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Original article

Applying performance data of military vehicles as a source of verification of technical specifications and criteria for implemented military equipment

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ABSTRACT

In the article the authors have attempted to analyze the specifications and criteria imposed on military vehicles acquired by the Polish Armed Forces. The issues of selection of the target operation standard, interval between periodic maintenance inspections, fault tolerance and reliability, which are defined in tactical-technical criteria by administrators, were addressed. The technical specifications are the essential component of qualification studies. The data obtained from research of prototypes and the initial years of exploitation of the new military equipment (SpW) constitute the source of verification for technical-tactical criteria (ZTT) or initial technical-tactical criteria (WZTT) adopted for implementation. The article also discusses the issues related to estimation of probability of the tasks to be executed by military vehicles in typical operating conditions depending on the lifetime, mileage or method of storage. Presumable combat losses, which are independent from the adopted operation system of the military equipment, have been omitted. The research works in the field of reliability are conducted in the Armored Fighting Vehicles Laboratory of the Military Institute of Armored and Automotive Technology in Sulejówek. Additionally, the authors have addressed the possibility of the application of computer simulation for the purpose of military vehicles reliability.

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KEYWORDS

technical criteria, military vehicles, mileage tests

Introduction

The Armed Forces acquire distinct types of vital military equipment in order to satisfy the requirements resulting from the establishment as well as sudden operational requirements. Military vehicles are acquired based on tactical-technical criteria (ZTT), initial tactical-technical criteria (WZTT) or exploitation and technical specifications (WET). The equipment specially designed and adjusted to military needs constitutes the former group of acquired vehicles, whereas vehicles commercially available, which are the subject of minor adjustments to the Armed Forces' requirements, form the latter group.

According to the Decision regarding Administrators and Central Logistic Authorities (COL), specifications for acquiring the new vehicles are prepared by a team of authors at the office of military equipment administrator. The knowledge of issues in the vehicles' acquisition field, their future exploitation and recycling is the task involving the extensive interdisciplinary experience and knowledge. This is due to the fact that the Administrator of Armoured and Automotive Service, who simultaneously executes the duties of COL, is responsible for the implementation and long-term usage of chassis for other administrators' equipment.

In the further part of the article, the analysis of selected technical specifications and criteria for vehicles acquired by the Armed Forces, in particular for the high mobility vehicles, will be presented. It results from recent acquiring a vehicle for the Polish Armed Forces – the successor to the legendary STAR 266, and the initiated procedure to purchase the successor to HONKER 2000 vehicle.

1. History of specifications for high mobility vehicles of military purposes

The execution of freight and personal transportation tasks on unsurfaced roads and sideways where the heavy equipment is engaged (e.g. tracked vehicles), undergoes with the usage of high and extended mobility vehicles. Pursuant to: 'The Concept of Road Transportation Structure of the Polish Armed Forces' the vehicles of the groups 1, 2, 3 and 4 dominate in this case (Fig. 1) [*Instrukcja*… 2013; *Koncepcja*… 1999].

The conditions set for these vehicles are specified in Defense Standard of 2005. On its basis, in 2007, following several-month of having positions consulted by correspondence, the then authority – the Armament Council accepted WZTT, which proceeded acquisition of a high mobility tactical truck. The budget line to finance the procurement was allocated in the Plan of Technical Modernization of the Polish Armed Forces. As a result of internal transformations, the existing producer of the successful truck of similar class STAR 944 and newly developed construction STAR 1466 – MAN Company from Starachowice withdrew the production of military trucks from the Polish factory in favor of manufacturing only civilian vehicles – urban buses. The MAN Company was not interested in delivering tactical trucks to the Polish Armed Forces. Despite the fact that the military vehicles commercially available met the requirements of Polish side, however, the purchase value excided the available appropriations under the budget of Ministry of National Defense.

Mercedes-Benz, AUTO-HIT (Iveco and Tatra models), MAN Polska (MAN vehicles), Volvo and Scania Companies deserve to be mentioned as potential providers or modernization bidders [Konczak 2016].

The engagement of the Polish Armed Forces in overseas operations proved the necessity to possess the transportation means with the augmented ballistic protection, which colloquially comes down to armoring selected elements of a vehicle such as:

a cab, fuel tanks and boards of loading platform. The suitability for armoring of medium capacity high mobility vehicles is to be considered insufficient due to the fact that the mass of appended armor modules adversely affects traction characteristics and decreases their utility values. In practice, the loading capacity of vehicles is reduced by half [Konczak 2016].

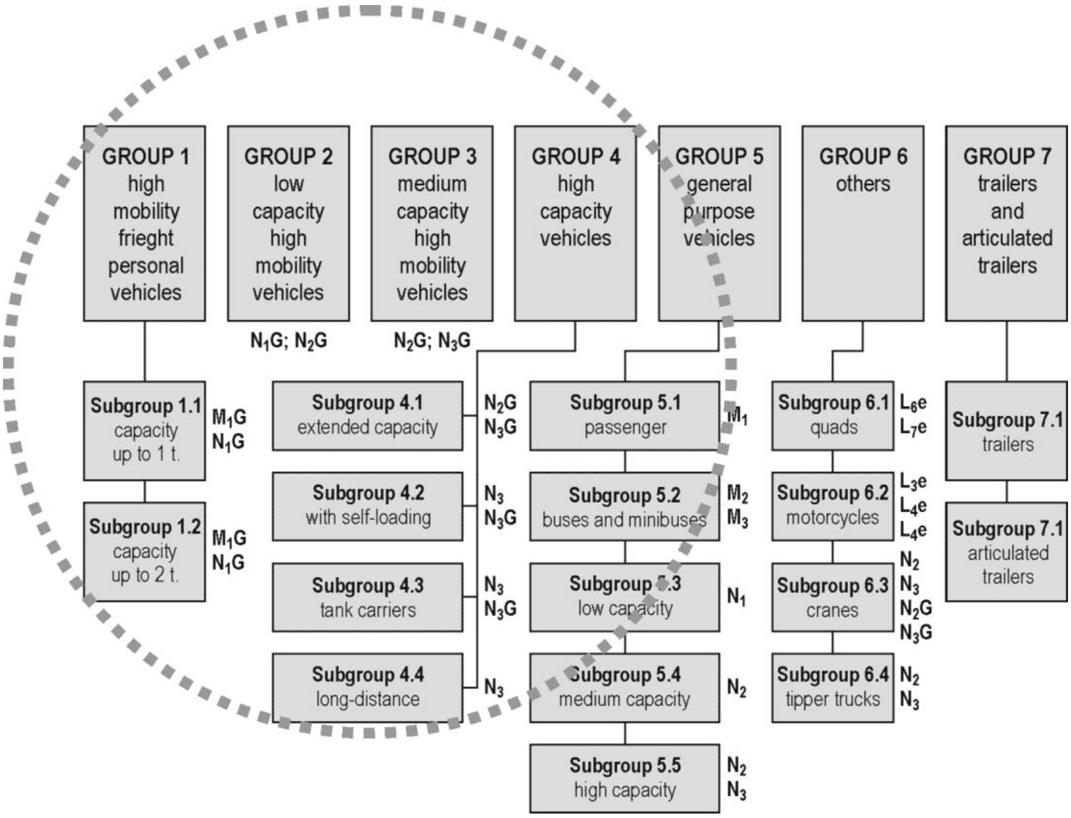

Fig. 1. Structure of the road transportation assets of the Polish Armed Forces amended by the Administrator of the armored and automotive equipment
Source: [Instrukcja… 2013; Koncepcja… 1999].

While drafting the purchasing plan for 2012-2018 and further years by the administrator of the automotive equipment, the concept of gradual replacement of the transport fleet in the group of medium capacity high mobility vehicles and the aspiration to have the biggest modernity index achieved was adopted under 'The plan of Technical Modernization of the Polish Armed Forces'. Effective acquisition of the technology and the restoration of the overhaul life of the equipment in service are dependent from granting the real resources from the budget of the Ministry of National Defense, however, this is outside the administrator's control [Konczak 2016].

The administrator in an effort to save the situation in this group of the vehicles decided to proceed with major repairs combined with modernization of Star 266 model. At that time the modernized version of that vehicle Star 266M2 was developed (in contrast to successful modernization of 292 pieces of Star 266 basic model realized by MAN Company in Starachowice at the beginning of 21^{st} century – the name of the modernized version Star 266M 'Emka' with the cab by Steyer Company and the engine

D0824 by MAN Company. Additionally, the administrator extended the target operation standards of Star 266 from 30 to 35 years, which seems to be a qualified solution due to worn components of braking, pneumatic or wiring systems resulting from long-term operation [Konczak 2016].

However, the works on WZTT continued. The administrator consulted the requests and suggestions of other administrators as for the technical parameters of a new tactical truck. In 2011, the WZTT for acquiring a medium capacity high mobility vehicle were approved by the Armaments Inspectorate [Kaliszuk 2011].

The truck acquisition procedure commenced. Initially pursuant to the Decision No 291/MON, thereafter in the form of public tendering – which did not bring a positive outcome. The Polish arms industry after the years of stagnation was included into the modernization program of the Polish Armed Forces executed by the Ministry of National Defense. By the end of 2013 the Armaments Inspectorate signed the contract with Jelcz-Komponenty Sp. z o.o. for the delivery of specially designed and tailored for the military purposes medium capacity and high mobility vehicles. During XXII International Defense Industry Exhibition (MSPO, Jelcz-Komponenty Sp. z o.o. Company presented its prototype) – 'fit for purpose' according to WZTT from 2011. Jelcz 442.32 is the truck characterized by high mobility, designed in the so-called classic European constructional layout, underpinned on screwed and welded bearing frame with the cab slightly forwarded behind the front axle [Konczak 2016].

2. Analysis and modification of selected WZTT specifications

The initial technical and tactical criteria for high mobility vehicles typically assume that a vehicle should be able to move on hardened and unsurfaced roads as well as on sideways. Nonetheless, neither the specifications determine any average speed of the vehicle nor they include a specific parameter characterizing the percentage of the mileage covered by the vehicle. However, they do contain detailed information regarding a target exploitation standard, interval between periodic maintenance inspections, fault tolerance and reliability.

The vehicle offered for the Armed Forces was designed based on the specifications incorporated in WZTT approved by the Administrator of the Armoured and Automotive Service, Armoured and Automotive Branch of the Inspectorate for Armed Forces Support (IWsp SZ) [Konczak 2016].

While analyzing the design of Jelcz 442.32 submitted for the assessment the scope of relevant amendments in WZTT was determined [Kruk 2001].

The basic vehicle was defined – point 4 of WZTT was refined and the notion was specified: "A medium capacity high mobility car is a vehicle suitable for transport goods/soldiers on the tactical level, of the maximum total weight not exciding 1600 kg and the capacity pursuant to point 5.2.2, with the load-carrying body equipped with sheet and a set of benches (in the balance of the vehicle mass the benches are treated as load) for transport of soldiers. The below-mentioned systems and sub-systems constitute the assembling of the basic vehicle:

– winch,
– transfer case with inter-axle differential gear,
– central type inflation system,
– road wheels with BMI inserts (vehicles with 2, 4 or 6-person unarmored cabs),
– towing bar,
– monitoring operation digital system SAKOT,
– trailers' towing attachments with diameters 40 and 76 mm,
– the vehicle will be equipped with a dual-circuit break system enabling connection with the pneumatic system of a trailer,
– container mounting frame enabling the installation of the 10 and 15 feet container – it applies to a specialized body (container, van body etc. – in the balance of the vehicle mass, the container mounting frame is counted as load)."

It was established that point 5.2.3 should be expunged from WZTT. In two following points the levels of maximum total weight for the version with unarmored (2, 4, 6-person) and armored (2, 4, 6-person) cabs were detailed. It is of utmost importance for *assembling the chassis in which the front axle will be.*

As a result of the analysis the provision of WZTT point 5.2.4 was modified and shall now read as follows: "The maximum total weight (DMC) of a vehicle with the unarmored 2, 4 and 6-person cabin should not extend 16 000 kg with the technical reserve of 10% DMC maintained for each axle."

The provision of 20% technical reserve for each axle was departed – 10% technical DMC reserve calculated for each axle is the condition likely to be achieved for reasons related to the design of the vehicle with the possibility to comply with a single axle loading standards, specified for road transportation, i.e. 8 t for a single axle.

WZTT point 5.2.5 was amended and it is to be read as follows:

"The maximum total weight (DMC) of a vehicle with the armored 2, 4 and 6-person cabin should not extend 18 000 kg."

The vehicle's variant with the 2-person cab was taken into account.

During the process of further analysis the Polish Standard PN-EN-55012:2008/A1:2010 was abandoned in favor of Defense Standards NO-06-A200:2008 and NO-06-A103:2005. The unification of military chassis assures acquirement of vehicles with improved characteristics i.e. lower values of emitted electromagnetic interferences than those determined in the Polish Standard.

WZTT point 5.10.1 was modified and is to be read:

"All medium capacity high mobility vehicles with unarmored cabs (2, 4 and 6-person) delivered under the tender ought to be manufactured with the maximum level of chassis unification and ensure full exchangeability of systems and sub-systems without the necessity of the usage of intermediate elements. Manufacturing a series of the vehicles with armored cabs with modified elements of power transmission, suspension and steering systems is permitted."

The requirement for the so-called multipurpose platform (for unarmored and armored cabs) having all chassis' basic essential elements identical (including driving axles) was abandoned due to economic reasons. In order to reduce costs of the rigid version and other versions with unarmored and armored cabs, mounting the so-called 'lighter' driving axles and other elements which are connected with suspension and power transmission systems was approved.

The provisions regarding standardization documents in WZTT point 5.11.4 were modified (the Polish Standard was abandoned in favor of Defense Standard). The provision concerning the verification of total resistance in point 5.11.5 was withdrawn. Due to the lack of possibility of conducting environmental tests of entire vehicle in the territory of Poland it was decided that research would be conducted based on selected elements – samples.

In WZTT point 5.12.2, sub-point a) the provision on the air transport: '(minimum C-130E class)' was deleted due to the fact that C-130E Hercules aircraft has the load capacity of 19000kg but the loading equipment of the aircraft does not allow embarking a biaxial vehicle of the load exciding 2268 kg on a single axle (according to ATTLA requirements). From the design perspective, the vehicle is adapted to air transportation but by other transport assets (larger than C-130E aircraft) used by NATO or contracted from independent (commercial) air carriers. The possibility of loading the truck into the cargo bay of C-130E was tested in practice and it was proved that Jelcz 442.32 can be loaded moving backward into the aircraft's hold with the sheet and the back side of the load platform removed and with the reduced tires pressure.

WZTT point 5.14.2 was altered for practical reasons with the following wording: "A vehicle should be painted with the paint of RAL 6006 color 'semi-mat'".

WZTT point 5.14.4 was supported with the following phrase: 'A vehicle should be adopted to carry external masking cover – e.g. 'Berberys', in view of popularization of this engineering asset in the Polish Armed Forces.

The provision of point 5.18.1 was modified and it is to be read as follows:

"The transfer case of the vehicle should be equipped with the mechanism enabling additional power take-off (using the gear box or the engine for that purpose is also permissible). The transfer case ought to be two-staged."

The solution with the inter-axle differential gear where the drive would be permanently transmitted on two axles was adopted. This is aimed at increasing the off-road capability of the vehicle, which is to be characterized by high mobility. The provision related to the possibility of shifting to neutral gear and assuring disconnection of the front axle drive was deleted.

In WZTT point 10.1.1, sub-point d) the provision was added it is allowed to use tires manufactured 6 months before the production of the chassis'.

The following provision was added to the WZTT point 11.11:

“The contractor is obliged to deliver three camouflage color profiles for the medium capacity high mobility vehicles, two – in the spring-summer version and one in the winter version for Eastern Europe territory, in accordance with the provisions in force in the Ministry of National Defense, within 8 months since the handover of the first piece (production batch) of the vehicle concerned.”

The medium capacity high mobility vehicles (in rigid version) were painted in RAL 6006 color. On the ground that they can be used in the territory of Eastern Europe, the contractor delivered the camouflage color profiles concerned as variants to adopt the vehicles to be used in assumed tactical conditions.

The provision of WZTT point 12.1 was amended and it is to be read:

“In order to confirm the compliance with specifications incorporated in the Initial Tactical-Technical Criteria (WZTT), the contractor is obliged to provide for tests the medium capacity high mobility vehicle in rigid version with the cab:

- 2-person unarmored,
- 2-person armored,
- 6-person armored.

The tests of the above-mentioned versions will be conducted successively in the full scope according to timelines of the equipment acquisition for the Polish Armed Forces. Whereas the other versions with 4-person unarmored, 4-person armored and 6-person unarmored cabs will be subjected to traction tests in limited scope and the tests with respect to complying with the basic parameters differentiating them from the versions tasted in the full scope.”

The other WZTT provisions were accepted for the implementation both by the contractor for delivery of the vehicles and the accredited testing agency – the Military Institute of Armoured and Automotive Technology in Sulejówek.

However, they do contain detailed information regarding the target exploitation standard, interval between periodic maintenance inspections, fault tolerance and reliability.

WZTT point 5.8 contains the reliability requirements, which specify in details:

5.8.1.1. The vehicle is allocated to following categories and types of reliability indicators:

- category A – a reusable device,
- type II – a device which beside the serviceable and unserviceable states can be located in intermediate states with reduced serviceability,
- a repairable device which can be reconditioned immediately after a failure has been noticed,
- the impact of failures on a task accomplishment – the outcome is proportionate to overall time of proper functioning.

5.8.1.2. Tm ≥ 2000 h, the expected time of proper functioning between failures the expected value of random variable describing the time of functioning between two subsequent failures.

5.8.1.3. Tz ≥ 30 years, the work capacity (the target operation standard) understood as a random variable expressed in calendar years determining the amount of vehicle work since the beginning of its operation until reaching the limit state.

5.8.1.4. Te, z ≥ 380 000 km, the target operation standard resulting from the mileage covered since the beginning of operation until reaching the limit state.

The aforementioned WZTT's criteria were established mandatorily. The method of assessment according to Level I was adopted.

5.8.2. Criteria related to sustainability (work capacity and working time).

5.8.2.1. Te, n ≥ 200 000 km.

The expected time of operation until the capital repair understood as the expected value of work capacity, expressed in kilometers, until the capital repair of the vehicle (if predicted by the vehicle's design).

5.8.2.2. The vehicle is to be suited for 24/7 use.

In the course of testing the vehicle one of the specified requirements appeared to be complicated to meet. It regarded the proper functioning between any failure occurrence on the level greater or equal to 2000 h. What does it mean in practice?

Assume that the average driving speed on a hardened public road equal to 60 km/h. Theoretically, the vehicle ought to drive 120 000 km between failures.

Assume that the average driving speed on unsurfaced roads and sideways equal to 10 km/h. Theoretically, throughout 2000 h the vehicle ought to drive 20000 km between failures.

Assume the average driving speed on a hardened public road in an urban area etc. equal to 30 km/h. Theoretically, throughout 2000 h the vehicle ought to drive 60 000 km between failures.

Having possessed practical knowledge as to the mileages which are annually covered by medium capacity high mobility vehicles it was stated that the annual mileage of the vehicle is characterized by the values of the range 3500…10 000 km. In practice, none of the above-mentioned situations can be fulfilled.

In this case the administrator also abandoned the tough requirement of the expected value of proper functioning between failures – the expected value of random variety that determines functioning between subsequent failures was established as greater or equal to 200 h. This value was positively verified in the course of tests.

As for the intervals between particular periodic maintenances, they were determined by the producer in consultations with the administrator and the Central Logistic Authority (COL) of the armored and automotive equipment. The work capacity (target operation standard) understood as the random variety expressed in calendar years determining the amount of vehicle work since the beginning of its operation until reaching the limit state was accepted on the level Tz ≥ 30 years for this design. Whereas the target operation standard resulting from the mileage since the beginning of its operation until reaching the limit state was adopted on the level of Te ≥ 380 000 km. The service life of the vehicle was declared by the producer on the level of Te = 580 000 km.

3. Reliability tests and simulations

Reliability tests of the vehicles from the group of Jelcz 443.32 were preceded by complementation of the authorial database for operational management, fitting it with the logical and computing algorithm for simulations and testing various groups of military vehicles [Kruk 2001]. The information generated by the database [Radzikowska et al. 2013] at the end stage was subjected to the final processing with the application of functional analyses in Excel program and on an ad hoc in order to verify the calculations in the Matlab environment.

The aim of the conducted analytical tests was the qualitative and quantitative defining the impact of available operational documentation in classical (paper) form on determination of reliability characteristics of medium capacity high mobility vehicles as well as the assessment of the adopted method with the special function in comparison to the classical mathematical model of the description of operational stages of the equipment intensively used after the long period waiting for assignment. Moreover, the influence of adopted determinants was assessed: average mileage between failures, recovery time, average usage intensity, total mileage at the beginning of fulfilling a task on reliability indexes.

The tests were conducted on the bench with the data collected in MS Access and MS Excel auxiliary tables in WITPiS [Radzikowska et al. 2013].

The time interval of one year (Jelcz 442.32 vehicles) to maximum eight years (Star 266) was approved in order to assess operational occurrences.

The collected data were drawn based on military operational documentation [*Instrukcja*… 2013; *Katalog*… 2014; Radzikowska et al. 2013] such as:

- trip tickets and worksheets,
- maintenance verification sheets and invoices,
- exploitation plan.

The operational stages were adopted as discrete values and the time as the constant interval T = from 365 to 2922 days.

The average operational intensity (*qśr*) was determined as the quotient of the annual vehicle mileage related to 356 days.

The authorial method for calculating the probability of the proper functioning of medium capacity high mobility vehicles with the use of Weibull distribution was implemented.

Figure 2 presents the characteristics of mileages between failures for the tested Jelcz 442.32 medium capacity high mobility vehicles. It was proved that the failures occurring before reaching the mileage of 3000 km belong to the group of failures stemming from design, technological, assembly or production defects. The majorities of defects oscillate around the average mileage value between failures, which is equal to 7000 km and compatible with new requirements, as well as was proved by qualification studies in WITPiS [Kruk 2001]. The tendency of the Su parameter growth with the increasing usage intensity after elimination of production defects was observed.

The analysis of the medium capacity high mobility vehicles' functional systems was conducted and the older generation vehicles were correlated with the new ones. The results are depicted in Table 1.

The characteristics of probabilities of the occurrence in inherent and task readiness for two selected pieces of Star 266 and 2 pieces of the new Jelcz 422.32 vehicles were prepared.

Star 266 vehicles, which became damaged more than 10 times within 8 years of operation, were used to illustrate operational and recovery stages. The cases with registered 1, 2 or 3 defects were omitted.

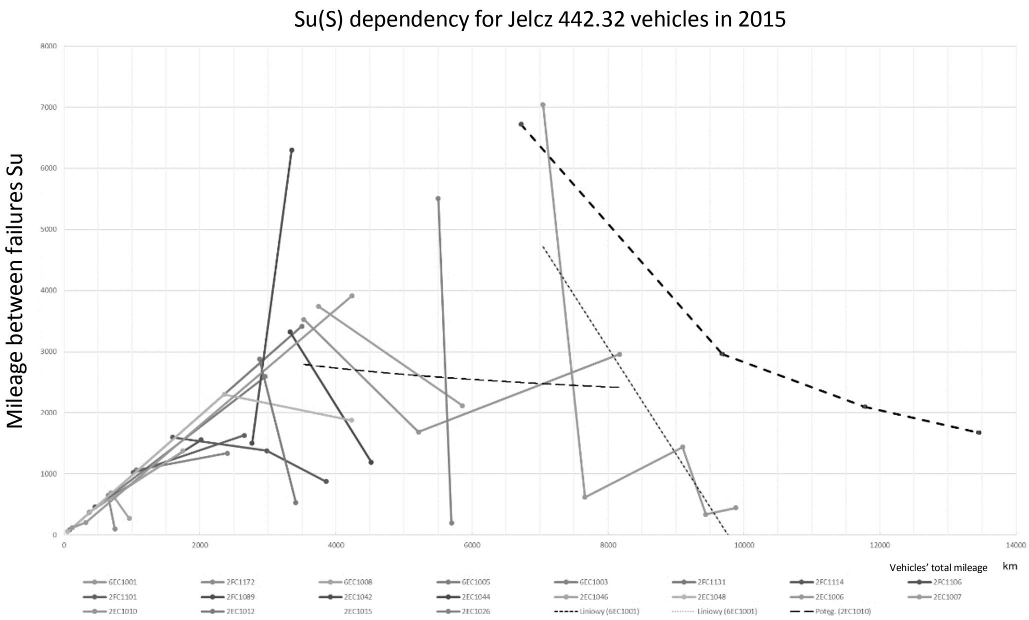

Fig. 2. Dependency of total mileages between failures in the function of the total mileage of Jelcz 442.32 vehicles

Source: [own elaboration].

Table 1. Number of failures of tested specimens and values of mean times of repairs and distances between failures

Jelcz 442.32			Star 266		
Number of failures in the specimen	MTBF Mean Time Between Failures [km]	MTTR Mean Time to Repair [h]	Number of failures in the specimen	MTBF Mean Time Between Failures [km]	MTTR Mean Time to Repair [h]
56	6800	7.2	339	1534	118.6

Source: [own elaboration].

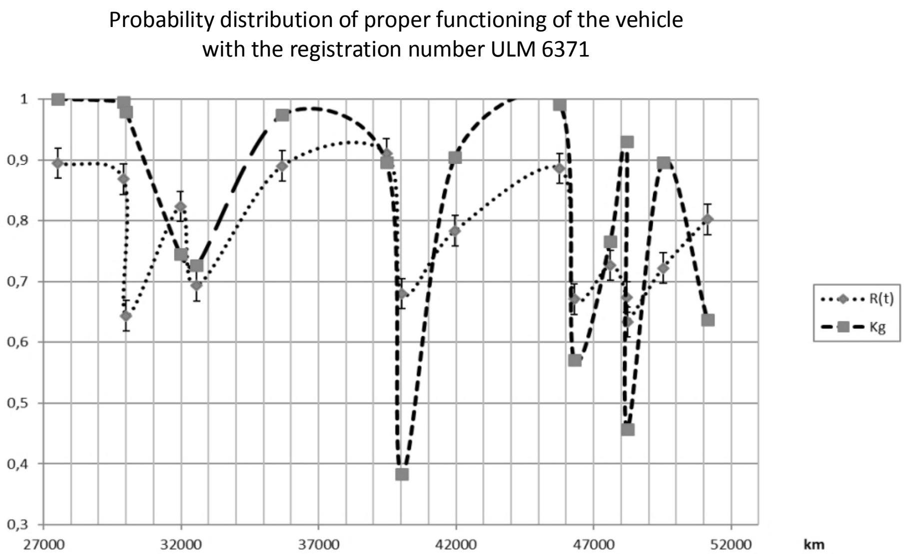

Fig. 3. Determined probability values of Star 266-1 proper functioning
Source: [own elaboration].

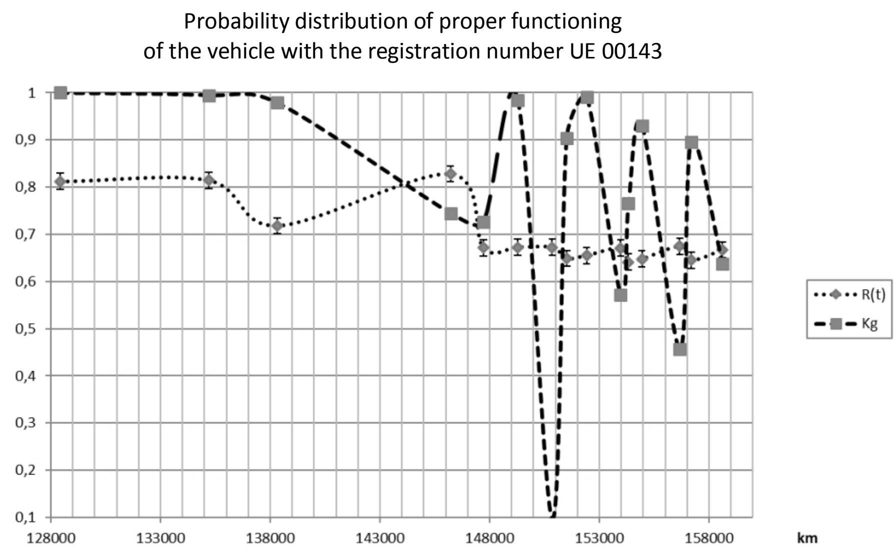

Fig. 4. Determined probability values of Star 266-2 proper functioning
Source: [own elaboration].

Figures 5 and 6 depict two characteristics of proper functioning probabilities of Jelcz 44.2.32 vehicles selected from five vehicles, for which more than one important failure was registered within one year of operation since the production date.

Probability distribution of proper functioning
of the vehicle with the registration number 2EC 1042

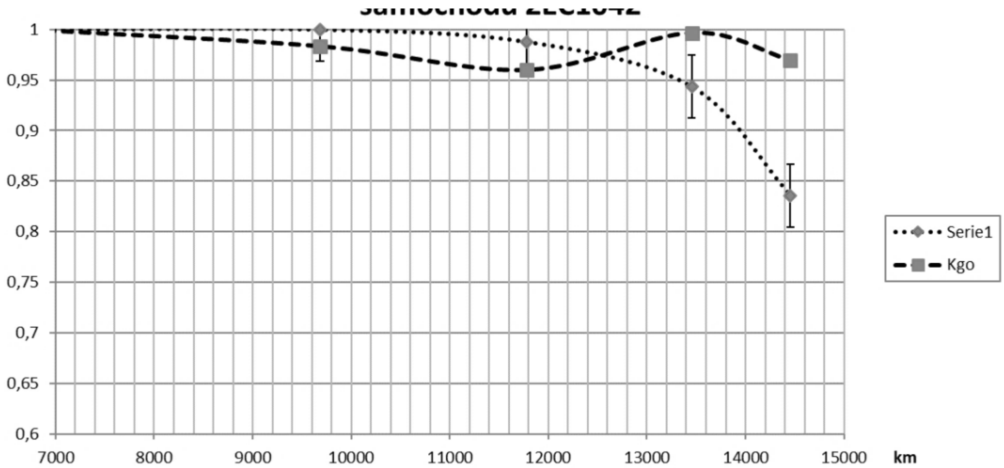

Fig. 5. Determined probability values of Jelcz 442.32-1 proper functioning
Source: [own elaboration].

The result of simulation tests proved the significant impact of usage intensity on the mean time between failures' values and total mileage. The findings of simulation tests turned out to be similar to those achieved during the tests of Jelcz 442.32 prototype.

Probability distribution of proper functioning
of the vehicle with the registration number 6EC 1001

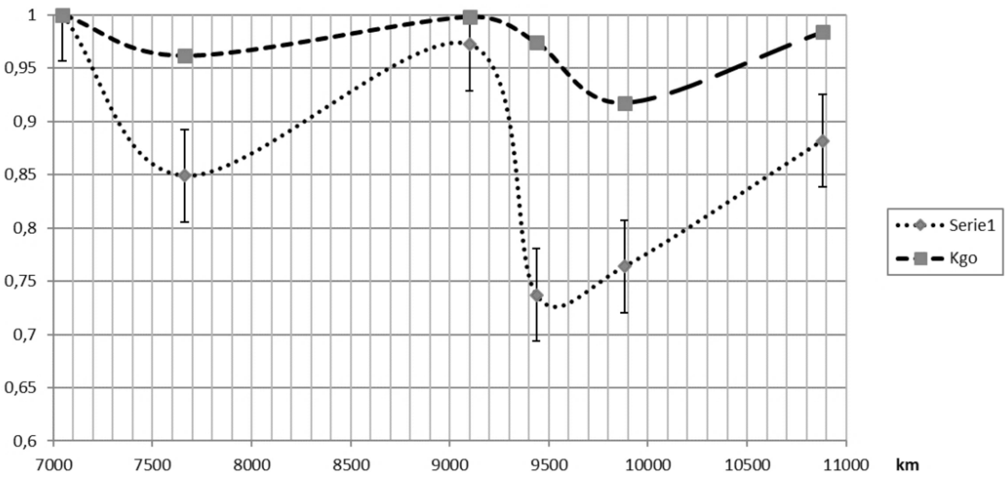

Fig. 6. Determined probability values of Jelcz 442.32-2 proper functioning
Source: [own elaboration].

Conclusion

The following conclusions were formulated based on the analysis of selected criteria contained in WZTT:

– drawing the appropriate specifications for military vehicle should be preceded by the in-depth analysis of current conditions of vehicles from a given group and consultations with a research agency as to the possibility to meet technical and financial requirement,

Table 2. Comparison of reliability indicators of analyzed military vehicles construction

Vehicle	Indicator's appellation Unit of measure Symbol and dependency						
	Average mileage between failures	Average intensity of failures	Average recovery time (repairs)	Average intensity of recovery	Average intensity of operation	Readiness indicator	Operational readiness indicator
	km	1/km	h	1/day or 1/km	km/day	–	–
	$S_{uśr}$ S_{avg}	$\lambda = \frac{1}{S_{avg}}$	t_{avg}	$\mu = \frac{1}{t_o}$ or $\mu = \frac{1}{t_o \cdot q}$	q	$K_g = \frac{S_u}{S_u + t_o \cdot q}$	$R(\tau)$
Star 266	1564.6	0.000639	49	0.020 or 0.6517	13.81	0.66…0.85	0.54…0.73
Jelcz 442.32	6800	0.000128	14	0.5 or 0.0272	18.36	0.92…0.98	0.82…0.89

Source: [own elaboration].

– medium capacity high mobility vehicles were subjected to the process of renovation. Deliveries of Jelcz 442.32 vehicle, specially designed for military purposes, contribute to improving the service life reserve. In this regard, the vehicles with overrun service life require being decommissioned. The armored and automotive COL fulfills its undertakings properly in this field, taking into account the current requirements of the Armed Forces in this group of equipment,

– while determining the probabilities of military vehicles proper functioning (without critical defects precluding a vehicle from execution a mission) the application of Weibull or exponential distributions becomes reasonable due to the fact that the potential failures are of random character and are regarded as the result of operation and natural wear and tear in line with the mileage covered or the time of the service in the Armed Forces,

– prior to coming into military service a vehicle should undergo the cycle of qualification tests in order to eliminate failures resulting from design and technological defects,
– the performance data of a vehicle gathered during initial years after introduction into the military service constitute the valuable source of information regarding reliability of vehicles characterized by intermittent and minor average intense usage in comparison to vehicles used by civilian entities.

Monitoring of performance data enables to verify the specifications and confirm the accuracy of adopted criteria of the implemented military equipment.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

ORCID

Jaroslaw Konczak – The author declared that he has no ORCID ID's

Marcin Walkiewicz – The author declared that he has no ORCID ID's

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