forces as per enginery regulation ZEN-24-14. This regulation exactly defines tactical parameters and way of using of this bridging technique. [4]

Fig. 1 Bridge vehicle AM-50
Source: [2].

3 SPECIFICATION OF SLOVAK ARMED FORCES NEEDS FOR BRIDGING EQUIPMENT

Slovak republic is part of the NATO since 2004. The basic principle for NATO collective defence is possibility for cooperation of the armed forces of its member states. This interoperability is important not only between equipment of fighting units but between heavy equipment and bridging or enginery technique also. Most of the allies of Slovak Armed Forces from NATO have different types of the heavy battle technique. In general, is valid that allies from NATO are equipped with heavier technique than Slovak Armed Forces. Below is table with main battle tanks of NATO allies. [2]

On Fig. 2 is visible comparison of tanks battle weight and AM-50 bridging technique load capacity. Yellow line is marking actual load capacity of AM-50 bridge as per enginery regulation ZEN-24-14. In case of increasing of bridge load capacity, AM-50 will be able to cooperate with much more types of heavy technique in armed forces of allies from NATO. To ensure interoperability with practically all main battle tanks of NATO member states is necessary to ensure load capacity for tracked vehicles on level of MLC70. [2]

Based on these facts is possible to evaluate that Slovak Armed Forces need for its interoperability with allies from NATO in field of bridging systems equipment which can take load of MLC70. This load capacity should be calculated, simulated and proved by rules stipulated in STANAG 2021.

Tab. 2 Battle weight of several main battle tanks in use of NATO member states [2]

Vehicle	Battle weight (kg)
M1 Abrams	60 000
M1A1	63 000
M1A2	65 200
AMX Leclerc Series 1	54 500
AMX Leclerc Series 2	56 300
AMX Leclerc Series XXI	57 400
Leopard 2	55 100
Leopard 2A5	56 000
Leopard 2A6	60 200
Challenger 2	62 000

Source: [2].

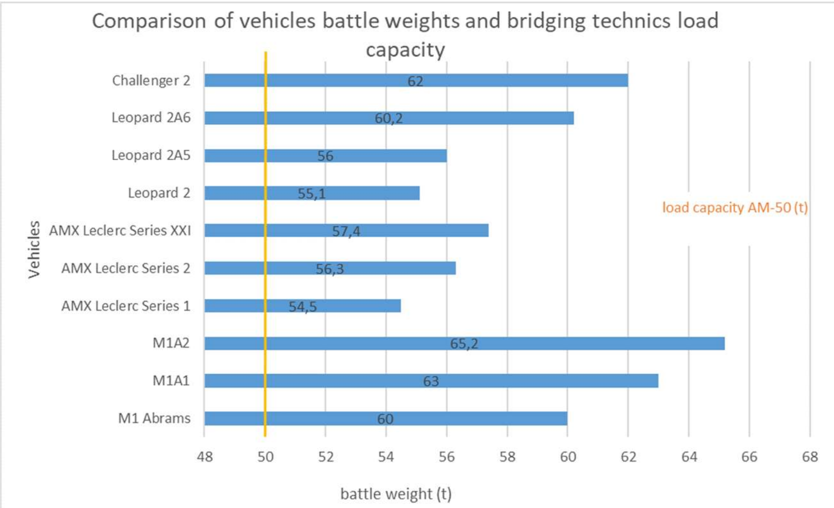


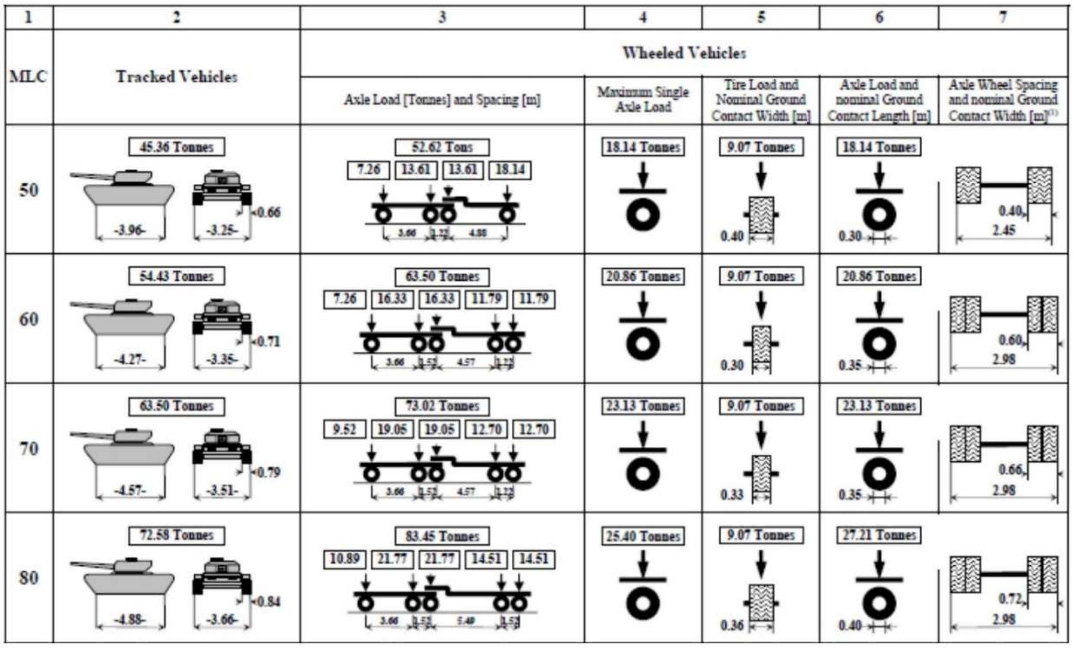
Fig. 2 Comparison of tanks battle weights and AM-50 load capacity as per ZEN-24-14
Source: [2, 5]

4 STANAG 2021

North Atlantic Treaty Organization is using standards STANAG (STANdardization AGreement), which define processes, procedures, terms or conditions for cooperation and interaction of armed forces of NATO. The one part of this standardization is a standard STANAG 2021 which deals with a classification of the different types of the bridging systems in armed forces of NATO member states. Each equipment should be classified in to the MLC (Military Load Classification) category based on its load capacity. Standard defines 16 MLC categories from MLC 4 up to MLC 150. Value of each MLC is exact load capacity of the bridge construction in the short tons. Standard also exactly defines hypothetical tracked and wheeled vehicle, their weight and size of the contact surface between tracks or wheels and the bridge based on which is possible to provide simulations and testing for specifying of maximum load capacity for each bridge device. [3]

Mobile bridging system AM-50 was not officially tested and classified in accordance of the standard STANAG 2021. Nowadays this bridging technique is used in accordance of the enginery regulation ZEN-24-14, which allows crossing of the bridge for tracked vehicles with 50 tons load and wheeled truck with trailer (wheeled set) with maximum load 70 tons.

Based on these parameters is possible to classify AM-50 to MLC 50 category, where maximal allowed load on the bridge as per STANAG 2021 is 45,36 tons and 52,62 tons for wheeled set. [3] It is possible to predict that the construction of the bridge and the trestle is enough oversized to allows crossing of heavier vehicles from MLC 60 category. STANAG 2021 define hypothetical loads for MLC 60 category, where maximum weight of tracked vehicle is 54,43 tons and 63,50 tons for wheeled set. [3]



1	2	3	4	5	6	7
MLC	Tracked Vehicles	Wheeled Vehicles				
		Axle Load [Tonnes] and Spacing [m]	Maximum Single Axle Load	Tire Load and Nominal Ground Contact Width [m]	Axle Load and nominal Ground Contact Length [m]	Axle Wheel Spacing and nominal Ground Contact Width [m][1]
50	45.36 Tonnes; 3.96; 3.25; 0.66	52.62 Tons; 7.26, 13.61, 13.61, 18.14; 3.66, 1.22, 4.88	18.14 Tonnes	9.07 Tonnes; 0.40	18.14 Tonnes; 0.30	0.40; 2.45
60	54.43 Tonnes; 4.27; 3.35; 0.71	63.50 Tonnes; 7.26, 16.33, 16.33, 11.79, 11.79; 3.66, 1.52, 4.57, 1.22	20.86 Tonnes	9.07 Tonnes; 0.30	20.86 Tonnes; 0.35	0.60; 2.98
70	63.50 Tonnes; 4.57; 3.51; 0.79	73.02 Tonnes; 9.52, 19.05, 19.05, 12.70, 12.70; 3.66, 1.52, 4.57, 1.22	23.13 Tonnes	9.07 Tonnes; 0.33	23.13 Tonnes; 0.35	0.66; 2.98
80	72.58 Tonnes; 4.88; 3.66; 0.84	83.45 Tonnes; 10.89, 21.77, 21.77, 14.51, 14.51; 3.66, 1.52, 5.49, 1.52	25.40 Tonnes	9.07 Tonnes; 0.36	27.21 Tonnes; 0.40	0.72; 2.98

Fig. 3 Table with hypothetical vehicles from standard STANAG 2021
Source: [3]

5 3D MODEL OF AM-50 BRIDGE BAY FOR SIMULATION

The basic supposition to make a FEM analysis of bridge load capacity is to have a valid 3D model of real bridge bay. Numerical calculation or virtual simulation by using of CAD and CAE software's is first step which should be approved by experimental testing in a real condition.

3D model of AM-50 bridge bay was made based on original drawings and measurements on real physical bridge bay. The result of 3D modelling is visible on Fig. 4 and Fig. 5.

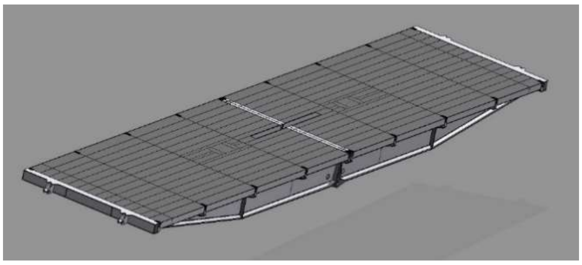


Fig. 4 Top view of AM-50 bridge bay 3D model
Source: author.

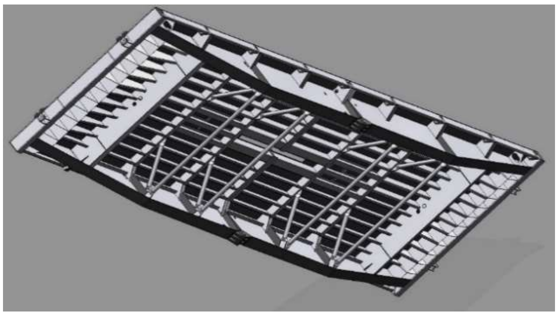


Fig. 5 Bottom view of AM-50 bridge bay 3D model
Source: author.

The bridge is consisting from two mirrored parts connected with two bridge pins in axis of bridge closing rotation and two safety pins in upper part of the bridge. During crossing of the vehicle, the both sides of the bridge are pushing to each other because their front surfaces are in permanent contact.

On figure 5 is possible to see that the bridge is steel welded construction. Basic bearing parts of the construction are two main beams which are connected with transoms. The transoms are connected in the same way with longitudinal beams. Width of the main components from a steel sheets are from 2,3 mm up to 12 mm. Thickness of the main longitudinal beam is 4 mm. Transoms have thickness of 3 mm and longerons 2,8 mm. Thinnest part of the bridge is its contact surface (roadway) on the top side of the bridge bay. For main construction material was used a special low-alloyed carbon steel with yield strength from 490 MPa up to 520 Mpa. The detail properties are shown on Fig. 7. There is shown detail chemical composition and main mechanical properties.

This material was used mostly in the defence industry because of its very good weldability, resistance against externalities and better mechanical properties than standard carbon steel. Currently is not possible to find direct replacement for this material on market. There are just only similar materials like S500MC for example.

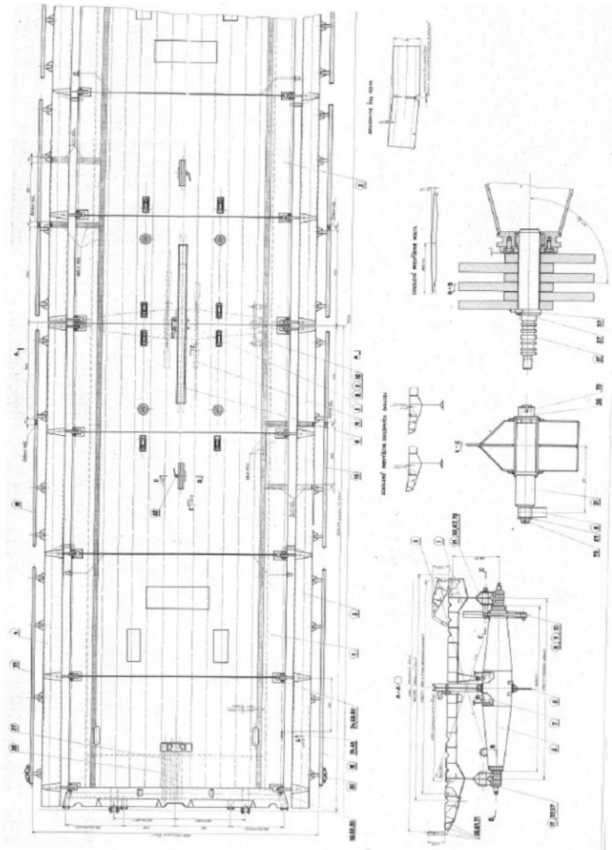


Fig. 6 original assembly drawing of AM-50 bridge bay
Source: author.

6 FEM SIMULATION OF AM-50 BRIDGE BAY

Actual load capacity of AM-50 bridge bay is as per ZEN-24-14 50 tons for tracked vehicles and 70 tons for wheeled vehicles (Truck with trailer). This is only specification that is existing. In ZEN-24-14 is not mentioned dimensions of contact surface between tracks or wheels with bridge surface. Also, information about number of axles and loads to each axle is missing too. Based on Fig. 2 and Tab. 2 can be evaluated that Slovak Armed Forces in present need bridging equipment with load capacity MLC70 plus. Increasing of AM-50 bridge load capacity up to MLC70 is unlikely. Because of that simulation is focused on loads as per MLC60 from STANAG 2021.

6.1 Specification of loads

Based on rules mentioned in the STANAG 2021 was simulated effect on the bridge structure from hypothetical vehicle in worst case of static load effect. The worst situation is when the hypothetical vehicle is standing in the middle of the bridge structure which means that center of gravity is exactly in the middle of the whole bridge. The bridge is fixed in 4 points. In real condition these points are fixed to the trestle on both sides of the bridge.

In first step was necessary to set a contact points and surfaces of the bridge construction to create a mesh of points which is basic step of FEM analysis.

In accordance of the table of hypothetical vehicles which is part of the standard STANAG 2021 was exactly specified the load which simulated weight and dimension of tracked hypothetical vehicle. In the standard is description of the wheeled set in the same way like for the tracked vehicles. It is possible to see description of both hypothetical vehicle in MLC 60 category in table 3.

Tab. 3 Description of hypothetical vehicles of MLC 60 category

Type of the vehicle	Weight of the vehicle	Length of contact surface	Width of contact surface	Outside distance of wheels/ tracks
Tracked vehicle	54,43 t	4,267 m	0,711 m	3,353 m
Wheeled vehicle	63,50 t	0,356 m	0,305 m	2,972 m

Source: [3].

In case of wheeled vehicle, it is important a layout of loads on each axle as well as a distance of each axle which is visible on figure 9 from original standard STANAG 2021.

CSN 41 5222 STN 41 5222	Fine-grained steel Cr-Mo-B For welded bearing constructions	Steel 15 222

Chemical composition [weigh %]

C	Mn	Si	Cr	Ni	Cu	Mo	B	Nb	P	S
0,14-0,18	1,00-1,40	0,20-0,40	0,50-0,80	max 0,30	max 0,30	0,50-0,65	0,002-0,005	0,02-0,06	max 0,035	max 0,035

Intermediate products

[1] hot rolled flat bars

[2] hot rolled thick metal sheets

[3] hot rolled wide steel

Mechanical properties

Intermediate product	[1]	[2]		[3]	
Dimensions t, d [mm]	5-10	5-10	11-30	5-10	11-30
State	.5	.5		.5	
Yield strength R_e [MPa] min	520	520	490	520	490
Tensile strength R_m [MPa] min	590-790	590-790		590-790	
Tensibility A_5 [%] along min.	18	-		18	
Tensibility A_5 [%] across min.	-	16		-	
notched toughness KCU 3^{-20} [J.cm^{-2}] along min KCU $3/5^{-20}$	39	39		39	

Temperature [°C]	100	200	300	350	400	450
Lowest yield strength R_p 0,2 [MPa] At elevated temperatures, intermediate product [2]	431	412	382	373	353	324

Physical properties

Density ϱ [kg.m^{-3}]	Specific heat capacity C_p [J.kg^{-1}.K^{-1}]	Thermal expansion coefficient α [K^{-1}]	Thermal conductivity λ_t[W.m^{-1}.K^{-1}]	Resistivity ϱ [Ω.m]
7 850	-	-	-	-

Resistance to degradation processes

FATIGUE RESISTANCE

Fatigue limit of machined welded joint with thickness of 25 mm in a throbbing stroke σ_c = 178 ± 127 MPa

Fatigue limit σ_c [MPa] under stress

R_m [MPa]	torsional			throbbing		
	bending	pull - compressive	torsional	bending	pull - compressive	torsional
-	-	20 ± 215 R = -0,91	-	-	200 ± 170 R = -0,08	-

Fig. 7 Material list of steel used for construction of AM-50 bridge bay (part 1)
Source: [4].

Technological information

HEAT TREATMENT

annealing	800-820°C	for thickness to 10 mm lag 1 hour above 10 mm 2 hours
normalization annealing	910-930°C	lag 1,5 min. for 1 mm of material thickness
soft annealing	800-820°C	cooling on air
stress relief annealing	520-560°C	cooling in furnace
tempering	550-660°C	for thickness to 2 mm lag 1 hour above 2 mm 2 hours

temperature of changes A_{c1} ~ 730-742 °C A_{c3} ~ 810-910 °C M_s ~ 350 °C A_{r3} ~ 832-795 °C A_{r1} ~ 758-720 °C

FORMABILITY

formability temperatures 1 250-850 °C cooling on air

WELDABILITY

in accordance of CSN 05 1310 - guaranteed for t ≤ 15 mm
- conditional guaranteed t > 15 mm

recommended additional materials for welding

electric arc manually	E Ni1MoCrV – 23B (ČSN 05 5096)
by automat under melt	wire AT – 232, melt F – 202
in protective atmosphere	wire C – 214

temperature of pre-heating during oxygen or plasma cutting at t > 15 mm – 150-250 °C

MACHINABILITY	turning, planing	milling, drilling	grinding
intermediate product [2] state .5,	13b	13b	

TECHNOLOGICAL TESTS

brittleness test in accordance of ČSN 42 0401

intermediate product [1] [3] state .5	bending angle α = 180°	mandrel diameter D = 2a (along)
intermediate product [2] state .5	bending angle α = 180°	mandrel diameter D = 2a (along) D = 3a (across)

Use

For welded bearing structures, pressure vessels and pipes, operating up to 450 ° C.

Other properties

type of steel based on production way	colour marking as per ČSN 42 0010	waste class as per ČSN 42 0030
martin or electro-steel	white – orange - blue	048

Fig. 8 Material list of steel used for construction of AM-50 bridge bay (part 2)
Source: [4].

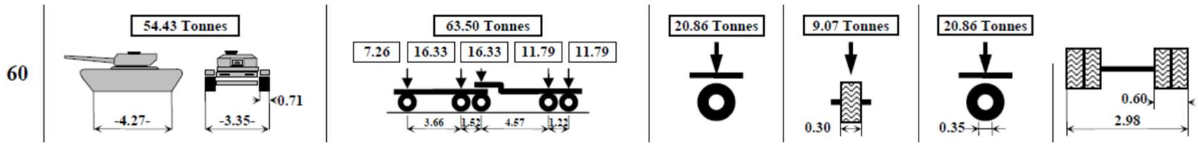


Fig. 9 Description of hypothetical vehicle from original STANAG 2021
Source: [3].

6.2 Set a simulation condition

The bridge is symmetrical along longitudinal axe, that's why only half of the structure was used for simulation. The result of the simulation is not affected by this solution but it has less requirements for used computing device.

On Fig. 10 is shown created mesh of points which is basic supposition for FEM load capacity analysis. The created mesh was combined mesh because it was not possible to set only triangular or square mesh withsame size of elements. The bridge structure and its parts are too complicated to create uniform mesh.

After creation of the mesh from the bridge model was necessary to set up a boundary conditions of bridge load simulation see figure 11. During this operation was necessary to take into consideration that for simulation was used only half of the bridge.

Fig. 10 Created mesh from the bridge model
Source: author.

The main binderies were set to bridge trestle pins and secondary along cut of half of the bridge.

After creation of boundary conditions was possible to set a contact surface with bridge roadway and load which was pushing on it. The force which was pushing on the bridge body was 272.150,00 N, which is half of the full static load which is affecting on the bridge from hypothetical vehicle as per MLC 60.

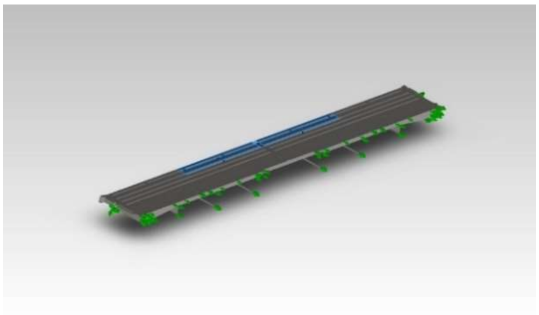


Fig. 11 Bridge boundary conditions
Source: author.

6.3 Result of the FEM simulation

Based on result of the simulation is possible to say that in the most parts of the construction the maximal tension in material σred is less than 380 MPa so safety factor of the bridge structure is on level k=1,3. Locally on bottom part of the main bridge beam was maximal tension more than 540 MPa.

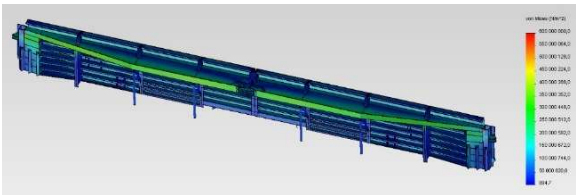


Fig. 12 Result of FEM simulation
Source: author.

For final classification of the bridge is necessary to take in to account also dynamic coefficient which is as per STANAG 2021 δ=1,075 and safety coefficient 1,5. These coefficients should be applied for static load on the bridge bay and as per STANAG 2021 there is no safety factor related to material allowed stress.

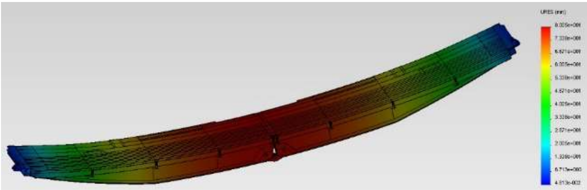


Fig. 13 Maximal elastic deflection of the bridge construction
Source: author.

On the figure 13 is possible to see maximal elastic deflection due to affecting of the static load on the bridge as per STANAG 2021 and MLC 60 category. The value of this maximal deflection is 87,60 mm.

7 CONCLUSION

On the result of the bridge static load simulation by hypothetical vehicle as per STANAG 2021 and MLC 60 category is possible to say that the bridge construction of AM-50 bridging system is able to carry these static loads. There were locally places in construction where maximal tension was more than 540 MPa which will create a plastic deformation of the bridge material but these places are of small size and probably result of the mesh errors of wrong connection of each parts of the structure. Generally, can be said that the bridge successfully complies load requirements as per STANAG 2021 category MLC 60.

Within this article was not checked simulation for wheeled set as per MLC 60. The reason is that as per enginery regulation ZEN-24-14 the bridge can carry wheeled set (truck with trailer) with maximum load 70 tons. Requirement as per MLC 60 is just only 63,50 tons. Based on that can be said that the bridge can carry this load. The only question and open point for next simulations is possible local plastic deformation of the bridge roadway surface due to wheel pressure on the surface.

For official classification of AM-50 bridge to MLC 60 category is necessary to check resistance of the bridge against local plastic deformation from wheel pressure on the surface, check of the trestle load capacity and all solution check by experiment in real condition and real loads. Based on that the bridge AM-50 could be classified like bridge of category MLC 60 as per standard STANAG 2021.

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Dipl. Eng. Peter **MAKO**
Armed Forces Academy of General M. R. Štefánik
Department of Mechanical engineering
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: p.mako.peter@gmail.com

Peter Mako – was born in Kosice, Slovakia in 1989. He received his Engineer degree in 2013 in field of Automotive production from From Faculty of Mechanical engineering of Technical University in Kosice. He is PhD candidate of Department of Mechanical engineering of Armed Forces Academy of General M. R. Stefanik. His research is aimed to military bridging systems of engineery units.

SENSITIVITY ANALYSIS IN RISK ASSESSMENT OF DRINKING WATER CHEMICAL POLLUTION CAUSED BY MILITARY ACTIVITIES

Serhiy OREL

Abstract: This paper presents the sensitivity analysis of environmental pollution risk assessment caused by military activities. Using the example of carcinogenic risk assessment of contaminated drinking water consumption, the role of sensitivity analysis for environmental decision-making is shown. Sensitivity analysis is a valuable tool in quantitative risk assessment by determining critical aspects and effects of variations.

Keywords: Quantitative risk assessment; Sensitivity analysis; Contaminated drinking water consumption.

1 INTRODUCTION

Military activities even during peacetime have a significant impact on the environment and lead to chemical pollution that affects human health for a long time, with a number of substances at low and ultra-low concentrations which do not carry toxic effects on man, but under certain conditions can cause cancer. Reliable methods are needed to determine the effects of chemicals on humans for making decisions on environmental protection measures.

Environmental risk analysis is an effective tool that integrates environmental data with management solutions [1]. Risk analysis consists of three phases: assessment, management and risk communication, where the risk assessment phase is the most important phase and consists of the following components [2]:

1. Identification of hazards - recording of all chemicals that pollute the environment to determine their toxicity to humans or ecosystems;
2. Evaluation of exposure - in general, purpose of exposure assessment is to characterize the mechanisms by which receptors are exposed to chemicals, and to quantify the magnitude of those exposures. This is also the assessment of received doses and the number of persons exposed to such exposure and for which it seems to be probable;
3. Evaluation of dependence "dose - response" - a search for numerical correlations that connect dose of substance with the prevalence of a particular adverse effect;
4. Risk characterization - includes evaluation of possible and real adverse effects to human health or the environment.

Risk assessment has some uncertainties on each stage of evaluation. The sources of uncertainties are:

1. During the identification of hazards - unidentified hazards, different results, quality and method of measurement in obtaining data, extrapolation of the results to the target population;
2. During the assessment of exposure - a conceptual model of contamination (a way of impact, distribution and transformation of pollutants in the environment, errors in determining and measuring the concentration of pollutants during field research), model of exposure (ways of getting contaminants into the body, determining the spatial and temporal boundaries), the determination of target population;
3. During the evaluation of dependence "dose - response" - errors in determining and measuring the concentration of pollutants in conducting epidemiological studies, interspecific and intraspecific differences in conducting toxicological studies, model of extrapolation from large to small doses of pollutants impact on the body;
4. While characterizing the risk the uncertainty of earlier stages has place.

In turn, the uncertainty can be divided into ignorance, i.e. the lack of knowledge about specific factors, parameters and models used in the analysis of risk, and variability, i.e. the inconstancy of parameters due to their natural heterogeneity [3]. If ignorance can be reduced by collecting additional data, increased measurement accuracy, improved models, etc., reduce the variability in this way is impossible.

In any case, the risk determination process can be represented as a specific model with input parameters at the output of which we obtain the desired risk value. In general, the uncertainty of risk is determined by the uncertainty of the input values and the sensitivity of the model (Fig. 1).

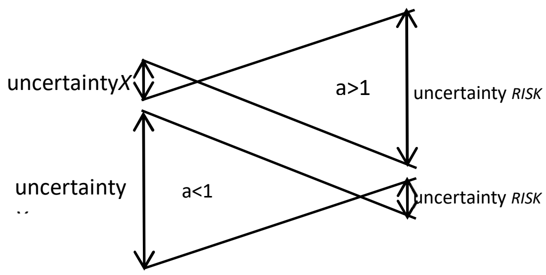

Fig. 1 Relationships between model sensitivity and risk uncertainty in a one-parameter model
RISK = *aX* (*a* - model coefficient)
Source: author.

From Fig. 1 follows that in the bottom model, the predicted risk value is not as sensitive to the input values of X because the model sensitivity is lower, even though there is high uncertainty in the X. In the top model, risk is highly sensitive to even the small X uncertainty because of the high model sensitivity.

Sensitivity analysis is the assessment of the impact of changes in input values on model outputs. Sensitivity analysis of risk models can be used to identify the most significant exposure factors to aid in developing priorities for risk mitigation. Sensitivity analysis can be used as an aid in identifying the importance of uncertainties in the model for the purpose of prioritizing additional data collection or research. Sensitivity analysis can also be used to provide insight into the robustness of model results when making decisions [4].

Sensitivity analysis methods may be broadly classified as mathematical methods, statistical (or probabilistic) methods, and graphical methods. This classification helps in understanding applicability of sensitivity analysis methods for different types of models, and in selecting appropriate methods according to their usefulness to a decision-maker.

Mathematical methods are useful for deterministic and probabilistic models. Statistical methods are generally used for probabilistic models. Graphical methods are usually complimentary to mathematical and statistical methods. Graphical methods can be used for any kind of model [5].

Mathematical methods assess sensitivity of a model output to the range of variation of an input. These methods typically involve calculating the output for a few values of an input within the possible range. For example, the output of a model can be calculated for the highest and lowest possible values of an input. Sensitivity is usually described in terms of relative change in the output. These methods assess the impact of range of variation in the input values on the output [6]. Mathematical methods are helpful in screening the most important inputs. Mathematical methods can be used to identify inputs that require further data identification and research in the case of deterministic models.

Statistical methods involve running simulations in which inputs are assigned probability distributions and assessment of the effect of variance in inputs on the output distribution. Depending upon the method, one or more inputs are varied at a time. Statistical methods allow one to identify the effect of simultaneous interactions among multiple inputs. Distributions for model inputs can be propagated through the model using a variety of techniques, e.g. Monte Carlo simulation and other methods [4].

Graphical methods give representation of sensitivity in the form of graphs, charts, or surfaces. Generally, graphical methods are used to give a visual indication of how an output is affected by variation in inputs. Graphical methods can be used as a screening method before further analysis of a model or to represent complex dependencies between inputs and outputs. Graphical methods can be used to complement the results of mathematical and statistical methods for better interpretation [7].

Methods for sensitivity analysis, their advantages and disadvantages are discussed in more details in [4,5,7].

The importance of the probabilistic assessment of the risk of chemical contamination for the exposure of people caused by military actions is considered elsewhere, for example, [8,9]. Probabilistic risk assessment uses probability distributions instead of point values to calculate the risk, getting to ultimately probabilistic distribution of risk values. In this case, you can get the value of the probability of exceeding the level of risk that is of interest, namely, to quantify the value of uncertainty, what cannot be done using deterministic values. Thus probabilistic risk assessment provides with unique and important additional information that is used for optimal risk management.

To assess the sensitivity in this case, statistical methods are the most preferred. In [5,7] discussed such statistical methods for sensitivity analysis, including linear regression analysis (RA), analysis of variance (ANOVA), response surface method (RSM), Fourier Amplitude Sensitivity Test (FAST), Mutual Information Index (MII), Categorical and Regression Trees (CART) and Sobol's method, their advantages and disadvantages were discussed also.

The analysis carried out in the [5,7] indicates that to some extent all statistical methods are suitable for assessing the sensitivity of ecological risk models. Some methods are easier to apply in practice than others. The ease of application may often constrain the feasibility of a method. A method is typically easier to implement when software tools already exist, especially if they have user-friendly interfaces. Of course, ease of implementation will be a function of software availability and programming skill level [7].

The objective of this work is, using available software, to demonstrate the importance and usefulness of sensitivity analysis in risk assessment of chemical pollution caused by military activities.

2 CASE STUDY

The materials of paper [10], which analyses the environment condition after the accident on ammunition depot in Novobohdanivka, Zaporozhye region, Ukraine that happened on 6 – 15 of May 2004, are the basis for the research.

After the accident, river Molochna, which was widely used by citizens of Troitske village as the only source of drinking water was contaminated by some chemicals that changed its composition. The risk assessment was performed in stages (by tiers), from simple (deterministic) to more complex (using the one-dimensional and later two-dimensional Monte-Carlo method). Studies have shown that water is not suitable for drinking and environmental measures are necessary.

In order to make an informed decision that is optimal in terms of financial costs, it is important to know the components that affect the water consumption of the population. In this sense, conducting a sensitivity analysis of an appropriate water consumption risk model will be very useful.

In order to evaluate possible uncertainties a probabilistic risk assessment was performed [10]. This gives possibility to use statistical methods for analyzing the sensitivity of a risk model and determine the most important components affecting the risk value.

Risk models are represented by the following equations.

Carcinogenic risk:

$$CR = \sum_{i=1}^{N_R} ICR_i, \tag{1}$$

CR – is the value of full individual cancer risk caused by the action of N_R carcinogens;

ICR – is the value of individual cancer risk caused by the action of *i*-carcinogen;

N_R – is the total amount of carcinogens.

$$ICR = ADD \cdot SF, \tag{2}$$

ADD – is an average daily dose of chemicals consumed by the recipient;

SF – is a slope factor for the particular substance, which characterizes the degree of increase of cancer risk with increasing of the dose per unit.

Non-carcinogenic risk is defined by hazard index *HI*:

$$HI = \sum_{j=1}^{N} HQ_j, \tag{3}$$

HQ – is the hazard coefficient of j-substance;

N – is the total amount of hazardous substances.

$$HQ = ADD/RfD, \tag{4}$$

ADD – the average daily dose of a chemical substance;

RfD – reference dose, quantity that characterizes the daily effect of a substance during lifetime and, probably does not result in appearance of an unacceptable risk to the health of sensitive groups.

$$ADD = C_W \cdot IR_W, \tag{5}$$

C_W – is the concentration of the chemical substance in water;

IR_W – rationed per human unit mass volume of drinking water consumed by a person per day.

According to [11] IR_W is determined by log-normal distribution with the parameters given in Tab. 1.

Tab. 1 Parameters for lognormal distribution of drinking water, consumed by a person per day (IR_W), ml / (kg · day).

Age group, years	Average value of natural logarithm IR_W	Standard deviation of natural logarithm IR_W
1-3	3.49	0.75
4-6	3.33	0.68
7-10	2.97	0.68
11-14	2.66	0.71
15-19	2.43	0.74
20-44	2.61	0.68
45-64	2.92	0.52
65-74	2.92	0.49
75+	2.88	0.50

Source: author.

Tab. 2 Concentration of soluble forms of inorganic compounds in surface waters of the Molochna River

Parameter	Cu	Mn	Zn	Cd	Pb	Cr	Ni	Fe
Ion concentration in water, mg/l	9,5±0,9	0,414±0,004	0,97±0,1	0,021±0,001	0,62±0,4	0,239±0,002	1,06±0,06	11,6±0,3

Source: author.

In the first approximation, we take the form of distribution of chemical pollution concentrations in river water as normal (Tab. 2).

Risk modeling and sensitivity analysis was performed using a spreadsheet Excel® with add-in Crystal Ball® software. Crystal Ball calculates sensitivity by computing Spearman rank correlation coefficients between every input and every output values while the simulation is running. Correlation coefficients provide a meaningful measure of the degree to which inputs and outputs change together. If this values have a high correlation coefficient, it means that the inputs has a significant impact on the outputs. Correlation coefficients can range from -1 to +1. The value of -1 represents a perfect negative correlation while a value of +1 represents a perfect positive correlation. A value of zero represents a lack of correlation. Positive coefficients indicate that an increase in the inputs is associated with an increase in the outputs. Negative coefficients imply the opposite situation. The larger the absolute value of the correlation coefficient, the stronger the relationship.

Method disadvantages: correlation does not imply causation; there can be a case where a third variable is influencing the two variables with high correlation; Spearman coefficients are inaccurate for non-monotonic models.

The strength of the relationship between inputs (x) and outputs (y) (Contribution To Variance) in Crystal Ball expressed by squaring the correlation coefficient and multiplying by 100. For example, a correlation of 0.5 means 25 % of the variance in (y) is "explained" or predicted by the (x) variable.

Tab. 3 shows the results of sensitivity analysis of carcinogenic risk significance from input values: drinking water consumption and concentrations and properties of carcinogens in it for children and adults.

Tab. 3 Results of carcinogenic risk sensitivity analysis

Values	**Contribution To Variance, %**	**Rank Correlation**
children		
IR_W (age 1-3)	49,29	0,49
IR_W (age 4-6)	48,08	0,48
C_{Ni}	2,52	0,11
C_{Cr+VI}	0,10	0,02
C_{Pb}	5,04E-05	0,00
C_{Cd}	1,06E-06	0,00
adults		
IR_W (age 15-19)	17,82	0,20
IR_W (age 20-44)	20,54	0,21
IR_W (age 45-64)	17,34	0,19
IR_W (age 65-74)	15,80	0,18
IR_W (age 75+)	14,35	0,18
C_{Ni}	14,04	0,17
C_{Cr+VI}	0,071	0,01
C_{Pb}	0,017	0,006
C_{Cd}	0,016	0,006

Source: author.

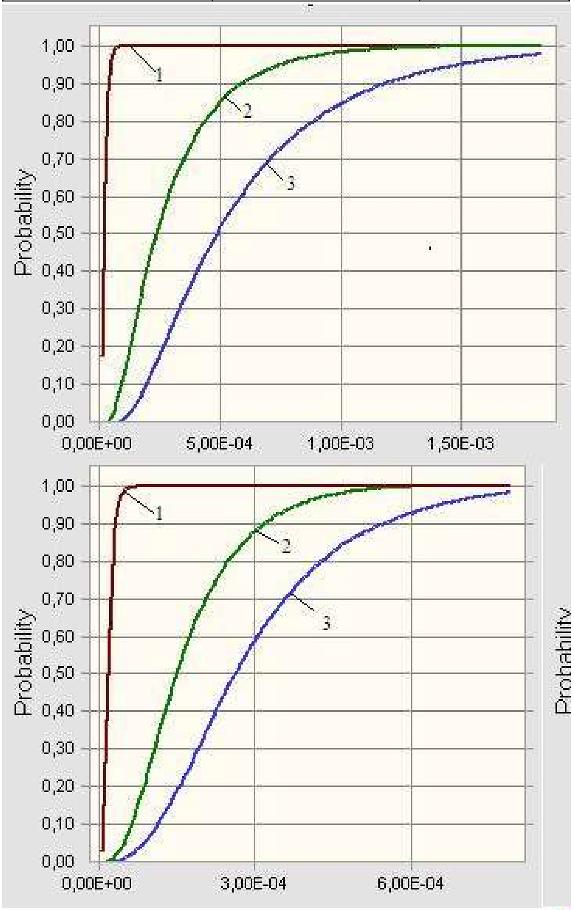

Fig. 2 Cumulative distribution function of carcinogenic risk from polluted water consumption: upper figure - children; lower - adults; 1 - halved consumption of polluted water; 2 - halved concentration of carcinogens; 3 - real water consumption
Source: author.

Tab. 4 Distributions statistical data

Statistic	**Children**			**Adults**		
Distributions	(1)	(2)	(3)	(1)	(2)	(3)
Trials	10 000	10 000	10 000	10 000	10 000	10 000
Mean	2,78E-05	3,07E-04	6,14E-04	2,24E-05	1,74E-04	3,00E-04
Median	2,55E-05	2,41E-04	4,90E-04	2,09E-05	1,50E-04	2,62E-04
Standard Deviation	1,19E-05	2,30E-04	4,42E-04	9,99E-06	1,05E-04	1,75E-04
Variance	1,42E-10	5,28E-08	1,95E-07	9,98E-11	1,09E-08	3,06E-08
Skewness	1,44	1,88	1,75	1,38	1,34	1,24
Kurtosis	7,18	7,60	6,95	7,72	5,26	4,8
Coeff. of Variability	0,43	0,74	0,71971	0,45	0,60	0,58
Minimum	5,08E-06	2,03E-05	7,62E-05	2,98E-06	1,47E-05	2,98E-05
Maximum	1,50E-04	1,83E-03	3,51E-03	1,25E-04	7,76E-04	1,20E-03
Mean Std. Error	1,19E-07	2,30E-06	4,42E-06	9,99E-08	1,05E-06	1,75E-06

Source: author.

An important conclusion can be drawn from the sensitivity analysis. The value of carcinogenic risk is mainly influenced by amount of consumed water (IR_W). The concentration of carcinogens, with the exception of nickel, plays a minor role. This is confirmed by model risk calculations with a halved consumption of polluted water and a halved concentration of carcinogens (Fig. 2). Table 4 shows the statistical data of the distributions.

It follows from the above data that reducing the consumption of polluted water by half, for example, while providing the population with clean imported water, reduces the risk of cancer to almost acceptable limits. Reducing the concentration of pollutants by half does not provide a sufficient reduction in the level of risk.

Ultimately, the way to reduce carcinogenic risk is determined by a feasibility study. However, sensitivity analysis in risk assessment provides additional opportunities for choosing the optimal decision to reduce risk.

3 CONCLUSION

Many different factors impact on extend to which a chemical pollution poses a risk to consumers of drinking water and some of these factors are more important than others. Therefore, it is important to focus risk assessment initially on the main factors. For this purpose one should start with sensitivity analysis.

Such an analysis will give insight to the important processes and phenomena and will show main-determining steps and relevant aspects. They can be helpful to determine hazards, determine main phenomena quantitatively important for risk, calculate the effect of changes in the process, and enable a wide range of operating strategies to be evaluated. The results can be used as the basis for decisions and to determine which stages or processes require more detailed analysis.

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Assoc. Prof. Serhiy **OREL**, PhD.
Hetman Peter Sagaydachniy Academy
of the Ground Forces
Maidan Heroes St. 32, Lviv
79012 Ukraine
E-mail: orelsm0@gmail.com

Serhiy Orel - is an assistant professor of Hetman Peter Sagaydachniy Academy of the Land Forces. In his scientific work, he focuses on research of environmental influence on military subdivision and, vice versa, environmental impact of military activity. Additionally he studies the risk like universal criterion of environment contamination estimation, especially probabilistic ecological risk assessment. Currently he is an author and co-author of about 120 printed publications, including a monograph *Risk estimation in ecological safety of troops* ISBN 978-966-269-942-5 (in Ukrainian).

TASKS AND ACTIVITIES EXECUTED IN THE FIELD OF THE SUPPORT OF THE STATE DEFENSE

Ján BREZULA

Abstract: The defence infrastructure is necessary element of supporting the state defense and it is formed by the services and activities provided to the Slovak Armed Forces for ensuring effective protection and defense of the state. The defense infrastructure consists of lands, buildings and facilities, telecommunication, energy and transport systems, information networks and supplies of state material reserves. An important part of the defense infrastructure is the services and activities provided to the armed forces to ensure the state defense. These services and activities include financial, medical, veterinary, transport, telecommunication, postal, supply, accommodation, research and scientific services, manufacturing, repair and construction activities. This paper deals with the tasks and activities executed in the field of the support of the state defense.

Keywords: State defense; Defense infrastructure; Slovak Armed Forces; Development Plan; War; State of war.

1 INTRODUCTION

An important part of the defense system of the Slovak Republic is the support of the state defense. Support of the state defense is, according to the proposal of defense strategy of the Slovak Republic prepared and maintained through defense planning and economic mobilization in the field of the state defense [1]. Security is generally associated with stability, certainty, order, reliability, equilibrium, the existence of a subject without threats, state and feeling of security [2].

Security of the Slovak Republic is not a static but highly dynamic state that reflects the development of security environment and security threats associated with security risks at a particular time [3].

In connection with the current development of the security environment, the Slovak Republic undertakes to increase the scope and usability of the support of the state defense by improving its preparation and maintenance.

2 DEFINITION OF BASIC CONCEPTS

Under Act no. 319/2002 Coll. on the Defense of the Slovak Republic, the support of the state defense is formed by the defense infrastructure, services and activities provided to the armed forces for the defense of the state, including their maintenance, development, protection and defense, which are paid from the state budget [4], which schematically illustrates Fig. 1.

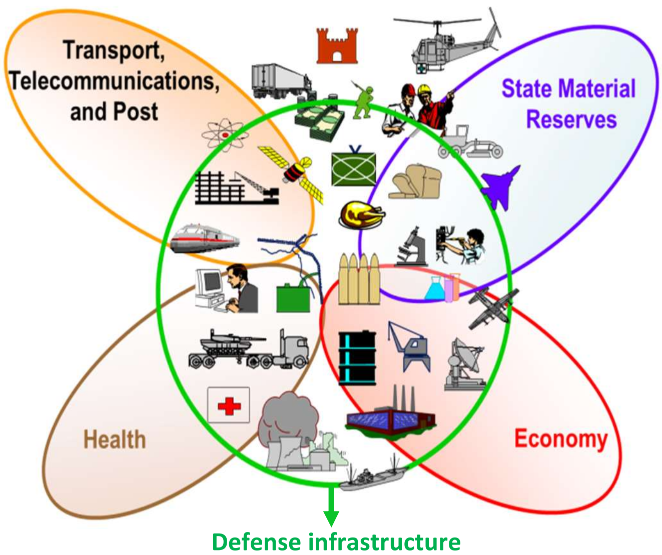

Fig. 1 Support of the state defense and its composition
Source: author.

An important part of the support of the state defense is the services and activities provided to the armed forces to ensure the defense of the state. Under Act no. 319/2002 Coll. these services and activities include in particular financial, health, veterinary, transport, transport, telecommunication, postal, supply, accommodation, research and scientific services as well as manufacturing, repair and construction activities.

The government of the Slovak Republic, commits itself to prepare, maintain and develop defense infrastructure focusing in particular on transport networks and transport objects, electronic communication networks, communication and information systems, objects of importance for ensuring cyber security, energy and gas distribution, management and constitutional activities authorities and command posts to the armed forces at the time of war and state of war, water point of supply, water resources and water supply facilities for the needs of the state defense, infrastructure of state material reserves and defense industry infrastructure.

Based on the above, it can be stated that the defense infrastructure is an essential part of the support of the state defense. The aim of this system is to achieve an improvement in the capability of the Slovak Armed Forces to carry out military operations and operations to eliminate the consequences of crisis situations and to support the public authorities.

3 BASIC DOCUMENTS IN THE FIELD OF THE SUPPORT OF THE STATE DEFENSE

Elaboration of the Program Declaration of the Government of the Slovak Republic in the Slovak Armed Forces for 2016-2020 represents the basic political-military document for the management and planning activities in the defense sector, which elaborates the individual tasks of the government's policy statement in the field of the state defense into tasks within the competence of the relevant components. As part of task no. 10 (part of the armed forces), the Government of the Slovak Republic undertakes to support the development of defense infrastructure and to improve the system of supply of goods, provision of services and activities to support the armed forces in defense of the Slovak Republic and allied forces in the fulfillment of collective defense tasks in the Slovak Republic as a host country.

The operational plan of the Chief of the General Staff of the Armed Forces of the Slovak Republic for the use of the Slovak Armed Forces at the time of war and state of war, prepared on the basis of the Plan of Use of the Slovak Armed Forces at the time of war, represents another basic document in the field of the support of the state defense. The document defines a new security threat in view of the strategic geopolitical and geographical position of the Slovak Republic, when the eastern borders of Slovakia are part of the borders of the eastern wing of NATO and the EU. The plan states that the enforceability of each operation must be reflected in the requirements of the Slovak Armed Forces to ensure the support of the state defense.

Another important document in the field of the support of the state defense is the Development Plan for State Defense Support to 2024 (hereinafter referred to as "Development Plan"). The Development Plan was elaborated in accordance with Act no. 319/2002, in particular § 26 par. 5, which defines the following: The preparation and development of the state defense support is provided according to the needs of the state defense on the basis of a plan drafted by the Ministry in cooperation with other ministries, other central state administration bodies, local state administration bodies, municipalities and higher territorial units [4].

The aim of the Development Plan is to implement the requirements of the Slovak Armed Forces to ensure the infrastructure of material, goods, services and activities necessary to ensure the defense of the state. On the basis of this plan, the Ministry of Defense of the Slovak Republic coordinates the application of requirements to those ministries and central state administration bodies directly involved in the defense of the state and support of the armed forces.

The Development Plan was developed in cooperation with the ministries concerned and other central government bodies with the intention to create key prerequisites for achieving synergies of all interested subjects in the limited resources of the state for fulfilling the tasks of the state defense. The plan specifies and elaborates the basic strategic document of strategic defense evaluation - the White Paper on Defense of the Slovak Republic, in the field of the support of the state defense. Financial resources for the fulfillment of the tasks were allocated in the budget chapters of those ministries and state administration bodies that are directly involved in its implementation. For the negotiation of the Government of the Slovak Republic in March 2015, it was submitted with a recommendation of the Security Council of the Slovak Republic.

4 REDISTRIBUTION OF RESPONSIBILITY FOR THE PREPARATION AND DEVELOPMENT OF THE SUPPORT OF THE STATE DEFENSE

The main objective of the Development Plan is to provide an adequate level of defense infrastructure to defend the state. Its structure is designed to describe the individual segments of the support of the state defense, including the determination of the individual coordinators responsible for performing the long-term tasks with the suggestion of the estimated financial resources necessary to ensure them.

In the area of state preparation for defense, the main efforts of selected ministries and other central state administration bodies are aimed at achieving mutual cooperation with the following aim:

1. With the emphasis on achieving interoperability with NATO and the EU, ensure a gradual modernization of the main and reserve place of the government defense. This task is managed by the Ministry of the Interior of the Slovak Republic in cooperation with the Ministry of Defense of the Slovak Republic and the Office of the Government of the Slovak Republic.

2. Provide adequate traffic networks or transit of allies within the Host National Support Area for the operational apportionment and deployment of the armed forces. Responsibility for this role lies with the Ministry of Transport and Construction of the Slovak Republic, whose task is at the same time to ensure the construction and maintenance of the supporting facilities and the necessary capacity of railway wagons and traction vehicles. The partial role of this ministry is also to create conditions for the transport of military post, fulfillment of tasks in the field of frequency management and provision of electronic communication support.
3. Ensure necessary medical services and bed capacity for hospitalization of members of the armed forces. This role was placed under the responsibility of the Ministry of Health of the Slovak Republic.
4. For the needs of the armed forces, the Ministry of the Environment of the Slovak Republic has been designated as the guarantor of the task to ensure the operation and maintenance of the abstraction points for water, designated water resources and water supply facilities.
5. For the needs of the armed forces to ensure to the required extent the food commodities, under the authority of the Ministry of Agriculture and Rural Development of the Slovak Republic.
6. Under the logistic support system, the armed forces provide supply, replenishment and usage of power to the armed forces by securing the production and supply of materials and technology. This role is fulfilled in full by the Ministry of Economy of the Slovak Republic.
7. Take measures that will lead in crisis situations to create conditions for a stable social environment and to organize social security. This role was placed under the responsibility of the Ministry of Labor, Social Affairs and Family of the Slovak Republic.
8. To ensure sufficient stocks of fuel and mobilization reserves, including the need for regular maintenance and replenishment. The Administration of State Material Reserves of the Slovak Republic, as the central authority of the state administration for securing the tasks arising from the Act on State Material Reserves, is directly responsible for this task.
9. To support the state defense and the development of the capabilities of the armed forces to ensure the development of science and research while the task of the task force was assigned to the Ministry of Defense of the Slovak Republic.

Tasks in the field of the support of the state defense are implemented in the Inter-departmental program of state the defense [5], the aim of which is to coordinate the tasks for the implementation of measures by which designated ministries and other central state administration bodies create prerequisites for securing state defense.

The Development Plan was processed on the basis of the requirements of the Slovak Armed Forces to provide defense infrastructure, materials, goods, services and activities, which are provided by the competent ministries and other central state administration bodies.

5 CENTRAL REGISTER OF DEFENSE INFRASTRUCTURE OBJECTS AND FACILITIES FOR THE SUPPORT OF THE STATE DEFENSE

In accordance with the Development Plan and Section 26 of Act 319/2002 Coll. the Ministry of Defense of the Slovak Republic, in cooperation with other ministries and other central state administration bodies with national competence is responsible for:

1. Regular maintenance and control of the functionality of defense infrastructure objects and facilities in the field of the support of the state defense;
2. Yearly refinement of defense infrastructure objects and equipment in the field of the support of the state defense;
3. Maintaining and regularly updating the central register of defense infrastructure objects and facilities for the support of the state defense.

The Development Plan defines tasks in the field of defense infrastructure also for the Chief of General Staff of the Slovak Armed Forces. He, through the Operational Planning Department of the General Staff of the Slovak Armed Forces, approves annually "Regulation of the Chief of the General Staff of the Slovak Armed Forces for Maintenance and Control of Defense Infrastructure Objects and Facilities in the Slovak Armed Forces", in accordance with:

- the Development Plan;
- the Guidelines on the establishment of permanent special equipment on road structures and on the objects of railway transport roads [6];
- the document Ensuring tasks of the support of the state defense in the field of the defense infrastructure [7].

The Strategic Planning Staff of the General Staff of the Slovak Armed Forces manages the field of defense infrastructure maintenance in the Slovak Armed Forces, processes requirements and coordinates their implementation within its scope.

The central register of defense infrastructure objects and facilities for the support of the state defense is headed by the Operational Planning Department of the Strategic Planning Staff of the

General Staff of the Slovak Armed Forces on the technical device of MILSEC Type 2. This technical device is located in the classification area, room no. 125, Building No. 8 of the Ministry of Defense of the Slovak Republic. The Operational Planning Department ensures for individual users the sharing of a unified central register in the defense sector through the intranet portal SHAREPOINT, managed by the Base of Stationary Communication and Information Systems Trenčín.

The central register is maintained through the software application of the defense infrastructure objects and facilities OBJEZA, in which the defense infrastructure objects necessary for securing the support of the state defense during the war and the state of war maintained by the Ministry of Defense of the Slovak Republic in cooperation with other ministries, central state administration bodies, local state administration bodies, municipalities and higher territorial units.

The objects and facilities of the defense infrastructure for the support of the state defense, kept in the central register in the software application OBJEZA, are controlled and maintained by:

1. Slovak Armed Forces;
2. Other central state administration bodies.

In the central register, the following objects and facilities of the defense infrastructure are maintained by the Slovak Armed Forces:

A. *Reinforced concrete shelters:*
   - built in the last century with regard to the tactics of the army in the battle to hide the living force;
   - destined to hide the living force at the time of war and state of war;
   - adequately protect the living force from the destructive effects of nuclear weapons, in particular against pressure wave, light radiation, penetrating radioactive radiation;
   - inadequately protect people against the effects of chemical and toxic substances.

B. *Ford crossings:*
   - predetermined at the time of the war and the state of war to deal with the substitute transport of the Slovak Armed Forces through watercourses while performing combat tasks;
   - located close to the building bridges with the possibility of connection to public paved roads;
   - at the time of security, there is the possibility of their use in training by engineer units, which are subordinate to the Land Forces of the Slovak Republic.

C. *Multi-purpose hardened helicopter surfaces:*
   - are intended for use at the time of war and the state of war to load and unload persons, materials and equipment for supply units and units deployed in combat by helicopters;
   - at the time of safety they are used for transport by helicopters during international exercises, visits to foreign delegations and visits to the highest constitutional officials of the Slovak Republic (President of the Slovak republic, Prime Minister of the Slovak Republic and Chairman of the National Council of the Slovak Republic);
   - possibility of their immediate use for transporting injured persons to medical facilities - for example, training trainers.

Defense infrastructure objects and facilities kept in central register maintained by other central state administration bodies:

A. *Airport sections*;
B. *Airport networks*;
C. *Special facilities on designated car road*;
D. *Special facilities on designated railway lines*;
E. *Drinking water supply points*;
F. *Emergency service stations*;
G. *Surrogate bridges*;
H. *Technical assistance station*;
I. *Multi-purpose hardened helicopter surfaces*.

In addition, objects of special importance and other important objects are kept in the central register of defense infrastructure objects and facilities.

The exact number of objects and facilities of the defense infrastructure for the support of the state defense, kept in the central register in the software application OBJEZA, represents the classified information of the level "RESTRICTED" and therefore it is not possible to mention it in this paper.

For the sake of clarity about the objects and facilities of the defense infrastructure, the Department of Operational Planning of the Strategic Planning of the General Staff of the Slovak Armed Forces maintains an overview of the maps at a scale of 1: 200,000, where it is stated:
(a) the name of the site;
(b) the military registration number of the building;
(c) the name of the user of the facility;
(d) the name of superior (headquarters);
(e) responsibility (for non-departmental institutions).

In order to ensure the centralization of information in the relevant area, the central register kept in the software application OBJEZA also includes the maintenance of project documentation processed by the building designer to the buildings on which the special facility is built.

6 DISCUSSION

After a comprehensive analysis of the researched issue, with an emphasis on the state of preparedness of objects and facilities for the support of the state defense, we state that the current situation in the field of the support of the state defense is not sufficient and does not pay attention to it.

In accordance with the Development Plan, the preparation and development of the support of the state defense is provided according to the needs of the state defense on the basis of a plan prepared by the Ministry of Defense of the Slovak Republic, in cooperation with other ministries, other central state administration bodies, local state administration bodies, municipalities and higher territorial units.

The Development Plan implements the Slovak Armed Forces requirements to ensure the infrastructure of material, goods, services and activities necessary to ensure the defense of the state. These requirements are then applied to those ministries and central administration bodies directly involved in ensuring the state defense and support for the armed forces. Based on the analysis of the current state of affairs in the field of the support of the state defense, we believe that cooperation of top defense management in the defense sector with other central state administration bodies is not sufficient and does not create the conditions for maintaining adequate defense state of the defense infrastructure.

The keeping and regular updating of the central register of defense infrastructure objects and facilities for the support of the state defense is within the meaning of paragraph 7.2. of the Development Plan and Section 26 of Act 319/2002 Coll. in the competence of the Ministry of Defense of the Slovak Republic, in cooperation with other ministries and other central state administration bodies with national competence.

After carrying out an analysis in the field of the support of the state defense, we state that the management, updating and refinement of central records in co-operation with other ministries and other central state administration bodies is not currently being specified and it does not create conditions for improving the quality and effectiveness of fulfilling the tasks of the support of the state defense and the international commitments of the Slovak Republic in ensuring the defense of the state and supporting the armed forces.

The Development Plan further defines the tasks of the Chief of General Staff of the Slovak Armed Forces, which is, in cooperation with the Ministry of Defense of the Slovak Republic, directly responsible for the control and maintenance of defense infrastructure objects and facilities maintained by the Slovak Armed Forces. After a detailed examination of the current situation, we believe that the responsibility and competences between the Ministry of Defense of the Slovak Republic and the General Staff of the Slovak Armed Forces in the field of the support of the state defense are not exactly defined, especially in the area of keeping, updating and comparing the central register of defense infrastructure objects and facilities, performing internal and external controls of defense infrastructure objects and facilities, carrying out own and takeover procedures of defense infrastructure objects and facilities and assessing projects to include new objects and facilities in defense infrastructure (special devices, airport sections, substitute bridges, water resources, etc.).

After a detailed analysis of the current state in the field of the support of the state defense, we note that another shortcoming in this area is the absence of the necessary legislative support from the Ministry of Defense of the Slovak Republic and the General Staff of the Slovak Armed Forces, especially the absence of medium-term plans, short-term plans, guidelines that would increase the effectiveness of fulfilling the tasks in the field of the support of the state defense within the Slovak Armed Forces and would also create a starting point for further investigation of this area. At the same time, we add that the database of defense infrastructure objects and facilities in the field of the support of the state defense has not been updated for a long time in terms of their technical condition, location and real use, and therefore these objects and facilities may currently be completely devoid of purpose.

On the basis of these shortcomings, we believe that the current situation in the field of the support of the state defense with the emphasis on the state of preparedness of objects and facilities requires a more comprehensive analysis and proper scientific research, which has not been done so far.

For this reason, we are convinced that further scientific research is needed. Based on its objective conclusions, systemic changes will be proposed, leading to improvement of the quality and effectiveness of fulfilling the tasks in the field of the support of the state defense in ensuring the defense of the state and support of the Slovak Armed Forces.

7 CONCLUSION

Given the current security risks and the worsening security situation in Central Europe, it is necessary to address the issue of defense infrastructure protection as a priority [10]. Indeed, its disruption, destruction or malfunctioning would cause a partial or complete failure of state security. That is why it is necessary to conceptually address and ensure readiness to protect and defend defense infrastructure in all areas of security.

The security environment will also be characterized in the future by increasing complexity, high dynamics of change and mutual interconnection of political, military and economic factors [8]. These impacts will also be reflected in the changes in the concept of effective implementation of defense planning and design [9].

However, it is important to realize that the protection of defense infrastructure is not a one-time activity, but a process that requires ongoing attention.

This means that the sectors responsible for each defense infrastructure sector must pay close attention to this issue and continually develop its methods and include the latest trends and knowledge in this area.

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Dipl. Eng. Ján **BREZULA**
PhD student
Armed Forces Academy of General M. R. Štefánik
Demänová 393
031 01 Liptovský Mikuláš
Slovak Republic
E-mail: jan.brezula@gmail.com

Ján Brezula - was born in Trencin, Slovakia in 1979. He received his Engineer degree in 2002 in Communication and Radio systems from the Military Academy in Liptovský Mikuláš. His research is aimed to national and international security, focused mainly on the field of the support of the state defense.

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031 01 Liptovský Mikuláš
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E-mail: kit@aos.sk
Phone: +421 960 423019
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