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THE ROLE OF PREVENTIVE MAINTENANCE OF FLEETS POWERED BY CONVENTIONAL AND ALTERNATIVE FUELS IN ROAD TRANSPORT OF DANGEROUS GOODS

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Abstract: The paper surveys two companies that have homogeneous fleets for the transport of dangerous goods. The observed companies use fleets of various propulsion, conventional diesel fuel and compressed natural gas to carry out the transport process, and strive to ensure greater reliability and availability of vehicles at the lowest possible cost of preventive maintenance. In that sense, the role of preventive maintenance of fleets with different propulsion, diesel and compressed natural gas is analysed, and differences in terms of construction and operational characteristics of vehicles, procedures and costs of preventive maintenance are presented. Fleet managers must take into account environmental impacts, requirements and regulations defined in the European Agreement concerning the International Carriage of Dangerous Good by Road when managing the operation and maintenance of vehicle fleet in the road transport of dangerous goods. The conducted research shows that vehicles with compressed natural gas drive achieve certain advantages in terms of preventive maintenance in relation to conventional diesel vehicles and can be successfully used in road transport of dangerous goods.

Keywords: fleet, preventive maintenance, transport of dangerous goods, maintenance costs, compressed natural gas.

1. Introduction

Vehicle maintenance has a significant role in the management and organization of road transport of dangerous goods. There are numerous examples of unprofessional and negligent conduct during the operation and maintenance of vehicles in road transport of dangerous goods, which resulted in negative impacts on people and the environment.

Dangerous goods that are transported represent a certain risk to people and the environment, and during the transport process the risk of a dangerous situation increases due to a series of processes that are performed during the transport of goods. Increased risks are observed related to sites where loading and unloading are performed, vehicle crew that perform the carriage of dangerous goods as well as the personnel that service the vehicles and are in the immediate vicinity of dangerous goods. So it is of essential importance for people and the environment that the vehicles involved in the transport of dangerous goods are

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reliable and roadworthy and that the risks of vehicle failures are kept to a minimum. Management and organization of transport of dangerous goods by road, as well as vehicles for transport of dangerous goods, must meet the requirements prescribed and defined by the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR, 2019). The ADR defines the necessary minimum requirements for the safe transport of dangerous goods, as well as a number of requirements related to vehicles, dangerous goods, and methods of control and testing.

The authors in the research (Vujanović *et al.,* 2012) state that for the purpose of efficient management of fleet maintenance it is necessary to observe the transportation process, maintenance process and their environment in an integrated manner, all in order to reduce transport and maintenance costs and increase energy efficiency of fleets. In order to avoid the risks of vehicle failure (its components, aggregates and assemblies) and minimize them, it is necessary to integratively observe the process of transport of dangerous goods, the process of vehicle maintenance and their environment (legal regulations related to the transport of dangerous goods, legislation on traffic safety and recommendations of manufacturers on the implementation of preventive maintenance interventions).

The construction and exploitation characteristics of vehicles as well as the concept of vehicle maintenance have an impact on the successful implementation of the transport process in companies that, with their own road fleet for the transport of dangerous goods, perform the transport service and make a profit. Preventive maintenance of vehicles in the transport of dangerous goods is extremely important and great attention is paid to it due to the complexity of the transport itself and the potential risk of accidents. The applied concept of preventive maintenance in the observed companies is implemented according to the determined time and exploitation resource of the vehicle. According to the author (Mobley, 2002), preventive maintenance represent the procedure of preventive upholding and replacement of elements after the prescribed fixed time and exploitation resource. Many authors in their research state the theoretical foundations and approaches of preventive maintenance (Mobley, 2002; Wilson, 2002; Dhillon, 2002); the same authors state that the planning of preventive maintenance work is based on controls or checks, as well as on predefined preventive activities of maintenance.

In that respect, in the process of maintenance of motor vehicles in road transport of dangerous goods, preventive maintenance interventions are carried out in certain time periods or at defined periodicities of the mileage covered by a vehicle. When managing the operation and maintenance of the fleet, the environmental impacts should be additionally taken into account (requirements and regulations defined in the ADR and the manufacturer's recommendations on the implementation of preventive maintenance interventions). The terms defined for the implementation of preventive maintenance are imposed by the requirements and regulations of the ADR (annual control of structural and operational characteristics of vehicles related to the vehicle as a whole and regular technical inspections for trucks to determine the technical correctness of motor vehicles), as well as vehicle manufacturer's recommendations on the implementation of preventive maintenance interventions, and their ultimate goal is to preserve the declared characteristics of vehicles, increase traffic safety and reduce the risk of vehicle failure that can cause traffic accidents.

In two companies that have homogeneous fleets with different propulsions (diesel and compressed natural gas(CNG)) for the transport of dangerous goods, comparisons of structural and operational features of their vehicles, represented preventive maintenance were performed and the costs of preventive maintenance were calculated for both fleets considered.

In that regard, the work is structured as follows. Chapter 2 will analyse the relevant literature, which deals with the issue of fleet maintenance management with a unified approach of monitoring the process of transport, maintenance and environment, as well as choosing the concept of preventive maintenance and improving the efficiency of fleet maintenance management. An overview of the relevant literature will provide detailed description of the importance of vehicle maintenance in road transport of dangerous goods, from factors (impacts) that partly result from changes in the technical condition of vehicles caused by inadequate use and maintenance of vehicles. In Chapter 3, a comparison of preventive maintenance of fleet with different propulsions (diesel and CNG) will be made in two existing companies engaged in the transport of dangerous goods. The given analysis describes the differences of the compared vehicles in terms of structural and operational characteristics, construction and conceptual solutions of the propulsion, preventive maintenance procedures and costs of preventive maintenance. While in Chapter 4 the conclusions and future directions of research are stated.

2. Literature Review

The performance of the transport of dangerous goods as the primary process of companies is accompanied by certain risks of the occurrence of an adverse event, which can cause a traffic accident. The importance of vehicle maintenance in the road transport of dangerous goods is reflected in the reduction of the risk of malfunction, and thus the possibility of an accident. Only a proper vehicle means a safe vehicle and as such it is one of the basic preconditions for safe transport. The vehicle as one of the most complex technical systems of today, in addition to extreme dynamic loads (caused by inadequate road infrastructure, sudden braking and impact loads caused by goods transported in tanker trailers), is constantly influenced by climatic conditions, which in due course has a high probability of the occurrence of malfunctions and failures of individual components or subassemblies, and eventually has a negative effect on the safety of use of such a vehicle in traffic. The complexity of the conditions for the exploitation of vehicles in the road transport of dangerous goods is another situation that further complicates the planning of vehicle maintenance and significantly complicates the matter of maintenance management. As such, keeping the vehicle in good condition is a complex and responsible task for fleet maintenance managers. The fact is (Erkut *et al.,* 2007) that the percentage of involvement of vehicles with dangerous goods in the total number of traffic accidents is very small. The authors in the research (Guo and Verma, 2010) state the effects of the selection of vehicles on reducing risks in the road transport of dangerous goods. The results in the referred research indicate that the vehicle is one of the sources of transport risk and as such should not be excluded, and its importance is indicated by the results presented in the research. In the mentioned research, the authors point out that the transport risk is directly related to the increase in the number of vehicles participating in transport.

Many authors in their research state the causes of malfunctions that lead to an increased risk of failure and traffic accidents. The most frequently mentioned are inadequate construction, irregularities in production in the assembly phase, errors in vehicle construction materials, improper use of vehicles, inadequate working fluids, inadequate use of sealing elements, deprecation, corrosion, fatigue, improper and inadequate maintenance (Krstić and Mlađan, 2007; Duboka, 2009). The authors in the research (Krstić and Mlađan, 2007) state the percentages of some defects on trucks. Defects caused by wear of elements and inadequate use are the most common (40%), followed by defects caused by plastic deformations (26%), which is associated with poor material choice, then fractures caused by material fatigue (18%), failures due to temperature oscillations (12 %), and other causes (4%).The research authors (Janjić *et al.,* 2013) state the advantages of using diagnostic systems to check the condition of vehicle components and the vehicle as a whole. Based on the correct diagnosis of the condition, a preventive maintenance procedure can be applied and the risk of failure can be reduced. The ways of manifestation of malfunction and failure are quite different and range from amplified noise through increased noise or shock to the complete and immediate cessation of operation of individual elements of the vehicle or the vehicle as a whole. Changes in the technical condition of the vehicle due to inadequate use and inadequate maintenance have an impact on the occurrence of the risk of failures and traffic accidents. The authors of the paper (Yang *et al.,* 2010) conducted the analysis of 322 traffic accidents that occurred during the transport of dangerous goods in China in the period from 2000 to 2008, where 31.4% accidents occurred due to some mechanical failure of elements (subassembly or assembly) of the vehicle or the vehicle as a whole, which are caused by inadequate use and maintenance. The paper authors (Blower *et al.,* 2010) state the causes of failures that led to traffic accidents, thus putting the vehicle braking system and its malfunctions in the first place (36%), and light-signalling devices in the second place (19%), further stating inadequate use and maintenance as the causes of failure occurrence. The authors (Shen *et al.,* 2014), conducted a study of 708 traffic accidents that occurred during the transport of dangerous goods in China in the period from 2004 to 2011. The analysis determined that the causes of accidents were the human factor (73.8%) and mechanical malfunctions (19.6%) on vehicles. The stated causes of failure are communication failures, inadequate use and maintenance. The paper authors (Oggero *et al.,* 2006), conducted a study of 1932 traffic accidents that occurred in road and rail transport of dangerous goods. The study found that the human factor (73.8%) and mechanical malfunctions (18%) on vehicles and railway cars were the causes of accidents. Communication failures and inadequate use and maintenance represent a type of the acknowledged specific causes of failure.

The research author (Vujanović, 2017) defines the effects of the vehicle maintenance process on the transport process and the environment. The impacts of the maintenance process on the transport process can be observed in terms of the use of roadworthy vehicles, while the impacts of the maintenance process on the environment can be observed through the probability of safe function in transport, which depends on the quality of preventive maintenance interventions. The research authors (Vujanović *et al.,* 2012) define the impacts of fleet maintenance process management, which include the impacts of transport, maintenance and environment on the performing of a given transport work and the realisation of higher profits of companies. The research authors (Vujanović *et al.,* 2018) present a methodology for integrated management of the fleet maintenance process, with the aim of increasing the energy efficiency of the fleet and reducing transport and maintenance costs. The paper authors (Vujanović *et al.,* 2012) state that for efficient management of fleet maintenance, it is necessary to observe integrated maintenance, transport and environment processes. The importance of integrated vehicle maintenance management directly affects the productivity and efficiency of fleets. The same authors state that in order to achieve efficient maintenance management, it is important to define the interdependent influences between the maintenance process and the primary process in the company and to direct maintenance management towards achieving the company's goals. The author in the paper (Vujanović, 2017) mentions improvements using the concept with a comprehensive approach in fleet maintenance management, the improvements are evident through the improvement of energy efficiency of fleets, reduction of transport and maintenance costs. A comprehensive management approach defines in detail the impacts between the vehicle maintenance process, the transport process and the environment, as well as the activities related to vehicle maintenance management at the strategic, tactical and operational levels.

In the following text, many authors in their research state the concepts of preventive maintenance for the improvement of the operation of technical systems to increase the reliability and readiness of the system. The research author (Mobley, 2004) states that preventive maintenance intervals can be performed at fixed time intervals or in relation to operating conditions. The same author states that the basic conditions for efficient performance of preventive maintenance work are precisely defined procedures for performing preventive maintenance interventions and conducting controls after performed preventive maintenance interventions. According to the author (Mobley, 2002), preventive maintenance is a proactive process, which aims to reduce the probability of failure and increase system availability. According to the authors (Wilson, 2002; Dhillon, 2002), the intervals of implementation of preventive interventions are defined by the manufacturers of technical systems. The same authors state that the concept of preventive maintenance should be purposefully adapted to the specifics of the technical system that is in operation. The authors in the researches account for improvements in the concept of preventive maintenance based on determined time moments, using mathematical methods, dynamic programming (Zhao, 2003) and linear programming (Chen, 2010), which relate to the optimisation of the interval of preventive interventions. Optimisation of preventive interventions is based on the criteria of minimum costs or maximum readiness. The authors in the research (Oliveira and Lopes, 2019) state the advantages of preventive maintenance through planning and organization of maintenance work, constant insight into the technical condition of machines, reducing the stock of spare parts and increasing staff productivity in maintenance work. The authors in the paper (Bouvard *et al.,* 2011) present the concept of dynamic programming for optimization and improvement of truck maintenance. The importance of the introduction of information systems is stated by the authors through the development of the efficiency of fleet maintenance, job reduction and decrease of total maintenance costs. The concept is designed to improve the efficiency of the maintenance process and reduce maintenance costs. The authors of the paper (Ivanović *et al.,* 2012) report improvements in fleet management using a purpose-designed software package in the field of vehicle maintenance. The software package is designed to increase the efficiency of the maintenance process by using data related to the planning, organization and control of vehicle maintenance. The authors in the research (Pantelić *et al.,* 2011) state that the introduction of information systems directly affects the productivity and efficiency of fleets. Thus, existing researches have shown that the risk of failure and dangerous situations in road transport of dangerous goods is partly influenced by changes of technical conditions of the vehicle caused by inadequate use and maintenance of the vehicle.

Based on the analysed literature, the next chapter will present in detail the two existing companies with different fleets in terms of propulsion, the differences in preventive maintenance will be determined on the basis of established time moments defined by the vehicle manufacturer. The structural and operational features of vehicles and construction and conceptual options of the propulsions of the compared vehicles, environmental influences (requirements and regulations defined in the ADR) on the management and maintenance of fleets, as well as the realised costs of preventive maintenance in the two fleets with different propulsions will be presented.

3. Analysis of Preventive Maintenance of Existing Fleets with Different Propulsion

The companies that deal with the transport of dangerous goods and use tractors of various construction and conceptual options of propulsion to perform the transport process were analysed. The first company uses conventional diesel fuel to power its vehicles, while the second company uses an alternative fuel, CNG, to power its vehicles. The tractors observed in the work are designed and intended for the transport of dangerous goods, classified in class 2 - gases and class 3 - flammable liquids, according to the requirements of the ADR. Within the activities of maintenance management at the strategic level and the defined goals of the two companies considered, fixed assets in the companies are defined. The fleets of the considered companies are homogeneous by manufacturer and type of vehicle. The vehicles of both companies were procured from different manufacturers according to precisely defined structural and operational characteristics in order to facilitate logistic preparation, use and maintenance, in the projected service life of the vehicle.

3.1. Structural and Operational Characteristics of the Analysed Fleets

In order to achieve the appropriate level of transportation quality, it is necessary to select the appropriate vehicle for the given conditions of exploitation in road carriage of dangerous goods. The authors in the research (Ivković *et al.,* 2007; Kaplanović *et al.,* 2007) state the criteria for vehicle selection by comparing different construction and conceptual options for vehicle propulsion. At the strategic level, managers should define which structural and operational features and conceptual options of vehicles correspond to the needs and requirements of transport companies (Kaplanović *et al.,* 2009). This group includes the selection criteria: powertrain, powertrain potential, displacement, fuel, power transmission system, braking system, maximum permissible vehicle weights, etc.

Structural and operational features of freight motor vehicles-tractors in road transport of dangerous goods, in essence, represent basic information about vehicles such as:

- Vehicle type, vehicle category and body shape;
- Dimensional parameters of the vehicle: maximum permitted length / width / height of the vehicle, permissible limit positions of the vehicle centre of gravity, wheelbase, front overhang, rear overhang, front approach angle, rear approach angle, ground clearance, wheelbase of each axle;
- Mass parameters of the vehicle: maximum permissible mass of the vehicle, maximum permissible mass of the set of vehicles, permissible axle load, maximum permissible mass of the trailer;
- Features of the suspension system such as the type of system (mechanical or pneumatic), method of performance, minimum turning radius of the vehicle;
- Axle subassembly characteristics: number of axles, type of axles and position of steering axles;
- Characteristics of the propulsion

system: type of propulsion system (internal combustion engines SUS, hybrid drive, electric drive, etc.), mode of performance (petrol, diesel, alternative fuels, etc.), rated power, rated speed, maximum torque and speed at the maximum permitted engine speed, in the case of SUS engine and displacement, number of cylinders, compression ratio, fuel type, number and volume of fuel storage tanks and characteristics of basic subsystems such as air supply system, fuel supply and exhaust system;

- Characteristics of the power transmission system: type of system (mechanical, hydraulic, etc.), drive formula, in case of gear transmission: type of gearbox, number of gears, gear ratio of each gear separately, maximum vehicle speed;
- Characteristics of the management system: type of system, existence and manner of performance of auxiliary systems (if any);
- Characteristics of the braking system: type of braking system, operating diagram of the system, existence and type of auxiliary braking systems, anti-lock braking device (ABS).

The most complete list of construction features can be found in the European Commission Directive 2007/46/EC (2007). The parameters that are directly related to vehicles intended for the transport of dangerous goods as well as the restrictions that apply to them are given in the ADR as well as in the document UN/ECE Regulation No 105 (2009). It is important to note that the norms single out only one from the basic set of construction features, which is the most influential part, and set minimum requirements for it that must be met in order for the vehicle to be used in the carriage of dangerous goods. These are, above all, systems such as: braking system, mandatory compliance with the requirements of the document UN/ECE Regulation No 13 (2015), mandatory existence of ABS (Anti-lock braking system), the existence of speed limitation devices in accordance with the document UN/ECE Regulation No 89 (2015), requirements for CNG tanks in accordance with the document UN/ECE Regulation No 110. (2018), requirements for the exhaust system on vehicles, requirements related to devices for connecting tractor and trailer vehicles, requirements for the system of electrical installation on the vehicle, etc. The main differences of the analysed fleets in the two companies are primarily in the fuel they use, the principle of operation of the engine powertrains, the fuel supply system as well as the method of installing the system in the vehicle. Detailed structural and operational features of the compared vehicles are shown in Table 1.

Table 1
Review of Structural and Operational Features of Analysed Tractors

Vehicle manufacturer	**IVECO**	**Mercedes-Benz**
Vehicle model	**Stralis AT440T/P CNG**	**Actros 1842 LS**
Fuel	CNG	Diesel
Year of production	2015	2015
Marking on the vehicle according to paragraph 9.1.1.2 ADR	FL	FL
Maximum permissible vehicle weight [kg]	19,000	18,000
Maximum permissible weight of a set of vehicles [kg]	44,000	44,000
Engine type	Cursor 8 vertical-linear 6-cylinder	OM 471 vertical-linear 6-cylinder
Exhaust emission level EURO	6 (six)	6 (six)
Engine displacement [cm3]	7800	12809
Net engine power	243	310
Fuel tanks	Pressure vessels, total volume 600 l (4x70l - 4x80l)	400l
AdBlue (diesel exhaust fluid)	No	85l
DPF (Diesel Particulate Filter)	No	Yes
Low pressure pump	No	Yes
High pressure pump	No	Yes
Spark plug	Yes	No
Number of axles and wheels	2/6	2/6
Device for connecting a towing vehicle and a trailer	JOST JCK 42	JOST JCK 42
Braking system	Pneumatic braking system, with three braking circuits, WABCO 4S/4M	Pneumatic braking system, with three braking circuits, WABCO 4S/4M
ABS/EBS	EBS/Wabco electronic brake control	EBS-E/ABS
Device for extended braking -retarder	Engine brake with constantly open valve	Engine brake with constantly open valve
Additional device for extended braking -retarder	ZF (DD) + IT 16,41-1,0 Intarder	Voith R 115 HV Retarder
Digital tachograph	VDO digital tachograph for two drivers, EC, printer of rotations number + additional printer, in compliance with ADR.	VDO digital tachograph for two drivers, EC, printer of rotations number + additional printer, in compliance with ADR.
Speed limiter up to (90) km/h	Speed limiter, electronic, 90 km/h	Speed limiter, electronic, 90 km/h
Electrical devices and installation	In compliance with Regulation R105 and ADR requirements.	In compliance with Regulation R105 and ADR requirements.
Devices and equipment for alternative fuel propulsion	Performed according to the Regulations R110.	No

Source: (IVECO, 2020; Mercedes-Benz, 2020)

The differences of the compared vehicles are related to the post-structural-conceptual option of the drive. Diesel vehicles have components (low pressure pump, common rail fuel injection system consisting of high pressure pump, high pressure lines and injectors), Diesel Particulate Filter (DPF), AdBlue system, which CNG vehicles do not have, which affects the greater volume of maintenance work.

3.2. Applied Concept of Preventive Maintenance

The analysed companies apply the concept of preventive maintenance based on established time moments for the implementation of maintenance interventions, which is recommended by the vehicle manufacturer as well as the requirements prescribed and defined in the ADR (annual control of structural features of vehicles related to the vehicle as a whole, which includes checks of the electrical installation on the vehicle, braking system, long-term braking system, fuel tank, propulsion system, vehicle exhaust system, etc.). The preventive maintenance concept is based on the optimal interval of implementation of preventive maintenance interventions while achieving the required reliability of the technical system (Mobley, 2002). The importance of the application of the preventive concept of maintenance is stated by the author through the reduction of the intensity of changes in the state of the technical system according to predefined periodic maintenance intervals.

The decision-making process and the choice of maintenance concept in the analysed companies are adopted by fleet managers at the tactical level of management, according to the needs and requirements of transport companies, to meet basic company goals, reduce maintenance costs, ensure greater availability and reliability of vehicles and reduce potential risk of dangerous situations.

The recommendations of vehicle manufacturers on the implementation of preventive maintenance interventions for the compared tractor vehicles differ in the scope and types of preventive maintenance interventions. Implementation of maintenance interventions, for the concept of preventive maintenance in the observed companies, is performed on the basis of elapsed time or exploitation resource (elapsed calendar time, operating hours and number of kilometres travelled). Vehicles powered by CNG in addition to the regular periodic interventions listed in (Table 2), have additional preventive inspections of alternative fuel systems (inspection of pressure tanks, gas reducers, control of solid and flexible CNG lines, CNG valve control, fuel filters, electronic control units, injector sprinkler control). Preventive compliance controls, of the systems for alternative fuel CNG, are performed every four years by an authorized legal entity, and as a positive report on the control performed, the request holder will be issued a certificate of control. The certificate is valid for four years, but may have a shorter validity period in cases when the control of the CNG system determines non-compliance with the relevant applicable regulations in this area.

In Table 2, there are the preventive maintenance recommendations for IVECO vehicles. The given recommendations are based on time (operating hours) or exploitation resource (number of kilometres travelled), and the stated maintenance procedures are marked with alphanumeric labels M_1, M_2 and M_3 that precisely define vehicle maintenance interventions. Regular service interventions include a series of checks and replacements, such as: system diagnostics, replacement of engine oil, transmission oil, oil and fuel filters, CNG fuel pre-filters, spark plugs and lambda probes, air dryers, air filters, air-conditioner filters, belts, water pumps; and examination of braking system, heating and cooling system, exhaust system, and the CNG line system. Additional service interventions marked with the alphanumeric label EP3 refer to maintenance interventions for manual transmissions; they include oil change every two years or after 4,800 operating hours. Recommended interventions are marked with alphanumeric labels T_1, T_2, T_3, T_4, T_5 and T_6, based on time intervals, as occasional maintenance interventions defined by the vehicle manufacturer. Interventions of recommended works include checks and controls of vehicle working fluids, replacement of vehicle coolants and oil replacement in differential power transmission.

Table 2

Vehicle Manufacturer's Recommendations Regarding Preventive Vehicle Maintenance IVECO Stralis AT440T/P CNG

Preventive Maintenance Interventions	**Criterion Type**		
	Time Resource [operating hours]		**Mileage [km]**
Regular preventive maintenance interventions	M_1	2,000	100,000
	M_2	3,000	150,000
	M_1	4,000	200,000
	M_3	6,000	300,000
Additional preventive maintenance interventions	EP_3	4,800	240,000
Recommended periodic preventive maintenance interventions	T_1	Every six months	-
	T_2	Annually, before winter	-
	T_3	Annually, before summer	-
	T_4	Annually	-
	T_5	On two-year basis	-
	T_6	On three-year basis	-

M_1 - The label represents regular maintenance interventions: system diagnostics, engine oil replacement, oil filter replacement, air filter replacement, air-conditioner filter replacement, oil vapour filter replacement, air dryer filter replacement, spark plug replacement, CNG pressure regulator filter replacement, lubrication work and if needed replacement of brake pads and discs.

M_2 - The label represents regular maintenance interventions: system diagnostics, engine oil change, rear axle oil change, oil filter replacement, intarder oil change, air filter replacement, air-conditioner filter replacement, oil vapour filter replacement, air dryer filter replacement, spark plug replacement, replacement of lambda probes, replacement of CNG pressure regulator filters, lubrication works and, if necessary, replacement of brake pads and discs.

M_3 - The label represents regular maintenance interventions: system diagnostics, engine oil change, rear axle oil change, transmission oil change, intarder oil change, oil filter replacement, air filter replacement, air-conditioner filter replacement, oil vapour filter replacement, air dryer filter replacement, replacement of spark plugs, replacement of lambda probe, replacement of CNG pressure regulator filters, lubrication works and, if necessary, replacement of brake pads and discs.

EP_3 - The label represents additional maintenance interventions for manual transmissions shown in the technical manual.

The T-label represents the recommended maintenance interventions: gearbox oil change, replacement of drive distributors, pollen filters, etc., shown in the technical manual.

Source: (IVECO, 2020)

Table 3 provides recommendations for the applied concept of preventive maintenance for Mercedes-Benz vehicles. Regular maintenance interventions are marked with alphanumeric labels G_1, G_2, G_3 and G_6. Regular preventive maintenance interventions include checks and replacements, such as: system diagnostics, replacement of engine oil, transmission oil, oil and fuel filters, fuel pre-filters, air dryers, air filters, air-conditioner filters, belts, water pumps; checks of brake system, heating and cooling system, exhaust system, lines, etc. Additional preventive maintenance interventions for vehicles that use diesel fuel for propulsion are marked with alphanumeric labels Z_3 and V_3 and refer to interventions for maintenance of the propulsion unit, checking the valve clearance of the propulsion unit and replacement of soot particle filters.

Table 3

Vehicle Manufacturer's Recommendations for Preventive Maintenance of the Vehicle Mercedes-Benz Actros 1842 LS

Regular preventive maintenance interventions		**Additional preventive maintenance interventions**
Criteria type		-
Time resource Mileage	Mileage [km]	-
G_1 - interventions each year	and/or 120,000	-
G_2 - interventions every two years	and/or 240,000	-
G_3 - interventions every three years	and/or 360,000	Z_3 - scope of additional interventions V_3 - check of valve clearance
G_6 - interventions every six years	and/or 600,000	Z_3 - scope of additional interventions V_3 - check of valve clearance
G_1 - The label represents regular annual maintenance interventions: system diagnostics, engine oil change, replacement of oil filter, fuel filter, air filter, air-conditioner filter, valve gasket set, air dryer filter; fuel water separator replacement, lubrication work and if necessary replacement of brake pads and discs. G_2 - The label represents regular maintenance interventions every two years: system diagnostics, engine oil change, replacement of oil filter, rear axle oil change, retarder oil change, replacement of fuel filter, air filter, air-conditioner filter, valve gasket set; fuel water separator replacement, replacement of air dryer filters, replacement of AdBlue filters, lubrication works and, if necessary, replacement of brake pads and discs. G_3 - The label represents regular maintenance interventions every three years: system diagnostics, engine oil change, rear axle oil change, transmission oil change, replacement of oil filter, fuel filter, air filter, air-conditioner filter; valve gasket set, fuel water separator replacement, replacement of air dryer filters, DPF cleaning, lubrication works and, if necessary, replacement of brake pads and discs. G_6 - The label represents regular maintenance interventions every six years: engine oil change, replacement of oil filter, rear axle oil change, retarder oil change, transmission oil change, replacement of oil filter, fuel filter, air filter, air-conditioner filter; valve gasket set, replacement of fuel water separator, air dryer filter, AdBlue filter replacement, DPF replacement, lubrication work, brake pad and disc replacement if necessary. Z_3 - The label represents the scope of additional maintenance interventions, DPF replacement, shown in the technical manual. V_3 - The label represents the scope of additional drive unit maintenance interventions, clearance check and adjustment of the engine valve and engine brake, shown in the technical manual.		

Source: (Mercedes-Benz, 2020)

There are components in Diesel vehicles (low pressure pump, common rail fuel injection system consisting of high pressure pump, high pressure lines and injectors), Diesel Particulate Filter (DPF), AdBlue system, which CNG vehicles do not have, which affects additional maintenance work. In addition to the fact that CNG vehicles have more frequent maintenance interventions due to lower periodicity per year compared to diesel vehicles, the scope of maintenance work is lower for CNG vehicles compared to diesel vehicles due to the lack of these components and systems on CNG vehicles.

Absence of components that are the integral part of design and conceptual solutions of diesel drive (low pressure pump, common rail fuel injection system consisting of (high pressure pump, high pressure lines and injectors), DPF, AdBlue system directly affect the reduction of costs and scope of preventive maintenance work on CNG-powered vehicles.

In order to preserve the declared structural and operational characteristics of the compared vehicles from the point of view of technical roadworthiness and their impact on health, safety of people and environment, in addition to the above recommendations of vehicle manufacturers regarding preventive maintenance, the analysed companies applied preventive maintenance in accordance with the ADR requirements, that represent the requirements of the environment.

When managing the operation and maintenance of fleet, it is necessary to jointly observe the interdependent influences that exist between the transport process of dangerous goods, the process of vehicle maintenance and the environment. The impact of the environment, the requirements of the ADR, on the transport process of dangerous goods are defined by the requirements that each vehicle must meet in order to participate in the road transport of dangerous goods. In addition to the requirements related to vehicles, the ADR also defines the conditions that must be met by the carrier of dangerous goods related to the handling of dangerous goods, vehicle selection, restrictions for road infrastructure, places of loading and unloading, etc. The impact of the ADR requirements on the vehicle maintenance process is represented by mandatory annual controls of construction and operational characteristics of vehicles prescribed in Part 9 of ADR and regular technical inspections of vehicles.

These requirements refer to the vehicle, and are related to its structure and annual controls of the structural and operational features of the vehicle. These interventions are part of preventive maintenance based on time determined by the competent state authorities (organizations authorized to control according to the requirements of the ADR, organizations authorized to perform technical inspections). In addition to regular inspections of the technical correctness of vehicles, which are defined and prescribed by the basic acts on traffic safety, there is a whole series of inspections, i.e. controls prescribed by the ADR in Part 9 and which are specific only to vehicles for the carriage of dangerous goods.

Controls carried out by the competent state authorities can be divided into two groups:

- Regular technical inspections, for trucks in road transport of dangerous goods, are performed twice a year to determine the roadworthiness of motor vehicles and trailers. Regular technical inspections are performed annually and semi-annually;
- Annual control of structural and operational features of the vehicle, which refers to the vehicle as a whole and is prescribed in Part 9 of the ADR.

When managing fleets in road transport of dangerous goods, managers must anticipate the effects of the environment on the transport process (legal regulations implemented by the competent state authorities) and impacts on the maintenance process (manufacturer's recommendations on preventive vehicle maintenance interventions and requirements defined by the ADR).

3.3. Preventive Maintenance Costs

The maintenance cost control is performed by managers at the tactical level of maintenance management. Maintenance budget in transport companies is defined within the strategic level of management, based on company goals, performed vehicle analyses and annual reports on fleet engagement. Based on real business conditions of transport companies dealing with transport of dangerous goods, there is a comparison of preventive maintenance costs in Table 4. The analysed vehicles cover approximately 100,000 km annually. Based on the recommendations of vehicle manufacturers on the implementation of preventive maintenance interventions defined by time or exploitation resource, as well as preventive inspections in accordance with the ADR requirements that are carried out after the prescribed time resource, Table 4 shows the differences in preventive maintenance costs. The costs of preventive maintenance at the annual level or 100,000 km travelled are shown, as well as the prediction of costs at the six-year period or 600,000 km travelled. In addition to the costs of regular preventive maintenance interventions, Table 4 also shows the costs of preventive inspections performed by the authorities (organizations authorized to control according to the requirements of the ADR, organizations authorized to perform technical inspections and in the case of vehicles manufactured by IVECO, organisations performing CNG system compliance check) on an annual basis and the cost predictions on a six-year basis in relation to current market prices.

Table 4
Overview of Preventive Maintenance Costs for Analysed Vehicles

Vehicle Manufacturer	**IVECO**	**Mercedes-Benz**
Vehicle Model	**Stralis AT440T/P CNG**	**Actros 1842 LS**
Fuel	CNG	Diesel
Review of Preventive Maintenance Costs on an Annual Basis or at 100,000 km Travelled		
Cost of periodic service on an annual level or at 100,000 km travelled [€]	846	1,099
Cost of conformity check according to ADR requirements [€]	100	100
Cost of CNG system compliance check [€]	-	-
Cost of technical inspection [€]	142	142
Cost of speed limiter compliance check [€]	100	100
Preventive Maintenance Costs per Annum [€]	1,188	1,441
Prediction of the Costs of Regular Preventive Maintenance in Six-year Period or 600,000 km Travelled		
Cost of the periodic maintenance service in the six-year period or 600,000 km travelled [€]	5,243	6,207
Cost of conformity check according to ADR requirements [€]	600	600
Cost of CNG compliance check [€]	180	-
Cost of technical inspection [€]	852	852
Cost of speed limiter compliance check [€]	600	600
Costs of Preventive Maintenance in Six-year Period [€]	7,475	8,259

The costs of regular preventive maintenance vary depending on the vehicle manufacturer, the number of years of operation of the vehicle and the scope of maintenance work. In Table 4 it can be seen that at the annual level or 100,000 km travelled, the costs of regular preventive maintenance for Mercedes-Benz vehicles that use diesel fuel are 21% higher than for IVECO vehicles that use alternative CNG fuel. The primary reason for lower preventive maintenance costs for vehicles that use alternative CNG fuel is in the construction of the propulsion unit and fuel supply system, i.e. the absence of components that significantly increase maintenance costs, such as: high pressure pump, DPF, AdBlue system. The absence of these components is the reason for the lower annual amount of preventive maintenance work for CNG vehicles, compared to diesel vehicles. In addition to annual costs or 100,000 km travelled, a prediction of preventive maintenance costs in six-year period or 600,000 km travelled is shown.

From the presented tabular presentation of data obtained from the manufacturer's representatives for the Republic of Serbia, the costs of preventive maintenance for Mercedes-Benz vehicles in the six-year period or 600,000 km travelled, are 10% higher compared to IVECO vehicles.

The additional costs of preventive interventions for the analysed vehicles conducted by the competent state authorities are the same. The influences of the construction-operational characteristics of the vehicle (drive concept) do not affect the costs of checking the conformity of the vehicle according to the requirements of ADR, speed limiter and roadworthiness of the vehicle.

At the tactical level, and based on pre-defined time intervals of preventive maintenance, managers plan the activities of the use of fleets. Preventive maintenance costs have a significant impact on the management of fleet functioning. Due to the close connection between the costs of preventive maintenance and the total costs of the company, the costs of preventive maintenance have an impact on fleet management activities, all with the aim of raising company profits, maintaining declared structural and operational characteristics of vehicles and increasing traffic safety.

4. Conclusion

The paper presents the importance and role of preventive maintenance in road transport of dangerous goods in fleets with different propulsions, as well as the necessary harmonisation of maintenance, transport process and environment to preserve the declared characteristics of vehicles and increase traffic safety. The preventive maintenance in the road transport of dangerous goods in analysed two companies has a significant role in preventing and reducing the risk of dangerous situations, as well as meeting the basic goals of the companies, such as reducing maintenance costs and ensuring greater availability and reliability of vehicles.

CNG-powered tractor units, in addition to more frequent preventive interventions recommended by the manufacturer, at the same time have a smaller scope of maintenance work compared to diesel-powered vehicles. Compared to CNG vehicles, diesel vehicles have some additional components (low pressure pump, common rail fuel injection system consisting of high pressure pump, high pressure lines and injectors) and DPF and Adblue systems as well, which affects additional maintenance work. The absence of these components in CNG-powered vehicles directly affects the reduction of the scope of preventive maintenance work, and thus the lower costs of preventive maintenance for CNG-powered vehicles, compared to conventional diesel-powered vehicles.

The annual preventive maintenance costs for vehicles powered by conventional diesel fuels for propulsion are 21% higher than for vehicles powered by CNG for propulsion. The prediction of preventive maintenance costs for the six-year period for vehicles using conventional diesel fuels for propulsion is 10% higher than for vehicles using CNG. The costs of preventive maintenance take into account the environmental requirements that affect the process of vehicle maintenance, which relate to the manufacturer's recommendations for the implementation of preventive maintenance interventions and requirements and regulations defined in the ADR. The requirements defined in the ADR certainly further affect preventive maintenance costs but do not differ in both considered vehicle types of propulsion. By fulfilling the requirements and regulations in accordance with the ADR and taking into account the above stated, the conclusion is that it is expedient to introduce vehicles on compressed natural gas into the system of road transport of dangerous goods, due to lower costs of preventive maintenance. The conducted research shows that vehicles powered by compressed natural gas can be successfully used in the system of road transport of dangerous goods in the Republic of Serbia. Vehicles that use compressed natural gas for propulsion due to their construction and exploitation characteristics are more cost-effective from the aspect of preventive maintenance, compared to diesel vehicles. In this regard, the subject of further research will be the monitoring and research of alternative propulsion vehicles in road transport of dangerous goods, by applying multi-criteria ranking of construction and conceptual solutions of trucks in order to create sustainable transport.

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