OPTIMIZING AN INTEGRATED MAINTENANCE SYSTEM FOR VEHICLES

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Configuring military structures, regardless of their specialization, to act in military operations requires a "projection" adaptable to the modern combat environment, as well as to the challenges posed by adapting new technologies to the military environment and even the use of artificial intelligence. Flexibility in approaching calculation methods, mathematical modeling and optimization of the projections of maintenance structures and microstructures will lead to obtaining optimal configurations both as military structures and especially as specific activities.

These can be calculated, modeled and optimized so that their configuration responds to both the missions and objectives as well as the principles of employing military forces in military operations.

Keywords: maintenance; system; design; configuration; optimization;

INTRODUCTION

One of the essential factors in achieving success in a military action or operation is the existence and capacity of a logistics system to ensure the needs of military forces, both those in contact and those in other situations. Regarding the logistical assurance of the military forces in contact, an important element is the existence, capacity and adaptability of the maintenance system of the military equipment used so that the military forces always have a high technical condition coefficient or high level of readiness and that allows them to fulfill the missions received.

The combat power of a military force derives primarily from its combat potential. The combat potential of a force, according to specialized military literature (Buța, Alexandrescu, Dumitru, 2004, p. 10), contains at least two components: the designed combat potential and the available combat potential.

Projected combat potential (du Bois, Hughes jr., Low, 1998, p. 78) refers to the latent capability of a force to achieve useful results in combat, organized, trained, equipped, supported, motivated, and led appropriately for the designated force against a planned threat. Basically, it is that state of physical existence of a military structure resulting from the way of organization, equipping with military equipment and systems, training and preparation for combat and used according to the principles and tactics established by military doctrine.

In the projected combat potential, the logistics support component that includes the maintenance system of military equipment, through its optimal design and configuration, can maximize or minimize the projectd combat potential of the military structure.

Available combat potential (Ib.) is the latent ability of a force to achieve optimal results in combat through the existence of organization, training, equipment, support, *including logistical support*, motivation and leadership. The available combat potential of a tactical-level structure represents that initial state of the military structure, influenced by *factors and variables*from the battlespace, andonce used in combat can produce planned/expected effects against an enemy.

In order to carry out an analysis, from a mathematical point of view, of the design and configuration of a flexible and adaptable maintenance system that has an available potential necessary for the repair of military vehicles, we will introduce and *integrate factors, variables and constants* that influence the dynamics of the vehicle maintenance system.

The projection, configuration and optimization of an integrated vehicle maintenance system starts from the fulfillment, at least at the theoretical level, of a ***minimum system balance condition***, namely: *the number of operational vehicles at a given moment must be equal to the difference between the number of vehicles with which the military operation begins and the difference between the numbers of destroyed vehicles removed from combat/action and repaired vehicles.* This minimum equilibrium condition, analyzed, broken down into variables and constants and subsequently their optimization, will provide us with the necessary information to configure an integrated vehicle maintenance system. The integration of these variables and constants will be done in accordance with the principles of the use of forces in military operations.

Mathematically, the expression that can ensure the balance equilibriumof the maintenance system can be formulated as follows:

$$N(t+1) = N(t) - (R_l - R_r)$$

where,

- **N(t)** - Number of operational vehicles at the start of combat t (first day of combat)
- **N(t+1)** - Number of operational vehicles after first day of ccombat;
- **R_l** - Rate of vehicles taken out of battle**;**
- **Rr** - Rate of repairable vehicles.

For the analysis and development of the mathematical expression that defines the equilibrium condition of the integrated vehicle maintenance system, we establish essential factors, variables and constants, as follows:

- **I(t)**: The number of damaged, immobilized, but repairable vehicles at time t. This number depends on the maximum capacity of the system to repair vehicles in a day;
- **C**: The maximum capacity of the maintenance system to repair vehicles per day.
- **r**: Daily vehicle loss coefficient. It is assigned based on historical data or even by military planners depending on the intensity of military actions/ operations. ($0.01 < \mathbf{r} < 0.9$);
- **P**: The irrecoverable/irreparable loss coefficient, is the number of damaged vehicles that are irreparably destroyed. $0<P<1$. (we assign it according to the type of military action, 0.3 for defense and 0.9 for offensive as an example).
- **R_l**- Rate of vehicles taken out of battle

The rate at which vehicles are damaged or destroyed in a day depends on the total number of operational vehicles at the beginning of that day. The more vehicles there are in the battle, the higher the probability of suffering losses.

Mathematically, the expression is:

$$R_l = r \cdot N(t),$$

where:

- R_l - is the number of vehicles taken out of battle in one day;
- **r** - is a daily loss coefficient (eg: 0.01-0.15, i.e. 1-15% of the defense fleet);
- **N(t)** - is the number of operational vehicles at the start of the day/military action.
- R_i- Rate of irreparable losses

Due to the military actions in the battle space from the total number of vehicles taken out of battle R_l**,** a part **P** is irretrievably destroyed.

$$R_i = P \cdot R_l = P \cdot r \cdot N(t)$$

- R_r - Rate of repairable vehicles

This is where the ability of the vehicle maintenance system to repair vehicles based on its organization, equipment and optimal operation comes into play. The number of vehicles that can be repaired is the difference between those taken out of battle and those irreparably destroyed, respectively (1–P). Entering the data into a mathematical expression theresult is:

$$R_r = R_l - R_i$$

Substituting the terms, we get:

$$R_r = r \cdot N(t) - P \cdot r \cdot N(t)$$

To simplify the calculations, we initially consider only one type of damage.

R_{rep} **-** Repair rate of the integrated maintenance system vehicles - SMAI

This is the constant capacity of our system, **C**. The actual repair capacity at any given time is limited by either the maximum repair capacity of the SMIA or the number of damaged vehicles available for repair.

$$R_{rep} = \min(C, I(t)),$$

where **I(t)** is the difference between retired and repairable vehicles and the repairability of the integrated vehicle maintenance system. Starting from the moment t+1, the number of vehicles that remain unrepaired from the previous day is added to the number of damaged/immobilized vehicles **I(t).** They cannot be repaired due to the limitation imposed by the system's daily repair capacity. These are repairable, damaged/immobilized vehicles already in the system/on hold.

Basically, it is the damaged/immobilized vehicles that exceed the repair capacity of SMIA and for which an action must be initiated. For the first day of military action **I(t)** is equal to $\mathbf{R_r}$.

We will use mathematical modeling and optimization to evaluate the importance of each variable, constant and factor that can reflect the equilibrium condition of the integrated vehicle maintenance system.

In general terms, *"the model represents an explicit interpretation of the understanding of a situation or at least an idea about this situation. It can be expressed mathematically, through symbols or words, the essential being the description of the entities and the relationships between them. The model can be descriptive or illustrative, but above all it must be useful."* (Dulău, Oltean, 2008, p. 9).

Optimization represents *"a set of methods and techniques that determine finding the best solution (optimal solution) for a given problem."* (Buneci, 2008, p. 7).

MATHEMATICAL RELATION FOR SYSTEM DYNAMICS

After defining the variables and constants regarding the balance of the system we can formulate the mathematical relationship that describes the transformation/modification of the fleet of operational vehicles from one day to the next:

$$\mathbf{N(t+1) = N(t) + R_{rep} - R_I}$$

or, extended:

$$\mathbf{N(t+1) = N(t) + \min(C, I(t)) - r \cdot N(t)}$$

Substituting some terms, we obtain a form in which we have the variables stated above:

$$\mathbf{N(t+1) = N(t) - R_i + (R_{rep} - R_r)}$$

Eliminating the brackets, we have the final mathematical relationship:

$$\mathbf{N(t+1) = N(t) - R_i + R_{rep} - R_r}$$

Explained, the mathematical model shows that for the next day of combat the number of operational vehicles of the fleet is equal to the difference between the number of vehicles with which the action or military operation began, from which we subtract the number of irreparably destroyed vehicles and add the number of vehicles that can be repaired from the number of existing repairable vehicles.

And, to keep track of damaged/immobilized vehicles that are repairable, the mathematical expression results:

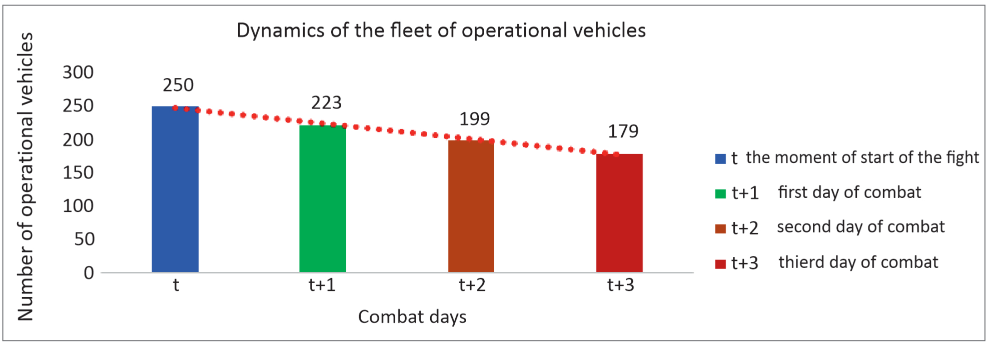
$$\mathbf{I(t+1) = R_r(t) - C + I(t)}$$

For the first day of military actions I(t) is equal to Rr, respectively the number of damaged/immobilized and repairable vehicles existing at the end of the day.

Next, we will enter data into the mathematical relationship to observe and analyze the obtained results and calculate, for a tactical level defense operation, for the first three days of combat increasing for each iteration the repair capacity of the integrated vehicle maintenance system by 10 vehicles per day.

The first calculation:

- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 10 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30).



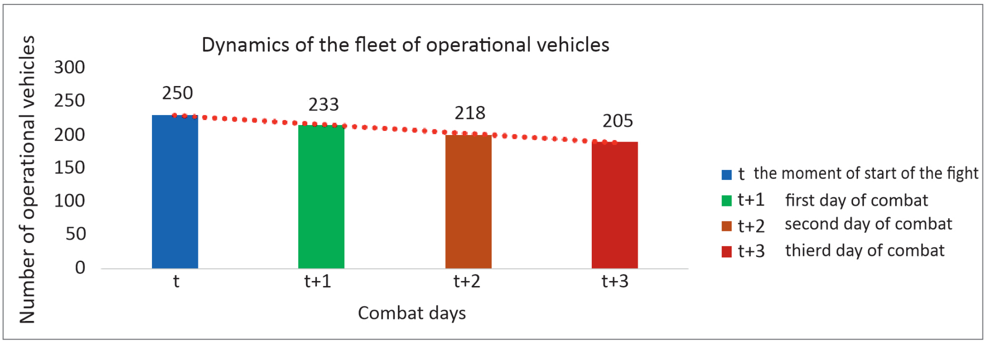
Graph 1: Calculation of fleet dynamics for the first three days of actions with the repair capacity of 10 vehicles per day (author's conception)

The second calculation:

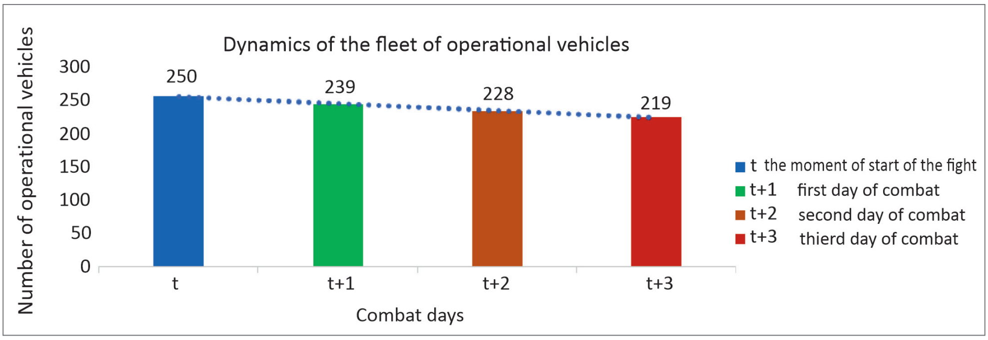
- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 20 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30).

The second calculation:

- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 30 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30).



Graph 2: Calculation of fleet dynamics for the first three days of actions with the repair capacity of 20 vehicles per day (author's conception)



Graph 3: Calculation of fleet dynamics for the first three days of actions with the repair capacity of 30 vehicles per day (author's conception)

In performing the calculations in the three graphs above we have increased the repair capacity of the integrated vehicle maintenance system from 10 vehicles per day to 30 vehicles per day to analyze how this affects the balance of the system by increasing or decreasing the number of operational vehicles in the fleet. It can be seen that with the increase in the repair capacity, the decrease in the number of vehicles in the fleet is considerably reduced, which results in more operational vehicles and implicitly a higher level of the combat capability of the military structure.

Model evaluation

This mathematical model, even in its empirical form, allows us to make important theoretical estimates, as follows:

❖ If the value of $\mathbf{R_{rep}} < \mathbf{R_r}$, the number of operational vehicles **N(t)** will decrease drastically. A *"pending repairable vehicle lot"* will be created, in which damaged vehicles await repair, they can only be repaired within the limit of the daily repair capacity, which will lead to a constant and rapid decrease in combat capacity. It can be seen in graph no. 1 that after three days of military actions the number of vehicles in the fleet is 179, a small number for the military structure to achieve the planned results. In this situation, the number of damaged/immobilized vehicles **I(t)** increases rapidly, which leads to an imbalance of the maintenance system and implicitly on the available potential of the military structure;

❖ If the value $R_{rep}>R_r$, the number of operational vehicles **N(t)** of the fleet will have an acceptable decrease for the actions of the military structure to be successful. At the same time the number of damaged/immobilized vehicles **I(t)** will decrease due to the high repair capacity and implicitly all of them will be able to be repaired daily. In this situation the maintenance system is able to cope with the pace of the conflict.

❖ We can ensure the balance of the integrated maintenance system ofvehicles by modeling the repair capacity of the maintenance system, respectively increasing or decreasing it. It is useful to maintain the reaction capacity greater than the repair requirement to be able to have an operational reserve of vehicle repairs, just as there are reserves of forces and means for a military action or operation.

❖ Carefully analyzing this mathematical model, it is found that in order to achieve the balance of the integrated vehicle maintenance system, so that at the end of the day the military structure has the same number of operational vehicles or a minimum number that ensures a minimum level of available potential and combat capacity, *it is necessary to introduce a new coefficient* into the mathematical relationship that will represent a stock or a reserve of vehicles to replace irreparably destroyed vehicles.

The SMIA model will be designed/configured and optimized to ensure that, in most scenarios, **the repair capacity/repair rate R_{rep} is greater than or at least equal to the repairable vehicle rate R_r**, thus maintaining an optimal number of operational vehicles necessary to continue military action as planned.

In order to get closer to the reality in the battle space, we will introduce into the mathematical model a **replacement coefficient** of irreparably destroyed vehicles, coefficient hereafter referred to as **S**, a stock or a reserve located at an optimal distance so that they can be introduced into the battle in a timely manner. Practically, the integrated vehicle maintenance system of the combat forces will be integrated into the logistics lines from the upper echelons. These vehicles can be new or repaired within the maintenance systems of the logistics lines of the upper echelons.

MATHEMATICAL MODEL WITH REPLACEMENT COEFFICIENT

We will keep the irrecoverable loss coefficient **P** defined at the beginning and add the new coefficient **S** for the replacement of damaged/irreparably destroyed vehicles.

We define the terms of the mathematical model:

- **N(t)**: Numbărof operational vehicles;
- **r**: Daily vehicle loss ratio;
- **P**: The irrecoverable loss coefficient (a portion of damaged vehicles)
- **C**: Daily repair capacityofSMIA.
- **S**: The coefficient of replacement of irreparably damaged/destroyed vehicles (from stock or reserve) representing the ability to reintroduce a number of operational vehicles into battle per day.

Extended mathematic relationship

The dynamics of the operational vehicles number of the fleet from one day to another N(t+1) will be influenced by three factors:

- Irrecoverable losses: Damaged/completely destroyed vehicles, which permanently reduce the fleet;
- Repairs: Vehicles repaired by SMIA and returned to combat;
- Replacements: Operational vehicles will be brought from stock or reserve and used to compensate for losses;

Entering the variables and factors into our model, we will have:

N(t+1) = N(t) − (Irrecoverable losses) + (repaired vehicles) + (replaced vehicles).

And, in mathematical expression:

$$N(t+1) = N(t) - P \cdot r \cdot N(t) + C + S$$

where,

- **P·r·N(t)** represents the number of vehicles irretrievably destroyed that day;
- **C**represent the vehicles repaired by SMIA and put back into battle;
- **S**represents the number of vehicles in stock or in reserve that replace irremediably destroyed vehicles.

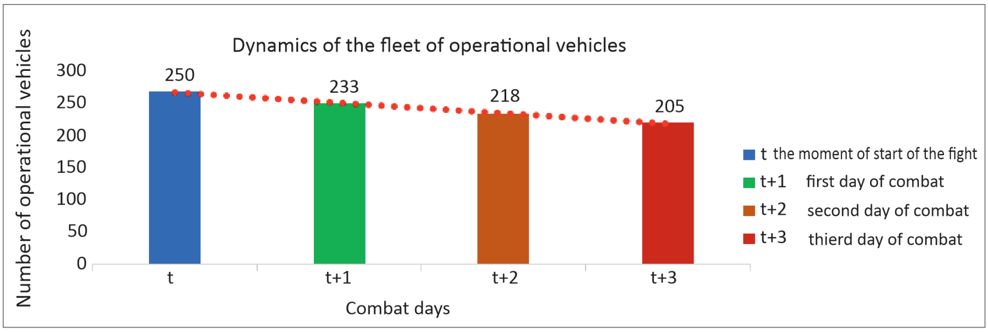
Practical example with replacement coefficient S

Let's say that there are a number of vehicles available in a stock or reserve fully repaired and tested at the level of the higher lines or in nearby, and a number of 10 vehicles per day can be sent to quickly replace breakdowns. The values of **S** can be assigned as a function of the number of vehicles existing at the time.

We will repeat the calculation, using the same inputs, to which we add the replacement coefficient **S**. We will calculate for three iterations increasing the repair capacity by 10 vehicles for each of them and adding the replacement coefficient **S**.

The first calculation:

- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 10 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30).
- The replacement coefficient **S:** 10 vehicles per day.



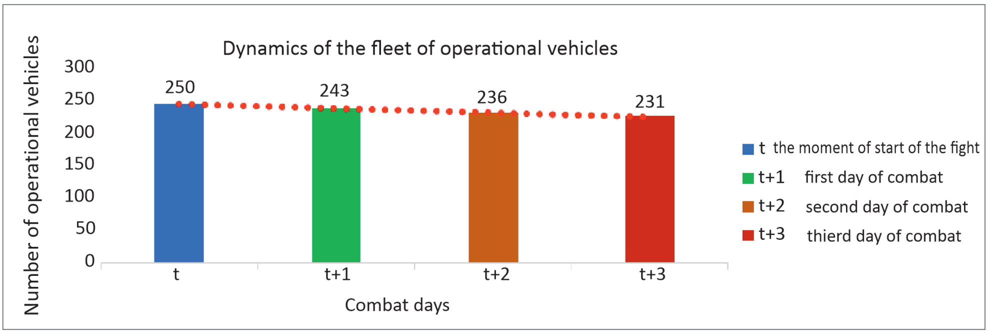
Graph 4: Calculation of fleet dynamics for the first three days of actions with the ***S*** *coefficient and the repair capacity of 10 vehicles per day (author's conception)*

The second calculation:

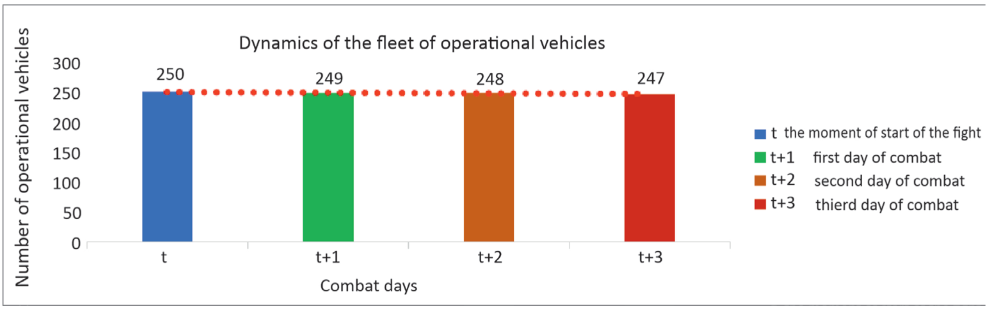
- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 20 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30).
- The replacement coefficient **S:** 10 vehicles per day

The third calculation:

- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 30 vehicle/day;
- Daily vehicle loss ratio **r**: 15% (0.15);
- The irrecoverable loss coefficient **P**: 30% (0.30);
- The replacement coefficient **S:** 10 vehicles per day.



Graph 5: Calculation of fleet dynamics for the first three days of actions with the coefficient S and the repair capacity of 20 vehicles per day (author's conception)



Graph 6: Calculation of fleet dynamics for the first three days of actions with the coefficient S and the repair capacity of 30 vehicles per day ((author's conception)

EVALUATION OF THE MODEL

In this form the mathematical model shows us that the use of a combined strategy, in which *the repairs carried out by the integrated vehicle maintenance system are supplemented with a stock or a reserve* to replace irreparably damaged/destroyed vehicles, has an amplifying effect on the combat capability of the military structure. In this case, with the daily or periodic replacement, depending on the situation in the battle space, of a stock or reserves of vehicles, the fleet can maintain a certain level of operational capacity, which leads to the maintenance of an available combat power potential.

We can observe that if we set the repair capacity to 10 vehicles per day and replace the irreparably damaged/destroyed vehicles with a stock or reserve, the number of operational vehicles of the fleet can be kept high only for the first two days of combat, i.e. above 85%. By configuring the repair capacity from 20 to 30 vehicles per day and replacing irreparably damaged/destroyed vehicles with 10 per day we can see that the number of operational vehicles in the fleet remains high at 90% for 25 days. Basically, the optimization of the repair capacity and the replacement ratio will give the optimal configuration of the integrated maintenance system of vehicles.

This optimized form of the mathematical model can give military planners options for designing, configuring, and deploying an integrated vehicle maintenance system to meet the vehicle repair needs of tactical-level military structures in military operations.

This simple exercise demonstrates that under the given conditions, i.e. a repair capacity of 30 vehicles per day and a replacement stock or reserve of 10 vehicles per day, SMIA meets the objective of maintaining a high level of vehicle fleet above 85%.

The model also helps us identify weak points. What happens if the loss rate **r** increases to 30%? Or if the sunk loss coefficient **P** increases to 50% due to the lack of rapid evacuation capability? The model allows us to simulate these scenarios and see how we should adjust the repair capacity C and the stock or reserve of vehicles S to compensate for irreparable losses.

MATHEMATICAL MODEL OF OPTIMIZATION

To translate the data into an optimization equation, we need to define an **objective** and the **variables** we can adjust. The key is to find a dynamic balance or resource optimization relationship.

We will use an equation *that balances loss rate with logistics capacity*. We can express it as a balance between the "adverse" part, i.e. the losses, and the "own side part", i.e. the repair capacity of the SMIA.

Our objective is to keep the operational fleet as close as possible to the initial level, N(0). We can achieve this goal if *the sum of our logistics capabilities equals or exceeds the sum of our losses.*

Textual terms of the equilibrium equation are:

Logistics capacity (own side) ≥ Total losses (counterparty).

Repair capacity + replacement capacity ≥ repairable vehicles
+ irreparably destroyed vehicles

Translated into mathematically, the equation becomes:

$$\mathbf{C + S \geq R_l + R_i}$$

Substituting the terms, we get:

$$\mathbf{C + S \geq r \cdot N(t) + P \cdot r \cdot N(t)}$$

This equation allows us to model and optimize both sides.

We will analyze each part of the equation to be able to model and optimize it by adjusting its terms.

Left side of the equation - Optimizing the repair capacity of SMIA

Here, we optimize our resources. **The variables** we can control are:

- **C** - **repair capacity**: We can increase this value by allocating additional technical staff, designing, configuring and equipping mobile workshops and specific necessary equipment;
- **S** - **replacement capacity**: We can increase this coefficient by creating a stock or a larger reserve of new or repaired vehicles and ready to be sent into battle at the right time.

The Right Side of the Equation - Threat Modeling

Here, we model the threat using estimates from historical data and tactical assessments. Variables are **influenced by the enemy**, but we can estimate and counter them:

- **r** - **Daily vehicle loss ratio**: it varies according to the type of conflict. We can estimate it for different scenarios (low, medium or high intensity);
- **P** - **the irrecoverable loss coefficient**: this value depends on the recovery capacity from the field. We can reduce it by increasing the rapid evacuation capacity (Line I), before the damaged technique is completely destroyed;
- **N(t)** - **Number of operational vehicles**: this is the dependent variable, which we track to see how it evolves over time and optimize it.

Using the above equation, we can find, at least on a theoretical level, answers to the following questions, such as:

- How much additional technical staff, for repair capacity C, do we need to keep the fleet stable, if the loss rate is, for example, 25% (r = 0.25) and the unrecoverable losses are 50% (P = 0.5)?
- How many vehicles in stock or reserve, **S**, do we need to cover a peak in losses if our repair capacity **C** is exceeded?

The system balance equation helps us dynamically to evaluate the integrated vehicle maintenance system and make informed decisions to allocate existing resources where they are most needed and at the right time.

We will continue with the development of the mathematical model by introducing and integrating *a maintenance response factor*, a factor that has a vital role because the speed of decision and intervention has a direct impact on the number of recoverable vehicles and the efficiency of repairs.

We set **M** to represent *the maintenance response factor* in our model. This coefficient will be a value between 0 and 1 and will directly affect the repair capacity. The maintenance response factor is defined by the available potential of the SMIA and refers to that state of organization and configuration of specific maintenance microstructures, the provision of workshops, sections and maintenance stands, staffed with the minimum necessary technical staff and the existence of a command and control system capable of planning and coordinating the evacuation and repair of vehicles.

Analysis of the role of the reaction coefficient – M

Definition: **M** represents the efficiency with which the SMIA system detects a breakdown, assigns a team and begins the repair or evacuation process.

- **M=1**: Optimal reaction. Teams are dispatched immediately and the reaction time is minimal, the ideal situation. The actual repair capacity of SMIA is close to its technical maximum capacity;
- **M<1**: Weak, delayed reaction. Delays can be caused by understaffing, slow decisions, parts shortages, poor communications or field access difficulties. The actual repair capacity is greatly reduced, even though the system has a large number of mechanics and workshops.

Impact on repairing capacity: A quick reaction increases the chances of recovering damaged vehicles before they are completely destroyed by the enemy. A slow reaction, a small **M**, increases the probability that a recoverable damage will become an unrecoverable loss.

Development of the mathematical formula with the reaction coefficient

We will integrate the new coefficient **M** into the extended model, focusing on how it affects our repair capacity **C**.

$$N(t+1) = N(t) + M \cdot C - r \cdot N(t).$$

Interpretation of the mathematical formula:

- Repair capacity: The expression **M·C** shows that the actual repair capacity of the SMIA system is not the maximum capacity **C**, but the maximum capacity multiplied by the reaction factor **M**. Thus, if the system can repair 30 vehicles per day, **C**=30, but has a reaction factor of only 0.5, **M**=0.5, the actual repair capacity is only 15 vehicles per day.
- Optimization: This relationship highlights an essential direction: to maximize efficiency, it is not enough to just increase the number of workshops and mechanics in the repair capacity **C**. We also need to invest in commandand control systems, communications and rapid decisions to increase the **M**-reaction factor.
- Maintenance reactionfactor **M** directly affects responsiveness by increasing or decreasing the number of repairs based on the battle conditions in the battlespace. As an example, **M** also reflects the fact that a slow decision delays evacuation movement, the start of work, and, implicitly, reduces the total number of repairs completed in a given period of time, which affects the combat power of the forces.

The mathematical formula with the maintenance reaction factor M and the replacement stock or reserve S

Integrating the maintenance reaction coefficient **M** to the existing model we will obtain the mathematical formula:

$$N(t+1) = N(t) + M \cdot C - r \cdot N(t) + S$$

The optimization condition:

In order for the operational fleet not to diminish, we need to ensure that the term of growth through repair and replacement is at least equal to the term of loss/ removal from combat.

$$M \cdot C + S \geq r \cdot N(t)$$

This equation allows us to ask an essential question: *"What is the minimum value of M that we need to keep the fleet stable taking into consideration our maximum capabilities?"*

We can express this mathematically as a critical equilibrium condition:

$$M_{equilibrium} = C \cdot r \cdot N(t)$$

If our actual M value is greater than $M_{equilibrium}$, the fleet increases. If it is less, the fleet decreases.

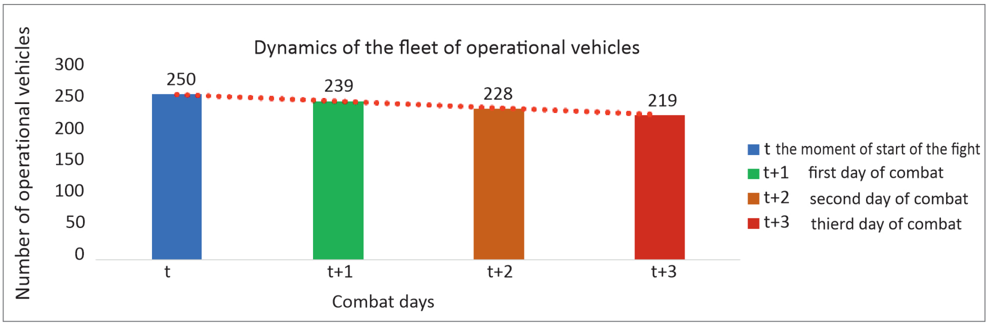
Applying the model to a simulation scenario

Input data:

- Total initial fleet N(t): 250 vehicles;
- Daily repair capacity of SMIA, **C**: 20 vehicles/day;
- Daily vehicle loss ratio **r** = 10% (0.1).
- The irrecoverable loss coefficient **P**: 30% (0.30);
- The maintenance reaction factor, M = 0.5, due to slow communication systems, the existence of a shortage of parts, the insufficiency of means of transport and evacuation, the unavailability of technical personnel at the time, etc.;
- The replacement coefficient **S:** 5 vehicles per day.

After entering the input data into the mathematical formula we obtain:

- Total daily losses (taken out of battle): $R_l = r \cdot N(t) = 0.1 \cdot 250 = 25$ vehicles taken out of battle;
- Irreparable losses: $R_i P = r \cdot N(t) = 0.3 \cdot 0.1 \cdot 250 = 7{,}5 \approx 8$ irreparably destroyed vehicles;
- Number of reparable vehicles: $R_l - R_i = r \cdot N(t) - P \cdot r \cdot N(t) = 17{,}5 \approx 17$ repairable vehicles;
- Actual repair capacity: $M \cdot C = 0.7 \cdot 20 = 14$ repaired vehicles;
- Operational fleet at the end of day 1: N(t+1) = 239 vehicles;
- Operational fleet at the end of day 2: N(t+2) = 228 vehicles;
- Operational fleet at the end of day 3: N(t+3) = 219 vehicles.

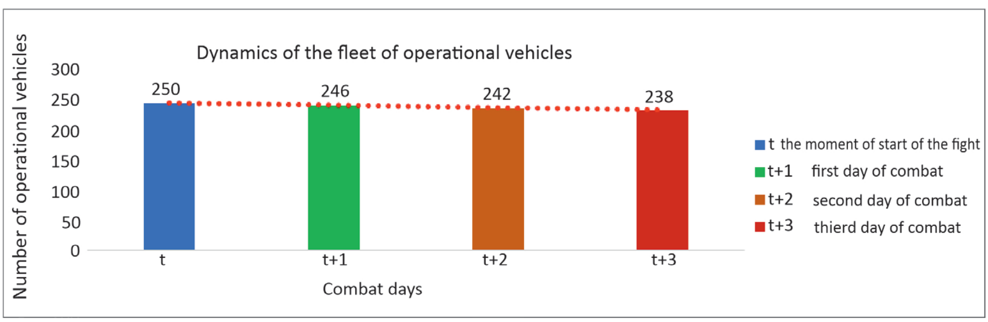


Graph 7: Calculation for the first 3 days with the maintenance reaction factor and replacement stock (author's conception)

Simulation evaluation with maintenance reaction factor and replacement stock

The maintenance reaction factor, after integration into the mathematical model and simulation, reduces the number of operational vehicles in the fleet because the conditions that led to the assignment of the value of 0.5 are real and existing in the battlespace and directly influence the repairability of the SMIA. Analyzing the results for the three days of combat in graph no. 7, we can see that even with the maintenance factor of 0.5, the number of vehicles is above the minimum level of 85%, a minimum level necessary to maintain a high available potential of the military forces and implicitly to continue the missions received.

To observe the impact of the maintenance reaction factor **M** we will repeat the calculation with the same input data minus its value which we will increase to M = 0.9 which means that SMIA has an optimal configuration of workshops, sections, personnel and equipment as well as the functional command and control system with a functional observation, evacuation and repair system that ensures the detection/observation, evacuation and rapid repair of a motor vehicle.



Graph 8: Calculation for the first 3 days with increased maintenance reaction factor and replacement stock (author's conception)

Doing the calculation with the value of M = 0.9, for three days of combat, we can observe, in graph no. 8, that the number of operational vehicles is higher than if the value of the maintenance factor **M** was **M = 0.5**. This demonstrates that the maintenance reaction factor has a major impact on the dynamics of repaired vehicles in a combat day and implicitly on the repair capacity of SMIA.

In order to have a reaction factor **M** as high as possible and implicitly increase the number of vehicle repairs, peacetime investment in command and control is as important as investment in workshops and specialized technical personnel.

CONCLUSIONS

The success of a military structure planned to carry out military actions or operations is determined, among many others, by the ability of the logistics system to ensure the needs of these forces, including the existence of a vehicle maintenance system. This integrated vehicle maintenance system can be designed and configured by using mathematical modeling and optimization to obtain and use the optimal maintenance structure with the least resources. Also, this maintenance system must be able to integrate and adapt the factors, variables and coefficients that influence its operation, in our case the repair capacity, the stock or reserve of vehicles and the maintenance response factor.

The integration of the factors, variables and coefficients that influence or have an impact on the actions in the battle space in a mathematical model and their optimization generates directions for the design and configuration of an integrated maintenance system of vehicles to meet the equilibrium condition, respectively to be able to ensure the repair needs of the military forces in military operations.

Through the given examples of the use of mathematical modeling and optimization, we observe how the equilibrium condition of the integrated vehicle maintenance system, optimized with the maintenance reaction factor and the replacement coefficient of irreparably destroyed vehicles, helps us to quickly evaluate the performance of the logistics system and especially its component elements that have a direct impact on maintaining the number of operational vehicles of the vehicle fleet. These models, developed and optimized, allow military planners and decision-makers to identify where to allocate additional resources (for example, increasing the repair capacity for certain periods of time of the conduct of military operations, allocating more vehicles as a stock or replacement reserve and at time intervals established by scientific calculations and not by estimates, creating a reserve of maintenance resources, etc.) to keep the available potential and combat power of the forces at a minimum level that ensures their success.

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