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THE ATTEMPT TO QUANTIFY OPERATIONAL AVAILABILITY OF EXPLOITED VEHICLES AWAITING FUNCTIONING

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Abstract:

Quantification of operational availability at any moment, of cars utilized in action operations is the result of the processed information from the monitoring of use and maintenance processes. The collection of information on the monitoring processes and its structure are secondary to the applied preparedness and reliability indicators.

This study, based on data from the literature and normative acts, contains the characteristics of the preparedness models used in the military transportation system and the indicators used for controlling its exploitation.

The specific issue in this approach is an attempt to indicate how to assess the impact of the vehicle wear on their preparedness, reliability and availability. Not only the need, but also the possibility to account for this impact, was justified by empirical characterization of damageability of the vehicles operated with varying intensity of use. Varying intensity of use of vehicles suitable for a variety of cargo shipments, is a characteristic phenomenon in the system with action specificity like the military transportation system in the status of waiting for the full functioning.

The study also attempted to utilize index, defined in the defence standards, for quantification of operational availability of vehicles utilized in the system with action characteristics, and also an attempt to identify their reliability and availability.

Keywords:

military means of transport, operational availability, reliability, dependability, indicators, intensity of use, service life, wear out

INTRODUCTION

Availability[12] is defined as "A measure of the degree to which and item is in operable and comitable state at the start of a mission when the mission is called for at unknown (random) time. Polish Military Standard[3] defines availability as an index as "the probability that of an event in which a product in the state of operability at any time t of its service life will remain in this state for a certain period of time.

What results from these definitions, is that the availability refers to these items, for which the necessity of being used to perform a task is random in time.

For vehicles used such situation concerns special systems, such as a military in peace time, natural disaster relief and recovery systems and the like.

There are two chief factors which decide about the availability of motor vehicles within these sorts of systems. These are [3,4]:

- technical operability at unknown time, which is specified as a instantaneous or average availability/technical readiness and expressed as probability indicator that an item is operable;
- technical operability during the performance of a mission/task is called reliability, and it is expressed as reliability indicator as the probability that an item can perform its intended function.

Probability of the item's operability during standby time depends on the parameters which identify the current properties of the vehicle, maintenance system and use system, as well as the capability of the logistics system to provide the necessary parts and tools, since this particular feature of the logistics system is what decides about the dependability[4] of the item used.

Individual properties are identified in relation to characteristic parameters relative to:

- the vehicle most often identified with the parameter of *failure rate;*
- maintenance system most often identified with the parameter of *repair rate;*
- logistics system which has an impact on the availability of the necessary "just in time" parts and tools, and is identified by e.g. *logistics delay*;
- use system which has an impact on the *operability time* which in turn is dependent on *failure rate*, as well as vehicle *intensity of use*.

[1] NATO Allied Vehicle Testing Publications AVTPs (11 -20). 1993, p.11.

[2] MIL-STD-721C Standard, United States Departament of Defence 1981, p.44.

[3] NO-06-A102:2005 Polish Military Standard; Uzbrojenie i sprzęt wojskowy. Ogólne wymagania techniczne, metody kontroli i badan. Wymagania niezawodnościowe (Armament and military hardware. General specifications, monitoring and testing methods. Reliability requirements), p.33.

[4] PN 93/N – 50191 Polish Standard Reliability: Quality of Service, p.51. Dependability is defined as "Property of an item to maintain itself in a state of being capable of performing its required function under given conditions or during a specific time internal with the assumption that the necessary parts and tools are provided".

The following part of the paper is dedicated to quantitative impact of the factors on operational availability of vehicles which includes wear out of vehicles during their active time.

Maintenance of the required operational availability is the goal of properly organized and managed operations activities.

As with any action, undertaking rational decisions is possible only when the state of affairs/items subject to such decisions is known and this state has been diagnosed reliably. Full diagnosis includes the following processes: identification and assessment of the current state, the reason behind this state and a prediction of future state.

Further part of the paper includes a review of the scope of monitoring the processes of vehicle use [5] directed at an assessment of operational availability of vehicles and their dependability and which also affects the accuracy of the diagnosis.

1. QUANTIFICATION OF OPERATIONAL AVAILABILITY AVAILABILITY INDICATORS

In quantitative approach, vehicle steady-state availability is most often referred to by a technical readiness index [1], which can be expressed either by the following formula (1) or formula (2).

$$Kg = \frac{Tu}{Tu + To} \tag{1}$$

where:

Tu - expected period of item’s operability,

To - expected period of item’s inoperability.

$$K_g = \frac{\mu}{\mu + \lambda}; \text{ where } \mu = \frac{1}{To}; \ \lambda = \frac{1}{Tu} \tag{2}$$

Individual parameters indicate:

λ - vehicle failure rate reported to the maintenance system;

μ - intensity of maintenance;

Tu - mean operating time between failures;

To - mean duration of maintenance.

For a set of vehicles, the number of which is *N* at any moment, technical readiness is the result of the following dependence (3),

$$K_{gt} = \frac{N_Z}{N_Z + No} \tag{3}$$

where:

No - number of inoperative vehicles (unready to work) aka. being maintained, $No \subset N$, Nz - number of operative vehicles (ready), $Nz \subset N$.

Instantaneous availability of the vehicle acc. to {1} and the data (*To* and *Su* mean miles between failures) also exerts impact on the intensity of vehicle use (q).

Intensity of use is defined as the ratio of the vehicle mileage to the time interval in which the said mileage was covered [1].

The intensity of use (q) defined in this manner can be described with the following dependences (4):

$$q = \frac{1}{t_2 - t_1} \sum_{i=1}^{n} Q_i, \text{ or } q = f(P_Q, Q) \tag{4}$$

where:

n-number of days during which the vehicle was used,

$t_2 - t_1$ - time interval during which the incidents are recorded; of active (vehicle operation) and passive use (standby),

Q_i - mileage as per the period of i during a specific day of that the vehicle operation,

T_w - mean vehicle standby time,

p_Q - relative frequency of use,

$Q_ś$ - mean mileage as per working day.

If the parameter of vehicle intensity of use is introduced into the formula and the operating time is expressed as the period of time between failures [5], the availability K_g can be defined using the following dependency (5)

$$K_g = \frac{Su_i}{Su_i + T_o\, q_i} \tag{5}$$

where:

Su_i - mean miles between failures of the given vehicle i, $n_i \in N_e,\ i = 1,2,\ldots N_e$;

T_o - mean duration of vehicle maintenance/servicing time;

q_i - intensity of use of the given vehicle i.

This index allows calculation of steady-state availability for each vehicle $ni \in N_e$ which is dependent on the reliability expressed as (Su) and the duration of maintenance (To), as well as intensity of vehicle use (q).

Exemplary steady-state availability of the vehicle for the data accepted (To, Su) versus intensity of use (q) is presented in Figure 1.

This characteristic illustrates the fact also vehicles characterized by low value of Su exhibit high steady-state availability value if the intensity of use is low.

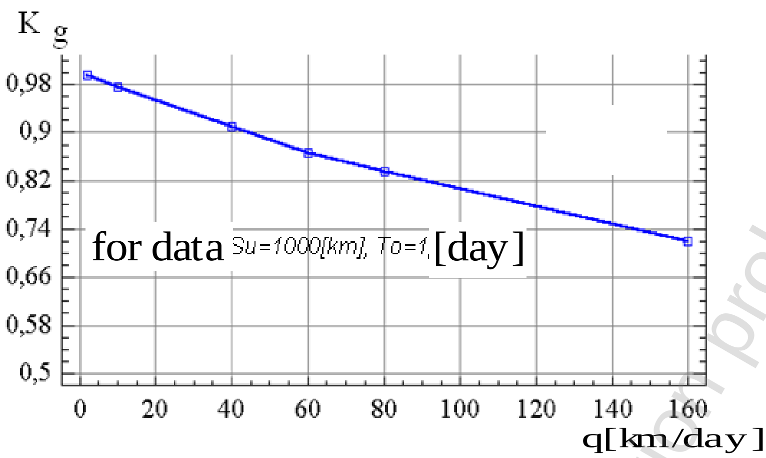

Fig. 1. Steady-state availability in function of vehicle intensity of use for the data accepted (To, Su)

Source: own elaboration

Therefore this indicator on its own does not provide enough information on the actual technical availability for mission. The knowledge should be supplemented with information on reliability of each vehicle used in relation to the transport mission planned.

If in the practice of vehicle maintenance vehicle failure rate $\lambda u = f(s,q)$ is known for exponential distribution, then reliability function for each vehicle $ni \in N_e$ can be determined with the formula [6].

$$F(Q) = e^{-\lambda u(s,q)Q} \quad \textbf{(6)}$$

Knowing both the steady-state availability and reliability of the vehicle allows the user to calculate its operational availability using the following dependence[5,](7),

$$K_g^o = Kg \times F(Q) \quad \textbf{(7)}$$

Exemplary requirements relating to medium tactical vehicles [2], such as operational availability, mean miles between failures (MMBF) and maintenance ratio (MR)[6] is included in Table 1.

Further part of the paper includes examples of empirical characteristics [3,4,5] containing the information needed to apply the above-listed indicators in determination of operational availability of vehicles (vehicle), their reliability and dependability.

[5] NO-06-A102:2005 Polish Military Standard: „Uzbrojenie i sprzęt wojskowy. Ogólne wymagania techniczne, metody kontroli i badan. Wymagania niezawodnościowe (Armament and military hardware. General specifications, monitoring and testing methods. Reliability requirements), p.46.

[6] MIL – T – 740G, "Military Specification Trucks: 5 Ton, 6x6, Military Design, M39, M39AL, M39A2 and M809 Series", *Washington 1989*, p.63.

Table 1. Exemplary requirements for vehicles to be used by the military [7]

Vehicle type	Operational availability (%)	Mean miles between failures (mil)	Maintenance ratio (MR)
2.5-ton cargo	91	2200	0.010
5-ton cargo	91	2000	0.014
Tanker	90	2000	0.015
Tractor	88	2500	0.012
Trailer	88	1900	0.003
Wrecker	90	1900	0.015
Ambulance	88	2000	0.011

Source: own elaboration

2. EXAMPLES OF EMPIRICAL CHARACTERISTICS AS TAKEN FROM PRACTICAL USE AND THEIR APPLICATION IN DETERMINING AVAILABILITY

The studies of vehicles conducted during their use [7] have been conducted on a very large number of passenger cars used intensively and they indicated increment of failures per unit of time. This is illustrated in Figure 2.

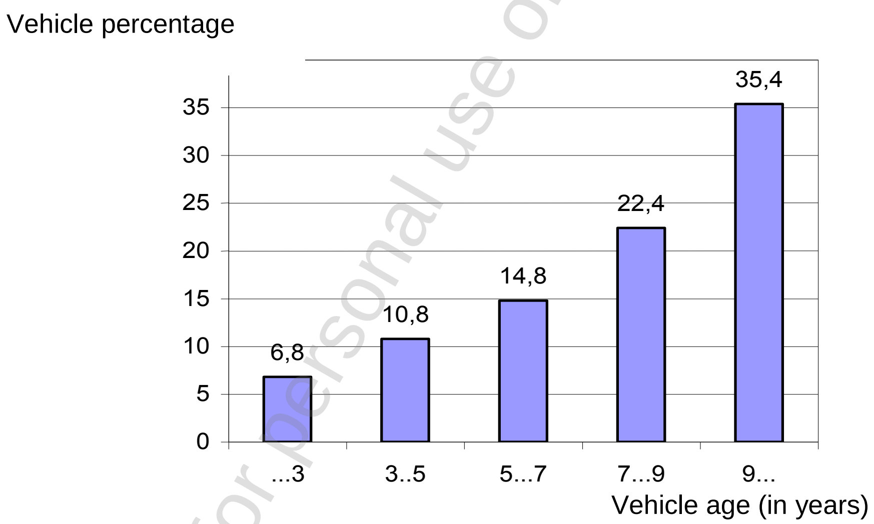

Fig. 2. Quantitative characteristics of failures detected in vehicles as dependent on their age [7]

Source: own elaboration

What results from characteristics in Fig 2, is that the vehicles over 9-years old are prone to five times more failures than the 3-year old vehicles.

[7] "Operational requirements for Family of Medium Tactical Vehicles (FMTV)" department of the army, office of the deputy chief of staff for operations and Plans DC 20310-04, Washington 1994, p.13.

Similar reliability characteristic was obtained following the tests relating to failures of high-mobility multi-purpose wheeled vehicles used intensively. They are presented in Figure 3.

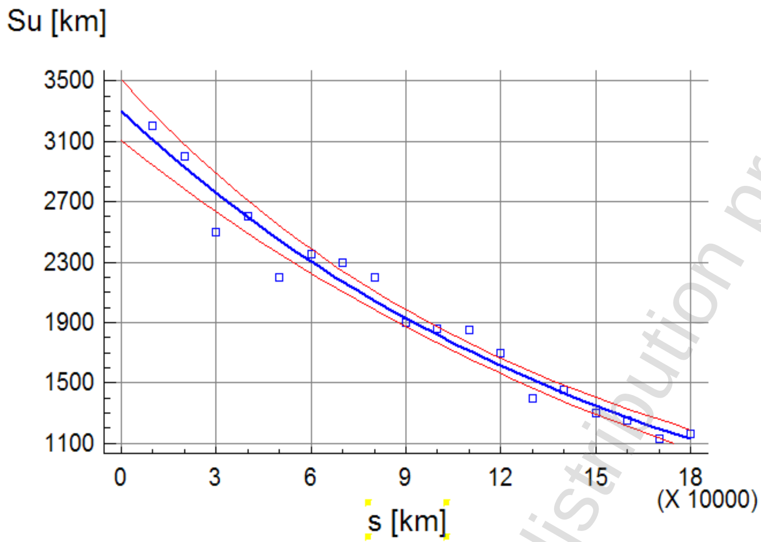

Fig. 3. Characteristics of mean miles between failures of a vehicle Su [km] in relation to the mileage [km] from the beginning of their service life [4]

Source: own elaboration

What can be seen from the analysis, it that the mean time between failures of trucks as used with varying intensity within the military system indicated very large scatter of results [3]. It has turned out that it is due to two factors, that is varied age of the vehicles and varied intensity of use during their uptime.

An exemplary distribution of vehicles from a selected group (N=120[units]), as dependent on their intensity of use within their standby time "P", is presented in Figure 4

Group q1 includes mostly those vehicles which were used on the average by 16 days per year (which results in the average standby time equal 23 [24-hour periods]); q2 45 days per year; in the q3 group 60 days/year and in q4 group over 85 days per year.

The data point to high variability of factors which directly influence the wear out process in vehicles which belong to different intensity of use ranges. In group (q1), the mileage between failures (Su[km} is dependent on lengthy standby time (Tw) and the impact of environmental factors. This impact is lower for higher intensity of use, as in case of q2, q3 and q4. For the vehicles used intensively (q≥q5), the mean miles between failures will generally be the result of their wear due the impact of fatigue and friction stimuli during their operation and only slightly depend on the wear out.

The information on mean miles between failures gathered throught the operation and maintenance practice have been ascribed to individual intensity of use. This was the first step to developing reliability characteristics for the tested vehicles relative to intensity of use ranges Figure 5.

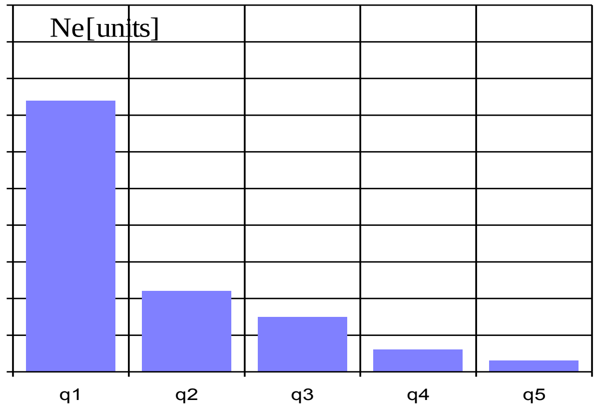

Fig. 4. Exemplary distribution of intensity of use within the tested group of vehicles [3]

Source: own elaboration

Figure 5. presents empirical characteristics of mean miles between failures in high mobility vehicles (as special purpose and general purpose ones by a selected manufacturer) used with varying intensity (q, where:q1<q2<q3<q4<q5) in the function of total mileage in active time.

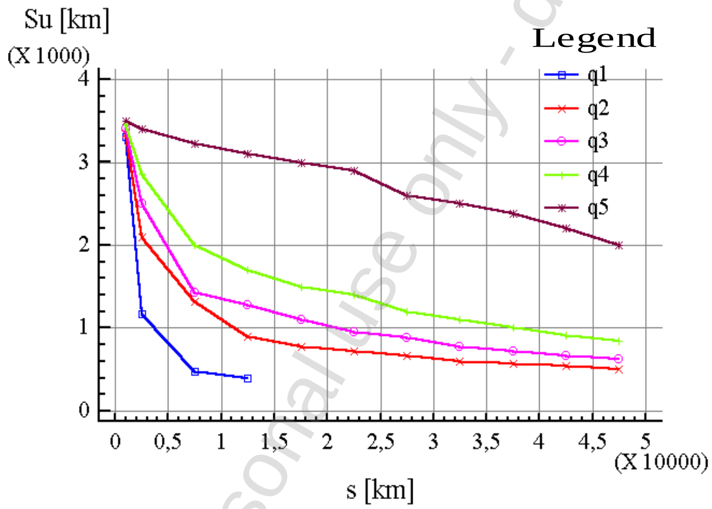

Fig.5. Exemplary characteristics Su = f(s) [km] for varying q [km/day} [3]

Source: own elaboration

Distribution of sets of vehicles relative to the percentage of service life used (where 100% is 20 years of service life/active time) at the time when the analysis has been conducted is illustrated in Figure 6. Example taken from maintenance practice and illustrated in Figure 6 concerns the distribution of the set of vehicles dependent on the degree of their service life being shortened (in percent, where 100% means 20 years of active time) at the time when the analysis has been carried out.

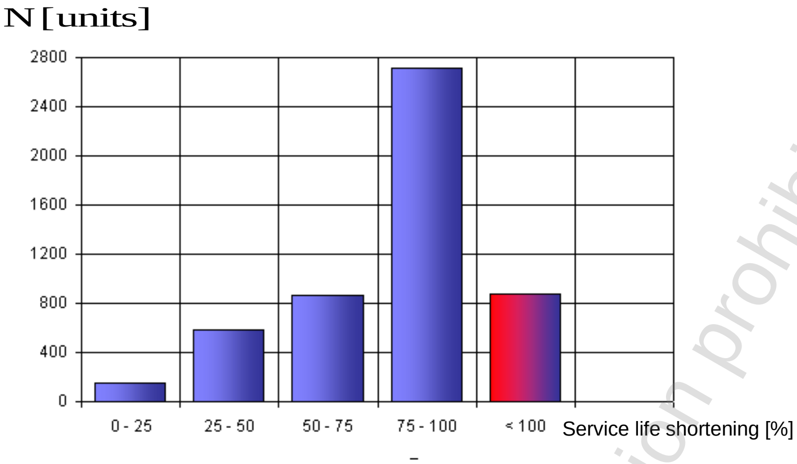

Fig. 6. Distribution of the set of vehicles as regards the degree of their life being shortened

Source: own elaboration

Then, Figure7 presents the characteristics of vehicle mean mileage between failures in function of the degree of their service life being shortened for the analyzed group of vehicles.

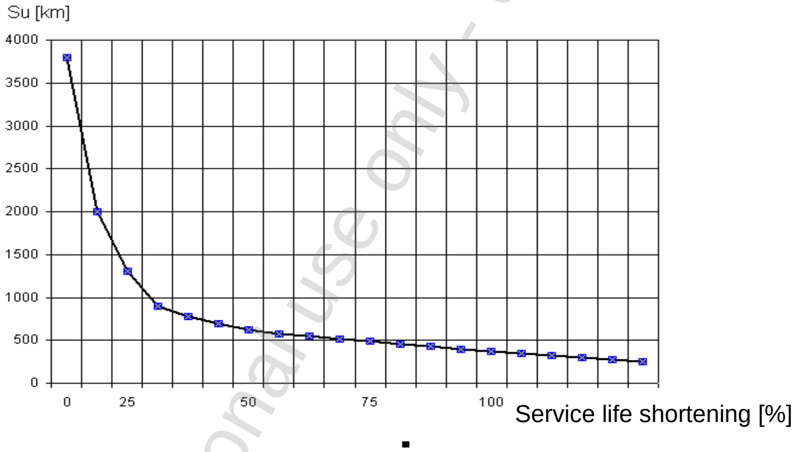

Fig. 7. Exemplary characteristics Su = f(s) [km] for the analysed group of vehicles

Source: own elaboration

Using the data from the empirical characteristic and formula {6}, it is possible to estimate success of a transport mission as expressed with the probability of correct vehicle operation over a specific distance (Q) in case of every vehicle belonging to a group characterized by a specific rate of service life shortening.

Example of accomplishing a transport mission over a specific distance (Q [km]) with vehicles with varying mean miles between failures (Su), as expressed by the dependency {6}, is presented in Figure8, whereas Figure 9 illustrates example of vehicle operational readiness acc. to [7] with varying degree of vehicle wear out and which perform transport missions over varying distances.

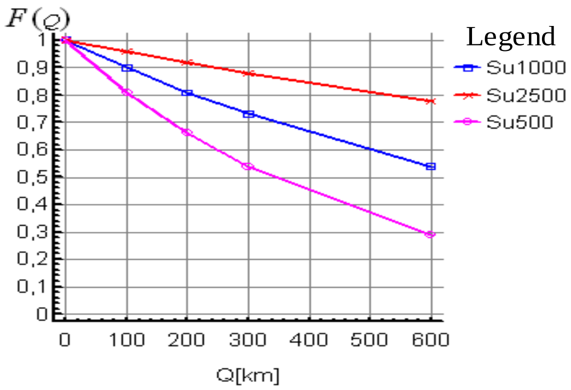

Fig. 8. Probability *F(Q)* of accomplishing a transport mission over a specific distance Q[km] for varying Su [km]

Source: own elaboration

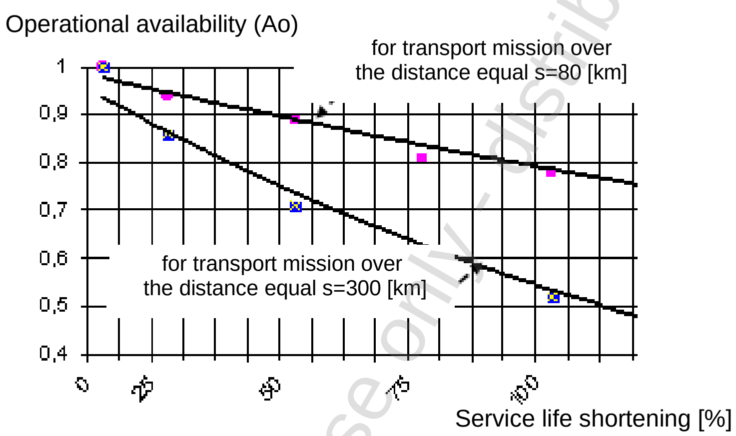

Fig. 9. Operational availability vs. the degree of vehicle life being shortened

Source: own elaboration

Specific circumstances of means of transport utilized within a system with standby time require that in order to provide dependability of a given group of vehicles, a need arises to predict maintenance and servicing needs at the transport mission planning stage, which could potentially take place. The comparison of these needs with the availability of parts, tools as well as maintenance and repair shops (both mobile and stationary ones) at that time provides information on operability of the vehicles used.

Mobile maintenance and repair shops are transported with the vehicles which do malfunction or in which failures occur depending on the degree to which the vehicle service life had already been shortened. That is why the reliability of vehicles which transport machine workshops should be treated (from an operation management point of view) as a key factor shaping the capability of an organization to provide the necessary means of service and within a given transport system.

Therefore the process of monitoring the capability of an organization providing means of restoring operability to the damaged vehicles should recognise the need to also include the current reliability of vehicles transporting maintenance and repair shops. The damage or failure of the vehicle of this sort means elimination of the shop from the technical support process. That, in turn, adversely impacts a whole set of vehicles which, at a given time and place, are to accomplish vital transport missions.

CONCLUSION

Vehicle operational availability assessment recognises the need of quantifying the instantaneous availability and reliability of each and every vehicle belonging to a given operation and maintenance system. The assessment of current dependability requires that the maintenance and repairs needs be compared with the capability of a logistics system to provide the necessary means of conducting the maintenance and repairs. Those needs stem from the current reliability and intensity of use.

Accomplishing these goals in the operation management process calls for monitoring of these parameters of operation processes which identify the properties of the vehicle(s), of the use and maintenance system, including the logistic system, particularly its capability to supply the measures needed "JUST IN TIME".

The knowledge in this area should be constantly verified and updated basing on proper algorithms processing data from the monitoring of the parameters of selected processes. The system based on the current ability to store and process information makes this task very difficult to carry out.

Effective performance of the task of thus kind is possible via properly organized information systems implemented as part of integrated ICT system recognized in the process approach. Since these systems perform several functions, such as process monitoring (including telematics), data analysis, reporting and planning with possibility of forecast, they could effectively support operation and maintenance management in a modern way.

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BIOGRAPHICAL NOTE

Zygmunt KRUK, Ph. D. – Doctor of technical sciences and adjunct researcher at Military Institute of Armoured Vehicle and Automotive Technology. He participates in research projects relative to all the stages of service live of vehicles, in particular in the areas pertaining to improvement of reliability and maintaining reliability. For several years, he managed over military vehicle operation and maintenance processes. For a number of years he was a lecturer of vehicle operation and maintenance at Warsaw University of Technology. He is an author of a number of publications on model-based and experimental studies relative to vehicle operation and maintenance, with regard to a specific feature of standby time. Both participant and project leader of several R&D projects commissioned by the Polish National Centre for Research and Development (Polish NCBiR).

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