CAPACITY TO CHOOSE ADEQUATE VEHICLE MAINTENANCE METHOD DEPENDING ON DRIVE TYPE

Mr Srdjan Filipović, Technical director, PUC "Public Services" Požarevac
Mr Nada Stanojević, GM, Institute for research and design in commerce and industry
Doc. dr Davor Vujanović, University of Belgrade, Faculty of transport and traffic engineering, Serbia
Miloš Vasić, University of Belgrade, Faculty of Mechanical engineering, Serbia

Abstract: *Main purpose of this paper is to give the review of existing methods of maintenance of the vechicles and to set parameters of choosing right methods and education of maintenance managers in order to achieve best available solution for maintaince of the vehicle.*

Another goal of this paper is to provide chronological analysis of used methods of maintenance, reliability methods and dynamic stress and strain projected parameters used.

Through evoulution aproach of the powering options of the vechicles paper will give review of nowstanding principles and methods and forecast future in maintnanace of the vechicles.

Near future and future development of the maintenance of the vechicles according to mechanical and electrical components and presence in the object of maintenance is the key element of this paper.

Artificial inteligence, self driving, self diagnostic systems and self maintenable systems aproach is used in this papers describing development of future maintenance.

All facts subjected to in view of Euromaint Project.

Keywords: *Leonardo da Vinci Project, Euromaint, maintnenance analysis, maintenance methods, AI*

1. MAIN GOAL OF THE PAPER

Main goal of this paper is to provide review of existing methods of maintenance of the vehicles and to set parameters of choise in accordance of suitable method of maintenance of particular model.

Next goal of this paper is to execute chronological analysis and historical review used methods in compare to type of propulsion generator and predict areas of education of the future vehicle maintenance managers of the future vehicles taking in consideration of main maintanenace methods and techniques all in nomenclature of European Federation of Maintenance Engineers Society EuroMaint Project a Leonardo da Vinci Project.

2. INTRODUCTORY REMARKS

This paper took care of only most important facts in the area of maintenance according to European Federation of Maintenance Engineers Society EuroMaint Project.

Vast variety of known methods of maintenance and techniques are not main goal of this paper but review of main methods and possible usage of them in future vehicles.

Setting characteristical timepoints of vehicles development was made using common historical facts all in order to make guide lines of vehicles development process. These corner stones should provide enough facts for anticipation of near future development of vechiles maintenance.

Main principles used for this kind of prevision are principles of evolution which would provide progressive and regressive branches of future development of vehicles and maintnenace of the vechicles all in respect to historical facts.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

3. HISTORICAL REVIEW OF VECHICLES PROPULSION METHODS

The presented time line describes the invention of the automobile and its development is set to provide basic facts about car drive development history. Through this time line one can easily put focus on propulsion methods.

1478. – *Leonardo da Vinci* invents the self-propelled car.

1769. – *Nicolas-Joseph Cugnot* builds the **first self-propelled road vehicle** in France.

1789. – American *Oliver Evans* receives the first US patent for **a steam-powered land vehicle.**

1801. - The **concept of the fuel cell** was first demonstrated by *Humphry Davy*

1807. – *Francois Isaac de Rivaz* in Switzerland invented an **internal combustion engine which uses a mixture of hydrogen and oxygen**

1823. – English engineer and inventor *Samuel Brown* invents an **internal combustion engine**. It has separate combustion and working cylinders, and is used to power a vehicle.

1828. – *Anyos Jedlik*, a Hungarian invented **electric motor powered** car

1832. – *Robert Anderson* invents the first crude **electric carriage powered by non-rechargeable primary power cells**.

1842. - invention of the **first working fuel cell** is credited to *William Grove*

1859. - **Rechargeable batteries** that provided a viable means for storing electricity on board a vehicle

1867. – German *Nikolaus August Otto* improves on the **internal combustion engine** first to efficiently **burn fuel directly in a piston chamber**.

1870. - *Siegfried Marcus***built the first gasoline powered combustion engine**

1877.- *Otto* builds the **four-cycle internal combustion engine**, which is the prototype for modern car engines.

1879. – American inventor *George Baldwin* files the **first U.S. Patent for an automobile**.

1880. - *Siegfried Marcus* car gasoline-powered engine **carburetor design and magneto ignition, steering, a clutch and brakes**

1881. -**invention of the lead–acid battery** by French physicist Gaston Planté.

1885. – German engine designer **Karl Benz builds the first true automobile powered by a gasoline engine**.

1886 – In Michigan, *Henry Ford* **builds his first automobile**.

1886. – *Gottlieb Wilhelm Daimler and Wilhelm Maybach* invent the **first four-wheeled, four-stroke engine** in Germany. It is known as the “Cannstatt-Daimler.”

1888. - The **first electric car in Germany** was built by the engineer *Andreas Flocken*

1893. – Brothers *Frank and Charles Edgar Duryea* invent the first successful **gas-powered car** in the United States., founded the Duryea Motor Wagon

1903. - in France 30,204 cars were produced, representing 48.8% of world automobile production that year

1908. -the Ford Model T, created by the Ford Motor Company five years prior, became the first automobile to be mass-produced. By 1927, Ford had produced over 15,000,000 Model T automobiles.

1959. - American Motors Corporation (AMC) and Sonotone Corporation announced a joint research effort to consider producing **an electric car powered by a "self-charging" battery**. nickel-cadmium batteries

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

1959. - **The first modern fuel cell vehicle** was a modified Allis-Chalmers **farm tractor**, fitted with a 15 kilowatt fuel cell,

1966. Chevrolet Electrovan **Fuel cell electric vehicle**

1967. - AMC partnered with Gulton Industries to develop a new **battery based on lithium**

1967. - NSU Ro 80 —**Wankel engine**

1971. - **Lunar rover an electric car** the first manned vehicle to drive on the Moon; it was first deployed during the Apollo 15 mission. The "moon buggy" was developed by Boeing and GM subsidiary Delco Electronics featured a DC drive motor in each wheel, and a pair of 36-volt silver-zinc potassium hydroxide non-rechargeable batteries.

1997. – present Toyota Prius, launched in the Japanese market and became the best known **hybrid electric vehicle** and also the world's top selling hybrid

2006. - there were between 60,000 and 76,000 low-speed battery-powered vehicles in use in the United States

2008–2012 Tesla Roadster — **first highway-capable all-electric vehicle** in serial production for sale in the United States in the modern era. Sold about 2,500 units worldwide.

2008–2013 BYD F3DM – **first highway-capable series production plug-in hybrid**, launched in China in December 2008, sold over 2,300 units.

2010–present, Nissan Leaf and Chevrolet Volt — all-electric car and plug-in hybrid correspondingly,

2012–present, Tesla Model S – Plug-in electric vehicle

2013. - BMW ActiveE, Coda, Renault Fluence Z.E., Honda Fit EV, Toyota RAV4 EV, Renault Zoe, Roewe E50, Mahindra e2o, Chevrolet Spark EV, Mercedes-Benz SLS AMG Electric Drive, Fiat 500e, Volkswagen e-Up!, BMW i3, and Kandi EV. Toyota Scion iQ EV .

2016, march, **Tesla Model 3 was unveiled With pricing starting at US$35,000** and an all-electric range, number of net reservations totaled about 373,000 as of 15 May 2016

2016. – August The Renault-Nissan Alliance achieved the **milestone of 350,000 electric cars**

2016, - In December **Norway became the first country where 5% of all registered passenger cars was a plug-in electric**

As described by the time line automotive industries suffered influence of petrol industry. In the early days of vehicle making all types of propulsion were engaged. Steam and electric powered vehicles were in advance of ICE (internal combustion engine) in many ways from polution to noise and mechanical advantages as gearbox needless.

Mass production of the car make ICE propelled vehicles more cheaper and thus more usable.

Advance in technology, law requirements and lack of nature resources in nowadays make car manufacturers to go electric hybrid, all electric or fuel cell propelled.

This make electric cars progressive branch in todays evolution of the vehicles, passenger or freight.

4. MODERN VECHICLES DRIVE TYPES

Concerns about climate change, urban air pollution, and dependence on unstable and expensive supplies of foreign oil have lead policy makers and researchers to investigate alternatives to conventional petroleum-fueled internal combustion engine vehicles (ICEVs) in transportation.

Because vehicles that get some or all of their power from an electric drivetrain can have low or even zero emissions of greenhouse gases (GHGs) there is considerable interest in developing and evaluating advanced

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

EVs, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel-cell electric vehicles (FCEVs). Zero Emission Vehicles (ZEV).

Todays EV's have higher initial costs but they might have lower operating and maintenance costs and as a result might have lower total costs over their lifetime. Something that could be changed in mass production.

In the time of this paper there are several drive types commonly used to propell the vehicle:

1. Internal Combustion Engine Vehicles(ICEV)
   - Petrol powered
   - LPG powered
   - Diesel powered
2. Hybrid Electric Vehicles (HEV)
3. Plug-in Hybrid Electric Vehicles (PHEV)
4. Battery Electric Vehicles (BEV)
   - Battery cells
   - Super capacitors
   - Solar power
5. Fuel Cell Electric Vehicles (FCEV)

5. COMPETENCIES OF MAINTENANCE MANAGERS AND METHODOLOGIES OF MAINTENANCE

There are several methodologies of maintenance management all of which in the case of this purpose we can divide in seven groups of competencies that managers of maintenance should be aware in choosing methodologies of adequate maintenance methods:

1. Business Administration
   - Life Cycle Cost (LCC)
   - Life Cycle Profit (LCP)
2. Asset management methods
   - ALCA models (LCC/LCP)
   - Total Quality Management (TQM)
3. Integrity Management
   - Failure Modes, Effects and Criticality Analysis (FMECA)
   - Fault Tree Analysis (FTA)
   - Risk Based Inspection (RBI)
   - Risk Based Asset Management (RBAM)
   - Risk Based Integrity Management (RBIM)
4. Maintenance management methods
   - Reliability centered maintenance (RCM)
   - Total Productive Maintenance (TPM)
   - Condition Based Maintenance (CBM)
5. Continious improvement
   - Lean Maintenance
   - Total Productive Maintenance (TPM)
   - Six Sigma
6. Information systems
   - Interaction Computerized Maintenance Management Software(CMMS) and Economy systems
7. Leadership, HR and Organization
   - Maintenance Manager as businessman
   - Risk management

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

- Contingency management

All of these competencies can mostly affect the ability of one to choose adequate method of vehicle maintenance.

The one will have to choose approach as level of its competency and/or level of management.

6. HISTORICAL REVIEW OF PROJECTED METHODS OF RELIABILITY

Reliability of mechanical components of vehicle relies on its strenght to overcome the stress it is exposed.

Throught the history in the early days of mass production (begining of 20th century) car makers was forced to find apropriate ways to reduce mass of the vechile as it was saving in production and making product (car) economically affordable to the customer (buyer).

On the other hand usage of parts and components with less material was subjected to mechanical failures so the tensile strenght research and stress and strain diagrams developed models of projected and calculated strenght of components and parts with everlasting usage.

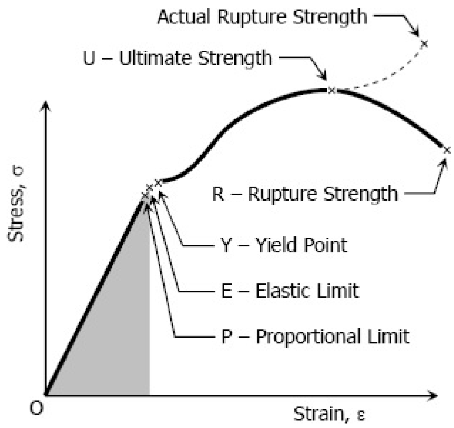

Fig.1 StressStrain diagram medium structural steel

Usage of engineering stress as method of projected reliabilty was insufficient in order to make vehicle that is economically potent for car makers as the similar forces and stress apeared on similar types of car.

The solution was to create time based reliable components and parts entering the area of time based ultimate tensile strenght. (as of 30’ of 20th century)

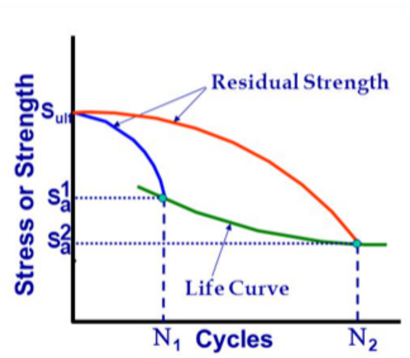

Fig.2 Remaining stress/strengft prediction

Time based ultimate tensile strenght gave new productional dimension of vehicles components which make car makers to calculate lifecycle of the vechicle and period preventive maintenance. Also this method provided saving in production making it more efficient and profitable.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

The WWII was the breaking point in mechanical industry since it made tremendous leap in several areas of engineering like mechanics of the fluids, reaserch of materials, logistics etc. all of which affected mechanical engineering.

New approach to production developed new technology and engineering techniques that led to funcional reliabilty particurly in space research programs.

All new technolgies and engineering knowledge transfered to car industry producing new methods of projected reliabilty as well as new types and methods of maintenance of the vechicles.

Profit based manufacturing also led to new methods of projected reliabilty and maintenance.

Structure of the car was mechanical and the percentage of mechanical components used in cars was very high in the long period of car history.

Electric components were introduced as parts of subsidery systems which made cars more safe and enviromental friendly in early 50' of the 20th century.

Semiconductor components introduced new era of electronics which made its way in car industry as of 1956.

The computer aided softwares and FEM and shell thery calculations made possible to inspect components before they were build or installed in car.

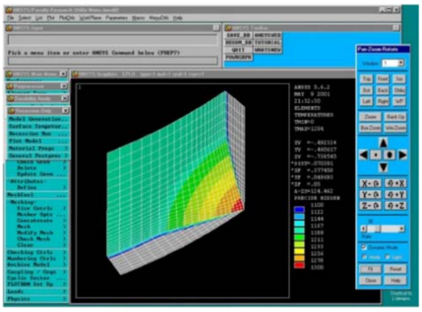

Fig.3. Finite Element Method computer software

Todays vechicles especially BEVs and FCEVs have specifically less mechanical parts than cars made fifty years ago.

All this stated shows that future car maintenace will be more dependable on techniques and methods used in maintaining of electrical, electronical and process(chemical) components.

7. REVIEW OF RELIABILITY METHODS OF MECHANICAL SYSTEMS (ICEVS)

Types of maintenance strategy

There are several general types of maintenance philosophies that could be identified, and they are stated in order of their common in use as a vehicle maintenance strategy or car production.

1. Corrective maintenance (CM)

Maintenance is carried out following detection of an anomaly and aimed at restoring normal operating conditions. This approach is based on the firm belief that the costs sustained for downtime and repair in case of fault are lower than the investment required for a maintenance program. This strategy may be cost-effective until catastrophic faults occur.

2. Preventive maintenance (PM)

Maintenance carried out at predetermined intervals or according to prescribed criteria, aimed at reducing the failure risk or performance degradation of the equipment.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

The maintenance cycles are planned according to the need to take the device out of service. The incidence of operating faults is reduced.

3. Periodic maintenance (Time Based Maintenance TBM)

The basic maintenance of equipment made by the users of it. It consists of a series of elementary tasks (data collections, visual inspections, cleaning, lubrication, retightening screws,…) for which no extensive training is necessary, but perhaps only a brief training. This type of maintenance is the based on TPM (Total Productive Maintenance).

4. Predictive Maintenance

It pursues constantly know and report the status and operational capacity of the installations by knowing the values of certain variables, which represent such state and operational ability. To apply this maintenance, it is necessary to identify physical variables (temperature, vibration, power consumption, etc.). Which variation is indicative of problems that may be appearing on the equipment. This maintenance it is the most technical, since it requires advanced technical resources, and at times of strong mathematical, physical and / or technical knowledge.

5. Condition-based maintenance (CBM)

Maintenance based on the equipment performance monitoring and the control of the corrective actions taken as a result.

The real actual equipment condition is continuously assessed by the on-line detection of significant working device parameters and their automatic comparison with average values and performance. Maintenance is carried out when certain indicators give the signaling that the equipment is deteriorating and the failure probability is increasing.

This strategy, in the long term, allows reducing drastically the costs associated with maintenance, thereby minimizing the occurrence of serious faults and optimizing the available economic resources management.

6. Risk-based maintenance (RBM)

Maintenance carried out by integrating analysis, measurement and periodic test activities to standard preventive maintenance.

The gathered information is viewed in the context of the environmental, operation and process condition of the equipment in the system. The aim is to perform the asset condition and risk assessment and define the appropriate maintenance program.

All equipment displaying abnormal values is refurbished or replaced. In this way it is possible to extend the useful life and guarantee over time high levels of reliability, safety and efficiency of the plant.

7. Zero Hours Maintenance (Overhaul)

The set of tasks whose goal is to review the equipment at scheduled intervals before appearing any failure, either when the reliability of the equipment has decreased considerably so it is risky to make forecasts of production capacity . This review is based on leaving the equipment to zero hours of operation, that is, as if the equipment were new. These reviews will replace or repair all items subject to wear. The aim is to ensure, with high probability, a good working time fixed in advance.

8. RELIABILITY PREDICTION BASICS OF MIXED MECHANICAL AND ELECTRICAL/ELECTRONICAL SYSTEMS (HEVS, BEVS, FCEVS)

Reliability predictions are one of the most common forms of reliability analysis. Reliability predictions predict the failure rate of components and overall system reliability. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas, trade-off system design factors, and track reliability improvement.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

The Role of Reliability Prediction

Reliability Prediction has many roles in the reliability engineering process. The impact of proposed design changes on reliability is determined by comparing the reliability predictions of the existing and proposed designs.

The ability of the design to maintain an acceptable reliability level under environmental extremes can be assessed through reliability predictions. Predictions can be used to evaluate the need for environmental control systems.

The effects of complexity on the probability of mission success can be evaluated by performing a reliability prediction analysis. Results from the analysis may determine a need for redundant systems, back-up systems, subsystems, assemblies, or component parts. **MIL-HDBK-217** (Electronics Reliability Prediction), **Bellcore/Telcordia** (Electronics Reliability Prediction) and **NSWC** (Mechanical Reliability Prediction) provide failure rate and MTBF (Mean Time Between Failures) data for electronic and mechanical parts and equipment.

A reliability prediction can also assist in evaluating the significance of reported failures. Ultimately, the results obtained by performing a reliability prediction analysis can be useful when conducting further analyses such as a **FMECA** (Failure Modes, Effects and Criticality Analysis), **RBD** (Reliability Block Diagram) or a **Fault Tree** analysis. The reliability predictions are used to evaluate the probabilities of failure events described in these alternate failure analysis models.

Reliability and Unreliability

First, let us review some concepts of reliability. At a given point in time, a component or system is either functioning or it has failed, and that the component or system operating state changes as time evolves. A working component or system will eventually fail. The failed state will continue forever, if the component or system is non-repairable. A repairable component or system will remain in the failed state for a period of time while it is being repaired and then transcends back to the functioning state when the repair is completed. This transition is assumed to be instantaneous. The change from a functioning to a failed state is failure while the change from a failure to a functioning state is referred to as repair. It is also assumed that repairs bring the component or system back to an “as good as new” condition. This cycle continues with the repair-to-failure and the failure-to-repair process; and then, repeats over and over for a repairable system.

The reliability prediction standards such as MIL-217, Bellcore/Telcordia and NSWC Mechanical assume the component or system to be non-repairable, in a new condition at time zero and have a constant failure rate, if evaluated over a very long time period and using an infinite or very large sample size of components or systems.

Reliability (for non-repairable items) can be defined as the probability that an item will perform a defined function without failure under stated conditions for a stated period of time. One must grasp the concept of probabilities in order to understand the concept of reliability. The numerical values of both reliability and unreliability are expressed as a probability from 0 to 1 and have no units.

Reliability stated in another way:

The **Reliability, R(t),** of a component or system is defined as the probability that the component or system remains operating from time zero to time t1, given that it was operating at time zero.

Or stated another way for repairable items:

The **Reliability, R(t),** is defined as the probability that the component or system experiences no failures during the time interval zero to t1 given that the component or system was repaired to a like new condition or was functioning at t0.

And:

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

The **Unreliability, F(t)**, of a component or system is defined as the probability that the component or system experiences the first failure or has failed one or more times during the time interval zero to time t, given that it was operating or repaired to a like new condition at time zero.

Or stated another way:

The Unreliability, F(t), of a component or system at a given time is simply the number of components failed to time t divided by the total number of samples tested.

The following relationship holds true since a component or system must either experience its first failure in the time interval zero to t or remain operating over this period.

$$R(t) + F(t) = 1 \quad \text{or} \quad \text{Unreliability } F(t) = 1 - R(t)$$

Availability and Unavailability

In reliability engineering and reliability studies, it is the general convention to deal with unreliability and unavailability values rather than reliability and availability. The numerical value of both availability and unavailability are also expressed as a probability from 0 to 1 with no units.

The **Availability, A(t)**, of a component or system is defined as the probability that the component or system is operating at time t, given that it was operating at time zero.

The **Unavailability, Q(t),** of a component or system is defined as the probability that the component or system is not operating at time t, given that is was operating at time zero.

Or stated another way:

Unavailability, Q(t) is the probability that the component or system is in the failed state at time t and is equal to the number of the failed components at time t divided by the total sample.

Therefore, the following relationship holds true since a component or system must be either operating or not operating at any time:

$$A(t) + Q(t) = 1$$

Both parameters are used in reliability assessments, safety and cost related studies. The following relationship holds:

Unavailability Q(t) ≤ Unreliability F(t)

For a non-repairable component or system:

Unavailability Q(t) = Unreliability F(t)

NOTE: This general equality only holds for system unavailability and unreliability if all the components within the system are non-repairable up to time t.

Reliability Prediction Definitions

Failure Rates Reliability predictions are based on failure rates.

Conditional Failure Rate or Failure Intensity, λ(t), can be defined as the anticipated number of times an item will fail in a specified time period, given that it was as good as new at time zero and is functioning at time t.

It is a calculated value that provides a measure of reliability for a product. This value is normally expressed as failures per million hours (fpmh or 106 hours), but can also be expressed, as is the case with Bellcore/Telcordia, as failures per billion hours (fits or failures in time or 109 hours). For example, a component with a failure rate of 2 failures per million hours would be expected to fail 2 times in a million-hour time period.

Failure rate calculations are based on complex models which include factors using specific component data such as temperature, environment, and stress. In the prediction model, assembled components are

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

structured serially. Thus, calculated failure rates for assemblies are a sum of the individual failure rates for components within the assembly.

There are three common basic categories of failure rates:

Mean Time Between Failures (MTBF)

Mean Time To Failure (MTTF)

Mean Time To Repair (MTTR)

Mean Time Between Failures (MTBF) Mean time between failures (MTBF) is a basic measure of reliability for repairable items. MTBF can be described as the time passed before a component, assembly, or system fails, under the condition of a constant failure rate. Another way of stating MTBF is the expected value of time between two consecutive failures, for repairable systems. It is a commonly used variable in reliability and maintainability analyses.

MTBF can be calculated as the inverse of the failure rate, λ, for constant failure rate systems. For example, for a component with a failure rate of 2 failures per million hours, the MTBF would be the inverse of that failure rate, λ, or:

$$MTBF = \frac{1}{\lambda} \quad OR \quad \frac{1}{2\ failures\ /10^6 hours} = 500.000\ hours/failure$$

NOTE: Although MTBF was designed for use with repairable items, it is commonly used for both repairable and non-repairable items. For non-repairable items, MTBF is the time until the first (an only) failure after t0.

Mean Time To Failure (MTTF)

Mean time to failure (MTTF) is a basic measure of reliability for non-repairable systems. It is the mean time expected until the first failure of a piece of equipment. MTTF is a statistical value and is intended to be the mean over a long period of time and with a large number of units. For constant failure rate systems, MTTF is the inverse of the failure rate, λ. If failure rate, λ, is in failures/million hours, MTTF = 1,000,000 / Failure Rate, λ, for components with exponential distributions. Or

$$MTTF = \frac{1}{\lambda\ failures/10^6\ Hours}$$

For repairable systems, MTTF is the expected span of time from repair to the first or next failure.

Mean Time to Repair (MTTR)

Mean time to repair (MTTR) is defined as the total amount of time spent performing all corrective or preventative maintenance repairs divided by the total number of those repairs. It is the expected span of time from a failure (or shut down) to the repair or maintenance completion. This term is typically only used with repairable systems.

Failure Frequencies There are four failure frequencies, which are commonly used in reliability analyses.

- Failure Density f(t) - The failure density of a component or system, f(t) , is defined as the probability per unit time that the component or system experiences its first failure at time t, given that the component or system was operating at time zero.
- Failure Rate r(t) - The failure rate of a component or system, r(t) , is defined as the probability per unit time that the component or system experiences a failure at time t, given that the component or system was operating at time zero and has survived to time t.
- Conditional Failure Intensity (or Conditional Failure Rate) λ(t) - The conditional failure intensity of a component or system, λ(t) , is defined as the probability per unit time that the component or system experiences a failure at time t, given that the component or system was operating, or was repaired to be as good as new, at time zero and is operating at time t.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

- Unconditional Failure Intensity or Failure Frequency ω(t) - The unconditional failure intensity of a component or system, ω(t) , is defined as the probability per unit time that the component or system experiences a failure at time t, given that the component or system was operating at time zero.

Relationships Between Failure Parameters The following relations exist between failure parameters.

$$R(t) + F(t) = 1$$
$$f(t) = \frac{dF(t)}{dt}$$
$$F(t) = \int_0^t f(u)du$$
$$r(t) = \frac{f(t)}{1 - F(t)}$$
$$R(t) = e^{-\int_0^t r(u)du}$$
$$F(t) = 1 - e^{-\int_0^t r(u)du}$$
$$f(t) = r(t)e^{-\int_0^t r(u)du}$$

The definitions for failure rate r(t) and conditional failure intensity λ(t) differ in that that the failure rate definition addresses the first failure of the component or system rather than any failure of the component or system. In the special cases of the failure rate being constant with respect to time or if the component is non-repairable these two quantities are equal. In summary :

λ(t) = r(t) for non-repairable components

λ(t) r(t) for constant failure rates

λ(t) ≠ r(t) for the general case

The difference between the conditional failure intensity (CFI)) λ(t) and unconditional failure intensity ω(t) is that the CFI has an additional condition that the component or system has survived to time t. The relationship between these two quantities may be expressed mathematically as

$$\omega(t) - \lambda(t)(1 - Q(t))$$

For most reliability and availability studies the unavailability) (tQ of components and systems is very much less than 1. In such cases

$$\omega(t) \approx \lambda(t)$$

Constant Failure Rates

If the failure rate is constant then the following expressions apply :

$$R(t) = e^{\lambda t}$$
$$F(t) = 1 - e^{-\lambda t}$$
$$f(t) = \lambda e^{-\lambda t}$$

As can be seen from the equation above a constant failure rate results in an exponential failure density distribution.

Repairable and Non-repairable Items

It is important to distinguish between repairable and non-repairable items when predicting or measuring reliability.

Non-repairable items

Non-repairable items are components or systems such as a light bulb, transistor, rocket motor, etc. Their reliability is the survival probability over the items expected life or over a specific period of time during its

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

life, when only one failure can occur. During the component or systems life, the instantaneous probability of the first and only failure is called the **hazard rate or failure rate**, r(t) . Life values such as MTTF described above are used to define non-repairable items.

Repairable Items For repairable items, reliability is the probability that failure will not occur in the time period of interest; or when more than one failure can occur, reliability can be expressed as the **failure rate**, λ, or the **rate of occurrence of failures** (ROCOF). In the case of repairable items, reliability can be characterized by MTBF described above, but only under the condition of constant failure rate.

There is also the concern for availability, A(t), of repairable items since repair takes time. **Availability, A(t)**, is affected by the rate of occurrence of failures (failure rate, λ) or MTBF plus maintenance time; where maintenance can be corrective (repair) or preventative (to reduce the likelihood of failure). Availability, A(t), is the probability that an item is in an operable state at any time

$$Availability\ A(t) = \frac{MTBF}{MTBF + MTTR}$$

Some systems are considered both repairable and non-repairable, such as a missile. It is repairable while under test on the ground; but becomes a non-repairable system when fired.

NOTE: Failure rate, λ, is applied loosely to non-repairable items. What is really meant in a repairable system, which contains a part, is that the part will contribute to the overall system failure rate by the stated part failure rate. The part being non-repairable cannot have a failure rate.

Failure Patterns (Non-repairable Items)

There are three patterns of failures for non-repairable items, which can change with time. The failure rate (hazard rate) may be decreasing, increasing or constant.

1. **Decreasing Failure Rate (Non-repairable Items)**

A decreasing failure rate (DFR) can be caused by an item, which becomes less likely to fail as the survival time increases. This is demonstrated by electronic equipment during their early life or the burn-in period. This is demonstrated by the first half of the traditional bath tub curve for electronic components or equipment where failure rate is decreasing during the early life period.

2. **Constant Failure Rate (Non-repairable Items)**

A constant failure rate (CFR) can be caused by the application of loads at a constant average rate in excess of the design specifications or strength. These are typically externally induced failures.

3. **Increasing Failure Rate (Non-repairable Items)**

An increasing failure rate (IFR) can be caused by material fatigue or by strength deterioration due to cyclic loading. Its failure mode does not accrue for a finite time, then exhibits an increasing probability of occurrence.

This failure pattern is also demonstrated by electronic equipment that has aged beyond its useful life (right hand side of the bath tub curve) and the failure rate is rapidly increasing with time.

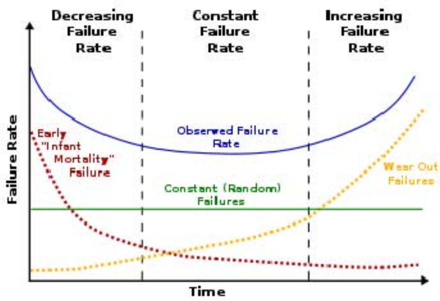

Fig. 4 Typical Bath Tub Curve

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

Wearout or Increasing Failure Rate Stage (End of Useful Life)

Steady-state or Constant Failure Rate Stage Prime-of-Life (Failures Occur Randomly)

Externally Induced Failures

Early Life or High Failure Rate Stage (Failure of Weak or Defective Components) (Burn-in Period)

Failure Patterns (Repairable Items) There are three patterns of failures for repairable items, which can change with time. The failure rate (hazard rate) may be decreasing, increasing or constant.

1. **Decreasing Failure Rate (Repairable Items)**

An item whose reliability is improved by progressive repair and / or burn-in can cause a decreasing failure rate (DFR) pattern.

2. **Constant Failure Rate (Repairable Items)**

A constant failure rate (CFR) is indicative of externally induced failures as in the constant failure rate of non-repairable items. This is typical of complex systems subject to repair and overhaul.

3. **Increasing Failure Rate (Repairable Items)**

This increasing failure rate (IFR) pattern is demonstrated by repairable equipment when wear out modes begin to predominate or electronic equipment that has aged beyond its useful life (right hand side of the bath tub curve) and the failure rate is increasing with time.

Redundancy

Redundancy is briefly defined as the existence of two or more means, not necessarily identical, for accomplishing a given single function. There are different types of redundancy.

Active Redundancy – Has all items operating simultaneously in parallel. All items are working and in use at the same time, even though only one item is required for the function. There is no change in the failure rate of the surviving item after the failure of a companion item. *

    - Pure Parallel – No Change in the failure rate of surviving items after failure of a companion item.
    - Shared Parallel – Failure rate of remaining items change after failure of a companion item.
- **Standby Redundancy** – Has alternate items activated upon failure of the first item. Only one item is operating at a time to accomplish the function. One item's failure rate affects the failure characteristics of others as they are now more susceptible to failure beause they are now under load.
    - Hot Standby – Same as Active Standby or Active Redundancy.
    - Cold Standby (Passive) – Normally not operating. Do not fail when they are on cold standby. Failure of an item forces standby item to start operating.
    - Warm Standby – Normally active or operational, but not under load. Failure rate will be less due to lower stress.

R-out-of-n Systems – Redundant system consisting of n items in which r of the n items must function for the system to function (voting decision).

9. MAINTENANCE OF FCEVS

Maintenance of FCEVs is dependant on procedures which are special to maintenance of fuel cell. In description of maintenance procedures we can conclude that main course of maintaining of FCEVs is preventive maintenance.
Procedures are shown below and mainly consists of two types of procedure:

1. FUEL CELL ENGINE PROCEDURES

- Ground fault monitor check and conditional de-ionizing filter replacement

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

- Water trap inspections
- Air system oil detector inspection
- Hydrogen diffuser inspection
- Stack vent fans check
- Cell voltage monitor check
- Fuel cell engine leak tests
- Power cable connection checks
- Glycol system integrity test
- Dump chopper resistance check

2. FUEL SYSTEM PROCEDURES

- Fuel circuit leak tests
- Fuel system inspections
- Hydrogen particulate filter replacement
- Motive pressure regulator solenoid valve check
- Ground integrity check
- Fuel cylinder inspections
- Pressure regulator diaphragm, seal and seat replacement

10.SAFETY AS IMPERATIVE OF MAINTENANCE OF THE VEHICLES

New drivetrain technologies includes batteries, hybrid components, fuel cells and its energy containers or transmitters.

Energy used for propelling the vehicle is electricity which demand special safety procedures and care due to high energy transfer is used whether vehicle use batteries or super conductors as energy storage.

On the other hand in FCEVs hydrogen is used. Although hydrogen storage technologies made hydrogen as safe as petrol or LPG storage special safety percautions had to made.

High power batteries are also highly flammable and special care has to made.

Ecological aspects of ZEVs or near ZEVs has to be considered in long term actions as batteries are very pollutant and the future production technologies must have recycle – reuse implemented actions.

11.PREDICTION OF VEHICLE DEVELOPMENT

Todays state of propulsion types

1. Internal Combustion Engine Vehicles(ICEV)
   - Petrol powered
   - LPG powered
   - Diesel powered
2. Hybrid Electric Vehicles (HEV)
3. Plug-in Hybrid Electric Vehicles (PHEV)
4. Battery Electric Vehicles (BEV)
   - Battery cells
   - Super capacitors
   - Solar power
5. Fuel Cell Electric Vehicles (FCEV)

Near future

1. Hybrid Electric Vehicles (HEV)
2. Plug-in Hybrid Electric Vehicles (PHEV)

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

3. Battery Electric Vehicles (BEV)
    - Battery cells
    - Super capacitors
    - Solar power
4. Fuel Cell Electric Vehicles (FCEV)

Future

1. Battery Electric Vehicles (BEV)
    - Battery cells
    - Super capacitors
    - Solar power
2. Fuel Cell Electric Vehicles (FCEV)

12.CAPACITY TO CHOOSE ADEQUATE VEHICLE MAINTENANCE

Capacity to choose adequate vehicle maintnenance lies in the fact of complexity of the vehicle.

Thee fact that different types od drivetrains have different needs for maintenance is illustrated in the table bellow.

Table 1. Table of intensity criteria of maintenance need

Drive type		Need for maintenance		
		Mechanical	Electrical	Process
Internal Combustion Engine Vehicles(ICEV) (SI)	Petrol powered	****	*	
	LPG powered	****	*	*
	Diesel powered	****	*	
Hybrid Electric Vehicles (HEV)		*****	***	
Plug-in Hybrid Electric Vehicles (PHEV) EREV		*****	****	*
Battery Electric Vehicles (BEV)	Battery cells	*	***	
	Super capacitors	*	***	
	Solar powered etc	*	***	
Fuel Cell Electric Vehicles (FCEV)		***	***	*****

Note: intensity criteria * very low; ** low: *** medium: ****high: ***** very high

Obviously EV's with battery or supercapacitors are vehicles with less maintenance needed compared with other types of propulsion. That is from fact that there are less mechanical and moving parts for example several thousand compared t several hundreds of parts which gives them better reliability and less maintenance action needed.

In the matter of maintenance this type of vehicles will be the choise of the future.

The actual ability of one to choose adequate maintenance relies on fact to choose right maintenance for propulsion construction.

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

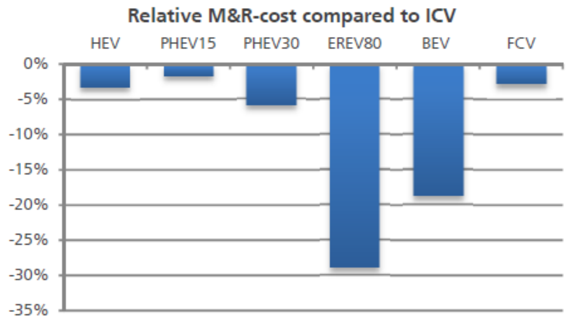

Fig. 5. Maintenance and repair costs compared to ICEV

Therefore if we can conclude that most complicated constructions like PHEVs are most sophisticated and more maintenance dependable also less reliable compared to actions needed for them to operate (more projected maintenance, more sophisticated manufacturing, more complicated maintenance…) all of which gives less revenue for car makers in sales but more in aftersales.

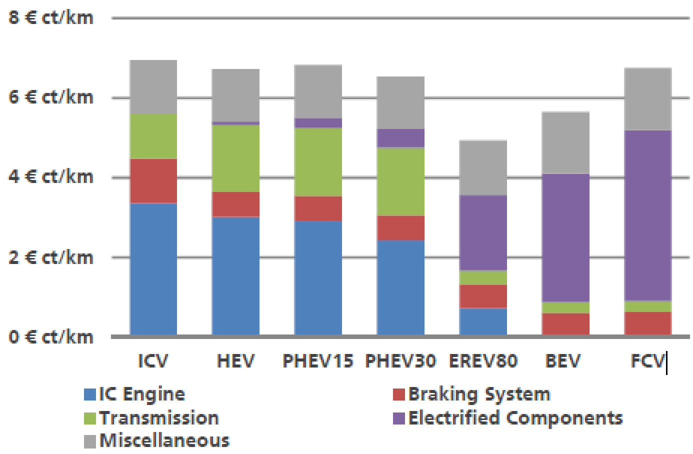

Fig. 6. Vechicle components costs per km

Simplicity of design of BEVs is something car makers of the future will take in serious consideration especially in sales division.

Also in aftersales, there will be less need for complicated procedures and highly competent technicians and engineers.

13.FORECAST OF MAINTENANCE OF THE VEHICLE

As the future vehicles would be…

- Self driving
- Self Diagnostic
- Self Maintained
- Modular
- Standardized
- Artificial inteligent

Structure of vehicles and ratio of mechanical and electrical components shall demand more percentage of electrical maintenance and less mechanical maintenance, because of:

- Less moving parts less friction

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

- Less wear and tear maintenance
- Modularity

Future maintenance of the vehicles should have:

- New techniques for electromechanical maintenance
- More self – diagnostics

As a result new vehicles should be

- Self - maintained vehicles

14.CONCLUSION

The progressive branch of future development of vehicles is showing tendenciesin several subbranches that should be leading factor of development as of vehicles as of maintenance of vehicles. There are is

- Development of new maintenance technologies
- Development of infrastructure for ZEVs
- Development of new propulsion systems
- Development of new production plants
- Development of Standards
- Development of AI vehicles

Mass production products are rarely subjected to best available technical solution but best aquinted economical solution

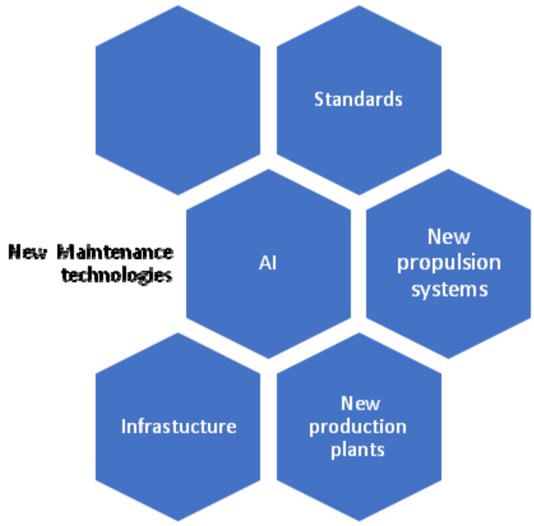

Fig. 7. Sinergy of elements

15. REFERENCES

/1/ Alan Wilson, Arjan de Bruin, Erlijn Eweg, (2008) Guide to Maintenance Management, Hogeschool Utrecht, University of Aplied Sciences, ISBN 978-90-813466-1-0

/2/ Mark A. Delucchi and Timothy E. Lipman (2010) Lifetime Cost of Battery, Fuel-Cell, and Plug-in Hybrid Electric Vehicles, University California Davis, Universizy of California Berkley, ISBN 978-0-444-53565-8, DOI: 10.1016/B978-0-444-53565-8.00002-6

/3/ Bernd Propfe, Martin Redelbach, Danilo J. Santini, Horst Friedrich, (2012) Cost analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values, Institute of Vehicle Concepts, German Aerospace Center (DLR), EVS26 Los Angeles, California, May, 2012

/4/ prof.dr.Branko Vasić, (1997): Maintnenace Management (Управљање одржавањем),

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com

NIRO“OMO“ID55447564, Belgrade

/5/ Hydrogen Fuel Cell Engines and Related Technologies: Rev 0, December (2001) Module 7: Fuelcell bus maintenance

/6/ Richard Raustad, (2017) Electric Vehicle Life Cycle Cost Analysis, Electric Vehicle Transportation Center, EVTC Report Number: FSEC-CR-2053-17

/7/ http://www.reliabilityeducation.com/ReliabilityPredictionBasics.pdf

*PUC "Public Services" Požarevac
srdjan.v.filipovic@gmail.com