



Expedient Repairs – Analysis of Possibilities and Needs

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Abstract:

The article presents organizational and technical conditions connected with the implementation of the system of military equipment expedient repairs (ER) for military technical support's functioning. Furthermore, the article mentions such issues as unification and adjusting the equipment in a design and production processes, pro-active diagnostics, procedural conditionings, training, technology and temporary repair. Each issue is discussed considering possibilities and needs of expedient repairs system implementation.

Key words:

Logistics, operation system, field repairs of the military equipment, telemetry maintenance system, temporary repair.

1. Introduction

A problem of unscheduled field repairs gains special importance in conditions of military operations during which the dominant source of equipment loss is combat and operation damage [1].

As the history and experiences of the last armed conflicts have shown, the enemy's use of modern agents of destruction is causing more and more military equipment losses [2]. In case of an arming system, the significant part of this equipment damaged during combat operations is recovered and included in further operations thanks to its repair directly within the area of operations. This is a basic source of providing units with equipment; especially in the conditions of peace and stabilization missions [1, 3].

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Expedient (Temporary) repairs process is executed in the field conditions and consists of the following stages:

- range of damage assessment,
- selection and elaboration of damage repair technology,
- making a decision concerning the repair providing that the repair can be done in an appropriate time period,
- execution of the repair in the field conditions or having the damaged equipment repaired in a parent unit or in a repair plant.

To make this process fully effective and to make the executed repairs low-cost, easy to perform, and sufficiently durable, requirements described in the below chapters should be met.

2. Equipment Unification

The complexity of the modern military equipment causes that in a scope of maintaining its operational readiness, a number of undertakings not only of technical nature must be involved. One must remember that armament systems are technical objects that have specific requirements essential to execution of their tasks [4].

Executing equipment for field repairs can be more or less complex and time-consuming and in other words, it can be more or less expensive. Everything depends on the level of equipment preparation for the mentioned actions. That is the equipment susceptibility to field repair execution [5].

The susceptibility to expedient repairs is an ambiguous notion that is difficult to define. Undoubtedly, it is a component of maintainability, which is shaped mainly at the stage of constructing and producing an armament system. Therefore, the Armed Forces of the Republic of Poland, when selecting and purchasing new equipment, should also shape its susceptibility to expedient repairs.

The susceptibility to field repairs execution is a property of a device that describes its adaptation to repair works execution. The estimation of susceptibility to repair is high when an object is:

- designed keeping the modularity of assemblies,
- equipped with quick-mounting joints that provide quick assembly and disassembly.
- equipped with a possibility of using standard devices and tools in a process of assembly and disassembly,
- secured with base surfaces (openings) of the components in order to use them in a repair process,
- labelled in a way that enables easy and proper assembly of cooperative components of the object,
- constructed in a way that makes an access to the most often damaged assemblies easy and, simultaneously, that enables easy mounting of damaged subassemblies or their repair without a necessity of disassembly,
- designed in a way that gives a possibility to use modern technologies and repair materials in a repair process,
- equipped with dedicated repair manuals in conditions of combat operations, and with special repair kits.

The especially significant element seems to be the modularity of assemblies together with the unification of parts, devices, and vehicles. Fulfilling this parameter

results in an easier and more available repair practice, as well as in adapting practices and repair kits to the whole family of vehicles or armoured fighting vehicles.

A positive example of this kind of approach to designing is HMMWV vehicle. In this vehicle, the driver, without any repair kits, is able to improve particular gears or assemblies [6]. The Armed Forces of the Republic of Poland should also require from the manufacturers constructing vehicles of high susceptibility to repair and of easy access to assemblies and subassemblies (Fig. 1).

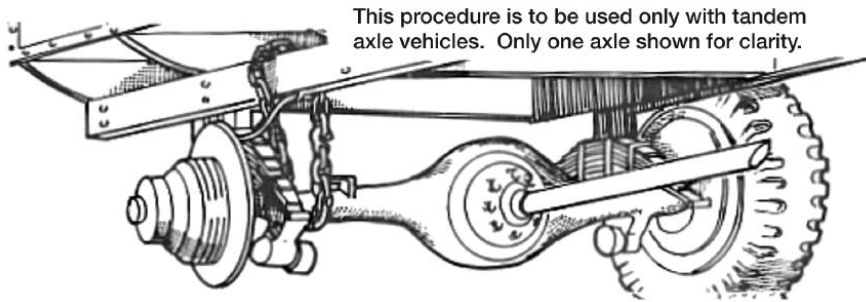


Fig. 1 The example of expedient repair [7]

3. Proactive Diagnostics

Maintenance based on technical conditions was gaining importance in the past decades with the expansion of technical diagnostics. It is especially preventive maintenance comprising of monitoring performance or parameters and of consequent measures. Its main benefit resides in consistent removal of failures. Particular worn parts and parts or whole assemblies in the risk of failure are repaired or replaced optimally in advance. Thus, failure occurrence is prevented.

Proactive maintenance is considered another higher level of maintenance. It is completely based on the previous predictive maintenance which it further improves, so that its basis is the utilization of more complex technical diagnostics. Basically it is the top current version of predictive maintenance based upon actual condition of the item operated. It is analysed in detail in the following chapter.

Proactive maintenance arose from the predictive maintenance type as a reaction especially to long-term findings that a certain group of failures repeats periodically upon clear causes. Known causes include mainly the following:

- Incorrectly organised maintenance work.
- Incorrectly performed maintenance (technical operation in the vehicle).
- Unqualified operators and maintenance personnel.

The proactive maintenance type is aimed at keeping inherent reliability of the vehicle on an acceptable level. As a source of information, technical diagnostics is utilized. The main objective of proactive maintenance is:

- Further reduction of maintenance and operational costs.
- Prevention of failure occurrence and thus extension of an interval to preventive maintenance, meaning extension of the vehicle durability.
- Statistic control of accidental and systematic influences affecting the vehicle operability [8].

An important feature of ER system is information about fault occurrence given as soon as possible. Knowledge of size and place of damage, as well as its impact on further operation of military equipment, has a direct influence on further actions that aim at restoring the equipment's efficiency.

The modern military vehicles use the civilian technology based on the CAN (Controller Area Network) bus for data transmission. However, for the needs of NATO armies, MilCAN system was created in 1999 dedicated to the newest and the most advanced armoured fighting vehicles manufactured in the NATO states. MilCAN is a deterministic protocol in which the CAN bus can be used in the technology determined by the ISO 11898 standard. Although this protocol was developed initially for the management system of the modern battlefield, the MilCAN is applicable wherever there is a requirement for deterministic data transfer.

The example of such a solution is the battlefield management system PBISA (*Platform Battlefield Information System Application*) used in British *Challenger II* tanks, and a part of this system is component of armoured fighting vehicle deck diagnostics (Fig. 2). Information generated by this component facilitates early detection and identification of faults; moreover, this information is of special importance for the ER system.

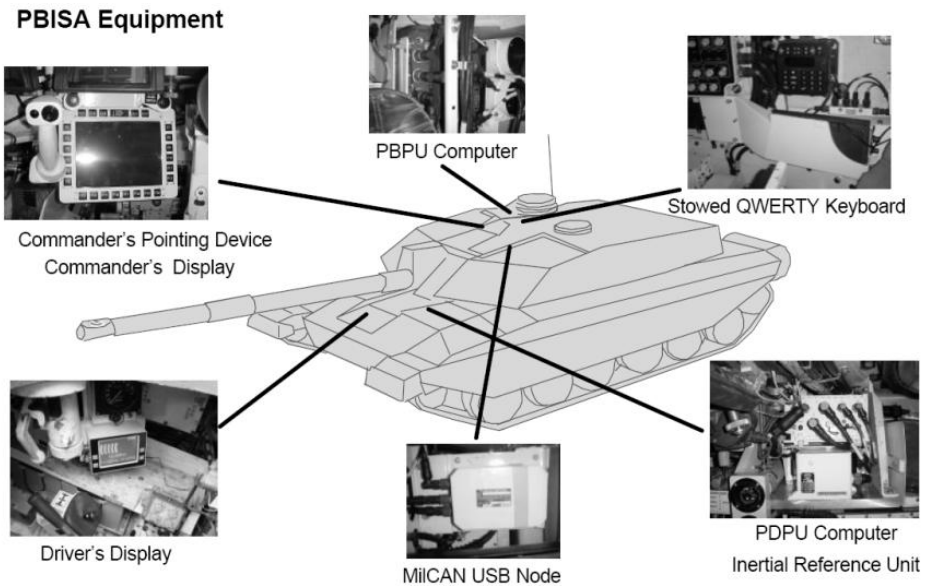


Fig. 2 Components of battlefield management system of Challenger II tank [9]

The final element in the deck diagnostics system is its diagnostics interface. Military vehicles compatible with OBD II/EOBD (On Board Diagnostic II/European On Board Diagnostics) system have got a unified diagnostics interface in order to provide easier data transfer and a possibility to interpret fault codes by different scanners and other data-reading devices. An example of Polish armoured fighting vehicles equipped with the deck diagnostics system is AMV Rosomak, whose system is compatible with OBD II/EOBD (Fig. 3).



Fig. 3 Data reading by means of diagnostics interface built in the dashboard of AMV Rosomak [personal photo]

The latest trend in the maintenance area is so called "telemaintenance", which may be explained as remote-controlled maintenance employing the proactive maintenance principle. In some publications, the term "Remote Diagnostics & Maintenance (RD&M)" is used [8]. It is based on wireless transmission of technical data about the vehicle. The main field of its utilization is in companies specializing in long-distance transportation and also in military environment. This method enables on-line monitoring of parameters upon sensors integrated in the vehicle and wireless transmission of the information to a remote computer. This is very helpful especially for securing missions on a foreign territory.

Telemaintenance may be divided into the following four levels:

1. Diagnosed vehicle with a driver.
2. Support logistics centre where a computer processed diagnostic information is located.
3. Experts performing the maintenance on the vehicle.
4. Vehicle manufacturer who supplies a technical database including drawings and technological procedures for maintenance [10].

Fig. 4 shows a schematic telemaintenance system based on wireless transmission of diagnosed data from the vehicle to the telemaintenance logistics centre and to the vehicle user. The vehicle electronic control unit makes performance indicators and error codes accessible for an analysis; these are sent to the logistics centre. There, in case of error messages an advisor informs the driver about the problem severity and advises on possible problem removal or provides necessary service support.

It means that the advisor ensures the vehicle maintenance or field repair with the use of a mobile workshop, or arranges maintenance in the maintenance and repair centre. If necessary, the logistics centre communicates further with the vehicle manufacturer who supplies the centre with new data materials for particular vehicle types.

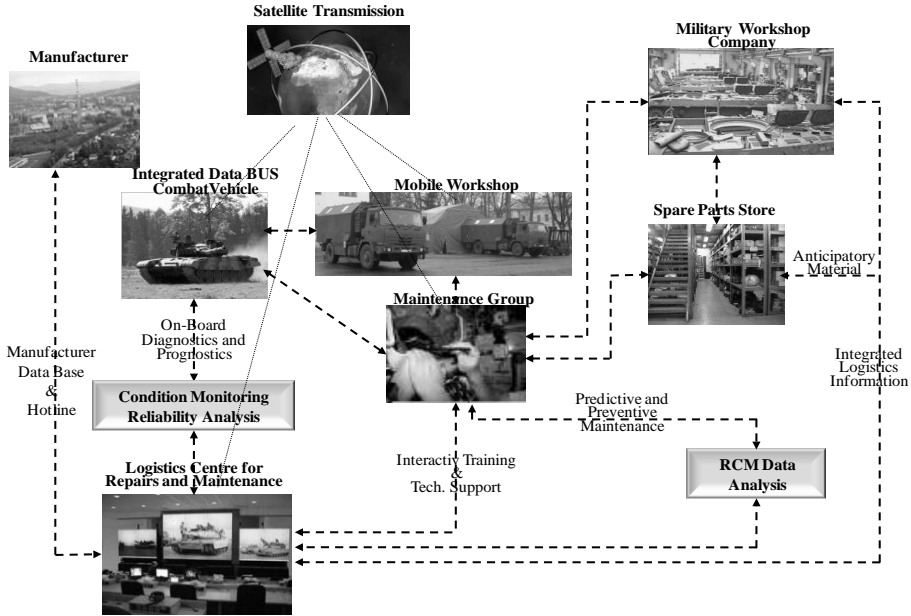


Fig. 4 Telemetry maintenance system in battlefield

4. Procedural Conditionings

It is hard to imagine quick and effective military equipment repair without proper procedures and repair manuals dedicated to particular types of equipment. The Armed Forces of the Republic of Poland have ratified the doctrine documents sanctioning the execution of the ER in combat operation conditions [11]; however, in Polish Army there are no typical ER repair manuals. The experience from other armies in this field has shown that the best solution here will be drawing up proper general manuals [7], as well as manuals dealing with particular type or family of equipment [6] (Fig. 5). In this kind of manuals the equipment’s user should find prepared simple algorithms of operation in case of the most common faults, which can be repaired by means of the available repair kits [11].

In case of weapon systems newly introduced to operation during peace time, the warranty and post-warranty conditions required by the manufacturer should be complied with. However, the expedient repair of such equipment could turn out to be troublesome exactly with regard to the procedures, and actually with regard to the lack of the procedures. In case of combat operations, a commander of a sub-unit or an armoured fighting vehicle should have clearly specified procedures of action. A commander must know what the range of repair that he can execute on his own is, which repairs require the superior’s consent, and which repairs can be executed by the specialized ER squads. The basic criterion during combat operations would be task execution (attaining the intended tactical goal), regardless of expenses and against the manufacturers’ recommendations.

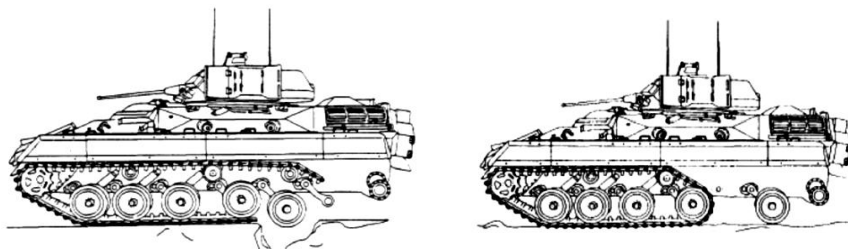


Fig. 5 The example of the expedient repair of the infantry combat vehicle M2A2 Bradley [7]

5. Training

When discussing the system of maintaining the technical ability of the military technology, we cannot ignore an issue of effective collecting, processing, and multiple times of using the experiences of specialists in this field. As a result of permanent restructuring of the Armed Forces of the Republic of Poland and especially the logistics system and logistics structure, the issue of systematic use of experience and knowledge of the experts in the field of the military technology repairs is heavily neglected. Another issue of the Polish Army is a cadre of the experienced mechanics and engineers who are getting older. Implementation of the professional army and young and inexperienced private soldiers' and non-commissioned officers' recruitment to repair sub-units causes that they are often unable to fulfil their tasks. There have been attempts to solve a problem of lack of experienced mechanics in the repair sub-units in a form of employing former professional soldiers who served in this type of formations. Their knowledge and competence are priceless, but except the interim use of their work, does anyone collect and use their experience? Besides, as it results from the interviews with commanders of repair battalions, the average age of the employed mechanics is still increasing. The additional impediment of filling in the generation gap is replacing vacant posts of mechanics with posts created by the National Reserve Forces Program [12].

The experience of the allied countries has undoubtedly shown that a very significant element of the field system of military equipment repairs is proper preparation of staff that assesses the range of damage and executes repairs. The proper level of training concerning people responsible for removing damage in conditions of combat operations is obtained by permanent conducting of training – both theoretical and, above all, practical training [13]. The most developed field repairs system operates in the Air Force of the USA, whose structure includes BDAR (Battle Damage Assessment and Repair) Chief Specialist Post. This Chief Specialist is a member of the Combat Logistics Support Squadron and he is also responsible for training of the subject staff. Furthermore, he is a consultant and, together with a unit's commander, he arranges BDAR training (in the Air Forces of the USA a unit's commander determines how much staff and who exactly is trained in a scope of BDAR). The US Air Force, when executing combat tasks in distant theatres, technically secure their aircraft fleet by, among others, executing BDAR. The repair squads are most often composed of 4 to 7 people who are properly trained and authorized to qualify aircraft for repair in field conditions, plan the repair and execute it, and, if necessary, put operational restrains on the repaired equipment. In the zones of combat operation the

squads are the part of logistics sub-units. These are equipped with so-called repair kits, in which the devices, tools, and materials necessary for repair execution are collected [14].

The operation of that kind of squads is based on technical documentation developed by the aircraft manufacturers and by the scientific research centres (research institutes). This type of operation is not only developed by the Armed Forces of the United States, but also by the Air Forces of Australia, Great Britain, Canada, or Finland [13]. The majority of countries developing the field repair system operate aircrafts manufactured in other countries. After purchasing aircrafts with the basic repair documentation they develop it further independently improving the field repair system by, among others, conducting research at their own scientific research centres.

To sum up, it should be stated that a proper human resources management in a scope of keeping the military technology objects in their operation ability should consist in:

- creating or appointing a centre that would be occupied with training and researching applications in a scope of ER technology;
- elaborating one digital platform for the whole Armed Forces of the Republic of Poland of data collecting, processing and making data accessible in a scope of technology, equipment, and repair materials, as well as information concerning executed repairs and their durability using a form mentioned in the standardization document [11];
- organizing, periodic training in a scope of the military equipment expedient repairs with participation of the experienced trainers – repair specialists in the selected centre;
- inviting scientists and civil companies that are occupied with keeping technical objects' operation ability to participate in sharing experiences and knowledge;
- disseminating information concerning repair techniques and methods among cadre of repair sub-units; e.g. by means of periodic newsletters.

6. Technologies

The essential link in the ER system are suitable technologies, tools, and materials by means of which a repair should be executed. Tools and materials should be arranged and stored in a well-considered way in proper repair kits. When watching other NATO armies it can be concluded that the best, the most effective solutions are repair kits dedicated to the particular family of equipment - as described in the literature [15]. Well-elaborated and constructed repair kit of the particular vehicle will considerably improve its susceptibility to ER (Fig. 6).

ER repair kits should include the newest repair materials that make execution of expedient repairs possible in field conditions. This kind of materials are adhesive materials, materials used to remove damages to pneumatic, hydraulic, and electric installations, as well as plastics elements. These should also include all-purpose repair materials as: regenerative tapes, zip ties, V-belts, seals, simmering, etc. Completing the kits should be based on scientific research, as well as on long-term practical experience, and this process should be continuous [17].



Fig. 6. Repair kits used in the Netherlands Army at the first level of BDR [16]

7. Principles of Expedient (Temporary) Repairs

According to Alliance documents "expedient repair is repair, which may be temporary, to restore an equipment to a specified condition by non-conventional/improvised repair, both deployed and in-barracks, bounded by legal constraints" [11]. Similar formulation of the problem was presented in European Standard EN 13306 [18], where is said that temporary was defined as: "physical actions taken to allow a faulty item to perform its required function for a limited time interval and until a repair is carried". In the past the temporary repairs of military combat vehicles proceeded spontaneously and depended on the circumstances to be dealt with. The repair progress was influenced by experiences, the level of combat vehicle complexity, technical facilities and individual skills. Applying a different technology, using a reproduction part, or performing a repair by a serviceman without the competence are typical features of temporary repairs.

7.1. Theoretical Principles of Temporary Repairs

It is good to realize that the temporary repair of combat vehicles cannot adequately substitute the repair performed in compliance with technical conditions and that is the reason why the next repair should be carried out in the shortest term. The reason for performing a regular repair is that a nonstandard procedure does not provide for dependability. In spite of all drawbacks, the temporary repairs can play an important part in a combat operation.

a) Temporary repairs in peace time

The aim of a temporary repair in peace time is to renew or partly renew mobility and to prevent from more extensive damage, as for example environmental pollution caused by the leak of hazardous substances, safety threat by making a trouble in operation, or the devaluation of a transported material.

Operating costs are not expected to be increased due to the temporary repair, therefore, when deciding whether to perform it, economical factor will be the main criterion. The economical factor can be expressed by the following formula [19]

$$N_O + N_{DO} + N_{ZiDO} \leq N_O + N_{ZiO} \quad (1)$$

where N_O – the costs of performing the repair, N_{DO} – the temporary repair costs, N_{ZiDO} – the loss incurred by the time the temporary repair is performed, and N_{ZiO} – the loss incurred by the time the repair is performed.

The loss can include the costs of the settlement of a possible breakdown, the devaluation of a transported material, penalty payments, repair assistance, the costs of reloading material, the recovery and evacuation of a vehicle, or the increased costs of the repair due to the wear-out caused by performing the temporary repair.

After modifying the equation (1), we get [19]

$$N_{DO} \leq N_{ZiO} - N_{ZiDO} \quad (2)$$

which is an economical requirement for performing the temporary repair. However, even much higher costs of performing the temporary repair as compared with the repair costs might be justified in this way, therefore the following formula must apply simultaneously

$$N_{DO} \leq N_O \quad (3)$$

and then it holds

$$(N_{DO} \leq N_{ZiO} - N_{ZiDO}) \cap (N_{DO} \leq N_O) \quad (4)$$

When deciding whether to perform the temporary repair, we should take into account not only the costs, but also the fact to what extent a vehicle or a workshop vehicle is equipped with tools and material, to what degree a vehicle can be adapted to temporary repair performance, and the level of operating personnel skills.

Another important factor used when we are to agree on performing the temporary repair is time t_{\min} , during which it is necessary to assure the main function of a temporarily repaired part until a regular repair is performed. The information stated above is followed by a requirement limiting the costs of temporary repair performance

$$N_{DO} \leq t_{\min} \frac{N_{ZiO} - N_{ZiDO}}{dt} \quad (5)$$

Therefore, when deciding whether to perform the temporary repair in peace time, it holds [19]

$$(N_{DO} \leq N_O) \cap (N_{DO} \leq t_{\min} \frac{N_{ZiO} - N_{ZiDO}}{dt}) \quad (6)$$

b) Temporary repairs in field conditions

The difference between the temporary repairs of combat vehicles performed in peace time and in field conditions is that we follow not only economical factors which are the most important in peace time, but also the provision of combat vehicle main functions, e.g. a weapon system, vehicle mobility and communication. The survival time of a vehicle (a crew) in a battlefield is crucial for deciding whether to perform the temporary repair. To put it simply, the recovery process of combat vehicle fighting power might be viewed as a geometric sequence [19]:

$$n_t = n_0 q^{t-1} \quad (7)$$

where n_0 is the number of combat vehicles before the operation began, n_t is the number of combat vehicles at the beginning of the day t , q is a sequence quotient, t – the number of days.

The magnitude of the sequence quotient q can be described as the ability to repair damaged combat vehicles with the extension of loss z , combat vehicle repairability ψ , and when considering the capacity and technical possibility of performing the repair with repair units ε . Therefore

$$q = 1 - z + \psi \varepsilon z \tag{8}$$

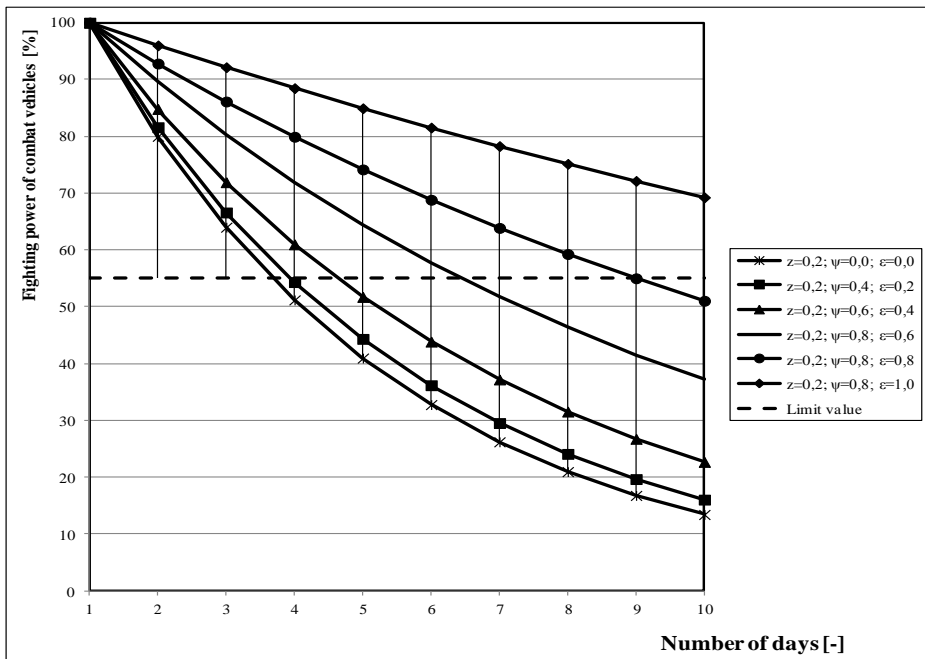
Then, sustainability time is given by a decrease in the number of combat vehicles at an acceptable level n_x

$$n_x = n_0 \cdot q^{t_x - 1} \tag{9}$$

and, therefore

$$t_x = \frac{\log n_x - \log n_0}{\log q} + 1 \tag{10}$$

when reaching the time t_x a unit must be replaced or supplied by another combat vehicle [19].



Graph 1 Fighting power of combat vehicles with 20 % daily losses

Performing temporary repairs helps to increase the capacity of repair units by labour saving, overcoming downtime due to the lack of spare parts, or involving crews in the repair process. This will be manifested in the rise in coefficient value ε .

Graph 1 shows the courses of the decrease in fighting power with average 20% daily losses z , the limit of 55% fighting power and different magnitudes ψ and ε .

The courses of single curves show that extending the capacity of repair units has a positive impact on the fighting power time of supplied units, e.g. when performing temporary repairs.

7.2. Temporary Repairs Technology

The aim of a temporary repair system is to increase the level of professional personnel and workshop specialist readiness for the recovery of combat vehicle fighting capacity and to prepare the means of logistic support to provide this repair [20].

The system takes into account the development and verification of technologies which can be used for performing temporary repairs including their material support. The temporary repair system should be targeted at well-arranged technological procedures focused on the temporary repairs of important nodes with labour input time evaluation, necessary tools and material [19, 21].

We suggest that general procedures are to be subdivided per systems or parts common for combat vehicles. In the text below there is a division scheme and the possibilities of performing temporary repairs [19].

Tanks

- smaller ruptures and leaks which might be fixed by bandaging or cementing with the use of fast-setting two-part sealants,
- disruptive breakdowns which might be repaired through a combination of bandages and packings, or packings made of different material,
- damaged tanks which might be replaced by connecting barrels, canisters or heat resistant cases capable of being closed with a specific medium.

Condensers

- leakage which can be stopped using substances added to a cooling liquid which solidify during the leak from a cooling system, or fast-setting sealants used in the place of the leakage or nearby,
- disruptive breakdown which can be fixed by squeezing a tube with pliers and then filling the hole with a sealant or hot lead,
- damaged condenser which can be isolated for a short time and a cooling system might be interconnected without the condenser, or the condenser may be replaced by another part, e.g. a barrel or a demountable fuel tank.

Pipe

- minor damage and the leak of a low-pressure pipe which might be repaired by bandaging or using two-part workable sealants,
- more serious damage to a low-pressure pipe (not including exhaust pipes) which can be solved by replacing a damaged part with a rubber hose fastened with a sleeve or a band,
- damage to a high-pressure pipe which can be mended by pipe's offset and cementing the ends with anaerobic sealants, or by complete replacing the pipe using a high-pressure hose with endings.

Air and hydraulic systems

- damage to the part of a system which might be disabled by blanking of a particular part, or providing a by-pass around a damaged part using hoses with endings.

Rods and shafts

- cracked rods can be joined by a thicker bond sheet metal, the ends of which will be drilled and screwed together, or there will be used a sleeve welded at the end,
- cracked shafts will be joined by welding to a sleeve where applicable.

Windings

- minor damage can be mended by using a threaded coupling with an anaerobic sealant,
- damaged internal thread might be fixed by drilling off and using threaded insets which renew the original winding.

Electric cables

- visible local damage might be repaired using insulation with both ends twisted and insulated by an insulation tape, or the joint is welded,
- damage difficult to detect can be fixed by bridging a proper circuit using a new cable, or, in case of power supply, by connecting with a cable assembly with nominal voltage.

8. Conclusions

The analysis conducted within the framework of the paper concerning possibilities and needs' analysis in a scope of arming systems' expedient repairs' implementation allows formulating the following conclusions:

- The military equipment expedient repairs executed directly in the operation area can be a significant source of retrieving damaged military technology and have a direct influence on combat ability of forces.
- Arming systems' survivability and field repairs should be formed already at the stage of equipment designing and manufacturing.
- Procedural conditionings are essential with regard to executing repairs directly in operation areas. Equipment operation and instruction procedures must precisely determine possibilities of using the expedient repair in the particular circumstances, which can ultimately contribute to further damage but still, it enables to complete a task or even to save human life on the spot.
- To implement ER system effectively, the trained and experienced staff having proper equipment and repair materials is essential.

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