

## IMPACT OF THE DECISION ON TRANSPORT SYSTEMS' RELIABILITY IN EMERGENCY SITUATIONS

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### **Summary:**

*In the study, the authors focused on determination of reliability indicators of the transport systems, which currently constitute the Polish Armed Forces' equipment. The methods of research of car fleets composed of distinct types of vehicles are presented. The algorithms of reliability indicators' determination addressed in the study can serve to analyze other set of transportation means used in rescue, seasonal transport and specialized transportation assignments, as well as to determine the security level of any mission conducted. The appearance of information technology allowed transferring the paper-based registration system of operational occurrences into an integrated information system. It enables to follow the history of transportation fleets including single pieces of the equipment. The knowledge of reliability of particular types of the vehicles allows for proper planning of missions within the framework of possessed transport assets capacity. The study presents the method of achieving the intended objective to increase the effectiveness of management of motor vehicles fleet used intermittently. The algorithm for the selection of a vehicle or a group of vehicles for execution of tasks, developed on the basis of analytical procedures, envisages the assignment of mobile assets, complication and complexity of their structures, the level of modernity, operational history and branch regulations. Determined reliability indicators for particular groups of vehicles can be implemented into the Multilevel Information System*

### **Keywords:**

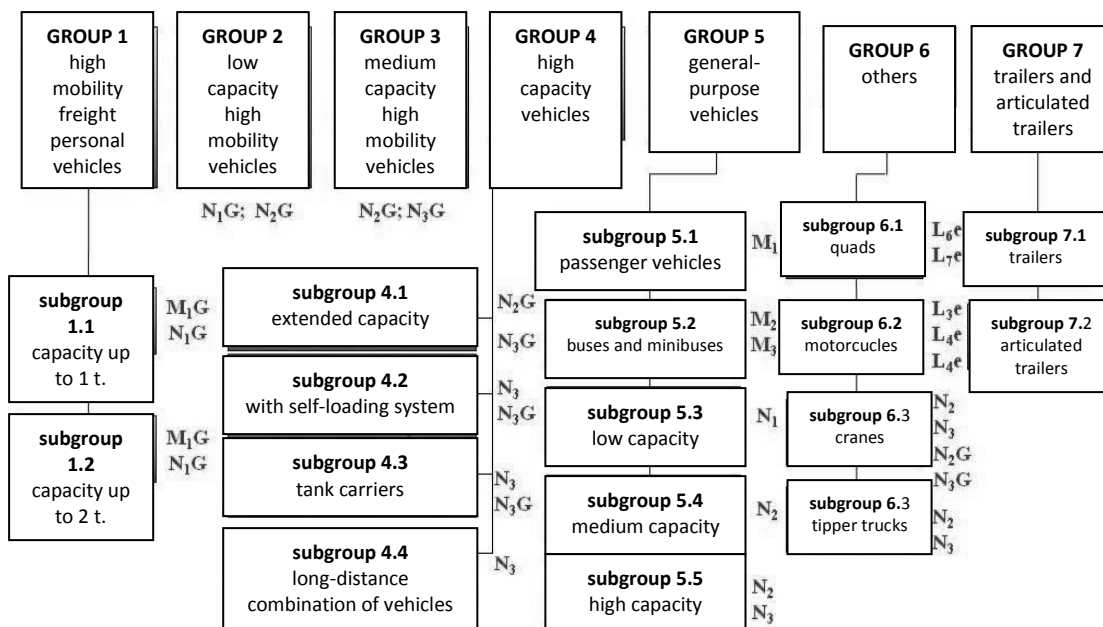
*reliability, transport systems, security*

## INTRODUCTION

Each army within its operational activity uses technical devices and military equipment that assure execution of tasks received by a state's military forces. These services in turn can be divided into combat, training, logistic and others depending on a current situation. At present, the quantity of possessed pieces of equipment does not determine the benchmark of the equipment efficiency, but it is shaped by appropriate and seamless functioning of essential components of a single piece of military equipment. A trained military transportation formation equipped with operable vehicles would accomplish a task according to the intention developed by a higher echelon simultaneously maintaining minimal own losses.

### 1. MILITARY TRANSPORTATION SYSTEM

The motor transportation's structure of the Polish Armed Forces was developed on the eve of joining NATO by Poland. While elaborating the structure, the thorough analysis of similar solutions in other leading NATO armies was conducted by an interdisciplinary team of military experts headed by specialists of the Military Institute of Armoured and Automotive Technology (WITPiS). The structure depicted in Figure 1 represents the requirements of the Alliance, which impose the adequate classification of the Polish Army vehicles.

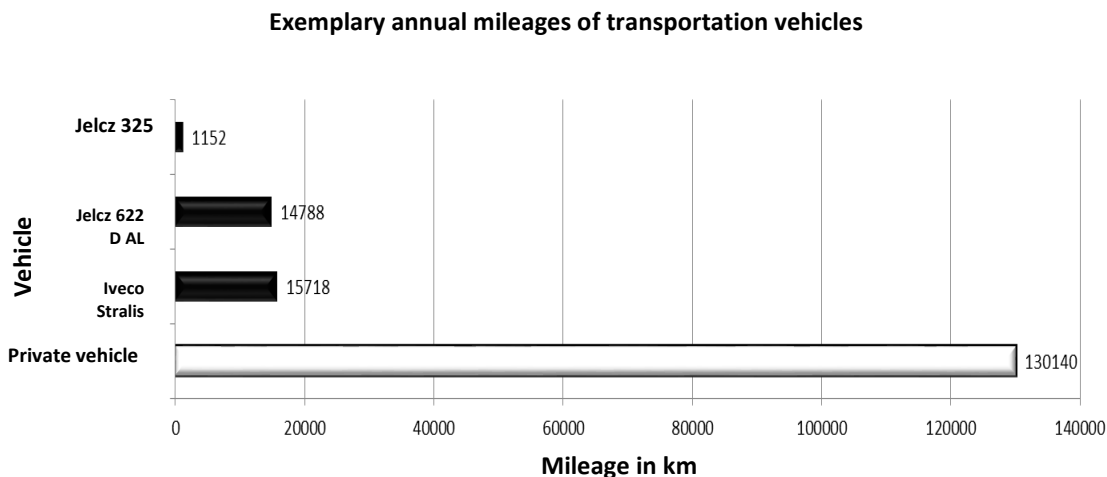


**Fig. 1.** Structure of the motor transportation assets of the Polish Armed Forces amended by the Administrator of the armored and automotive equipment [4] [1]

Source: Kończak J., Kalwasiński M., „Pozyskiwanie technicznych środków materiałowych w procesie odtwarzania sprawności technicznej sprzętu wojskowego”

Classification of a vehicle to the adequate group according to The Concept of Road Transportation Structure of the Polish Armed Forces [4,15], in case of transportation assets, plays significant role in the adopted modus operandi while determining the in-

dicators of stationary or operational readiness. Table 1 supports the above assumptions.



**Fig. 2.** Comparison of annual mileages of military vehicles (marked in black) with a vehicle used by a private company

Source: own elaboration

**Table 1.** Features of taxonomy division of vehicles into generic groups [15]

Taxonomy division criteria		Group of vehicles according to the concept												
		1	2	3	4				5					
					4.1	4.2	4.3	4.4	5.1	5.2	5.3	5.4	5.5	
Level	tactical	•	•	•	•	•								
	operational and central				•	•	•	•	•	•	•	•	•	•
Mobility	high	•	•	•										
	extended				•									
	no requirements					•	•	•	•	•	•	•	•	•
Capacity	low	•	•								•			
	medium			•								•		
	large				•	•	•	•						•

Source: *The Concept of Road Transportation Structure of the Polish Armed Forces*

The vehicles from the groups 1, 2 and 3 are characterized by high mobility, are designed to move on heterogeneous miscellaneous surfaces to overcome off-road obstacles. In order to comply with the tactical level specifications these vehicles are characterized by low (from 1 to 4 tones) or medium capacity (up to 7 tones) and are

equipped with systems and mechanisms that assure high mobility. Hence it follows the complication of those vehicles design.

Groups 4 and 5 consist of variants of vehicles commonly used by the civil sector, which are adopted for military purposes. They are equipped with typical, commercial components and functional (including executive) systems enabling transportation of goods and additional devices (group 4 vehicles) e.g. mobile cranes, hook systems or flatbed trailers. The construction of vehicles' chassis is characterized by lower number of components and systems, which reduces the risk of occurrence of failures.

## **2. OPERATIONAL DATA OF TRANSPORTATION VEHICLES**

In the previous period (1960-2010), developed executive logistics with fully manned functional divisions i.e. material and technical with branch heads, officers and non-commissioned officers for operation and supply existed in each military unit. The logisticians were supported by clerks at their work – civilian personnel (PW), whereby recording the operational occurrences posed no difficulty. The reform of logistic structures motivated by savings from the budget of the Ministry of National Defense for the so-called personnel costs (maintaining soldiers and civilian workers) had positive effect in terms of significant reduction of financial contributions for maintaining considerably decreased personnel of logistic branch. However, the regulations concerning the use of military equipment (SpW) were not amended which did not facilitate the operational management for the new structures in Military Support Units (WOG).

The time of accumulation the tasks has come for logisticians, where the nature of supported units (e.g. the Air Forces, the Land Forces, the Navy or other special formations such as the Military Police and the Special Forces) is to be taken into account, with small-scale structures of branch sections which within 8-hour typical duty time are not capable of processing the information coming from supported units, reach proper decisions and generate logistic documentations. It must be stated that the human resources working in logistics are overburden.

Trip tickets (equipment worksheets) or maintenance worksheets, depicted in Figures 3 and 4, constitute the basic documents that accompany the operation of transportation vehicles.

It is worth noting that pursuant to the regulations in force in the Armed Forces in this area, trip tickets are destroyed after two years, whereas maintenance worksheets are subjected to destruction after five years. Based on those documents the utilization plan of military equipment is kept. However, manual entry of data carries the risk of, for example, an erroneous record. It is to be stated that the data related to the utilization of transportation vehicles are dispersed and the system-based tool owing to which manually recorded operation documentation would serve as a source of data regarding reliability of vehicles does not exist. The access to the information about dates, mileages and defects becomes limited or impossible. Thus, the idea of their collection in the digital form of a database package arose.

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Marka pojazdu (sprzętu) Iveco Stralis nr rej. WC-0398A grupa 1 przyczepa nr rej. W-0100A

Kierowca p. Józef Woźniak Podstawa 14000000000000000000

Dysponent	p. Woźniak J.	p. Woźniak J.	p. Woźniak J.	p. Woźniak J.	p. Woźniak J.	p. Woźniak J.	Przebieg jazdy (licznik)																
							1	2	3	4	5	6	7	8	9	10	11	12	13				
Trasa	Katowice	Katowice	Katowice	Katowice	Katowice	Katowice	300	200	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cel wyjazdu	Praca	Praca	Praca	Praca	Praca	Praca																	
Rodzaj przewozu	Transport	Transport	Transport	Transport	Transport	Transport																	
Pojazd wystąpił z parku	data, godz.	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00	20.09.2016	10:00

Data	Trasa	Stan licznika	Rozliczenie pracy pojazdu (sprzętu)																				
			1	2	3	4	5	6	7	8	9	10	11	12	13								
20.09.2016	Katowice - Katowice	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000

**KARTA USŁUGI TECHNICZNEJ** 91/W1/2016

WYKONAWCA: Warsztat GZ 22 MARKA I TYP SPRZĘTU: JELCZ 622 DAL NUMER: U102790 SPRZĘT NALEŻY DO: 10 Blag Dąbiec TERMIN WYKONANIA: 15.09.2016

ZADANIE: Wykonac NB - naprawa układu hydraulicznego podnoszenia kabiny, wymiana uszczelki pod głowicą, (pomoc w drodze) p. Józef Woźniak 15.09.2016

Zadający: szef. warsztatu p. Józef Woźniak (data, dzień)

W ZOBACZENIU WYKONANO (BADANIE DIAGNOSTYCZNE) STWIERDZONO KORNICZNOŚĆ WYKONANIA NASTĘPUJĄCYCH PRAC:

UWAGI PRZYMUJĄCE:

Nr dokumentu: I-811129 Stan licznika km: 193374 Stan licznika mth:

Lp	Opis prac, czynności	Zupełn.	Data wykonania	Wykonano	Podpis	Zużycie części i materiałów		Ilość	Nr asygny	Uwagi
						Wyszczególnienie	Odzwierciedlenie katalogowe			
1	Demontaż głowicy, wymiana uszczelki uszczelnienia	100%	15.09.2016	Wykonano	W. Woźniak	Wielkość pod głowicę	533071070257	1	193374	
2	Montaż głowicy, wymiana uszczelki uszczelnienia	100%	15.09.2016	Wykonano	W. Woźniak	Wielkość pod głowicę	533071070257	1	193374	
3	Wymiana uszczelki hydraulicznego podnośnika kabiny, wymiana uszczelki pod głowicą	100%	15.09.2016	Wykonano	W. Woźniak	Wielkość pod głowicę	533071070257	1	193374	
4	Wymiana uszczelki hydraulicznego podnośnika kabiny, wymiana uszczelki pod głowicą	100%	15.09.2016	Wykonano	W. Woźniak	Wielkość pod głowicę	533071070257	1	193374	

Fig. 3. Exemplary trip ticket issued for large capacity Iveco Stralis vehicle

Source: own elaboration

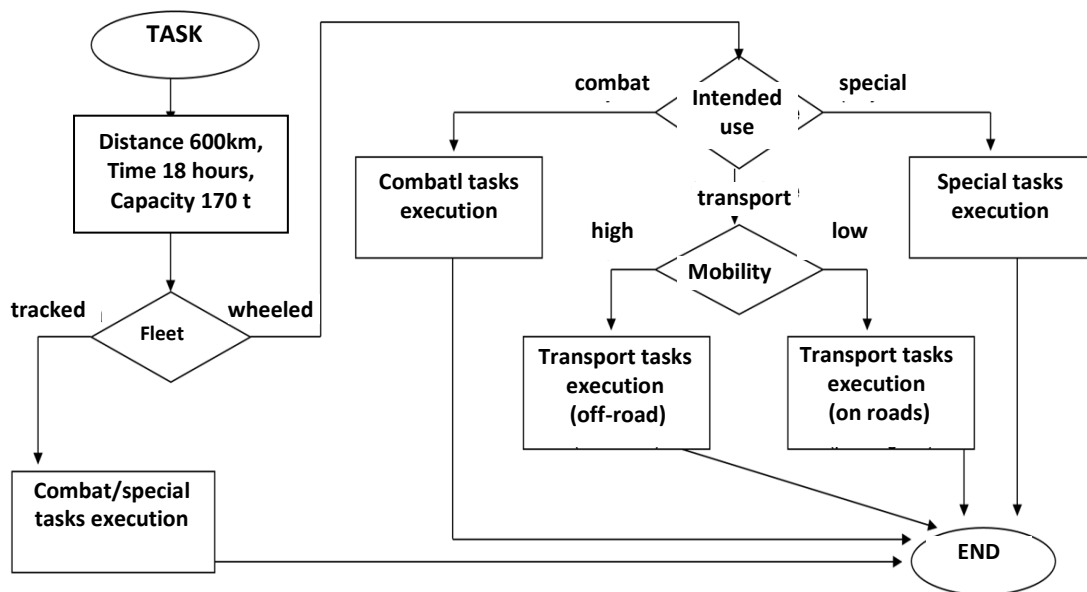
Fig. 4. Exemplary maintenance worksheet issued for large capacity Jelcz 622 DAL vehicle

Source: own elaboration

### 3. RELIABILITY OF MILITARY TRANSPORTATION VEHICLES

The idea describing the adopted method of the database creation together with the algorithm (Fig. 5) consists in the application of:

- a set of military provisions collected in branch manuals of distinct logistical services – e.g. armored and automotive or POL,
- the currently functioning system of operational occurrences recording (more than 60 years in service) and human habits (human factor) in this area,
- innovative technical solutions (telematics) for monitoring technical condition, logistic condition and location of vehicles,
- the simplified proxy of ZWSI RON system PM module in the form of an authorial information system for collecting and processing data according to proposed algorithms regarding vehicles and registered operational occurrences.

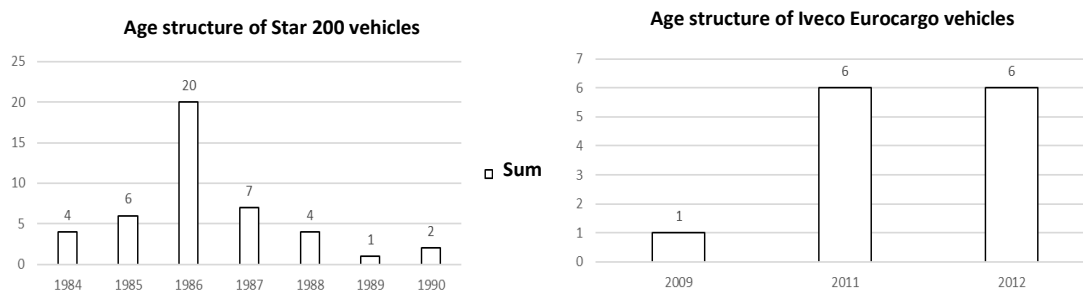


**Fig.5.** Graphical illustration of the method (own study).

The algorithm can be applied for all the Polish Armed Forces; vehicles (wheeled and tracked)

The conducted research of transportation assets risk estimation of the use covered:

- preparation of characteristics: the age structure of tested vehicles and annual consumption of operation limits;
- preparation of inherent and task reliability characteristics of tested vehicles in the function of total vehicle mileage;
- designation of limiting probabilities of transition between operation stages;
- Figure 6 presents exemplary age structures for selected sample of 56 general-purpose medium capacity vehicles.

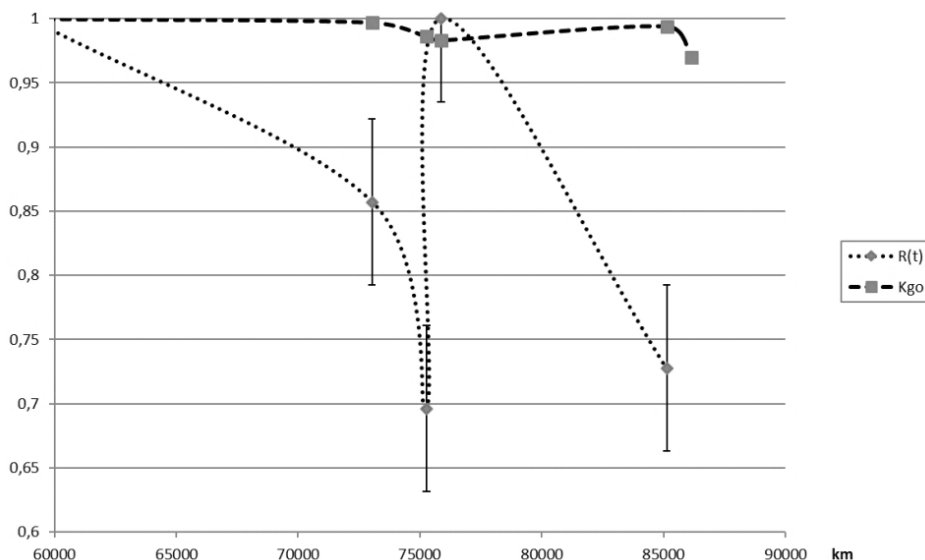


**Fig. 6.** Age structures of tested samples of Iveco Eurocargo and Star 200 general-purpose medium capacity vehicles

Source: own elaboration

The reliability characteristics of the analyzed transportation assets were compiled while conducting the research. They take into account a vehicle’s natural tear and wear over the time and mileage covered.

**Probability distribution of proper functioning of the vehicle with the registration number UC 02191**



**Fig. 7.** Exemplary reliability characteristics of Iveco Eurocargo general-purpose vehicle

Source: own elaboration

Reliability indicators for transportation vehicles were determined after the tests. They were summarized in Table 2.

**4. EHICLES’ OPERATION TARGETED AT RELIABILITY**

The Polish Armed Forces possess the specialized mobile military equipment, which cannot be sourced from the national economy in case of a crisis or a war outbreak. Prototypes of military vehicles are subjected to a cycle of qualification tests [3,14,16]. During such tests the design errors, described as ‘teething problems’, are eliminated.

Thereafter, they come into military service waiting the long-term period for a task. It is characteristic for operation of military vehicles in the peacetime conditions. Therefore, occurring defects or failures will be associated with natural operational tear and wear, escalated by erosion or corrosion factors of structural materials. The application of the distribution of the exponential character seems to be legitimate to describe the above-mentioned phenomenon, where inoperativeness stages are a random variable not possible to be precisely determined [12, 13]. For that matter, the orientation of military equipment management towards reliability – RCM method was adopted [7,8, 9, 10, 11].

**Table 2.** Summary of reliability indicators of selected vehicles

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	-	-
	$S_{avg}$	$\lambda = \frac{1}{S_{avg}}$	$t_{avg}$	$\mu = \frac{1}{t_o}$ or $\mu = \frac{1}{t_o \cdot q}$	$q$	$\frac{K_g S_u}{S_u + t_o \cdot q} =$	$R(\tau)$
Star 200	1590,1	0,000628	53	0,0188 or 0,00595	8,27	0,68..0,88	0,59...0,79
Iveco Eurocargo	13062	0,000076	14	0,071 or 0,000925	33,1	0,92..0,99	0,69...0,96
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	7800	0,000128	14	0,5 or	18,36	0,92..0,98	0,83...0,94



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 0,0272	km/day	-	-

Source: own elaboration

Monitoring of technical conditions in an information system (recording/entering information regarding operation occurrences) and utilization of the information concerning reliability from a single piece of the military equipment up to a group of the equipment enables the possibility of the military technology operation process management with the application of the RCM method – oriented toward reliability.

Owing to such the approach, measurable economic effects during preventive maintenance aiming at elimination of corrective maintenances can be achieved. During operation of transportation systems the reliability of the entire fleet is of the significant importance. An interesting view on that issue was presented in a publication [17] related to intermodalrapid transport.

### 5. TELEMATICS AND INFORMATION SYSTEMS

Development of information technology by the end of the 20<sup>th</sup> century resulted in PC-class computers appearing in the military since the mid-1990s. Modern computer equipment possesses such a powerful computing power that processing information collected in databases created e.g. in common programs of commercial MS Office packet such as: MS Excel or MAS Access does not pose any issues during their processing. It has practical application - in everyday work [3]. A program designated to integrate the wide-ranging management including quantity/value recording, human resources field and material management into a single information system has been under development in the military.

The works on creation of the Integrated Multilevel Information System of the Ministry of National Defense (ZWSI RON) started from the indexation of the Armed Forces' property. Despite the recording modules, ZWSI RON provides the module called 'PM' for logisticians – for operational management. The amount of data which will require

to be manually entered by ZWSI RON operators is so significant that demands a substantial labor, extending working hours provided by the legislation [1, 2]. During their daily work in WOGs, logisticians are forced to process a significant amount of information and answer questions from superiors' side. A PC with a database application developed in the MS Access program can be used for this purpose. The operation management package, which is successfully used in 2 RBlog (2 Regional Logistic Base) and WITPiS was developed in 14 WOG [2, 4, 5, 6]. The facilitation of tasks execution resulting from the provisions regulating the activities of technical services in support and military units and the automation of military motor vehicles fleet management with confined to minimum manning of armored and automotive sections in WOGs constitutes the essence of the suite depicted in Figure 11.

The software package requires standard accessories in the form of a PC-class computer with the Windows system, connected to MILNET-Z network and with Access 2017 or 2010 database of MS Office. The package allows for creating any number of simplified database's copies used in individual branches of military units and WOGs. The package has the qualities of resistance against entering incorrect data by a user, preventing their duplication. The work with the package necessitates individual clearing of a single trip ticket, a worksheet or a maintenance worksheet in a classical way with the application of traditional computing methods, in accordance with the provisions of POL and armored and automotive branches. However, as soon as the data are entered on a monthly basis, the summing as per groups of vehicles or a type of fuels is not required. The data are automatically processed in the technical-economic analysis and the operation plan of the military equipment. Additionally, the package supports the settlement of the workshop work through generating maintenance worksheets.

EKSPLLOATACJA FORMULARZ

Znajdź nr rejestracyjny UC02781 Edytowanie

Nr rejestr. UC02781 MARKA IVECO STRALIS

SAM. OGÓLN. PRZEZN. ŁAD. IVECO STRALIS Grupa ekspl. E

Limity Przebiegi i zapasy Przydział Normy eksploatacji Dane techniczne Plan obsł. gwarancje Pojemności ukł. adów Wymiana liczników Dokumenty materiałowe

Rodzaj paliwa: ON

Odśwież

Zużycie przebiegów i paliwa z lat poprzednich			
Rok	Km	Mtg	Paliwo
2012		0,0	10556
2011		0,0	0

Limit:		
przydzielony	wykorzystany	pozostały
Limit km	25 000,0	13 879,0
Limit mtg	0,0	0,0
Limit paliwa	7 500,0	4 848,0

Przewidywane zużycie paliwa 9 375,0

Suma limitów dla JW według rodzaju paliwa

Jednostka Wojskowa	JW	Limit w kg	Limit w litrach
JW 4226	ON	271520	323 238,1

Suma zaplanowanego limitu km 1 627 190,0

Suma zaplanowanego limitu mtg 12 033,0

Suma zaplanowanego limitu paliwa w litrach 368 399,7

Pozostały limit paliwa: 327 957,6

Przepracowane kilometry: 205 539,0

Wykorzystanie limitów

opcje limitów	Marka	Nr rej.	Limit paliwa	Pozostały limit paliwa	Pozostałość limitu procent
<input type="radio"/> Przekroczony limit km	AUTOSAN H10	UD00727	2 800,0	2 800,00	100,0%
<input type="radio"/> Przekroczony limit mtg	AUTOSAN H10	UD00849	3 360,0	3 360,00	100,0%
<input type="radio"/> Przekroczony limit paliwa	AUTOSAN H10	UD00868	3 360,0	3 360,00	100,0%
<input type="radio"/> Wykorzystanie limitów w %	AUTOSAN H6	UD00869	1 760,0	1 760,00	100,0%
	AUTOSAN H9	UD00883	260,0	260,00	100,0%
	AUTOSAN H9	UD00238	1 300,0	1 300,00	100,0%

Fig. 8. General view of operation management panel in MS Access application

Source: WITPiS

Performed preventive maintenances and repairs noted in the system are automatically transferred to the operation plan. The packet facilitates in a transparent manner the management of an equipment fleet on the WOG (equal) or military unit level. The establishments (tables of equipment) of military units or sub-units being supported in accordance with the logistic allotments plan were addressed in the package. The package allows for the management of equipment groups depending on the allocation to a relevant group: equipment in service (group E) or in storage (group K) taking into account a type of the storage e.g. short-term, long-term or with the application of static or dynamic dehumidification.

Information technologies despite the development of equipment facilitating office work are also used in the automotive technology. Contemporary vehicles, mainly due to requirements regarding ecology and economy of have been equipped with a whole range of sensors, electronically controlled executive systems and, naturally, the heart of a vehicle information system - the onboard computer integrating and managing other computers e.g. the ABS braking system, filter-ventilation and air-condition systems, suspension, gear box or computer controlling an engine. The following statement was proposed 'What if a vehicle was able to communicate with a computer of an armored and automotive section head or with a repair bench in a maintenance battalion?'

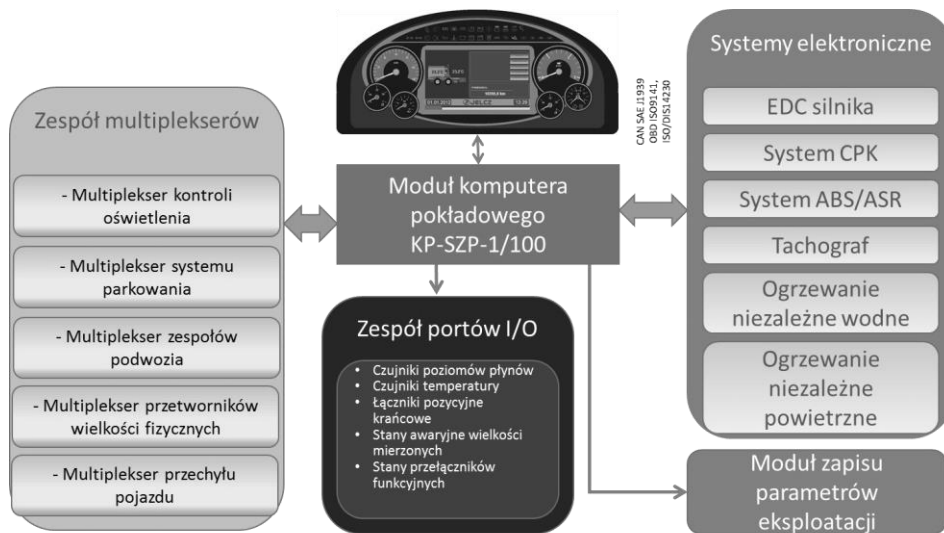
A significant number of the military vehicles branch personnel would answer – 'Impossible' However, the answer to the question is reversed despite the fact that requirements regarding operational management of the equipment used in the Polish Armed Forces divert significantly from the realities of the operation of civilian vehicles (where generating a profit for a company constitutes a supreme value).

### **5.1. The Polish solution - proposal of Jelcz sp. z o.o. company**

The Jelcz Sp. z o.o. Company manufacturing various versions of trucks for the Polish Armed Forces considers maintaining the required reliability indicators of road vehicles with the priority. For that reason it sees the correlation between recognition of failures and passing the instructions related to periodic maintenances to a crew. Therefore, it offers the Vehicles Automatic Service Control System in the new produced vehicles of Jelcz brand (Fig. 12), which enables execution of tasks within granted permissions on appropriate levels:

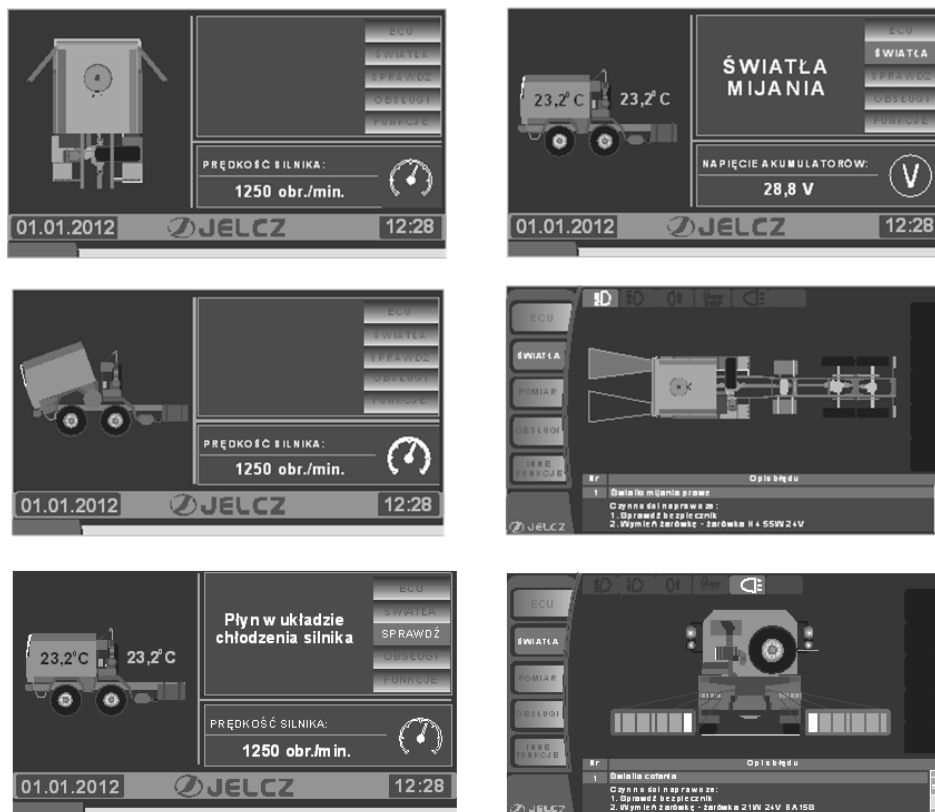
- level 1 - a driver - current information regarding operation of a vehicle and repair activities associated with recognized defects which can be fixed with the use of an onboard toolset;
- level 2 - diagnostic - designated for technical services, with the full access to the complete diagnostics of electronic systems installed in a vehicle and with the access to encrypted data, according to the rights granted by system administrators;
- level 3 - vehicle fleet management - designated for vehicles operation management (WOG and higher e.g. the Armored and Automotive Department of the Inspectorate for the Armed Forces Support) enabling the full access to entire data registered in the system.

Retrofitting of the on-board computer with the operation control and preventive maintenance management systems pursuant to the military provisions in this area is the original solution of Jelcz engineers.



**Fig. 9.** Functional diagram of the on-board SAKOP system by Jelcz Sp. z o.o. Company [2]

Source: *Inventory of operational occurrences of the armored and automotive equipment in peacetime, a look in the future*



**Fig. 10.** Selected functions of SASOT system by Jelcz Sp. z o.o. Company [2]

Source: *Possibilities of perfecting technical support in combat operations, Waplewo*

In the system the prompts/messages (Fig. 13) for a driver or a serviceman within the actions necessary to perform and essential consumables during preventive maintenance or possible repair were transparently implemented. The system registers all operational occurrences (with the accuracy up to a day, an hour, a minute and a driver operating the vehicle) that can appear in a vehicle. The system allows for exchanging information between a vehicle and a maintenance service as well as an operational manager in a military unit, which facilitates the management of the vehicle or the entire fleet on the tactical or operational levels. The communication is executed through a widespread standard USB port. Crucial information is transferred in the correct sequence in the so-called 'data packages' that can be read on a PC-class computer with the use of an Internet browser or MS Excel program. The SAKOP system and its newer version SASOT (the Vehicles Automatic Maintenance Management System) are characterized by the open architecture. In the near future transferring data for operational management in military units/WOGs will be possible in the wireless form [2].

A computing and reporting algorithm regarding the status of technical readiness on relevant levels of command in the Polish Armed Forces is under development in WIT-PiS. The algorithm envisages the risk level of a mission execution, set by the system operator, which during the decision-making process will allocate transportation tasks for individual vehicles. If the level of the operational readiness of the individual vehicle is lower than the risk level then the system will not allocate this vehicle to conduct the mission. Otherwise, the issued task, with high possibility, will be executed correctly.

Development of a computer application that collects the data obtained from a single vehicle and transfers them into the ZWSI RON PM module becomes necessary. At present there is possibility to integrate new trucks, of Jelcz 442.32 type, equipped with SASOT with the simpler authorial application developed with the adoption of the MS Access environment and in the near future with the ZWSI RON system [2].

## CONCLUSIONS

Among the users there is the existing demand for the information system facilitating operational management of vehicles in the Polish Armed Forces through the planning support of widely understood recording of operational data, analyzing the units and consumables as well as generating data inventories and basic documents.

Further research and implementation of the reliability criterion of the assessment of vehicles technical conditions in the Polish Armed Forces ought to be conducted with the time of an object staying in various operational stages applied as the primary criterion. Collected data regarding the mileages covered should constitute a complement in the management system of military motor vehicles fleet. The information system smoothly provided with 'on-time' and 'on-line' information about the status of directed objects should form a basis for the management

The commencement of the use of vetronics represented by the Vehicles Automatic Maintenance Management System should assure the constant monitoring of technical conditions of selected systems of vehicles, which enables the effective management of

preventive actions, reducing the probability of a vehicle failure occurrence and the risk of a transportation mission success.

The algorithm, developed and tested on the MS Access database platform, offers a real opportunity to be implemented into the ZWSI RON information system as the complement of its operational management PM module. The network accessibility in the military structures to the ZWSI RON system constitutes the additional advantage of the solution adopted. Only such the approach will guarantee the optimal management of the vehicles fleet in the peacetime, crisis and war situations.

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