

## DISCRETE-EVENT SIMULATION OF PUBLIC PROCUREMENT

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### *Abstract*

Procurement in the field of defence is a complicated and long-term process, whose success strongly depends on the corresponding legislation of the EU level, state level and internal directives of the MoD. Despite this fact, there are several possibilities for how to make public procurement within the MoD more efficient. The aim of this paper is to show the critical points of the public contracts awarding process and find out the options for its improvement by using discrete-event simulation as a technique for analysis of the current system built up the statistics data. The final experiment brings possible scenarios for decision-makers (the MoD contracting authorities) related to the adjustment of the logistical channel structure and its specific procedures timing in order to improve the system of public procurement within (not only) the MoD and its efficiency.

**Key words:** public procurement, discrete-event modelling and simulation, procurement efficiency

### 1. INTRODUCTION

The main objective of this paper will be to ask basic research questions – is it possible to make the public procurement process in the Czech MoD more efficient? Which activities or subjects significantly slow down public contracts awarding? Is it possible to speed up the logistical channel of all activities which form the above-mentioned process?

This topic is one of the crucial in the Czech public administration because public contracts awarding is really complicated and time-consuming process which can negatively influence the speed of goods and services deliveries to the end users. Based on the simulation results (part 4 Results discussion), the contracting authorities know on which phases of the awarding process to focus on in the process of their improvement. They can also be inspired by the winning scenario which suggests the

optimal periods for tenders evaluation and for the whole open procedure duration and also shows how these factors can influence the number of successfully finished public contracts.

This paper can also contribute to the science theory – the result of the literature review shows that the application of simulation software in the public contracts awarding domain is quite new so it extends the variety of possible simulation software applications.

Improvement possibilities will be based on the findings from the discrete-event simulation technique application (Simio software) and data taken from the two public procurement information systems: Journal of public contracts and NEN (National electronic tool). The MoD contracting authority is obliged to use both of these systems in order to publish the most important data related to public contracts, excluding contracts involving confidential nature of the information or dealing with the protection of the essential security interests. (Act 134/2016 Coll., of 19 April 2016 on Public Procurement, 2016, Rozkaz Ministra obrany č. 55 o úplatném nabývání majetku, služeb a stavebních prací v rezortu Ministerstva obrany, 2017).

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

Building a model and simulation in itself doesn't require knowledge of many data. The problem is when it comes to validation of the model. The more and more accurate data we provide in the model, the more precise results we get. Compared to real-world experimenting, the simulation doesn't consume so many resources. Still it requires time to build a model and also financial resources (Brunclík et al., 2018).

Discrete event simulation help people think introspectively about their systems and realize efficiency gains. An animated version of the system being modeled is often a major outcome of the modelling activity. These animations can provide the best available way to engage untrained people in the application of all types of operations research and systems improvement activities (Allan, 2011).

Literature review has been prepared from three points of view: simulation of logistical problems in general, application of simulation software in the field of public administration and implementation of simulation software in the field of public procurement.

Modelling and simulation is used within some main domains of man's bussiness activities such as supply chain management (Hennet, 2009), manufacturing system planning and scheduling (Merkuryeva et al., 2009 and Hadas et al., 2015). Further usage is in the transport domain (Guash et al., 2009, Uruscu et al., 2009, Eroles et al., 2009), hospital resource management (Chinea et al., 2009), fresh food supply chain (Bruzzzone et al., 2009), warehouse order picking (Merkuryev et al., 2009) or material handling (Neumann, 2009). Simulation software in the field of inventory management of selected retail stores has been implemented in Germany (Trauzettel, 2014).

Transport optimization or decrease of out-of-stock ratios belong to the main aims of simulation software application in general but simulation implementation in the procurement process is missing.

The research has been conducted related to using of simulation and other visualisation methods in practice of logistical companies in Poland. The result is that only minority of them use simulations because of the lack of financial resources, human qualification and problems with reliable data (Jankowski-Guzy et al., 2018).

Business and supply chain management is not the only domain, where the modelling and simulation is used in order to analyse and solve particular problems. There are even other domains in **the field of public administration**. The possibility of computer-based simulation games implementation in educational proces of bachelor and master degree students of municipal finance branch was analysed at the two Russian universities (Kutergina, 2017). It has been proved that this interactive approach of study should improve the students scores compared to traditional lectures. Multi-agent-based spatial simulation model was used for analysis of locational changes in Japanese residential areas due to aging and low birth rate (Karashima et al., 2015). This situation should influence public services appropriate deployment. Simulation software has also been applied on the metro transportation hub operation in Yekaterinburg, Russia (Zhuravskaya et al., 2018). The simulation was used in order to determine the required level of services for metro passengers and main characteristics of the system.

Concernig the **public procurement**, the usage of modelling and simulation is quite rare. I suggest that is caused due to its strong framing by the law and difficulty to predict the time consumption of all activities within this process. Application of discrete-event simulation software Stroboscope in the field of public works contracts has been used in the USA. The above mentioned software has been applied in order to prove that web based application can improve mutual cooperation among bidders and contracting authorities, resp. shorten reaction times to bidder inquiries and increase number of solved public contracts (East et al., 2009).

The term simulation based acquisition (SBA) is used for a concept of product development and manufacturing and also simulations to estimate system performance and mission effectiveness, combat training, the product modeling and manufacturing processes, simulations to support maintenance, training, logistics simulations to relate support plans and resources to readiness and simulations to address system disposal issues (National research council, 2002). The U. S. Navy LPD-17 program belongs to examples of SBA using in practice. The main factor of simulation was not the public procurement process but three-dimensional product model creation for the purpose of supporting engineering design. Thanks to simulations application the program saved 6 million dolars in design costs (Sanders, 1997).

Based on the above mentioned literature review results, it is possible to say that application of simulation and modelling in the public procurement process in the MoD is not widely common and there is a significant lack of information in this domain.

## 2. CREATING OPEN PROCEDURE MODEL

Methodology of a simulation project has been prepared according to a general approach consisted of four macro-stages:

1. Problem analysis.
2. Modelling and programming.
3. Validation of the model.
4. Experiments on the model (running simulations).
5. Report/ratio and conclusions (Fontanili et al., 2008).

Ad 1: All of the Czech MoD public contracts (about 150 contracts) being awarded via open procedure within the period May 2018-May 2019 were statistically analysed. The main aim of the analysis was to find out duration of each awarding procedures phases and choose the critical ones from the time point of view.

Ad 2: The model of open procedure steps (the flowchart) was created during the stage 2 according to the legislation valid in this domain and the open procedure simulation model was prepared based on the flowchart (see Figure 1 The open procedure simulation model).

Ad 3: After that first simulations were carried out to check the correct working of the model together with retrospective validation – comparing the simulation results with historical data generated by the real system (Chinea et al., 2009).

Ad 3: The dynamic behaviour of the system was tested in the stage 3. Experiment was carried out, consisting of 5 scenarios, where the time of tenders evaluation was set as the control variable. Thus, the time for tenders evaluation decreases in each scenario by 30 days. All scenarios were executed 50 times in order to obtain results on the appropriate level of statistical confidence. (Details in the part 3 Running the simulation).

Ad 4: The relevant data and a graphics package were used to explain which phases of the awarding process are the most problematic and which activities can be done more efficiently without legislation changes. (Details in the part 4 Results discussion).

The objective of the model creation and running is to show different variants/scenarios of public contracts awarding via open procedure under different conditions for the process participants.

An open procedure will be used for the model preparation as the most appropriate type of award procedure determined by the legislation of the European Union (DIRECTIVE 2014/24/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on public procurement and repealing Directive 2004/18/EC, 2014) and the Czech Republic (Act 134/2016 Coll., of 19 April 2016 on Public Procurement, 2016) as the EU member state. In this procedure, contracting authorities invite maximum number of tenderers to submit their tenders and to prove participating conditions fulfilment. Therefore the result should be the selection of the most efficient offer based on the wide spectrum of competitors (if possible). This procurement procedure cannot be used for the procurement involving defence or security aspects but despite this fact, the MoD still has to procure common and generally available products, services and public works like other „classic” contracting authorities.

All the contracting authorities in the Czech Republic have to use the NEN system in which they publish tender documentation, communicate with the potential suppliers and save awarding procedures results (Usnesení vlády ze dne 21. června 2017 č. 467 o uložení povinnosti využívat Národní elektronický nástroj při zadávání veřejných zakázek, 2017).

Preparation of the open procedure phases flowchart was essential as the basis for the simulation model creation.

Limits for the open procedure flowchart have been stated as follows:

- Focus “only” on a period which starts by tender documentation publication in the NEN system and lasts until the day of contract conclusion.
- Specification of the subject-matter of the public contract has already been prepared and approved by responsible MoD bodies.
- Future expenses from the MoD budget have been approved by the responsible persons and departments as stated in the internal MoD directives (Normativní výnos Ministerstva obrany o jednotném postupu při úplatném nabývání majetku, služeb a stavebních prací v rezortu Ministerstva obrany, 2017).

The flowchart of open procedure starts with the sending of the call for tenders to the Czech Republic Journal of public contracts. Right after the contracting authority has to publish tender documentation of a particular public contract on its profile which is in the case of the MoD the profile in the NEN system. Now, the economic operators have 30 days (minimum) for the preparation of their tenders and submitting them electronically via the NEN system. They can also ask the contracting authority for the explanation of conditions or requirement, which are not clear to them in the tender documentation. The contracting authority is then obliged to answer and publish the answer in the NEN system in order to be accessible to all of the economic operators. All operators shall be treated equally in a transparent manner according to the EU and the Czech legislation (DIRECTIVE 2014/24/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on public procurement and repealing Directive 2004/18/EC, 2014, Act 134/2016 Coll., of 19 April 2016 on Public Procurement, 2016). If after these questions is necessary to change the parameters of the tender documentation, contracting authority has to prolong the time limit for receipt of tenders. After this period, the tenders are accessible to the contracting authority for the process of their evaluation and verification if all the formal conditions have been met by the tenderer. Different situations can then occur:

- No tender is submitted (the awarding procedure is cancelled and the new awarding procedure has to begin).
- Only one tender is submitted via the NEN system (the tenderer becomes the winner if it meets all conditions stated in tender documentation).
- More than one tender is submitted (contracting authority has to evaluate all of the tenders and verify if all formal conditions have been met).
- If the tenderer does not meet the criteria crucial for tenders evaluation, it has to be excluded.

- If the tenderer does not meet the formal conditions stated in the tender documentation, it can be appealed by the contracting authority for the completion of the missing documents or for the explanation of reasons of abnormally low tender price, if necessary.

Now the winner can be chosen among the tenderers which met not only the tender criteria but also the formal conditions of the tender. Information related to the winner is then published in the NEN system but the contract cannot be concluded yet. The contracting authority has to wait for a minimum of 15 days for objections of unsuccessful suppliers against the contracting authority decision related to the selection of the most appropriate supplier. Different situations can then occur as well:

- If there are no objections, the contract can be concluded right after 15 days of waiting for objections.
- If the objection has been submitted, the contracting authority has to decide if it is reasonable or not. If it is reasonable, the contracting authority has 15 days for its settlement. If not, the contracting authority informs the tenderer about the possibility to appeal against its decision to the Office for the Protection of Competition (the Office). Maximum 10 days after the contracting authority's decision about the reasonability of the objection, the tenderer has to appeal to the Office and the Office has to deal with it. The time limits for that are not exactly determined in the Act.
- If the Office decides, that the objection is reasonable (even if the contracting authority disagrees), it can suspend the awarding procedure until both the tenderer and the contracting authority find the solution of the situation or it can even cancel the awarding procedure.
- The Office can also refuse the objection of the tenderer and the contract can be concluded.
- The Office can also impose a ban on contract conclusion until the contracting authority proves the reasons to continue with the contract performance.

If the situation with objections is solved, the contract can be signed.

Conceptual model of the MoD open procedure is based on the above-mentioned legislation: the Act on public contracts and internal MoD directives. The elements of the model are represented by the main phases and specific legal acts and relationships among them, necessary for the public contracts awarding operation. Minimum and maximum time limit of operation was assessed for each of the phase. The real-time periods were determined thanks to the analysis of data taken from the Czech Journal of public contracts and the NEN system:

**Table 1.** Open procedures in the Czech MoD (May 2018 - May 2019) - table excerpt

contract number	procedure publishing date in NEN	changes in tender documentation (TD)	reasons of TD changes and delays	tenders receipt till:	time for tenders receipt (days)	contract conclusion date	open procedure duration in days	objections	evaluation time in days (-15 days for objections)
1	2	3	4	5	6 (5-2)	7	8 (7-2)	9	10 (7-5-15)
1.	8. 2. 2019	TD changes	TD explanation 3x	3. 4. 2019	54	14. 5. 2019	95	0	26
2.	14. 12. 2018	TD changes, prolonged	TD explanation 3x	31. 1. 2019	48	29. 4. 2019	136	0	73
3.	12. 11. 2018	TD changes	explanation 1x	13. 12. 2018	31	16. 4. 2019	155	0	109
4.	8. 2. 2019	TD changes, prolonged	explanation 1x	26. 3. 2019	46	2. 5. 2019	83	0	22
5.	4. 2. 2019	TD changes, prolonged	explanation 1x	25. 3. 2019	49	29. 4. 2019	84	0	20
6.	14. 12. 2018	TD changes	0	17. 1. 2019	34	26. 4. 2019	133	0	84

Source: author's own based on Informační systém o veřejných zakázkách

Switching times from one phase to the other were determined as  $t=0$  because the majority of documents are prepared in electronic form so the delays caused by e-mail or publishing documents on the particular website or database are not probable.

The simulation model will be focused on the following open procedure phases: publication of the tender documentation, tenders' evaluation and dealing with objections. It will be interesting to discover if the change of time of some of the above-mentioned processes can significantly influence the whole public contract realization time.

Tender documentation is the monitored entity. It comes into our model prepared for publication, so we suppose that it involves all data necessary for the call for tenders announcement. The documentation is published right after its entry to the information system NEN (element „Tender documentation publishing“ in the model).

Evaluation of tenders is the next phase right after the expiration of the time limit for tenders preparation (element „Tender evaluation“ in our model). Random variable,

the number of tenders is than generated. If the tenders' number = 0, an open procedure is finished. If the tenders number is > 0, all of the tenders have to be evaluated by the contracting authority.

The results of the competition among the tenderers are published in the NEN system and the period of waiting for objections starts now and takes max. 15 days. This phase is involved in the model as Supplier selection. Right after the time limit for tenders receipt ends (public contract comes to the point `Output@supplierselection`), the existence of objections is tested.

If objections are submitted by the unsuccessful supplier, they have to be solved by the contracting authority or the Office (elements Objections - contracting authority, Objections - Office). If there are no objections, the contract can be concluded and realized.

Solving of objections operates within the time limits determined by the Act on public contracts. If the objection is solved, the contract can be signed or, if not, it is cancelled and the new awarding procedure has to be prepared.

Within the analysis of time limits determined for each phase of the process by the legislation, it was not possible to confirm the type of statistical distribution. Despite this fact, it was possible to determine data, which enable to use random numbers generators built in the simulation software. Examples of some variables generation:

- Time period for tender documentation publishing: Triangular (23, 35, 60).
- Time period for tenders evaluation: Triangular (0, 39, 183).

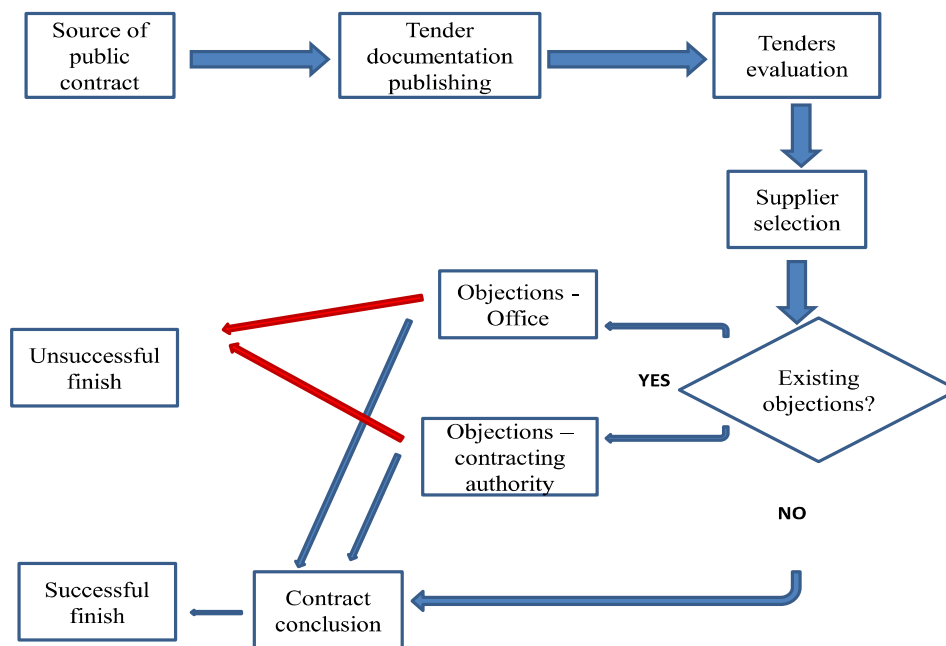
Functions enabling to generate values related to the probability of existence were used for objections generation. Two situations can occur for the variable "Objections existence": 1 – objections exist, 0 – no objections. Based on the data from statistical analysis of about 150 open procedures, it can be assumed, that objections were submitted in 10% of situations. Based on this calculation, the function "Objections existence" is generated:

Random discrete (0, 0.9, 1,1).

Based on the above mentioned findings, the final model of open procedure has been created (figure 1).



**Figure 1.** The open procedure simulation model



Source: author's own

### 3. RUNNING THE SIMULATION

The complex model was tested during the first run mainly because of the procedure logic and possible mistakes in the process, variables or commands in the processes, which are defined behind specific acts. We can avoid some syntax errors found out by simulation software during the simulation process (software is able to warn us about that).

The experiment was created in order to obtain the results related to the whole open procedure duration, which lasts from the procedure announcement to the successful or unsuccessful finish. The Experiment consists of 5 scenarios, where the time of tenders evaluation is set as the control variable. Thus, the time of tenders evaluation decreases in each scenario by 30 days. All scenarios were executed 50 times in order to obtain results on the appropriate level of statistical confidence.

After the run of the experiment all necessary information has been obtained for further analysis including processing time of all involved activities within the whole process, their minimal, maximal and average values, number of evaluated tenders, the solution of the evaluation and also numbers of objections. There is plenty of another information provided from simulation, but we are focused just on the mentioned ones due to the purpose of this simulation.

#### 4. RESULTS DISCUSSION

The simulation proposes the results of the experiment explained above. As we can see from table 2, the number of public contracts entering the system is not significantly changing and its average is approximately 180:

**Table 2.** Number of public contracts entering the system

<b>VZ - NumberCreated – Total</b>						
<b>Scenario</b>	<b>Data Source</b>	<b>Category</b>	<b>Average</b>	<b>Half Width</b>	<b>Minimum</b>	<b>Maximum</b>
Scenario1	[Population]	Throughput	183,0	1,2	176,	193,
Scenario2	[Population]	Throughput	182,8	1,3	175,	192,
Scenario3	[Population]	Throughput	182,6	1,0	173,	189,
Scenario4	[Population]	Throughput	183,0	1,2	174,	194,
Scenario5	[Population]	Throughput	183,4	1,0	176,	190,

Source: author's own based on Simio simulation software

This is logically correct because it was generated by the same probability function for all scenarios, which was set by the historical data from the NEN system.

We put focus mainly on time for tenders evaluation. This is the main point in the whole process, where the time of processing up to the data from the NEN system varies in the largest scale of values (see Table 1 Open procedures in the Czech MoD (May 2018 - May 2019) - table excerpt).

Simulation results related to tenders evaluation time are involved in table 3 and the average times oscillate between 68 and 34 days:

**Table 3.** Time for tenders evaluation

<b>Tenders evaluation - TimeInStation - Average (Days)</b>						
<b>Scenario</b>	<b>Data Source</b>	<b>Category</b>	<b>Average</b>	<b>Half Width</b>	<b>Minimum</b>	<b>Maximum</b>
Scenario1	Processing	HoldingTime	67,4	0,9	59,5	76,8
Scenario2	Processing	HoldingTime	60,5	0,8	54,3	66,1
Scenario3	Processing	HoldingTime	51,7	0,6	47,4	58,3
Scenario4	Processing	HoldingTime	42,7	0,5	38,7	46,4
Scenario5	Processing	HoldingTime	33,4	0,3	30,2	36,5

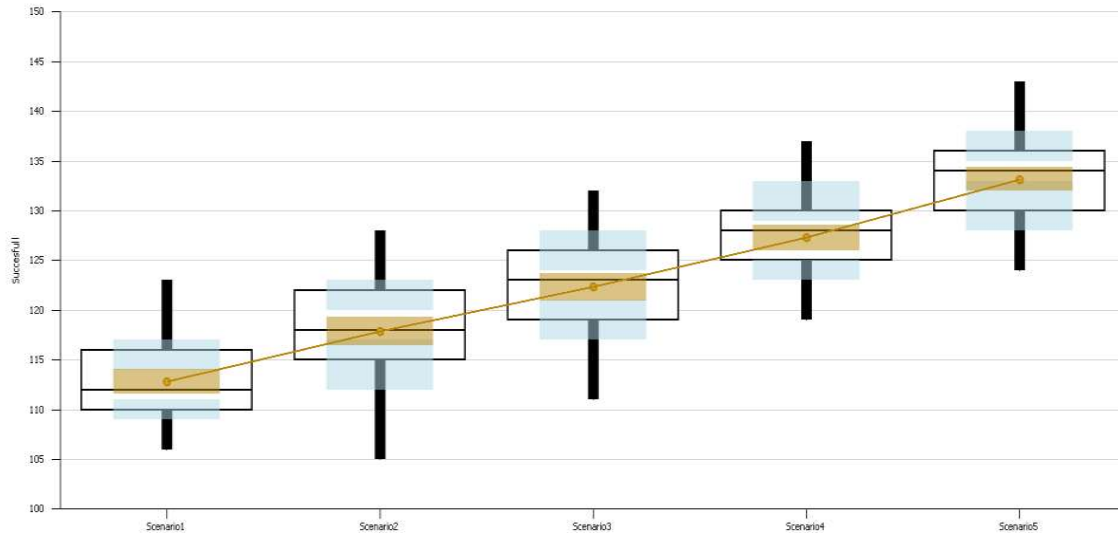
Source: author's own based on Simio simulation software

The law does not define exact time for decision-making, which means, that contracting authority can set some internal procedures in order to force its own evaluators to finish evaluating without non-eligible prolongation. Therefore, time of

tender evaluation was set as the control variable, to set several scenarios in the experiment.

The difference is visible if we monitor the number of public contracts, which were solved in the course of the awarding process, no matter if the result is positive or negative (the contract has been concluded or awarding procedure has been cancelled). From the plot diagram 1 is obvious, that the number of solved public tenders grows depending on the decrease of time for tenders evaluation:

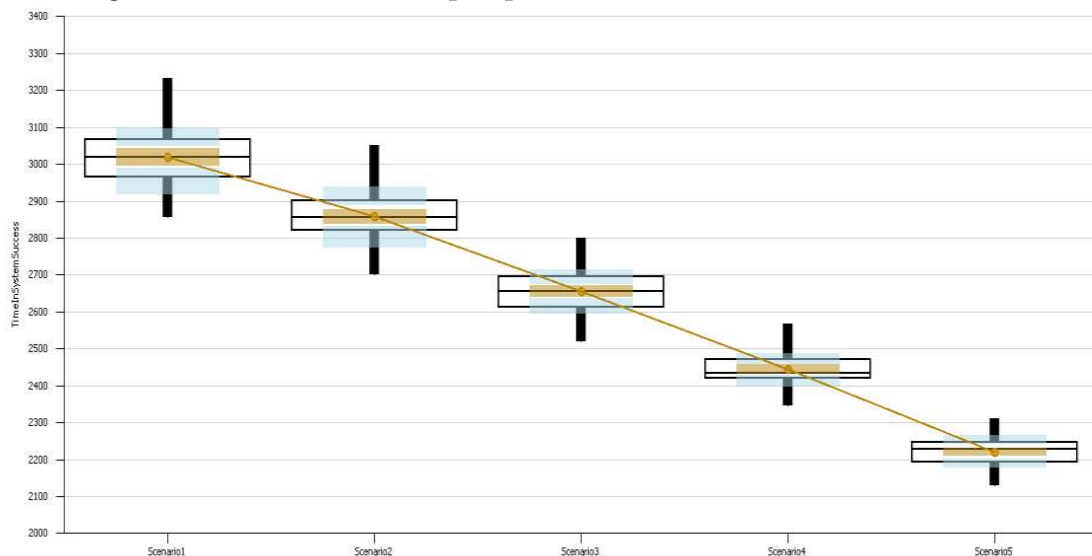
**Plot diagram 1.** Number of successful public contracts



Source: author's own based on Simio simulation software

We can also monitor the decrease of the whole open procedure time period (time in system, successful finish, in hours) thanks to the shortening of the tenders evaluation period:

**Plot diagram 2:** Duration of the open procedure



Source: author's own based on Simio simulation software

The best result based on Simio simulation application should be the scenario 5 with the shortest duration of time which all of the contracts spend in the awarding process (plot diagram 2, time in hours) and maximum number of successful contracts finished by the contract conclusion (plot diagram 1). Time period for tenders evaluation should oscillate around 30 days. The results need to be verified by the public procurement specialists and it mainly depends on the subject-matter of a particular contract (more details in the part Conclusions).

## 5. CONCLUSIONS

Public procurement is the process with quite strongly defined framework, determined by the legislation and internal procedures of the contracting authorities. This framework defines the main roles and responsibilities of each element, but still propose some level of freedom during the whole process. This setting allows us to design appropriate model of this system, put it under an analysis, and run the simulation in order to see the impact of possible adjustments of several procedures. Also, some kind of legislative freedom gives the possibility to improve efficiency of the procurement process without changes in the Act on public contracts, just within the responsibility of the contracting authority as for example the MoD.

Otherwise, it is necessary to pay attention about the available data from the information systems. If there are some gaps in the information, the model could be set wrong and thus the results could be inappropriate. It means that all authorities should pay more attention to the quality and accuracy of information which they have to publish in these systems (NEN, Journal of public contracts).

Finally, this model shows the possibility of using modelling and simulation for analysis of this process in order of further adjustments before it is applied into practice. It means that the MoD can analyze the impact of prepared changes of the procurement system before their implementation. That can save a lot of worktime, energy and money instead of putting inefficient changes into life and their further corrections.

The approach suggested by the researchers is universal. All of the contracting authorities regularly procure common and generally available products through open procedures. Particular steps of each open procedure are the same for all of the contracting authorities in the Czech Republic. This type of awarding procedure also enables significant improvements especially from the point of view of time savings and mutual cooperation among contracting authorities, users, economic operators and tenderers.

Variety of public procurement aspects is still waiting for further research. It will be necessary to consider different subject-matters of public contracts. Public works contracts are definitely more time-consuming from the point of view of tender documentation preparation and tenders evaluation than office stationery contracts etc. So public contracts should be divided into groups according to their subject-matters and different periods of time should be considered for tender documentation preparation and tenders evaluation.

Another important issue to consider is the number of evaluated tenders. It would be possible to statistically evaluate numbers of tenders submitted for each public contract and then assume appropriate time period of tenders evaluation for those subject-matters of the public contracts which are mostly awarded.

Database of public contracts with all the necessary data related to time periods of each awarding process phase and subject-matters of contracts should involve longer period of time than one year in order to obtain more reliable results based on simulation software application.

It would also be interesting to find out if the MoDs contracting authorities of other states are obliged to use similar information systems (as NEN for the Czech MoD) and which type of data they have to publish in. After that it would be possible to compare time lengths of tenders evaluation phases or time periods for tender documentation preparation (within the same subject of the contract) which belong to the most critical phases of the public contracts awarding process.

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