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Research Article

Conceptual Modelling in Simulation of Military Logistics Processes – Field Maintenance Modelling

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A B S T R A C T

Conceptual modelling is one of the most challenging parts in simulation modelling where more knowledge fields meet each other. The main goal of the paper is to present the process of creating a conceptual model as an important step in simulation model development. The starting point is a description of a real entity given by subject matter expert, and output is one consistent, algorithm-like, conceptual model. As a real entity here is used a process of field maintenance of main weapon system in a brigade-size military unit in combat operations. The point of the paper is to emphasize the translation of the conceptual description of the real process given from the subject matter expert, towards a formalized conceptual model that is understandable to the simulation modeller and computer programmer.

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I. INTRODUCTION

This paper presents the development of a conceptual model for Monte Carlo simulation of the field maintenance process in a brigade-size military unit in combat operations. The main point is to emphasize the translation of the conceptual description of the real process given from the subject matter expert, towards a formalized conceptual model that is understandable to the simulation modeller and computer programmer. The paper touches two interesting classes of problems: the first one is conceptual modelling and the second one is field maintenance process in a battle situation.

Conceptual modelling [1], is a fundamental part of the general simulation modelling methodology [3]. It is an important issue in the field of military modelling and simulation as well [4]. Conceptual modelling starts with a description of a real system of interest. Information about real system comes from the subject meter expert (SME) – a person familiar with all important aspects and details of real system: elements of structure, relations and dependencies among elements, characteristics, processes, data sets (values, types), time frame, input and output variables, etc. A good way to obtain a description of a real system is interviewing SME by a simulation system analyst. Also, SME declares what is expected from the simulation model: what kind of information he wants to get as output variables. Usually, the simulation model is expected to effectively support various possible cases (variants) for the system under study: minor changes in the structure of the model, or varying values and variable types in input data sets. Those types of demands are expected from a subject matter expert, as he wants to make insights in the heart of the problem and to conduct "what-if" analysis.

Field maintenance, as a part of forwarding logistical support of combat units, is very important for sustaining the operational capacity of military units in their mission. It was the case in the past, and it is the case in contemporary warfare. In favour of this statement, there are some findings from recent military engagement [5], where it is confirmed the need for close, timely and effective logistical support even in the case of high-tech military units as it is the Stryker brigade. Due to the high complexity of real military processes and systems of interest, simulation modelling is a logical choice of researchers. Some authors point out the lack of published research efforts related to simulation of the field maintenance in service systems [6], even though they appear from time to time [7].

II. MODELLING FIELD MAINTENANCE IN BRIGADE

The main goal of field maintenance in battle conditions is to perform battle damage repairs (BDR), as well as to fix all other types of failures, to contribute to sustaining the operational readiness of the unit at the highest possible level. Here, the main purpose of the simulation model is an evaluation of filed maintenance process for main combat items (armoured vehicles) in the considered brigade that consists of three armoured battalions, one mechanized battalion, and two fire support battalions. This structure of hypothetical brigade corresponds to similar real brigades in many armies (there are some additional units in brigade structure, but those are not of special interest at the moment).

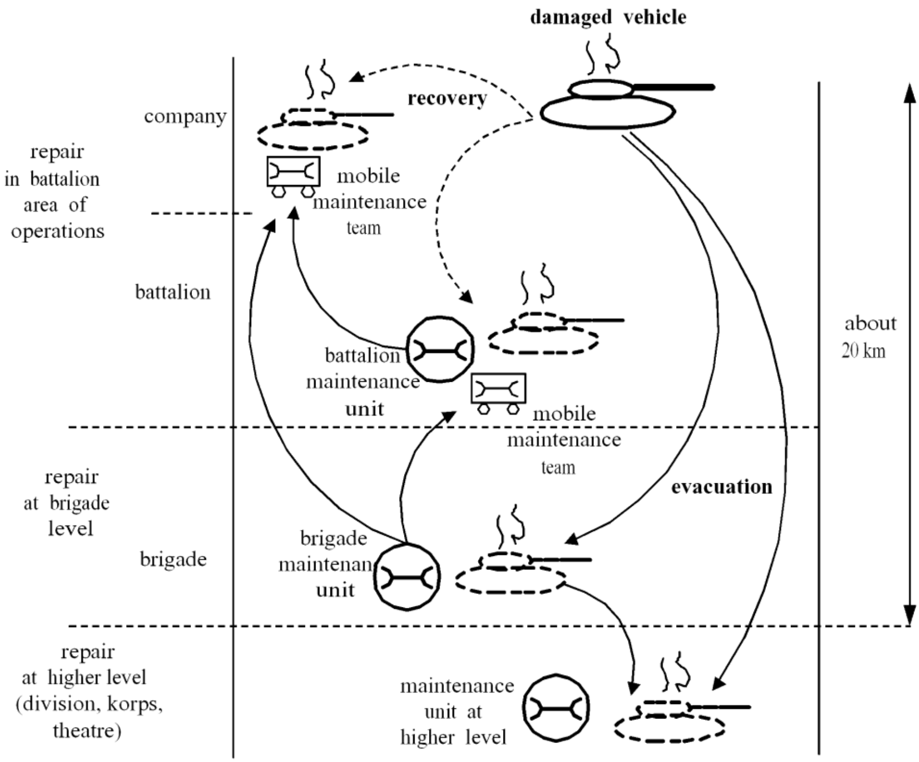

Figure 1. The tactical procedure with a damaged weapon system [8].

The starting point in making conceptual model is a set of information given by subject matter expert (SME), for example, it may be brigade maintenance officer or even main logistic officer in the brigade. It is supposed that SME can give a clear consistent description of the real process of field maintenance, including all relevant structural elements, their relationships, operating procedures, limitations and other facts. This description could be given by words, by graphical schemes, or combined. An initial sketch of a field maintenance process for the main combat item is shown in Figure 1. It presents one typical military logistics problem during a battle [8]. That problem could be described with words or by the picture as we did. This kind of scheme comes from the area of the subject matter expertise – it should be clear to all logistics officers regardless of the level of his simulation knowledge.

Figure 1, presents the following situation: when the military unit performs its battle job, as well as in other non-battle missions, it happens that some vehicles need maintenance. That need could be a consequence of a battle, bad terrain, minefields, poorly trained crew, other accidents or simply a matter of technical reliability of the item. We do not know in advance when a maintenance demand will appear, where it will be, or what kind of maintenance will be needed. This is a completely stochastic event.

The general goal of maintenance as one of the military logistic functions is to obtain all technical items in the right conditions and ready for use. When maintenance demand appears the goal is to execute needed maintenance activities and send back in a mission repaired item as soon as it is possible. Every army develops some maintenance resources and prepares them for such a situation. In this simple scheme, it is assumed that some resources are at battalion and brigade level, and of course at the levels above brigade. There are some logical principles for maintenance organization in the military: higher the level, better maintenance (able to repair heavier damage); however, higher the level, further from the first battle lines and users. In general, repairs that consume short time should be done at the lower lever (maintenance resource comes towards the damaged item).

In a case of damaged heavy items, like tanks, armoured personnel carrier, truck and artillery weapons, the engagement of other specialized vehicles for transportation could be needed. Short distance transportation is known as recovery, and that could be done by the help of other similar vehicles (one tank/vehicle helps the damaged one of the same sort or lighter). Long-distance transportation is known as evacuation, and then it is used heavy equipment transporter (HET) -commonly a special large capacity truck. Evacuation is a time-consuming activity. Heavy items like tanks are very important for the strength of military units and their ability to perform assigned missions. To make overall repair time as short as possible, whenever it is possible, mobile maintenance teams could be sent to the area of operation to fix the damaged item.

III. Distilling Conceptual Algorithm from the SME Model

Conceptual algorithmic model of the process described above is shown in Figure 2 (it corresponds to the "design-oriented" model [1]). From the Monte Carlo simulation modelling aspect, this is a conceptual model of the situation presented in Figure 1. Subject matter expert, SME, (in this case it is a maintenance officer and a logistics officer too) is authorized and qualified to describe real system or situation with an appropriate graphical scheme like the one in Figure 1 (it corresponds to the "domain-oriented" model [1]).

To make conceptual model, two kinds of knowledge, subject matter expertise and simulation modelling expertise, should be brought together (regardless of a form: two men with different knowledge, or one man with both kinds of knowledge). Subject matter expert gives the essence of the real system or process under study (structure, elements, relations, rules, data, etc.), while simulation modeller transforms it towards more formalized conceptual algorithmic form. That conceptual model is very much alike to an algorithm for a computer program, but still not the same: it is free of technical details of computer programming and standard shapes and syntax for computer algorithms.

The conceptual algorithmic model should be of such quality that subject matter expert sees it as his vision of the tactical situation, however only with slightly different symbols. For simulation modeller, the conceptual model should be one consistent system of clearly defined elements, structure, cause-and-effect relations, rules, data, and frames. For him, this is a general representation which can be relatively easy translated in more detailed and formalized computer algorithm with concrete programming syntax.

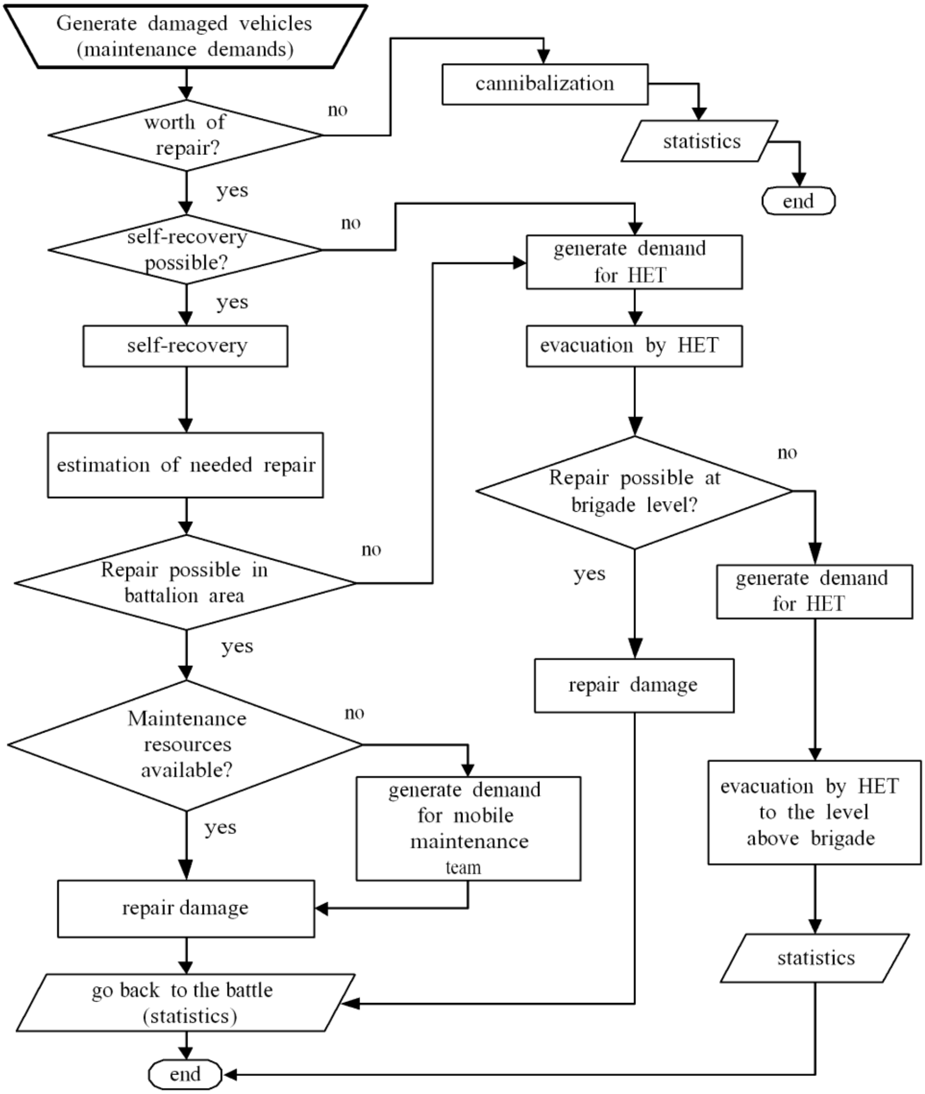

Figure 2. A conceptual model for damaged item process [7]

A conceptual model is a place where two worlds meet each other: the real world and the abstract world of simulation modelling. This is the main entity where validation of the model is tested. Here, simulation modeller should discuss with subject matter expert and eventually point out things which are not possible to present in a model. Making of a conceptual model is more an art than a formal science. That is also an iterative process with mutual benefits for both sides.

In Figure 2, there are collections of various entities: source or sources of demands, decision points (crew, a unit commander, a maintenance officer and mechanics), few kinds of services (making decisions, recovery, evacuation and repair). Looking at this presentation as one queueing system, it could be concluded that it is one multi-phase, multi-channel queuing system with the general type of stochastic distributions, with possibly high utilization and even overloading of service channels capacity, and with a finite time of engagement. Trustworthy modelling of military systems and processes that could be presented as queueing systems could intrude some new topics for research, like transient queueing analysis [9], and questions about accuracy in simulation modelling of queueing systems [10].

Patterns and intensities of incoming demands and servicing processes should be defined by subject matter expert. SME judges based on his/her experience or historical data if available. SME is the one, who knows: battle parameters (mission task, enemy, terrain, weather etc), own forces (maintenance resources, readiness, training level, even morale). There can be more sets of those input variables, particularly when more than one course of action (alternative scenarios) should be considered.

In Figure 2 there are a set of various decision points of stochastic nature, like: it is expected that in 40% (or 10%, or 70%, etc.) of demands for maintenance will be possible self-recovery; repair in the battalion area will be possible in 60% (or any other number); and so on. This data should come from subject matter expert. When judged about concrete values of input variables model makers (both: SME and simulation modeller) are occupied by the problem itself. It is normal, logical and needed. However, they are not obligated to think on eventual restrictions that may exist in particular theory which corresponds with their model. For example, if modellers judge that pattern of arriving demands for maintenance is not exponential then by a normal distribution, then it should be respected in the model, besides the fact that classical queueing theory mainly deals with exponential patterns. If a whole mission is planned to be finished in few days (or months), then we cannot deal with infinity in this queueing task besides queueing theory treat mainly stationary behaviour (infinite time).

Regarding other types of models for simulations [11], our case belongs to the “closed simulations”. That means that all relevant factors and aspects, including the human factors, of the real system or process under study, will be incorporated in the model by a set of appropriate functions, rule mechanisms and input data. Besides numerous structural elements and their relationships, the model is made more complex by involving stochastic variables which describe stochastic behaviour of the real system or at least some of its parts. Due to that, this kind of simulation is better known as Monte Carlo simulation, or simulation of stochastic processes, or shorter as a stochastic simulation. Due to the specific mechanism for support of the dynamic behaviour of the model, it is also known as a discrete-event system specification (DEVS) simulation. In any case, conceptual modelling as a specific and crucially important step in simulation modelling has gained wide recognition in the simulation community [12], including the military and defence branch.

IV. Structuring Computer Simulation Model

The final step in the development of simulation model is “translation” of the algorithm of the conceptual model to the exact computer algorithm with the appropriate syntax of the chosen programming language, and then writing the computer program code. Next to it is testing the model (verification and validation phases in simulation model development methodology [3]). With good, adequately developed, organized and displayed algorithm of the conceptual model, it should be relatively easy to produce computer code in the chosen programming language. However, in practice, it is not always the case and additional efforts and time are associated with simulation model creation. Due to space constraints, it is not presented detailed computer algorithm or code. Nevertheless, it is not even necessary because there are so many different programming languages and accompanying syntax differences. Instead, there are given some notes of the concrete model.

A simulation model for field maintenance of main combat item in considered brigade consists of the following functional modules:

- Declaration module. In the concrete example, there are few dozens of input variables which define resources related to maintenance of main combat items in brigade consisting of four combat battalions, two combat support battalions, logistics section in brigade headquarters, and maintenance related resources in brigade’s logistics support battalion. Majority of variables are stochastic and are presented with: mean expected value, deviation value, and type of probability distribution function.
- Maintenance demands generation modules. This is the place where military tactics play important roles and more scenarios could be defined, as the type of operation (attack, defence); the concept of operation (number of echelons, number and type of battalions in each echelon; the expected influence of enemy (losses); etc.
- Modules for demands processing and conducting maintenance activities (series of decision-making points related to the estimation of damages; possibilities and needs for self-recovery or recovery; estimation of possibility for maintenance inside area of operations or declaring the need for evacuation outside of the forward area of operations; availability of resources for conducting maintenance; repair actions itself; etc).
- Modules for gathering statistical data for chosen variables during simulation experimentation. Number and size of modules of this type depend on desired statistics that are of interest for investigation.
- Time simulation module.

In the sense of visual composition, this simulation model is organized correspondingly to the organization structure of the brigade: there are modules for each simulated battalion, logistics section in the brigade headquarters, and evacuation and maintenance resources from logistics unit at the brigade level (logistics support battalion). Each of those “brigade units” modules contain elements of functional modules related to maintenance demands generation, maintenance demands processing, and gathering statistic during simulation experiments.

Besides this simulation model relates only to field maintenance of main combat items (heavy vehicles: tanks, armoured personnel carriers and self-propelled guns), it may become relatively large consisting of few hundreds of computer program blocks in one local school version of GPSS/FON simulation language.

V. Conclusions

Conceptual modelling is a fundamental part of the general simulation modelling methodology. A conceptual model is a place where two worlds meet each other: the real world and the abstract world of simulation modelling. Conceptual modelling starts with a description of a real system of interest. Information about the real system comes from the subject meter expert, bringing all important aspects and details of the real system: constitutional elements, their relations and dependencies, and other contextual data.

Synergetic clash of real system knowledge and simulation modelling expertise leads to the creation of the conceptual algorithmic model. From that point, if it is successful, there are small steps towards the full development of computer implementation of the simulation model, that is, to the computer program written in the chosen programming language. However, the whole process is iterative spanning from subject matter expertise, across a rough conceptual model, towards computer implementation.

Future research is seen towards these directions: popularization of conceptual modelling in the field of education, following modern trends in the development of conceptual modelling, and deeper investigation of scientific topics that arise from applied trustworthy simulation modelling (like problems of transient queueing analysis).

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