SAFETY ENGINEERING OF ANTHROPOGENIC OBJECTS

DEPENDABILITY FOR THE MILITARY VEHICLES IN THE SAFETY ASPECTS

Kamil Przybysz
Military University of Aviation

Abstract
The article discusses the essence of dependability for the military vehicles, the knowledge of which ensures success in the mission and provides an appropriate level of the crew safety while executing combat tasks. The paper also includes an analysis of factors affecting the dependability for the military vehicles.
Key words: military vehicle, availability, reliability

INTRODUCTION

One of the directions of research and development with regard to modern military vehicles should be striving to shape an adequate level of dependability for military vehicles, as one of the main factors determining the success in the mission and maintaining the appropriate safety of the crew, in the course of the performance of combat tasks. By estimated the level of dependability, we can determine the level of risk in combat tasks related to the reliability of military vehicles, the participation of which in most combat missions is significant.

Dependability of vehicles is an essential element affecting the combat ability of any military unit, without regard for its nature, purpose and assigned main task. The essential equipment of ground troops, which determines the performance of the main task, are combat vehicles or other equipment mounted on platforms that constitute military vehicles. Taking into account only the essential military armament and equipment (UiSW), it can be wrongly assumed that only in ground troops, dependability of vehicles has a significant impact on combat capability. However, it should be borne in mind that all military units of the armed forces have a logistical support of troops, the main element of which is also military vehicles. As part of the logistical support, vehicles perform many functions in individual subsystems, a complex system, which is military logistics.

According to the research procedures [1,p.11], dependability is defined as “Measuring the degree to which an element is capable of operating and to perform a specific task, determined at the beginning of this task, under conditions where this task can be performed at an unknown (randomly selected) moment of time.”

These requirements are determined by the nature of modern combat operations and the requirements imposed on NATO's armed forces. NATO forces have been divided into forces capable of being displaced and forces on the ground. Specific categories of combat readiness have been assigned to individual military units, which indicate specific requirements for completing essential military armaments and equipment and personal condition. However, the most important requirement for each category of preparedness is the time to be ready to take action, i.e. the time it takes to prepare a unit for use for its war designation. Achieving readiness to take action is a random event, difficult to predict, initiated by a crisis or war.

Taking into account the above conditions, dependability will be shaped by two main factors listed in [11, p.21] i.e.:

- the state of technical worthiness at any time, referred to as temporary or average availability/technical readiness and expressed as a probability that the facility is technically suitable to act,
- the state of technical suitability during the task undertaken, referred to as reliability and expressed as a reliability indicator as a probability of completing the task undertaken.

Over the past years, dependability has been developed in the Polish Armed Forces, focusing mainly on first factors mentioned, i.e.. maintaining high technical readiness of vehicles using a planned-preventive operating system. Components detached from the Polish Armed Forces, as part of allied commitments in NATO, have made us aware of the importance of the second factor regarding maintaining task worthiness. Vehicles in the conflict area must be subject to high equipment reliability to ensure the required level of security of soldiers. In addition, it has been pointed out that there are problems with the rapid restoration of task worthiness in the event of its loss.

These problems are related to the undeveloped system of rapid ad hoc repairs in our army on the battlefield, directly in the area of action, commonly used by the US army and other NATO armies, abbreviated as BDAR (Battle Damage Assessment and Repair) - assessment and repair of combat damage (a term used by the U.S. Army) or BDR (Battle Damage Repair) - repair of combat damage (a term used by most NATO countries). The more general term introduced by STANAG 2418 is the concept, determined in abbreviated form as ER (Expedient Repair), is an improvised repair, a concept used in NATO, which defines an improvised and often temporary repair, in order to rapidly restore the technical efficiency of the equipment at the site of damage, for the purpose of task performance [12, 13].

It is not difficult to see that the basis for the implementation of the above systems in the Polish Army is the execution of independent tests for individual types and brands of vehicles to ensure an adequate level of efficiency of the functioning of these systems repair. These reliability studies are not only an essential element in estimating dependability, but also needed to maintain the required level, which is determined by the requirements of safety and the modern battlefield.

ROLE AND IMPORTANCE OF REALIABITY STUDIES IN THE OPERATION OF MILITARY VEHICLES

Reliability studies play a major role in operation, especially if the test facility are vehicles that are operated under variable external conditions. A particular group is military vehicles, which are often used in conditions which are significantly different from those typical of civilian vehicles. This is due both to the variety of terrain and weather conditions in which vehicles have to carry out their tasks and the different skills of driving military vehicles by drivers who change during use.

The frequency of damage may also increase due to a lack of adjustment of the scope and quality of the service performed to the current technical condition of the vehicle, or their omission or execution not in time due to the lack of spare parts or long waiting period , which is a common occurrence in the military. Many problems could be avoided knowing the likelihood of these damage occurring.

Damage to multi-element systems, and such a system creates a motor vehicle, they are among the very complex damage over time. They can be divided generally into:

- sudden damage,
- gradual damage.

In case of sudden damage, the intensity of damage is constant over time, does not take into account aging processes, that is, the consumption of operational potential is not taken into account. The mileage of the car until the next damage can then be expressed in the form of exponential distribution with the following formula:

$$R_n(t) = e^{-\lambda t} = exp(-\lambda \cdot t) \quad (1)$$

where:

$R_n(t)$ – reliability of components with sudden damage,

λ – distribution parameter – the intensity of the damage.

For gradual damage, the intensity of the damage varies over time due to a change in the value of the operating parameters as a result of aging. For this type of damage, the course of the components between the damage is described by various distributions: normal, logarithmnormal, Weibull and others presented in the works [2,3,4]. In general, reliability features can be described as a formula:

$$R_s(t) = exp(-\int_0^t \lambda(x)dx) \quad (2)$$

where:

$R_s(t)$ – reliability of components with gradual damage.

Taking into account the motor vehicle as a complex multi-element system, the overall form of the reliability equation may be represented as follows:

$$R(t) = R_n(t) \cdot R_s(t) = exp(-\lambda \cdot t) \cdot exp(-\int_0^t \lambda(x)dx) \quad (3)$$

where:

$R(t)$ – probability of proper operation, the probability that until the time of t there will be neither sudden nor gradual damage to the car.

Reliability tests allow you to determine the reliability function and determine the weak links of the object, then we can rationally plan the operating system, or the level of spare parts maintained. Achieving these objectives increases the efficiency of the operating system, thereby increasing facility readiness and operational safety.

The availability of a technical object is a fundamental feature which shapes its operational quality. The availability of technical facilities operating on the battlefield acquires particular significance, which translates directly into success in the combat mission and the safety of soldiers. The importance of military technical facility availability was underlined in the work [6], where it was found:

„During a period of armed conflict (war), facilities should achieve high availability and low damage. It is also important that new facilities achieve low damage in the shortest possible time since launch, which requires the elimination of errors and damage already in the production phase. Knowledge of the so-called errors and damage to production is therefore a key problem for the readiness of weapons systems in a possible armed conflict”.

By analyzing the above quote, we realize the importance of reliability testing of objects in the first phase of operation, where the intensity of damage is quite high, that is, the high risk of damage, which is graphically illustrated in figure 1.1.

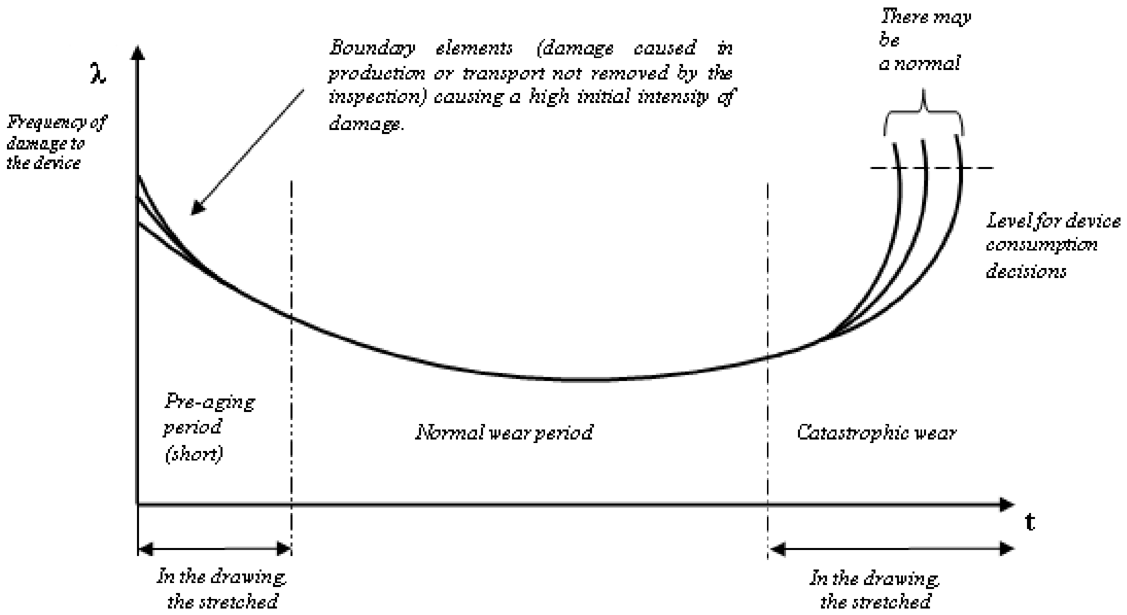

Fig. 1.1. Typical risk function λ(t) [5]

This period has been called in the literature a period of reaching technical maturity, during which the object comes from an understated level of readiness to the nominal, achieved in the second phase of operation. The readiness of the facility in the third phase of operation decreases rapidly, during a period of monotonic increase in the risk function λ(t), where there is catastrophic wear and further operation of the facility ceases to be justified.

This function, labelled as λ(t), determines which part of the objects that have survived functional in the range (0,t) likely become nonfunctional in the range (t,t+dt). Some of these objects are determined by λ(t)dt. Risk function shape analysis has become an important part of evaluating the reliability properties of an object. Knowing the mileage of this function in each time frame, you can predict and plan the operation of objects quite precisely in all stages of operation.

Knowledge of reliability functions is one of the prerequisites for proper assessment of the dependability of a technical facility, allowing you to determine a forecast of the adequacy of the facility's resources and the ability to maintain technical efficiency during the task accomplishment.

Estimating the dependability of the technical facility $G_o(t)$, in practice, reduces to determining the functional readiness of the technical facility $K_g(t)$ and determining its reliability function $R(\tau)$ and taking into account the following relationship:

$$G_o(t,\tau) = K_g(t) \cdot R(\tau) \tag{4}$$

where:

$K_g(t)$ – functional readiness function, expressed in the momentary probability of an event in which the object will be in a functional state,

$R(\tau)$ – technical facility reliability function, defined as the probability of an object completing a task within a time interval of τ.

When the time of technical facility operating $t \to \infty$, function value $K_g(t)$ may aim for a limit value called the stationary value [7]:

$$K_g = \lim[t \to \infty]\ K_g(t) = \frac{ET}{ET + EU} \tag{5}$$

where:

ET – expected value of random variable of time of functional suitability of a technical object,
EU – expected value of random variable of time of unsuitability of a technical object.

Function $G_o(t,\tau)$ for the life of the technical facility $t \to \infty$ may aim for a limit value, called stationary, in this case, taking into account the dependence (5) [7]:

$$G_o(\tau) = \lim[t \to \infty]\ G_o(t,\tau) = \lim[t \to \infty]\ [K_g(t) \cdot R(\tau)] = K_g \cdot R(\tau) \tag{6}$$

where:

K_g – index of stationary availability,

$R(\tau)$ – technical facility reliability function, defined as the probability of an object completing a task within a time interval of τ.

Knowledge of the dependability function shown above (6) allows the object to be estimated with a specific probability of completing the task within an assumed time frame τ, as for military vehicles performing combat tasks is of great importance. Information regarding the likelihood of the undamaged vehicle within a specified period of time, which may be expressed in mileage units, e.g. in the case of a vehicle the number of kilometers travelled between the damage is useful both for the operating decisions taken and for ensuring an optimal level of crew safety.

Anticipating damage to military vehicles on the battlefield resulting from cumulative errors arising in all phases of the object life and the process of physical aging and wear of vehicle components should be an essential tool for crew safety evaluating.

The loss of technical suitability by a military vehicle on the battlefield, not resulting from the means of destruction of the enemy, is a poorly made operational decision, not taking into account the knowledge of the reliability and dependability of the facility.

ANALYSIS OF FACTORS AFFECTING DEPENDABILITY OF MILITARYVEHICLES

When analyzing factors affecting the dependability of military vehicles, all the incentives to interfere with the maintenance of vehicles in a functional state should be taken into consideration, indicating the possibility for the facility to carry out the function set in accordance with its designation for a specified period of time and task suitability, indicating the ability to perform tasks under certain operating conditions and loads, within a randomly variable period of time. Disruptions in the maintenance of these types of suitability directly translate into changes in dependability levels.

The maintenance of vehicles in a state of suitability is strictly dependent on the intensity and nature of the damage. The determination of factors affecting dependability amounts to examining the causes of vehicle damage. The most relevant in this range are primary damage, which are independent of each other and occur randomly, the analysis of their frequency is the basis for estimating the basic operational characteristics of the individual components of vehicles, such as durability and reliability.

So far, it has already been noted that the search for the root causes of military motor vehicle damage should not be limited to the phase of operation, which is the last phase of the vehicle's existence. In paper [8], the different life phases of the motor vehicle are specified, i.e..:

- needs,
- design and construction,
- manufacture,
- operation.

The above study concluded that the errors made during each phase of the object's existence are the source of potential future vehicle damage.

The first mistakes are made already in the first phase at the stage of defining needs. The main source of these errors is poorly developed tactical and technical assumptions. The requirements set out in the above assumptions to meet for the individual vehicle systems and the entire vehicle and its operating system are not always adequate to the actual operating conditions under which the vehicle will be used.

A common occurrence is also the problem of quantification of specific needs. Requirements that cannot be quantified are disregarded in the documentation. The most important reliability requirements for military vehicles, which mainly shape the dependability level of vehicles, are included in this documentation too generally. The small number of reliability indicators described, both operational-tactical and technical indicators specified in the defense standard [9,10], do not sufficiently specify the requirements for work efficiency or basic reliability properties (non-damage, reparability, durability and survivability).

The operating phase is the most important phase of the life of the facility, with regard to the verification of assumptions made at the design and construction stage. Any shortcomings and mistakes made earlier in previous phases of existence are revealed during operation. The variable operating conditions typical of military vehicles generate damage, signaling the need for modernization, replacement or improvement in the operation of the various components of their construction. The operating phase is characterized by a large number of factors affecting a vehicle with various intensity in its respective operating states.

The process of physical aging and wear of the vehicle components has a destructive effect on its technical condition, causing an increase in the occurrence of damage. The commensurate division of these processes under randomly variable load conditions determined by the operational tasks performed by the vehicle results in the loss of technical suitability of the individual components or of the vehicle as a whole, in situations which are sometimes difficult to predict. These processes are caused by overlapping of numerous factors, acting simultaneously, which result from operating conditions, exploitation errors and the entire operating environment.

Taking into account the causes of damage, the inducing factors can generally be divided into three groups of [5] i.e.:

- working factors (internal), acting at the time of vehicle operation,
- external factors resulting from environmental conditions, operating independently of the operating state of the vehicle (use, repair, or downtime),
- anthropotechnical factors, resulting from human activity during operation and servicing.

All of the above-mentioned factor groups are related to each other, as shown in figure 2.1. The appearance of some forces the occurrence, or intensification of the other. When considering the genesis of their formation, most often anthropotechnical or external factors cause an increase in internal factors, contributing directly to damage.

– The mutual impact of these factors is so significant that the cause of the damage cannot be considered for only one group of factors to fully explain the cause of the loss of technical suitability.

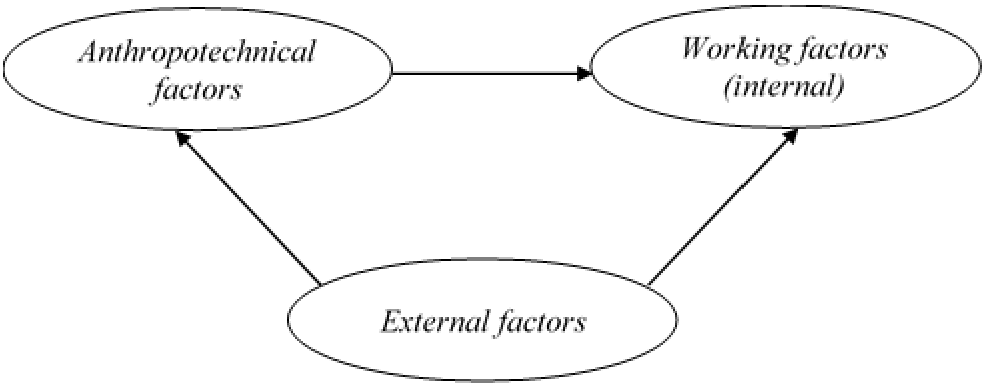

Fig. 2.1. Graphic illustration of relationships between groups of factors which induce damage

CONCLUSION

Execution reliability tests for military vehicles on the basis of which dependability can be estimated should also constitute a basis for operating process control, also in the safety aspects, during combat tasks executing.

Making rational decisions in the operating management system increases the efficiency of the system, e.g. the reliability of technical facilities used, readiness of the system to carry out the assigned tasks, as well as safety of operation.

For military vehicles, the research on availability and reliability as widely as, for example, in the case of aircraft, have not been carried out so far. The main reason for this is the lack of basic data on the damage to vehicles operated in military units. The guidelines for conducting operational documentation for military vehicles do not take into account reliability analyses, the knowledge of which is of great importance for shaping efficient operation and dependability.

In conclusion, it should be noted that it is possible to ensure the required level of efficiency of the operating system and thus the required level of readiness of the vehicle operating system is possible only in the case of control of the said operating system by optimizing the decision-making process.

A prerequisite for optimizing this process is to have a collection of information obtained through reliability analyses using mathematical models, developed using decision-making theories of stochastic processes. Extensive application in the modeling of operating processes have found the Markov’s and semi-Markov’s processes, such as in works [14, 15].

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