GENERAL JONAS ŽEMAITIS
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THE DIESEL ENGINES RELIABILITY IN THE DIFFICULT CONDITIONS OF AFGHANISTAN

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Agenda

Subject: OVERVIEW OF ENGINE RELIABILITY STUDIES

1.1. Introduction
1.2 Factors determining engine reliability
1.2. Reliability of engine operating personnel
1.3. Numerical models for climate and weather assessment
1.4. General conclusions

INTRODUCTION

- Automotive engine reliability represents an important feature of engine performance while determining use of a vehicle in an ever globalizing world. Cars are often adapted to be capable of driving on different roads and to operate under various conditions. For this reason, when designing and producing land motor vehicles automotive manufacturers focus not only on their design and comfort level but also on their operating reliability. Given the currently prevailing worldwide trend to develop automotive road systems with rigid pavements, automotive manufacturers tend to develop cars intended for operation on this type of roads.

INTRODUCTION

- However, in some cases a need emerges for vehicles operable off-road under complicated climatic conditions, for example, for the purpose of exploratory works or to be used on international missions. For the purpose of tasks completion different vehicles are often used effectiveness of which depends on their reliability. As the need for such vehicles is limited, there is a lack of their research, and furthermore, findings and results of not all studies are reported and published, all of which leads to the lack of recommendations on vehicle operation under difficult conditions.

INTRODUCTION

- Internal combustion engines (hereinafter – ICE) used in cars are also mainly designed for operation under normal conditions, and the need to adapt series engine for use in vehicles operating under difficult conditions is often accompanied with different problems. Problems are often caused by engine operation in locations with complicated climatic and geographic conditions – mountains, desserts, rapid rivers, increased air dustiness, diurnal temperature variation, and solar radiation.

INTRODUCTION

- The research examines issues covered by diesel engine reliability theory, and factors relevant for discussion of engine reliability as a technical reconstructive (repairable) system “ICE–environment” excluding time required for system reconstruction. Research suggests and presents indicators for the assessment of engine reliability, and quantitative function for the evaluation of engine technical condition. The integrated effect of mountainous dessert on automotive engines is also examined that has received little research attention so far, whereas analysis results of quantitative criteria intended for reliability assessment under difficult conditions have not been publicly reported as they have been accomplished by manufacturers of military vehicles.

INTRODUCTION

- Research was carried out in mountainous dessert of Afghanistan having difficult climatic conditions. To collect precise and accurate data, vehicles used by the Provincial Reconstruction Team (hereinafter – PRT) situated in Ghor province (Afghanistan) were selected for the research. Their operation course, failures, and repairs can be tracked and captured more precisely than those of civilians as their data are recorded in data logs.

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INTRODUCTION

- Actual reliability indicators of diesel engines used in vehicles operating in Ghor province of Afghanistan do not exactly satisfy modern requirements as their operating conditions differ from those that they have been initially designed and produced for. Actual use of automotive resources depends on intended tasks and season of the year. In summertime, daily mileage of a car varies from 0 to 40 km with the engine running for 10 motor hours per day, whereas in winter these are by half lower. In case of more complicated tasks, the engine runtime increases significantly.

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INTRODUCTION

- The following are the main factors determining engine operating conditions in the region under investigation: layout and profile of roads, their altitude above sea level, climatic and geographic conditions, airborne concentration of abrasive substances, patterns of use of vehicles, engine oils and car fluids used, fuel used in Afghanistan (having different properties than normal diesel fuel), and rotation of drivers each half-year. The factors mentioned herein have influence on engine operation and its costs.

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Research material

- The Research material analyzes performance of twenty nine diesel engines operating under difficult conditions: sixteen vehicles Toyota Land Cruiser 100 (LC) with diesel engines 1HD-FTE, and thirteen high-mobility multipurpose wheeled vehicles M998A2 (HMMWV) with diesel engines GM6.5L. Fuel and engine oil SAE 15W-30 (API CF-4) used for these engines are investigated as well. All the vehicles were used under conditions of mountainous desert from the very beginning, i.e., starting with summer of 2005 till January 1, 2012.

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Factors determining engine reliability

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Factors determining engine reliability

- **Engine reliability theory**
  - •non-perishability, durability, maintainability and durability properties or combinations thereof.
  - •it does not include engine maintenance convenience, design, etc. t. criteria.

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Factors determining engine reliability

- **The main engine reliability indicators are:**
  - average and gamma percentage resource, failure probability,
  - failure rate or density of failure distribution, failure intensity,
  - failure flow parameter,
  - average repair time between repairs,
  - average repair flow parameter.

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Factors determining engine reliability

- **Engine reliability is characterized by the following features:**

1. The reliability assessment of engines shall apply to the production and operation of multiple engines.
2. It is necessary to consider (evaluate) the random factors that affect the engine life, failures and other indicators of its reliability.
3. The results of experiments or tests on the reliability of engines must be evaluated by a mathematical-statistical method.

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Factors determining engine reliability

- **Research into the causes of engine failure allows the development and identification of measures to increase engine reliability.**
- **The following factors can be used to assess physical and chemical processes: wear of engine parts, aging of engine parts, breakage of engine parts in excess of allowable loads, cavitation, burns, coke and varnish on engine parts surfaces, various forms of corrosion, engine deformations and engine parameters manufacturing inaccuracies, assembly, operation and maintenance.**
- **The fault is described by its main feature and main criterion. The sign of a failure is the manner in which the failure occurs, and the failure criterion is the quantitative value of the engine system or assembly or the technical condition of the engine as a whole that is directly related to the failure.**

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Factors determining engine reliability

- **Application of statistical methods in engine reliability theory:**
- **The normal distribution** is most often used to describe wear failures, to determine the total operating time of repaired objects before overhaul, to repair the repaired object, to determine the distribution of external loads between machine parts and assemblies under various operating conditions.
- **The logarithmic normal distribution** is appropriate for examining cyclic load data, changes in the processing of accelerated test data for some objects, and can be used to determine the time to failure of non-repairable objects due to fatigue failure.
- **The Weibull distribution** is best suited to describe the strength and durability of machine parts and mechanisms, as well as the service life of machine parts and mechanisms where load changes over time are possible (eg fatigue tests).
- **Exponential distribution** - another distribution widely used to predict engine failure time; in other words, it is the time between failures. According to this law, the time of objects working in difficult conditions is divided between the duration of failures, object control, maintenance or repair.
- The presented distributions meet practically all needs in terms of engine reliability.

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Factors determining engine reliability

- **The operating conditions of the engines** include the way they are used, the intensity of engine use, the types of engine loads and their sequence, the tactical situations and the nature of hostile behavior, environmental parameters, engine maintenance and repair service system and culture, qualifications of drivers, mechanics and engine maintenance personnel, provision of repair and diagnostic equipment, etc. t.
- **Vehicles operation research** is mainly carried out in areas with a good road network and in the maintenance and repair of engines according to the manufacturer's requirements.

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Factors determining engine reliability

- **Difficult engine operating conditions** typically include low air temperatures, deep snow cover, frequent blizzards, and downpours. Also in desert areas with a hot climate, poor road network, lack of forest plantations and water, increased air dust, large changes in daily temperature; mountainous areas with sparse air and low atmospheric pressure; strongly changing terrain; off-road and road overturning scales. Difficult regional operating conditions also include high humidity in the region.

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Factors determining engine reliability

- The complex combinations of mountain roads, consisting of various slopes and inclines of varying sizes with varying high-intensity meanders and small turning angles, sometimes with a radius of 10 m and a turning angle of up to 180 ° (see figure), result in uneven rolling resistance.
- The essential factor is the height of the road above sea level and sudden fluctuations in that height, which can reach hundreds, sometimes thousands of meters.

Factors determining engine reliability

- **The specificity of the highland desert,** which is characterized by the terrain and geographical position above sea level, which in turn has an impact on the climate, causes the engines to operate over a very wide range of speeds and power. The performance of engines can differ significantly from their performance in the Lithuanian plains. Mountain terrain instability can be a major cause of a car's engine operation, and changes in climatic conditions can affect engine performance.
- **Another factor in the operating conditions of engines is the climate,** the specificity of which depends on the climate zone. The climate is divided into four main types: temperate, cold, tropical and arctic, dividing the highlands into a separate group. Climate is rated by scores in climate harsh areas, where engine operating conditions are very different from ours.

Factors determining engine reliability

- **The main climatic factors:** temperature, air impurities, humidity, solar radiation, and the geographical factor - atmospheric pressure - are directly involved in the formation of the engine thermodynamic process in the engine cylinders.
- **The decrease in atmospheric pressure** with increasing altitude is uniform and does not depend on the terrain. The terrain factor can insignificantly lead to a drop in atmospheric pressure creating atmospheric pressure instability at different altitudes in different areas of a mountainous system. It is also affected by dynamic changes in atmospheric pressure caused by wind, and temperature has a greater effect on the atmospheric pressure regime. According to the international standard model of atmospheric pressure, the average air temperature gradient is 6.5 ° C for each 1000 m above sea level, but when considering the operation of engines in high altitudes, the actual temperature changes differ from the standard atmospheric conditions.

Factors determining engine reliability

- **Under actual engine operating conditions,** changes in air temperature are affected by altitude, solar radiation, the geographical location of the area, the location of mountain slopes, the shape of the terrain, the surface vegetation and cover, and other less significant factors. As the altitude rises, the temperature changes differently in the open atmosphere and near the ground due to the difference in the solar radiation balance. This effect is weaker at the tops of round mountains due to stronger heat exchange with the environment. Therefore, **the greatest effect of temperature change is close to the ground - up to 2 m;** it is in this area that cars are operated. In the mountains, vol. y. on mountain tops and mountain slopes, the daily and annual temperature amplitudes are higher than in their valleys.

Factors determining engine reliability

- **Solar radiation affects the ambient heat balance,** on which the ambient air temperature depends and, according to S. Kadirov, it has a special effect on the change of engine fuel hardware parameters and determines engine power, torque, fuel consumption. In addition, exhaust temperatures are rising and environmental performance is deteriorating. Increased ambient temperature increases the heat loads of the engine, leading to changes in the chemical and physical properties of fuels and oils. Due to the increased oil temperature, irreversible decomposition of oil and additive molecules occurs and the oxidation of the oil accelerates, the oil loses its properties faster.

Factors determining engine reliability

- **Climatic factors that affect engine performance also include humidity (the volume of water vapor in the air) that reduces the amount of dry air drawn into the engine cylinders.** As you ascend into the mountains, the amount of water vapor decreases and even at an altitude of 1000 m above sea level, even in tropical areas, the water vapor pressure is no more than 1%. The composition of the main air components - oxygen and nitrogen - hardly changes up to 5000 m, only the amount of air impurities and water vapor in the air differs (Mahaldiani 1968). Desert winds form at high temperatures and very low relative humidity. They are usually associated with the effects they cause - sandstorms. Local desert winds are formed where the blowing wind is quite strong to lift fine particles of sand and carry them over long distances. In the deserts of the northern hemisphere, sand storms form when cyclone formations in the tropical zone disrupt the prevailing northern winds. A wind system is forming in the eastern periphery of the cyclones. Huge amounts of sand are then lifted into the air and transported over long distances.

Factors determining engine reliability

- **Sandstorms are also characteristic** of the front part of the cold atmosphere front, where air currents lift the sand particles and form a sand wall that can stretch several hundred kilometers horizontally and merge with spherical rain clouds at the top. Dust vortices - derivatives of the vertical axis - are often formed in deserts. They are formed on hot, clear days when solar energy mainly heats the surface rather than evaporating moisture. The atmosphere near the surface becomes very unstable, intense ground convection flows form, and warm air rises to the top. The blowing wind, when it encounters an obstacle (hill, tree, etc.) in its path, bypasses it, its direction changes and this can give torque to the rising air. Dust vortices are usually short-lived and are usually only a few tens of meters high.

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Factors determining engine reliability

- **Wind** is usually the horizontal movement of airflows at a known speed, but there are also vertical movements of airflows, especially in the mountains. Wind speed and direction are determined by the movement of atmospheric air masses on the earth's surface and depend on the difference in the horizontal gradient of air pressure, time and time of day, terrain and other factors. The wind force depends on the difference in air pressure. Atmospheric circulation determines the mountain climate and air. **Car engines are operated at altitudes up to 2 m above the ground,** so wind data is relevant in this section.

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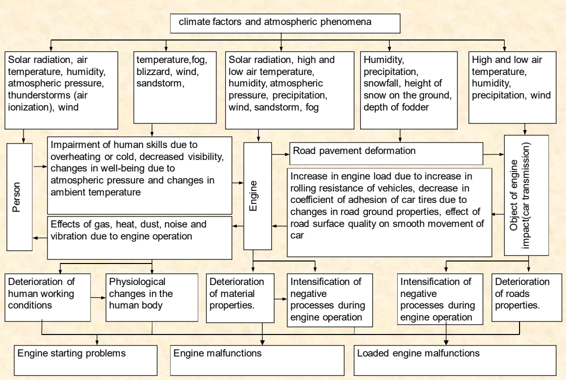

Scheme of influence of climate factors, direct and indirect relations in the system operator-engine-load (Koch 1981)

Factors determining engine reliability

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Factors determining engine reliability

- Another factor that reduces the reliability of the engine and causes its **parametric failures** is the wear of the engine parts. Abrasion of engine parts and mechanisms is an inevitable process. It is a gradual change in the shape and dimensions of the frictional parts as the materials appear and separate from the surfaces of the parts or permanent deformation occurs. The material properties of the parts also change. At present, the hypotheses of the causes of wear have been raised, as the wear process of details is a function of many variables that are difficult to determine.
- The wear marks on the parts are not homogeneous; several decomposition processes take place at the same time: surface roughness wears out, abrasion products of softer parts stick to harder ones, the structure of materials changes due to the effect of temperature, chemical reactions take place, and so on. t.

Eil. Nr.	Autor	Mathematical dependence	Wear type
1.	I. Kragelskij	$J_{di} = i\frac{A_r}{A_c};$ (1.1)	Tired wear
2.	V. Zorin	$J_{di} = K_t a_p K_k p_d E^{t_y - 1}\left(\frac{H_b}{R_b}\right)^{0,1t_y} \Delta_s^{0,4t_y}\left[\frac{K_m f_m F}{\sigma}\right]^{t_y};$ (1.2)	
3.	I. Kragelskij	$J_{di} = \frac{tg\,\theta}{2(\nu_m + 1)}\frac{P_n}{H};$ (1.3)	Abrazive wear
4.	M. Hrušov	$J_{di} = \frac{CFa\ \psi}{H_B S};$ (1.4)	
5.	T. Malhern, L. Samuels	$J_{di} = \frac{\rho Fe\ \psi}{P_{vid}\ k\varphi};$ (1.5)	
6.	D. Etimoto, T. Cukidzo	$J_{di} = \frac{1}{6}\frac{tg\,\theta}{[P_\tau]}F;$ (1.6)	Mechancle wear
7.	D. Holm	$J_{di} = \frac{zF}{H_B};$ (1.7)	
8.	D. Arčiard	$J_{di} = kA_r;$ (1.8)	
9.	C. Ratner	$J_{di} = J_0 \exp\left[-\frac{U_0 - \lambda f_{tr} F}{RT}\right];$ (1.9)	
10.	A. Čičinadzė	$J_{di} = \frac{h}{d}\frac{1}{n(\nu_m + 1)}\frac{A_r}{A_c};$ (1.10)	
11.	V. Zorin	$J_{di} = K_{2m} 15^{\frac{2t_y}{5}} a_g K_{1m} pE^{t_y - 1}\tau_0^{\frac{1}{2}}\left(\frac{1}{a_g^{\frac{t_y}{2}}}\right)\left[\frac{K_k f_m}{\sigma_0}\right]^{t_y},$ (1.11)	

Biological factor

- ICE is subject to biological environment effect of a specific form: microbial, fungal, viral effects, and effect from rodents and insects. This factor is mostly evident during engine downtime due to different reasons associated with machine idle time. In other words, biological factor influences retention of engine. Biological environment reacts to certain ICE materials and releases reaction products that are acidic in nature. They accelerate decomposition of plastic materials and their substitutes, metals and their alloys. Rodents are especially prevalent in the territory of Afghanistan; they damage insulation of electric cables leading to failures of electric insulation.

Biological factor

- According to Uzbek scientists A. Chamrajev, R. Achmerov, some insects, especially termites, have the ability to eat organic matter: cellulose, artificial and natural leather, wool, textiles, paper, and so on. t. When termites lack food, they can erode rubber products, various plastics, insulating materials, fiberglass fabrics, including electrical insulating fabrics. Termites can damage aluminum and lead cable sheaths, as well as break down wooden buildings, masonry limestone, clay, gypsum, and lime products. Mentioning these non-termite features has been of particular concern recently. This indicates that termites have a fairly wide range of food supply options. In the history of vehicle operation (African, Asian, American continents) there are facts that termites were the cause of vehicle breakdowns, but the negative effects of termites on cars in the Ghowr region have not been observed, but there are isolated cases in other regions of Afghanistan insulating materials.For a variety of fungi, viruses, microbes found in automotive fuel filters, samples were taken from automotive engine fuel filters and water-limiting media. In Afghanistan, mushrooms grow wherever there are hydrocarbons and favorable conditions: high air temperature, humidity, dust-contaminated surface.

Reliability of engine operating personnel and maintenance staff

RELIABILITY OF MAINTENANCE STAFF

- Psychologists treat reliability of the maintenance staff as the ability to exploit a car and thus an engine without any errors under any road conditions full-time. Great part of the systems regardless of automation requires human intervention, and where the person works, the errors are inevitable. Errors occur independently of human training, qualifications and experience. Therefore, the forecast of technical reliability do not reflect the exact result without assessment of human reliability [1].
- S. B. Dhillon (1981) in his book there presents classification of following errors, caused the human fault: design errors, operator errors, manufacturing errors, maintenance errors, brought errors, check (diagnostic) errors, and communication errors.
- The **main causes of these errors are such: low maintenance personnel skill levels or inadequate its preparation, failure to comply with maintenance and operating procedures, poor working conditions (e.g.: very high temperature, very low or high weather humidity, inadequate supply of the required tools and equipment, poor service staff motivation, which prevents achieving optimal level of quality of work).**
- The main factors, determining reliability of maintenance staff, are its professionalism, and proper preparation.

RELIABILITY OF MAINTENANCE STAFF

- Reliability of maintenance staff is the ability to retain functional parameters to ensure safe vehicle operation under appropriate vehicle use and maintenance conditions. Reliability of maintenance staff is an integral and complex property, which affects the technical incorruptibility, repair, storability, and durability.
- A significant impact on the wellbeing of staff has its presence in alpine. **Large number of troops there, especially the first week in the mountains of Afghanistan were feeling dizziness, headaches, slight nausea, decreased appetite, insomnia, fatigue, rapid heartbeat, Cheyne-Stokes breathing during the night, sometimes a slight pain in the chest, sigh, cough, and muscle weakness.** All these sensations meet the signs of hypoxia, and hypoxia is likely to cause a deviation of human's ability to evaluate properly his actions in difficult conditions. When communicating with medical staff, it became clear that there are abnormal blood tests of those soldiers who stayed for a long time in alpine: increase in total red blood cells and hemoglobin in the blood and increased blood viscosity but lost feelings, which occur the first month of arrival.

RELIABILITY OF MAINTENANCE STAFF

- Reliability function of operation of maintenance staff under continuous operation can be generally expressed by the expression of instantaneous probability of human unerring work [1]:
- $$P_p(t) = e^{-\int_0^t e(t)\,dt} \quad (4)$$
- here: Pp (t) – probability of human unerring work; e(t) – incidence of errors caused by man, at the load and the time t.
- Man-reliability characteristics similar to the reliability of technical indicators are as those: the average working time to the occurrence of an error, the average working time to the occurrence of the first error, the average working time between human errors.

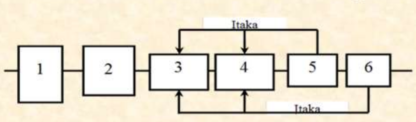
RELIABILITY OF MAINTENANCE STAFF

- Man has the ability to correct his mistakes, and so it is the function of human ability to fix errors: probability that an error occurred during working hours will be corrected in time t under the current situation conditions corresponding to the current task. The mathematical expression that is suitable for continuous and instantaneous correction of errors
- frequency [1]:
- $$P_k(t) = 1 - e^{-\int_0^t e(t)dt} \qquad (5)$$
- here: P_k (t) – correction of human error, at time t and load, e(t) – incidence of errors caused by a man, at the load and the time t.

RELIABILITY OF MAINTENANCE STAFF

- Thus formulas presented by Dhillon **can not be applied** to assess the system „man-vehicle" **in Afghanistan conditions** because of the local climatic factors, not included in the formula.
- **H. A. Graver [3] studies reveal the importance of climate assessing the human ability to work at a given temperature.**
- Operational reliability of maintenance staff depends on many factors: age, intoxication from alcohol or drugs, fatigue, fitness, training, attitude towards work, and working environment.
- S. B. Dhillon (1981) indicates that human-caused error rate depends on the time. **Frequency of errors is in accordance with the laws of Weibull, Gamma distribution and Logarithmic normal distribution, and is well compatible with experimental data**. Correction time of the first human error is in accordance with a law of Logarithmic normal distribution.

Structural scheme of reliability of an internal combustion engine



- 1 – maintenance staff; 2 – ICE electric start system; 3 – cylinders block with **AŠM**; 4 gas distribution mechanism, 5 - lubrication system, 6 - ICE cooling system.

$$P_S(t)=P_O(t)+[1-P_O(t)]\cdot K_p\cdot\left[P_p\cdot P_V+(1-P_p)\cdot P_k(t)\right] \qquad P_O(t)=\prod_1^n P_i$$

here: : *$P_o(t)$* – ICE reliability of incorruptibility; *P_i* –reliability of incorruptibility of *i* element; *n* – number of elements in system; Kp – readiness factor of maintenance staff; Pk(t) – probability of errors correction by maintenance staff; Pp(t) – probability of reliability of job of maintenance staff; Pv(t) – probability of maintenance staff actions carried out timely and necessary to be carried out.

Three main reasons to technical incapacity and Technical failures

- Technical maintenance experience in Afghanistan reveals **three main reasons to technical incapacity**: fighting damages; scheduled repair after reaching set working hours; accidents and failures during operation of equipment (operational failures). **Technical failures of engines** are divided into three main categories, as well: catastrophic, parametric and combined one. When calculating the overall reliability of engines is expected that each type of the failure is an independent event and has mathematical expression, as follows:

$$P_o(t) = P_m(t) \cdot P_{pm}(t) \cdot P_{km}(t)$$

- here: Pm(t)– reliability of incorruptibility of ICE at sudden failures;
- Ppr(t)– reliability of incorruptibility of ICE at parametric failures;
- Pkm(t)– reliability of incorruptibility of ICE at combined failures.

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Numerical models for climate and weather assessment

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Numerical models for climate and weather assessment

- **Climate** is a perennial weather regime in a certain area at the Earth's surface or in the atmosphere at a certain altitude. It is a set of statistical properties of a system consisting of interacting meteorological elements (air) and a variety of land surfaces with long finite periods of change.

- **Weather** - the current physical state of the atmosphere (temperature, atmospheric pressure, wind direction and speed and other atmospheric indicators), describes the totality of the main meteorological elements and atmospheric phenomena observed at a given point in the geographical space.

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Numerical models for climate and weather assessment

- **Normal conditions** are a set of environmental factors and meteorological phenomena in which the properties of objects change slightly and can be disregarded. Normal conditions are 293 ± 5 K (20 ± 5 ° C) air temperature, 1013 ± 50 hPa air pressure, 60 ± 5% relative humidity, 14 ± 4 hPa water vapor partial pressure, air density at 293 K, 1, 20 kg / m3, 120 W / m2 solar radiation energy exposure, 120 J / m2 solar radiation energy exposure, 0.25 ± 0.25 m / s wind speed.
- **These conditions are considered essential for the design and manufacture of various basic products.**

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Numerical models for climate and weather assessment

- In order to achieve a high degree of accuracy in the mathematical modeling of complex climate effects, it is necessary to develop mathematical models for the operation of climate and air-unfavorable vehicles when engine are operated separately in cold and hot mountainous regions (Koch 1981). The effect of the intensity of a complex of climatic factors on the properties of materials can be described as the technical severity of the climate.

$$N_c, N_w, S_c, S_w = f[Q_s(t_{vv}), T_{ot}(t_{vv}), U_{\%}(t_{vv}), B_a(t_{vv}), A_m(t_{vv}), v_{vg}(t_{vv}), n_{ar}(t_{vv}), b_V(t_{vv}), t_{hl}],$$

where: Nc, Nw is the aggregate of cold climate and cold weather disruption for vehicles; Sc, Sw - common indicator of hot climate and hot air unfavorability for vehicle operation; Qs - total solar radiation; Tot - air temperature; t vv - time of action of factors; U% - relative humidity; Ba - atmospheric air pressure; Am - average non-periodic amplitude of air temperature fluctuation, vvg - average wind speed; nar - atmospheric phenomena affecting the reliability of internal combustion engines; thl - duration of exposure to high and low temperatures per year; bV - effect of biological factor.

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Numerical models for climate and weather assessment

- the climatic characteristics are independent of each other (this allows the use of the analytical expression of probability theory (Koch 1981), and a significant parameter - the failure of the engine under time t under the influence of the main climatic factors will be:

$$P(t) = [1 - q_Q(t)][1 - q_T(t)][1 - q_{A_m}(t)][1 - q_{U_{\%}}(t)][1 - q_{n_{ar}}(t)][1 - q_{thl}(t)][1 - q_b(t)]$$

where: qi (t) is the probability of engine failure due to the action of the i-climate factor at time t; qQ (t) - probability of failure due to solar radiation; qT (t) is the probability of failure due to exposure to air temperature; qAm (t) is the probability of failure due to the amplitude of the average air temperature fluctuation; qU% (t) is the probability of failure due to the effect of relative humidity on the engine; qnar (t) is the probability of failure due to atmospheric phenomena affecting the reliability of the engine; qthl (t) is the probability of failure due to the duration of exposure to high and low temperatures; qb (t) is the probability of failure due to the duration of exposure to the biological factor.

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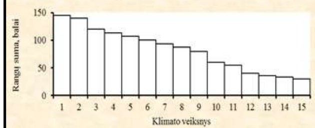
Numerical models for climate and weather assessment

$$S_c = K_{a.s}(0,55T_{\max.vid} + 0.2T_{\max.abs}) \cdot (1 + 2,5 \cdot 10^{-7} Q_h) \cdot (1 + 0,0075 A_h) \cdot (1 - 0,03 v_h) \cdot \left(1 + \frac{0,08}{U_{\%h}}\right) \cdot (1 + 0,009 n_{th}) \cdot (1 + 0,012 t_{th}),$$

$$N_c = K_{a.z}(0,75T_{\min.vid} + 0,25T_{\min.abs}) \cdot (1 + 0,015Q_c) \cdot (1 + 0,0075A_{nz}) \cdot (1 + 0,07v_c) \cdot (1 + 0,26U_{\%c}) \cdot (1 + 0,014n_{zm}) \cdot (1 + 0,022t_c),$$



Mr Koch proposed to divide the range of airworthiness scores into five groups), ranging from 0 to 60 conditional scores in hot weather and from 0 to 170 in cold weather. Such a breakdown is convenient for assessing the overall impact of climatic factors on vehicles.

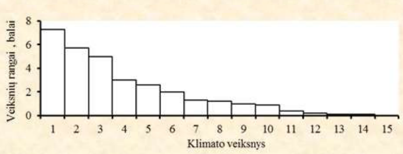
Non-periodic diagram of Koch climate factors: 1 - average air temperature during the three coldest months, °C; 2 - average air temperature during the three hottest months; 3 - average relative humidity; 4 - direct solar radiation; 5 - average non-periodic amplitude of air temperature fluctuations per day; 6 - average wind speed; 7 - sandstorm; 8 - scattered solar radiation; 9 - hot period; 10 - fog; 11 - maximum wind speed; 12 - amount of precipitation; 13 - atmospheric pressure; 14 - air temperature fluctuations within 0 °C; 15 - wind direction

Numerical models for climate and weather assessment

In other sources, such as MIL-STD-810G (2008), Army Regulation 70-38 (1997), Ch. Ryerson (2005) and S. Harmin, W. King (2005) et al.). Other atmospheric factors (precipitation, wind, sandstorms), biological and geographical location, including terrain, are assessed separately by compiling criteria for the assessment of very important environmental factors from 1 to 5 points and also dividing them into groups.

Detailed lists of criteria for the assessment of relevant environmental factors are given in S. Harmin, W. King, Ch. Ryerson et al. (2005). Each criterion is evaluated by summing the scores: the higher the score, the more difficult and unfavorable the operating conditions of the vehicles.

Numerical models for climate and weather assessment



Non-periodic diagram of the ranks of Kozhevnikov climatic factors: 1 - lowest average air temperature, °C; 2 - amount of precipitation; 3 - maximum wind speed; 4 - average wind speed; 5 - average relative humidity; 6 - average amplitude of air temperature fluctuation per day; 7 - direct solar radiation; 8 - scattered solar radiation; 9 - the highest average air temperature, °C; 10 - fog; 11 - hot period; 12 - atmospheric pressure; 13 - air temperature fluctuations within 0 °C; 14 - sand storm; 15 - wind direction

Numerical models for climate and weather assessment

For the assessment of unfavorable impact of climatic factors on military vehicles the Entropic information statistical method proposed by Kozhevnikov was applied. The entropic approach provides the possibility of numerical evaluation, while maintaining the distance from specific objects. The assessment is based on entropy in its information and statistical interpretation. The major advantage of this approach consists in the possibility of taking account of the type of probability density distribution curve for random meteorological factors' values for a selected period as well as in the opportunity of their direct summation.

The Entropic information statistical method is based on information theory of Shannon.

Unfavorable climate impact

The Entropic information statistical method is based on information theory of Shannon]. According it, the information loss due to disinformation under the effect of climate factor is designated with the sign "minus" and the entropy change as proposed by Kozhevnikov is calculated according the following formulas:

$$(-Q_{Fi}) = A_{Fi}^{q} \cdot t; \qquad (-q_F) = \frac{(k \cdot ln\, N)}{\Delta t};$$

$$A_{Fi}^{q} = \left| \frac{(-q_F)}{(X_F - X_F^N)} \right|; \qquad k = \frac{1}{ln\, 2} = 1{,}4427;$$

$$(-Q_{KM}) = (-Q_A) + (-Q_B) + \ldots + (-Q_M);$$

where: $(-Q_{Fi})$ - change in entropy over time t; A_{fi}^{q} – the slope angle coefficient of the linear regression line; $(-q_F)$ – the rate of climate factor information (transmission), bps; X_F^N – the value of the climatic factor under normal (rated) conditions; X_F – the actual value of the climatic factor; N – the number of divisions (intervals) with the value ΔX, which is within the interval with the actual value ; $(-Q_{KM})$ – the change of complex (total) entropy of climatic factors; , , ..., $(-Q_A)$, $(-Q_B)$, ..., $(-Q_M)$ – the change of entropies of climate factors) $A, B, \ldots, M$ over time t.

Unfavorable climate impact

Unfavorable impact of the climate factor on vehicle's operation is calculated as the ratio of the change in complex climatic entropy over time t and the change in climatic entropy under normal conditions over time *t*:

$$K_N = \frac{(-Q_{KM})}{(-Q_F^N)}.$$

Review of scientific studies on reliability of internal combustion engines

Review of scientific studies on reliability of internal combustion engines

- Reviews the theory of engine reliability as a science studying patterns of variation in indicators of engine operating systems and mechanisms during engine performance and physical causes behind engine failures, as well as determining methods and ways for ensuring required durability and efficiency of the engine under minimum time and economic costs.
- The most interrelated features of engine **durability and indefectibility are as follows: frequency of engine failures tends to reduce its durability, and when running failures turn into resource-type problems, the limit technical state of the engine is reached.** Investigation of engine failures is initiated only upon occurrence of the failure which is described based on its core feature and main criterion.

Review of scientific studies on reliability of internal combustion engines

- Aside of engine durability and indefectibility features, the indicators of engine reliability have been distinguished – a quantitative characterization of a single or multiple features defining reliability of the engine. Reliability of the engine allows for using the car according to its intended purpose for a required period of time with the particular effectiveness. Reliability of an engine can be quantitatively evaluated using indicators associated with the characteristics of a car, operating conditions, and outcomes resulting from failures.

Review of scientific studies on reliability of internal combustion engines

- **Engine operating conditions represent a significant factor** for analysis of vehicles performance under **difficult conditions that include low air temperatures, in case of deep snow coverage – frequent snowstorms and snowbanks on roads; regions with hot dessert climate, poorly developed network of roads and driveways, lack of afforestation and water, increased air dustiness, considerable diurnal temperature variation; mountainous terrains with thin air and lower atmospheric pressure; highly variable terrain profiles and considerable diurnal temperature variations; off-roads and scales of road aggravation.** Difficult engine operating conditions are also considered to include regions with high humidity levels.

Review of scientific studies on reliability of internal combustion engines

- Each of the above-mentioned factors of engine operating conditions has an influence (mostly negative) on operation of automotive engine. The **altitude (elevation) of the road location above sea level** and violent variations thereof is a fundamental factor determining ICE loading regimes. **Difficult combinations of driveways at mountainous locations comprised of downhills and uphills different in size with variable high-intensity road winding and small turning radiuses determine uneven rolling resistance of a vehicle.** Another subtype of operating loads involves the climatic factor with parameters such as temperature, air impurities, air humidity, solar radiation (the latter is not attributed to the difficult operating conditions however it is directly linked to the temperatures of air and Earth's surface).

Summary of Review of scientific studies on reliability of internal combustion engines, the following tasks were set for the research

- This subtype is also considered to include the geographical factor – atmospheric pressure, which directly takes part in shaping the process of engine operation in the cylinders of the engine. The third factor accountable for reduced engine reliability and determining its parametric failures is the wear of engine parts. Operating (characteristics of fuel and engine oil and their quality, quality of spare parts, etc.) and biological factors (rodents, funguses, vegetation, etc.) might also be distinguished.

Summary of Review of scientific studies on reliability of internal combustion engines, the following tasks were set for the research

- One of the operating factors – trustworthiness of the work done by the automotive maintenance and service personnel is discussed individually as it may determine occurrence of engine failures due to human fault. Climatic factors and weather conditions are closely related to human physical and mental activities.
- Given the discussed conditions of engine operation, numerical climate and weather models are arranged allowing for assessment of the climate and weather in the region under consideration.