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Tridesettreći skup o prometnim sustavima
s međunarodnim sudjelovanjem
AUTOMATIZACIJA U PROMETU 2013

33rd Conference on Transportation Systems
with International Participation
AUTOMATION IN TRANSPORTATION 2013

November 20-23, 2013
Osijek – Croatia

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Pomorski i riječni promet / Maritime and River Transportation

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EXPERT SYSTEM MODEL FOR VEHICLE MAINTENANCE INTERVAL ASSESSMENT

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Abstract

Vehicle maintenance refers as a vital factor for vehicular proper functionality, reliability and longevity. Time based and usage conditioned maintenances are often prescribed by vehicular manufacturers and they are mandatory if warranty should be kept. Conditioned servicing intervals and actions are prescribed in manner of securely shorten vehicle usage period between two maintenances to avoid significant vehicle functioning incidents instead. That raises maintenance costs even if vehicle can function normally for additional period of time without need for actual servicing. Servicing period extension is hard to predict and depend on numerous of variables. In this paper is presented an expert system model for vehicle maintenance interval assessment according measurable objective and subjective vehicle parameters.

1. INTRODUCTION

Vehicular maintenance represents critical action in a whole vehicle life-span. For their longevity and reliability, regularly checking of a vehicle vital systems are mandatory. Which system are vital and critical that depends on a vehicle types but all of them shares most of these systems, such; engine system, workload system and assembly structure. In practice, maintenance mostly relies on time-based maintenance actions alongside irregular, condition based system checks. Time based maintenance actions are prescribed by vehicle manufacturer based on specific system part checks and preventive part replacements in function to prevent system malfunctions. These actions doesn't analyses whole condition of vehicle nor analyses system parts wearing state. Irregular checks relies on a, again, manufacturers prescribed actions but conditioned by a vehicular exploitation environment and usage. Condition based maintenance is just one of several types of technical maintenance. Generally, this kind of maintenance is based on the state of an object or system to be maintained.

All of these maintenance actions don't reflect real state of vehicle system, in general. Preventive replacing of system parts can be very costly in manner of parts alone and servicing costs by servicing providers. Also, during servicing interval, vehicle isn't in operating state nor does his task so, exploitation cost rises and productivity declines.

Right time servicing interval assessment in function of lowering system costs and rising system productivity is a very interesting topic in vehicular exploitation area. That is very actual problem and represents whole field of scientific research, especially in mass transportation systems such air-transportation, railroad transportation and etc., where vehicle operating vs. non-operating state is very important in function of raising a benefits and lowering total costs, [1..3].

In this paper is presented an expert system model for vehicular maintenance interval assessment based on analysis of measurable vehicle parameters, making a vehicle decomposition model and maintenance interval prediction, respectively.

2. EXPERT SYSTEM MODEL

As is stated in introduction chapter, vehicular maintenance refers as a critical factor for their proper functionality, reliability and longevity. If you want lower maintenance costs and keep vehicle functionality then maintenance interval should be determined by general state observation assessment and replace or repair only these parts which are at the end of their functional life. How to determine a right time for maintenance? That is very hard to predict and represents hard issue in scientific research. Numerous of factors influences on reliable maintenance schedule prediction but there are no general models which can solve that problem. There are several approaches with more or less success. Most of them relies on combining regular maintenance intervals with on board vehicle diagnostics where by synergy of both system readouts maintenance interval is determined, such in [4, 5]. These systems rely on a question-answer system database queries where for given issue a solution is determined from previously known failure-solve knowledge. Problem with these systems represents through "what to do when for a specific question the answer doesn't exist"?

In this paper is presented an expert system model which does not rely on exact solutions, it generates maintenance interval prediction based on statistical component reliability and observation parameters through a grey-model system decomposition.

2.1. Maintenance and maintenance types

First of all, there must be determine what maintenance is and what types of maintenances system supports. Related to vehicles, maintenance is sequence of action what inspects/checks system functionality, determine and localize problematic systems and replace or repair these systems. Types of maintenances are; *Condition Based, Reliability Centered, Lean, Total Lifecycle Costs Strategy* and *Total Productive* maintenance. How to choose appropriate strategy to use depends on several factors, depicted in Fig. 1.

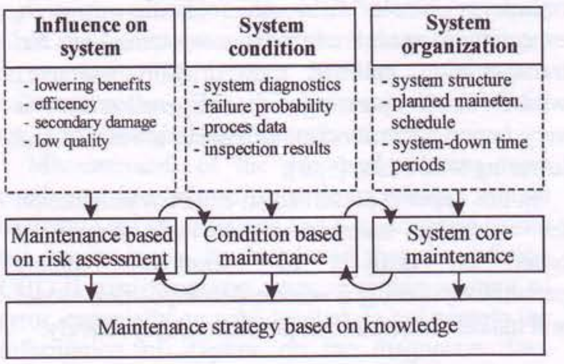

Fig. 1. Strategy choosing pathway.

Depending on maintenance action influences, system condition and system organization a maintenance strategy is chosen. All of these strategies are based on previous knowledge on system structure, actions and failure appearances in function of keep system alive, functional and keep its longevity.

2.2. Condition and reliability based maintenance assessment

Condition based maintenance is a combination of periodical maintenance and maintenance after failure occur. Main idea of this approach is to minimize regular scheduled maintenance and maximum exploitation of spare parts. Downside of this approach is relatively long inoperable time of vehicle where system cist arises. Because of this downside of condition based approach reliability centered maintenance is observed alongside condition based one. Reliability centered maintenance relies on risk assessment strategy where failure occurrences and part costs are important. Total risk, R, of a system malfunction is assessed through (1),

$$R=\Sigma R_i=\Sigma S_i H_i \quad (1)$$

where, R_i is component failure risk, S_i is component cost and H_i is component failure reliability. On the other side, a component cost, S_i, is determined by (2)

$$S_i=\Sigma R_i=\Sigma S_i H_i \quad (2)$$

where W_s is cost of inoperable device, t_i is component repair time, L_i is number of inoperable actions and K_i is cost of repair. In sum, total risk of system malfunction and inoperability relies on component reliability by a principle "System is reliable as is its weakest component". So, determining, localizing and failure prediction of that component is main task of this method.

Alongside, all component failure occurrence assessment is based on previously, historical, observations and often cannot be considered as reliable information. Also, information's provided by component manufacturers are often unavailable or not suited for real environment usage so another maintenance strategy data analysis must be observed such method based on system decomposition and evidential reasoning explained in chapter 3.

3. MAINTENANCE INTERVAL ASSESSMENT

This expert system for maintenance interval assessment is based on condition and reliability based maintenance assessment in conjunction with model decomposition and evidential reasoning.

3.1. Model feeding data

Real life data needs to be gathered to feed model. All gathered data are quantitative by its nature but they need to be translated to qualitative domain to be comparable and suitable to maintenance model structure where only magnitude of reliability and data dispersion measurement is important. Methods, used by this transformation, often rely only on expertise of system operator and nature of information by itself. Input data can be; *continuous variables*, *exploit time* and *discrete variables*. Continuous variables are translated to their qualitative equivalents using *Gaussian* distribution to define its classes, b_n, and measurement deviation σ_n, (3), fig. 2.

$$b_n = \frac{1}{\sigma_n \sqrt{2\pi}} e^{-\frac{(x-\bar{x}_n)^2}{2\sigma_n^2}} \tag{3}$$

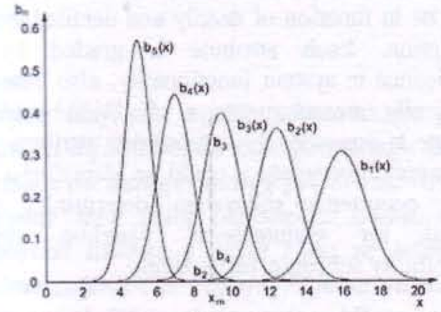

Fig. 2. Representation of continuous variables.

Exploit time variable is represented similar as continuous variable, as a *Gaussian* distribution, but with difference that component reliability functioning R, (4), is observed.

$$R(t) = e^{-\int_0^t \lambda \, dt} \quad \rightarrow \quad \sigma_n = \frac{1}{R_n \sqrt{2\pi}} \tag{4}$$

Parameter λ defines failure occurrence and directly influences on component operability. Deviation σ_n now defines total probability of failure class time.

Discrete variable by its nature can be qualified according quantification scale in a way where lowest quantification values are poorest one and highest the best one or vice versa.

3.2. System model decomposition

To make assessment of complex technical system there must be gathered, processed and interpreted a mass of qualitative and quantitative process data. All these data must be transformed into qualitative domain to suit model feeding requirements. Decomposition model of one technical system consists of numerous of attributes which, according measurable and observable parameters, can sufficiently describes general health of such system. Some attributes can be assessed by direct parameter measurement and other, non-directly assessed, through lower order attribute interpretation. For example, directly assessable attributes in vehicle is condition of engine lubrication system by direct oil pressure measurement.

Vehicle

First order attr.	Second order attr.
- General attributes	- Age, mileage, vizual impression...
- Engine	- Power, torque, exhaus gasses, temperature, cleanliness, knocking...
- Fuel system	- Leakage, consumption, pressure, flow
- Exhaust system	- Pressure, temperature, rust
- Transmission	- Gear rumbling, ease of shifting, temperature,...
- Wheels	- Age of tires, pressure, detrition
- Electric system	- Voltage, power consumption,
- Chassis	- Cracks, rust, bumps, deformations

Fig. 3. Example of road vehicle decomposition model.

For non-directly assessable attribute example can be combustion cycle regularity where through exhaust gas analysis, engine temperature and knock detection can be determined whether or not combustion mixture and/or piston-cylinder-valve system is ok or not. Main idea of system decomposition is to make a description model of whole system which can be described through general and basic attributes with their level of significance in system functionality.

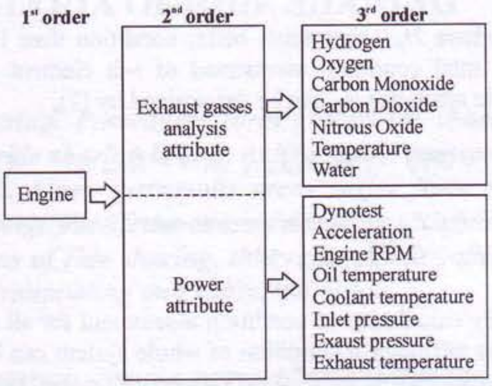

Fig. 4. Detailed model decomposition of *Engine* attributes (partially).

That is not easy task. Primarily, each system should be decomposed on as more as is possible, even directly or indirectly assessed, attributes in function to make more reliable system model. An example for vehicular system modeling is given in Fig. 3. Each decomposition model consists of several attribute levels, hierarchically sorted. Each attribute consists of several sub attributes with their own measurement and condition assessment. For example, engine system can be decomposed on several other attributes with sub attributes condition assessment, fig. 4.

3.3. Condition estimation and maintenance interval assessment

Condition estimation relies on evidential reasoning where each of attribute has its own grade, (poor, sufficient, good, very good and excellent), weight of attribute significance and assessment reliability grade. Also, hierarchically attribute relation system is determined. For example, by exhaust gasses condition assessment (second order attribute) of petrol engine system (1st order attribute) a concentration of CO and CO_2, H and O_2 is measured and graded from poor to excellent, significance of each attribute is also known and assessment reliability grade is determined by measurement quality. According measurement results a whole combustion cycle condition, engine health respectively, of petrol engine can be determined.

Generally, there can be assumed L basic attributes (1st order) e_i $(i=1..L)$ and they are subset of general attribute Y, (vehicle). So, it can be defined a set of basic attributes, E, (5).

$$E=\{e_1, e_2, \dots e_L\}, E\in Y \tag{5}$$

Each attribute has its own weight $\omega=\{\omega_1,\omega_2,\dots\omega_L\}$, where $\omega_i \in [0..1]$. Also, attributes condition grades, H, must be defined, (6).

$$H=\{H_1, H_2, \dots H_n\} \tag{6}$$

where H_{n+1} represents better condition than H_n. So, total condition assessment of i-th element of basic attributes, e_i, can be determined by (7),

$$S(e_i) = \{(H_n,\beta_{n,i})|_{n=1\dots N}\},\ i = 1,\dots, L \tag{7}$$

where $\beta_{n,i}$ represents assessment reliability grade and $\beta_{n,i} \geq 0$, $\sum_{n=1}^{N}\beta_{n,i} \leq 1$.

By calculation of condition assessment for all of basic attributes a condition of whole system can be determined and located a component that should be repaired by spotting attribute with lowest grade, and determining a maintenance interval respectively.

4. CONCLUSION

Determining right maintenance interval is great factor for sustainable vehicular usage and lowering maintenance costs. It is hard to predict it only with objective and subjective measurements and observations. An expert system model based on system attributes decomposition is proposed in conjunction with evidential reasoning mechanism for reliable maintenance interval estimation in function to keep system alive and functional with minimum maintenance costs. Minimum maintenance costs results with better vehicle usage yield and functional availability. Modeling of this system relies on knowledge data base structured by measurable attributes and condition assessed sub attributes (with graded weight and assessment grade reliability determination). Whole system should be decomposed on as much attributes as it could be in function of deeply and detailed system description. Each attribute is graded by its significance in system functionality, also based on historically measurements a condition grade of attribute is assessed. By determining attribute with lowest condition grade it could be identified a first failure occurrence subsystem, determining right interval for maintenance, planning system inoperability schedule, respectively.

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