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MODEL FOR ASSESSING THE MOBILITY OF THE FUEL SUPPLY SYSTEM IN AN OPERATIONAL-TACTICAL TROOP GROUPING

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Abstract.
A model for assessing the mobility of the Fuel Supply System (FSS) of an Operational-Tactical Grouping of troops (OTG) is proposed to support command decisions in dynamic combat conditions. Rapid restructuring of logistics systems and uncertainty in initial data make it difficult to assess whether fuel-supply tasks will

be completed on time. Available approaches rely on static parameters and rarely capture transformation of the system during an operation. The research niche of this article is the development of a probabilistic-analytical tool for quantitative assessment of FSS mobility that explicitly incorporates structural transformation into command-and-control decision support. The purpose of the study is to provide Fuel Service command authorities with a method to estimate the probability of timely task execution and to compare managerial options under uncertainty at a specified confidence level. The research hypothesis assumes that combining probability theory with network-planning methods and transformation parameters yields a more adequate mobility assessment than conventional models. The methodology applies probabilistic modelling and network scheduling to compute expected task durations and execution probabilities. The results include an algorithm for calculating an FSS mobility indicator and a procedure for synthesising and evaluating alternative restructuring options under time constraints. The conclusions confirm that the proposed model improves the reliability of mobility assessment and reduces the risk of fuel supply disruption, thereby increasing the effectiveness of logistical support for troops in OTG operations.

Keywords:
operational-tactical troop grouping; fuel supply system; fuels and lubricants; probabilistic model; logistic support

Problem Statement and Literature Review

Based on the requirements imposed on the fuel supply system of an Operational-Tactical Grouping (OTG; formation or unit) it is evident that the key characteristic of the mobility of such a system is represented by non-deterministic time variables describing the duration of tasks related to changes in its structure (relocation of command posts or individual system elements) (Kubal 2018, pp. 132–136; Druzhynin 2020). Assessing the mobility of the OTG fuel supply system (formation or unit) using existing models (Lytvinovskyi, Olenev and Ostapenko 2001, pp. 124–130; Chernevko 2020; Vlasov, Vorobiov and Uhrynovych 2020; Gatsenko 2015, pp. 85–90) is not always feasible. This is due to the difficulty of obtaining reliable input data under the specific conditions of combat operations, which is consistent with the general characteristics of logistics systems operating under uncertainty (Simchi-Levi et al. 2008).

Existing approaches are generally valid; however, under modern conditions they do not fully reflect the essence and specific features of the functioning of the OTG fuel supply system during the dynamic processes of preparation and conduct of combat operations, nor do they allow determination of the reliability level of accomplishing tasks related to changes in the system structure, which is a known limitation of traditional logistics modelling approaches (Christopher 2016).

The parameters used in the mathematical frameworks of existing models adequately characterise classical forms of past operations. Nevertheless, under contemporary conditions such parameters are difficult to determine and lack a clear physical interpretation, particularly under conditions of stochastic task execution and dynamic system restructuring (Pinedo 2016). These challenges are also reflected in modern military logistics doctrine emphasising adaptability and responsiveness of support systems (NATO 2013).

The ultimate outcome of structural changes in the fuel supply system during an OTG operation is the readiness of the system and its elements to accomplish tasks ensuring timely and uninterrupted fuel supply to troops while minimising time expenditures. In this regard, in order to assess the expected outcomes of managerial decisions, it is necessary to have the capability to forecast the results of the process of restructuring the Fuel Supply System (FSS) under dynamic combat conditions.

Therefore, to address the identified research gap, the research strategy of the study is formulated as follows.

Research strategy

The aim of this study is to develop a tool whose application enables quantitative assessment of the mobility of fuel supply systems at different command levels in order to substantiate decisions aimed at ensuring timely and uninterrupted fuel supply to troops.

The research problem arises from the lack of adequate methodological tools that allow command authorities to quantitatively evaluate the probability of timely task execution when the structure of the fuel supply system changes under dynamic combat conditions.

The main research question is whether the integration of probability theory and network planning methods with parameters reflecting structural transformation processes can improve the reliability and practical applicability of mobility assessment of fuel supply systems.

The research hypothesis assumes that the proposed integrated probabilistic-analytical approach provides a more accurate quantitative assessment of fuel supply system mobility compared with existing methods and enables forecasting of managerial decision outcomes with a specified level of confidence.

Main Content

One of the key conditions enabling an Operational-Tactical Grouping to accomplish combat missions or maintain readiness for combat employment is the timely receipt of the required volumes of materiel resources (Problems of logistics development 2017).

The logistics support system deployed within an OTG is a system of military purpose, functionally integrating the subsystems of the respective materiel support services. Such a system is not formed as entirely new; rather, it is built on the basis of pre-existing subsystems, which are also spatially distributed and function to ensure comprehensive support for OTG troops in operations (Baranov et al. 2019, p.

291). One of these subsystems is the Fuel Supply System (Kubal 2018, pp. 132–136; Viiskovyi tyl 2015).

The fuel supply system for Operational-Tactical Grouping troops in wartime is designed to meet the troops' requirements for fuel and technical resources during combat operations. The troops' requirements refer to the quantity of fuel and lubricants (F&L) necessary to accomplish the assigned combat tasks of the OTG and to establish the mandated reserves of F&L for the subsequent period of combat operations across all levels of the system's hierarchy (see Figure 1).

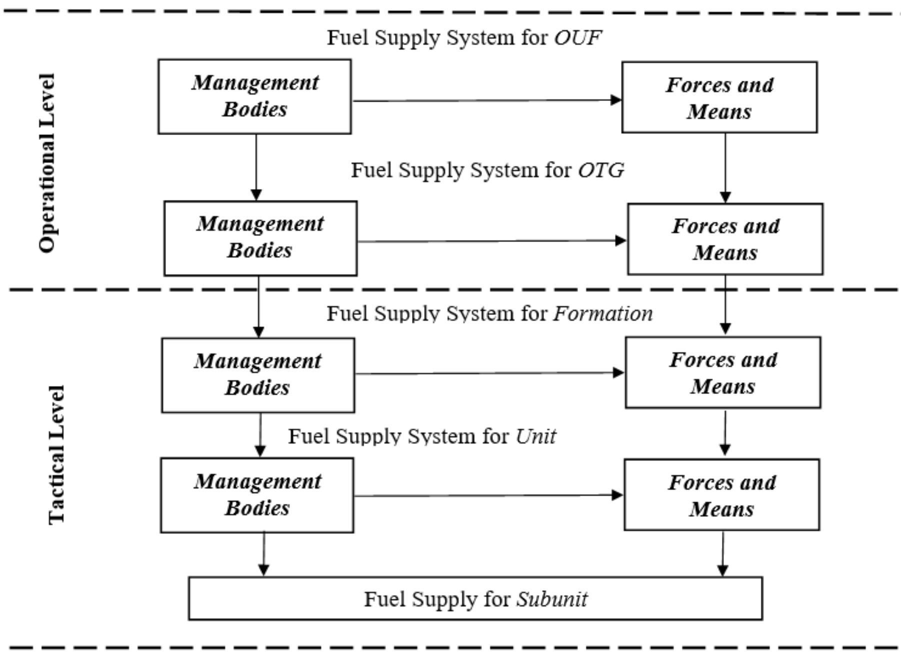

Figure 1. Hierarchy Levels of the OTG Troops' Fuel Supply System
Source: own study

In developing a model to assess the mobility of the troops' fuel supply system during operations (combat activities) across various management levels, the article employs the conceptual framework of the "Troops' Fuel Supply System." The use of this term is justified by its presence and application in directive documents and specialised academic literature (Kubal 2018, pp. 132–136; Chernevko 2020).

A critical aspect of managing the fuel supply for troops is the ability of the Fuel Service Management Bodies (FSMB) to evaluate the capabilities of the Troops' Fuel Supply System (TFSS) to ensure timely and uninterrupted fuel delivery to the troops.

The parameters of the actual process of moving TFSS elements – such as the time required to deploy and withdraw control points (system elements), the composition and capabilities of motor transport, the speed of convoy movement, and the length of routes – are inherently unpredictable.

Thus, when assessing the mobility of alternative options for restructuring the TFSS at the decision-making stage, fuel service management officials may be concerned not only with the temporal parameters of restructuring the system or its elements as a whole but also with the question of whether the system, in its proposed configuration, can partially restructure itself within a predetermined timeframe.

The mobility of the troops' fuel supply system is defined as its ability to adapt its structure promptly in response to changes in the combat situation.

Figure 2 shows the fragment of the OTG TFSS Structure: Fuel Supply Direction between the Joint Command Post (JCP) of the OTG and the Rear Command Post of a Separate Mechanised Brigade (RCP SMB), (option) the number of which is determined by the tasks and the operational structure of the troops in the OTG operation.

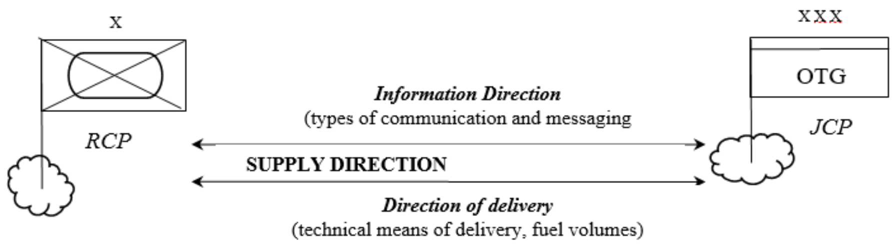

Figure 2. Structure of the Supply Direction in the TFSS between the OTG Joint Command Post (JCP) and the Rear Command Post (RCP) of a *Separate Mechanised Brigade (SMB)* (Option)

Source: own study

In the context of modern combat operations, the tasks undertaken in OTG operations and the time allocated for their completion impose strict temporal constraints. Considering these constraints, FSMB officials carry out fuel supply tasks within the available timeframe ($T_{РОЗП}$) (Chernevko 2020).

Decisions made must be well-founded and avoid contradictions between the available time and the time required by the system (or its elements) to complete the assigned task (T_{B3}).

To achieve successful and timely task execution regarding the restructuring of the system (or its elements), it is advisable during the planning stage to conduct predictive assessments of the temporal parameters of the restructuring process and determine the probability level (degree of reliability) of accomplishing the assigned combat task.

The time required to complete tasks (T_{B3}) for restructuring the system must not exceed the normative time (T_{HOPM}), stipulated by directive documents (e.g., Combat Regulations of Land Forces of the Armed Forces of Ukraine, the Unified Standards for Deploying Command Posts (CP), Armed Forces of Ukraine's doctrines, commander's combat orders, or senior commander's directives). Given that the average task execution time (T_{B3}) is a random variable, the time for its successful completion must be guaranteed to be less than the normative time (T_{HOPM}).

The primary parameters of the actual process of restructuring the TFSS (or its elements) are the duration of sequentially executed tasks and the intervals between them, which are random (non-deterministic) variables following a near-exponential distribution.

Thus, at the decision-making stage, the process of task execution can be characterised by the TFSS mobility indicator – the probability of completing the task within the normative time – expressed as follows (Druzhynin 2020):

$$P_{CB3} = 1 - e^{-\frac{T_{HOPM}}{T_{B3}}} \tag{1}$$

where T_{HOPM} is normative time for task completion.

T_{B3} is average time to complete the set of measures for restructuring the TFSS.

From equation (1), it is evident that the probability of timely task completion depends on the ratio of the normative time to the total time required for the set of measures It is practical to define this ratio as the Coefficient of Timely Task Execution (K_{CB3}) and determine its permissible value. The reliability of task execution can be measured by the probability of its timely completion (Druzhynin 2020; Chernevko 2020).

In practice, the probability of task completion can be set at two levels: at a level of 0.95, representing the principle of "*practical confidence*" in the event's occurrence, and at a level of 0.99, representing the principle of "*practical certainty*" in the event's occurrence.

Let us consider the K_{CB3} threshold at the level of 0.95. In this case, the mobility of the TFSS or specific tasks related to its restructuring can be assessed using the K_{CB3} as follows:

$$K_{CB3} = \frac{T_{HOPM}}{T_{B3}} \tag{2}$$

and the probability of timely task execution (P_{CB3}) as given in equation (1).

In the practical activities of management bodies, there is an approach to assessing the mobility of military systems where the (K_{CB3}) coefficient is compared to unity. It is assumed that if $K_{CB3} > 1$, the available time is sufficient to complete the task (set of measures), whereas if $K_{CB3} \leq 1$, there is a real risk of failing to complete the task within the stipulated timeframe.

However, this approach is not entirely accurate, as it involves comparing random variables with deterministic ones. Such assessments may not always yield objective decisions, as the average total time may be acceptable, but the probability of completing the task within the normative time (due to the probabilistic nature of the process) may be low.

From equation (1), practical interest lies in determining the management parameters defined by the average task execution time (T_{B3}) in equation (2). In this article, (T_{B3}) is considered the time required to complete a set of activities (e.g., task assignment, movement/march, system deployment, system withdrawal).

For practical calculations, (T_{B3}) can be determined using the network planning and management method, where the expected duration of task execution (T_{B3}) is calculated based on three estimates – optimistic (t_O), most likely (t_{HI}), and pessimistic (t_{Π}) – as shown in Table 1 (Kotenko 2001, pp. 1–320):

$$\overline{T}_{B3} = \frac{(t_O + 4t_{HI} + t_{\Pi})}{6} \tag{3}$$

Table 1. Forecasted Temporal Parameters for Different States of OTG TFSS Command Posts (Fragment of an Option)

State of the CP from the OTG TFSS (or its element)		Activities	t_O	t_{HI}	t_{Π}	$\overline{T}_{B3}$	σ_t^2
State "1" (RCP)							
SMB	0-1	Task assignment for CP withdrawal	6	8	10	8	0.44
	1-2	CP withdrawal	30	35	45	35.8	6.25
	2-3	Task assignment for march	5	7	10	7.16	0.69
	3-4	March execution	35	45	55	45	11.1
	4-5	Task assignment for CP deployment	10	15	20	14.1	0.69
	5-6	CP deployment	40	45	55	45.83	6.25

Source: own study

The variance of the expected duration of activities is calculated as follows:

$$\delta^2 = \left[\frac{1}{6}(t_П - t_О)\right]^2 \tag{4}$$

To determine the level of reliability in completing the set of tasks (activities) related to restructuring the TFSS (or its elements), it is necessary to evaluate the average value of the task execution time parameter $T_{В3}$ to enable its subsequent comparison with the deterministic $T_{НОРМ}$.

The probability of timely completion of the task (set of measures) to restructure the Troops' Fuel Supply System (1) with a level of practical certainty of its solution (at the level of P=0.95) can be determined using the following expression:

$$T_{В3} = \frac{T_{норм}}{-ln(1-P_{СВ3})} = \frac{T_{норм}}{-ln(1-0.95)} = \frac{T_{норм}}{-ln(0.05)} \approx \frac{T_{норм}}{3} \tag{5}$$

Using the Coefficient of Timely Task Execution at the 0.95 level ($K_{СВ3}$), the reliability of completing the set of measures (activities) for restructuring the TFSS (or its elements) with a practical confidence level can be assessed under the condition:

$$K_{СВ3} = \frac{T_{НОРМ}}{T_{В3}}\Big|_{P_{СВ3}=0.95}\Big| \approx 3 \tag{6}$$

From this expression, it can be concluded that, to reliably complete the task with a practical confidence level (e.g., relocating the (RCP or individual elements of the TFSS), the average time to complete the set of measures (activities) must be at least three times less than the normative time:

$$3T_{В3} \leq \quad_{НОРМ} \tag{7}$$

The calculation procedure consists of the following steps: identification of restructuring tasks; estimation of optimistic, most likely and pessimistic durations; calculation of expected task durations and variances; determination of the expected total restructuring time; comparison with the normative time; calculation of the timely task execution probability; and selection of the restructuring option that ensures the required confidence level. Using equation (7) it is possible to realistically assess the degree of practical reliability in completing tasks related to restructuring the Troops' Fuel Supply System in Operational-Tactical Grouping's formations and units. The mobility of the entire Troops' Fuel Supply System of the OTG can be evaluated during the planning of structural changes with a practical confidence level of 0.95, based on the minimally acceptable task execution times for the task .

This expression allows for the assumption that, among alternative proposals (developed action options for task resolution) for restructuring the OTG's Troops'

Fuel Supply System, the least favourable option will determine the possibility of task completion with a practical confidence level of at least 0.95.

The composition of input and output data of the proposed model and the algorithm for calculating the mobility of the OTG's Troops' Fuel Supply System (for formations, units), taking into account the level of practical confidence (reliability) in completing tasks (or a set of tasks), enables officials to perform quantitative evaluations of the expected outcomes of decisions made. In the process of preparing a decision, the opportunity arises for the interactive synthesis of action options for restructuring the Troops' Fuel Supply System, alongside enhancing the efficiency of task resolution (execution of activities) by adjusting the temporal parameters of management decisions (e.g., deployment locations of Command Posts, movement routes, number of convoys, task volumes, etc.).

Conclusion

The results of the study confirm the research hypothesis that the integration of probability theory and network planning methods with parameters reflecting structural transformation processes provides a more adequate assessment of the mobility of the Fuel Supply System compared with existing approaches. The obtained results answer the research question by demonstrating that the proposed model enables quantitative evaluation of the probability of timely task execution and improves the reliability of decision-making under dynamic combat conditions.

The developed model can be applied by fuel service command and control bodies to obtain probabilistic assessments of task execution both for individual materiel support units at different command levels and for the Fuel Supply System of the entire Operational-Tactical Grouping. The reliability of the results is supported by the correctness of the selected mathematical framework, consideration of the most significant influencing factors, and positive outcomes obtained during staff practice and training exercises.

The proposed approach improves the effectiveness of managerial decision-making by enabling the selection of rational options based on probabilistic assessment rather than empirical trial-and-error methods within the dynamic work of logistics staff.

At the same time, effective implementation of the model requires appropriate real-time information support of the fuel supply management process (Demianchuk and Levchenko 2023; Horodnov 1987). This necessitates the application of automation tools, updated operational algorithms, and personnel training, including the preparation of input data and maintenance of relevant databases.

The algorithmic structure of the model allows further expansion through the inclusion of additional indicators, ensuring its adaptability to evolving logistics systems and prospective automated logistics management developments. Future research may focus on integrating the model into automated decision-support systems and expanding the set of influencing factors to improve accuracy under complex operational conditions.

The developed model may therefore be considered a practical decision-support tool applicable within various levels of materiel support management in an Operational-Tactical Grouping.

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