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CAPACITY TO CHOOSE ADEQUATE VEHICLE MAINTENANCE METHOD DEPENDING ON DRIVE TYPE

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1. Main goals 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
- 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.

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."

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MAINTENANCE FORUM 2018

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

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, air pollution, and unstable and expensive oil have lead to investigate alternatives to (ICEVs) in transportation. Zero Emission Vehicles (ZEV).

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
- Contingency management

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

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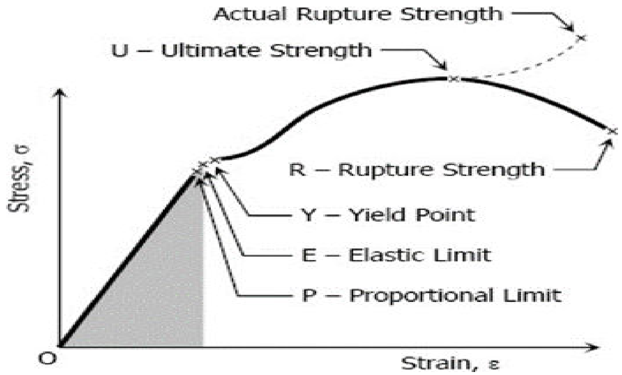
6. Historical review of projected methods of reliability

- 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.



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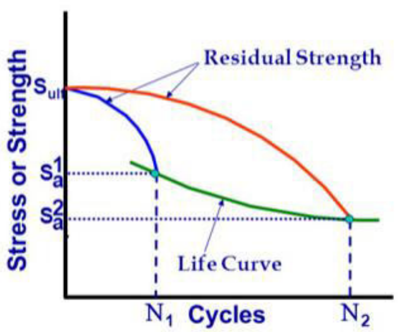
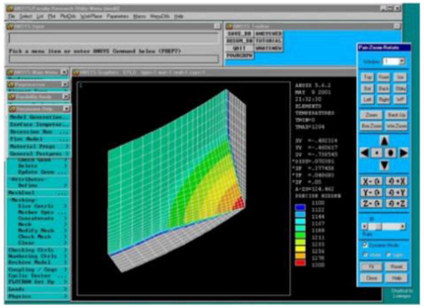
- Usage of engineering stress as method of projected reliabilty was insufficient in order to make vehicle that is economically potent for car makers as the similar forces and stress apeared on similar types of car.
- The solution was to create time based reliable components and parts entering the area of time based ultimate tensile strenght. (as of 30’ of 20th century)
- 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.



- 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.
- 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)

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.

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)

It consists of a series of elementary tasks (data collections, visual inspections, cleaning, lubrication, retightening screws,…) 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.

5. Condition-based maintenance (CBM)

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

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6. Risk-based maintenance (RBM)

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

7. Zero Hours Maintenance (Overhaul)

The set of tasks whose goal is to review the equipment at scheduled intervals before appearing any failure,

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.
- **The Role of Reliability Prediction**
- The ability of the design to maintain an acceptable reliability level under environmental extremes can be assessed through reliability predictions.
- 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.
- 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.

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:

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

$$= 500.000\ hours/failure$$

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

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

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

Mean time to repair (MTTR) 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.

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

$$R(t) + F(t) = 1$$

$$f(t) = \frac{dF(t)}{dt}$$

$$F(t) = \int_0^t f(u)du$$

$$r(t) = \frac{f(t)}{1 - F(t)}$$

$$R(t) = e^{-\int_0^t r(u)du}$$

$$F(t) = 1 - e^{-\int_0^t r(u)du}$$

$$f(t) = r(t)e^{-\int_0^t r(u)du}$$

Repairable and Non-repairable Items

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

Non-repairable items are components or systems such as a light bulb, transistor, rocket motor, etc. 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) . 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.

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)**

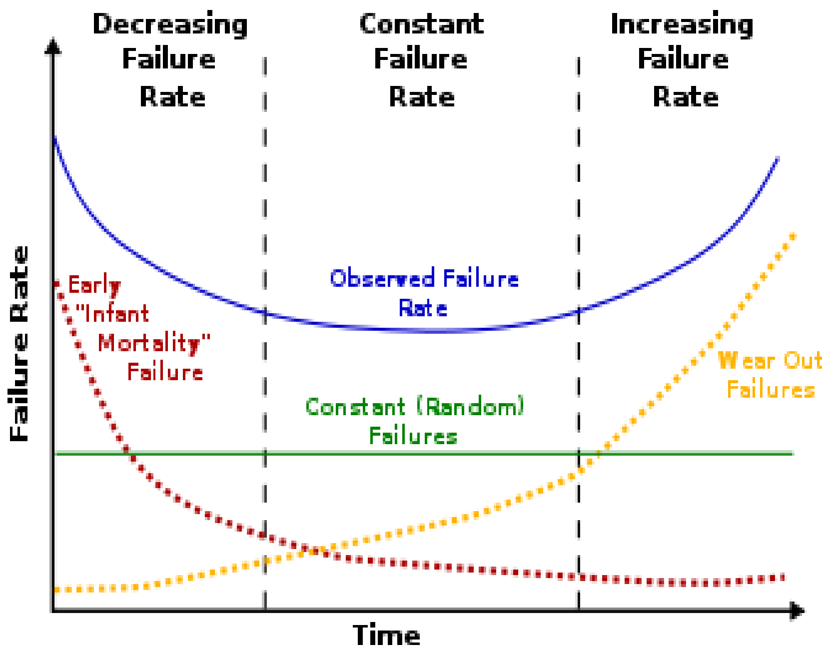
A decreasing failure rate (DFR) can be caused by an item, which becomes less likely to fail as the survival time increases. This is demonstrated by electronic equipment during their early life or the burn-in period. This is demonstrated by the first half of the traditional bath tub curve for electronic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



- 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

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.

1. FUEL CELL ENGINE PROCEDURES

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

1. 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 be 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 powere

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)
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

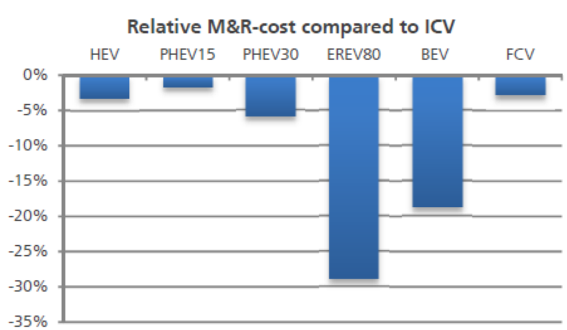
2. Fuel Cell Electric Vehicles (FCEV)

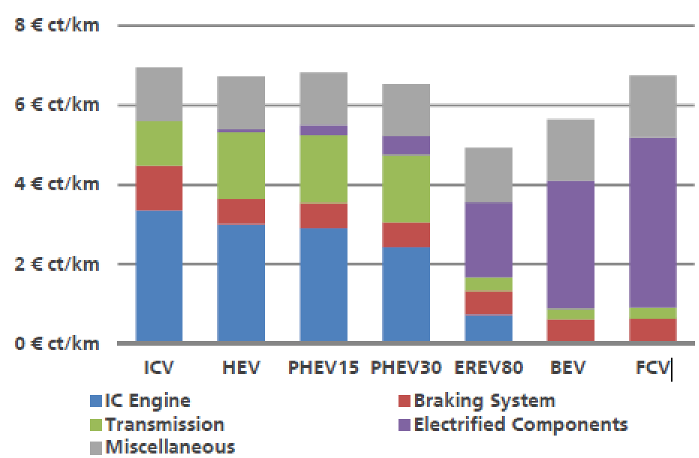
12. Capacity to choose adequate vehicle maintenance

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.





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- 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.
- 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
- 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

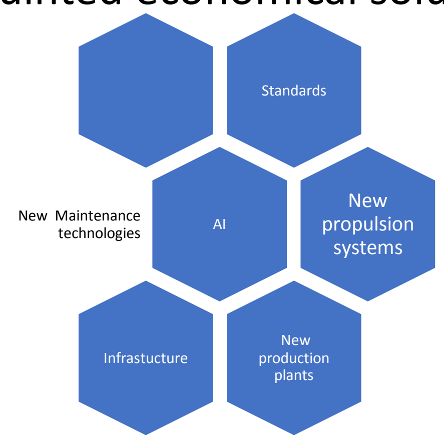
- Self - maintained vehicles

14. Conclusion

The progressive branch of future development of vehicles is showing tendencies in several subbranches that should be leading factor of development as of vehicles as of maintenance of vehicles. s

- 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



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Thank you!