RELIABILITY PREDICTION OF VEHICLES BY PATTERN RECOGNITION

By

P. MICHELBERGER, GY. BARTA and T. FARKAS

Department of Transport Engineering Mechanics, Technical University, Budapest

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Reliability examination of vehicles, one of the decisive factors of the development of vehicle traffic, commands a world-wide increasing interest. Systematic analysis of research achievements, observations made at factories, research institutes and universities point out measured economically rather proficient in traffic: reduction of manufacturing, operation and repair costs, improvement of labour and material management.

Problems of increasing the reliability can only be solved after clearing theoretical problems of, and developing a unified system of collecting information on, the increase of vehicle reliability.

The concept of reliability

Reliability is an ability of the vehicle to operate as specific under given service and surrounding conditions, remaining in the state of rating during effective operation [1].

Effective operating time is magnitude of the destinatory vehicle operation indicated with the number and the unit (e.g. km, h, etc.). Satisfactory state of a vehicle is that where it meets all requirements in technical specifications including operational indices. Operational requirements are specified by productivity, velocity, power, fuel and lubricant consumption indices, as well as by other important, casual parameters.

Reliability of vehicles depends on their maintainability, storability, as well as component longevity. Reliability is a complex characteristic comprising the entity of indices of maintainability, faultlessness, storability and longevity, or sometimes in different compositions. In certain cases, a single property from the four above may be selected to refer to the vehicle reliability.

Reliability is mostly understood as probability of trouble-proof operation during a given period. Probability of trouble-proof operation $P(t)$ is that of no damage under given service conditions during a working period from 0 to t (Fig. 1).

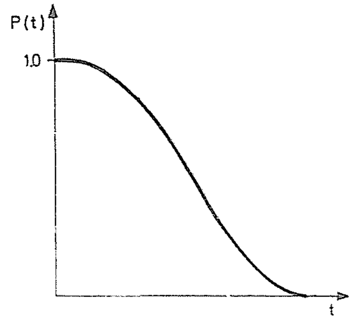

Fig. 1. Probability of faultless operation

$P(t)$ is approximated as the ratio of operating to examined items (sample):

$$\hat{P}(t) = \frac{N_0 - n}{N_0} \quad \text{or} \quad \hat{P}(t) = \frac{N(t)}{N_0}$$

where $N(t) = N_0 - n$ number of items in working order after working period t;

Table 1

RELIABILITY

FAULTLESSNESS	DURABILITY	MAINTAIN-ABILITY	STORABILITY (TRANSPORT-ABILITY)
Survival probability	Mean time to first restoration	Mean time of repairs	Mean time of storability
Mean time between failures	Service operation between repairs	Probability of repair in a given interval	Guaranteed storability time
Renewal density function	Service operation until scrapped	Probability of spare part availability	γ-quantile of storability time
Renewal function	γ-quantile of service operation		Vibration resistance
	Guaranteed effective operation		Impact resistence
	Warrant time		Heat sensitivity
	Lifetime to first overhaul		Tightness
	Lifetime between overhauls		Directional sensitivity
	Lifetime until scrapped		
	γ% quantile of lifetime		

N_0 — number of examined items;
n — number of items damaged in working period 0 to t.

But also other interpretations of reliability exist, namely the multiplicity of practical problems stresses ever different characteristics of the given item's reliability. For instance, in certain cases, a maximum period of no breakdown is required, in other cases a maximum probability of safe operation during a given service period T is expected; other quantitative indices may be necessary, or even the maximum level of reliability has often to be achieved according to several indices. Sometimes these latter requirements may be contradictory [2].

Thus, reliability has several quantitive characteristics, of them one or another is of importance, as the case may be. Particulars referring to the vehicle reliability have been compiled in Table 1. The most frequent complex parameters of reliability have been compiled in Table 2.

Table 2

Complex reliability characteristics
Availability factor
Ceofficient of availability
Coefficient of operational availability
Technical maintenance costs In particular: Technical maintenance expenditure Technical maintenance labour demand
Repair costs In particular: Repair time demand Repair labour demand

Correlation between technical condition and reliability forecast

Reliability is a characteristic determining the technical condition of the product. At a difference from other characteristics, reliability cannot, however, be directly measured but only experimentally determined by examining a population.

Forecast of the technical condition means quantity prediction of technical characteristic values, in either form such as classification of characteristics, or the probable time for a selected parameter value to attain the admitted tolerance, essentially, forecast of damaging. Reliability forecast means quantity prediction of reliability parameters of the product based on the preestimation of gradual and sudden failures [3].

In cases where operable state of the product depends on a single characteristic, the gradual variation of which entrains breakdown of the product, forecasts of technical condition and of reliability are coincident. In the general case, reliability forecast depends on several heterogeneous factors, and requires computations, tests and simulation.

Reliability of complex systems

A vehicle or its unit can be considered as a complex system, namely:

- it comprises structurally independent subsystems and system elements with self-contained functions;
- connections between subsystems and system elements permit the structure to be transformed and to be *a priori* redundant;
- certain partial damages only reduce the system efficiency rather than to cause breakdown. (Any state of multistate complex systems can be described by the proper efficiency index.)

Efficiency is determined by characteristics or group of characteristics selected with a view on peculiarities of the service function.

The efficiency analysis of technical products has several trends such as economical, technical, operative, etc.

The sphere of reliability is mainly related to technical efficiency, to be understood in the following as an efficiency — suitability, fitness — determined by technical characteristics of the tested vehicle or its part unit (power, reliability, resistance to damaging processes, etc.).

Technical efficiency may have the following indices:

- probability of fulfilment of a given task;
- productivity (performance rate, performed magnitude);
- information processing and obeying time;
- etc.

The rate of technical efficiency of a complex system of different part systems and elements is — in general:

$$E = \sum_{n=1}^{n} P_i E_i$$

where:

P_i — probability of the system to be in the ith serviceable condition;
E_i — efficiency of the system in the ith serviceable condition.

The concept of reliability is applied to evaluate the technical condition of the system, and that of efficiency, to evaluate results obtained by using the system, concepts not to be confused or confronted.

The actual, generally agreed concepts of the terminology of reliability refer to the examination of products in either of two conditions: serviceable or unserviceable. In vehicle engineering, however, the situation is much more complicated: both the vehicle and its part unit may have several different operable states, imposing special care in formulating the concept of failure.

Let us consider first a main unit, e.g. the engine. In spite of the several possible technical conditions of subsystems (cooler, lubricator, fuel supply, valve regulator, crank gear etc.) there exist some criteria typical of the engine reliability (starting ability, endurance power, specific economy indices etc.).

The same is true for the vehicle as a whole. First of all, personal and material security has to be guaranteed, a criterion in itself. Now, if the maintenance of traffic is a political,and that of transport a military question, failure criterion will be serviceability. In this case the vehicle has to be examined as a series-connected system, namely the engine has to work, the gear has to provide for the desired speed, doors have to function, etc. Inasmuch as the traffic needs are incumbent on an enterprise under given economy controls, operable state does not suffice in itself. The concept of damaging has to be determined on the basis of spare part consumption. After technical-economical determination fo a limiting value, the possible conditions get divided into two groups, permitting to determine the vehicle reliability just as that of any simple element of two alternative conditions.

Reliability of welded structures

Reliability of vehicle products sres ses the importance of the reliability of welded frames, special car bodies. Production costs of these structures amount to a high percentage of the total production costs of the vehicle, further stressed by maintenance and repair demands. Yet, the Hungarian vehicle industry often exports the welded frame in itself, other main vehicle units originate from foreign cooperation.

It should be noticed that actual methods for determining the failure criterion, for diagnosticizing the technical condition of welded vehicle frames with several redundancies are rather subjective.

Welded structures need no different terminology, either. The concept of the reliability of welded frames is the same as that specified in the COMECON standard: — a property of the product or object to tulfil its given task — fitting any system including welded vehicle frames (4).

Different timely evolution of damaging permits to distinguish between sudden and gradual failure. As a first approximation, it is advisable to consider these two kinds of failure as independent, in conformity with the running practice. In this case, the most important index of welded structure reliability is probability of faultless operation:

$$P = P_h - P_f$$

where P_h and P_f are probabilities of faultless operation in sudden or gradual damaging.

Also other reliability indices may be applied, depending on the actual circumstances of the application of the welded structure: mean time to failure $\widehat{T}$, mean time to repair $\widehat{T}_h$, average life-time x, availability factor K, etc.

Reliability of welded constructions depends on a score of factors, that of the quality of welded joints being the most important, especially for the vehicle reliability, function itself to several factors (Figs 2, 3).

Various limiting states may be distinguished as a function of type and service conditions of the construction, such as plastic deformation, fatigue,

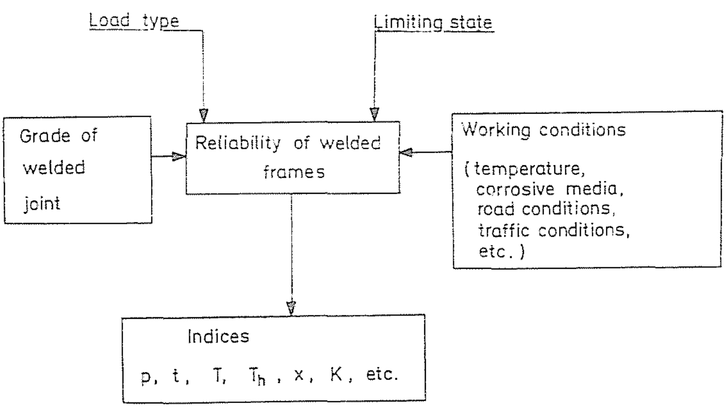

Fig. 2. **Major factors affecting the reliability of welded frames**

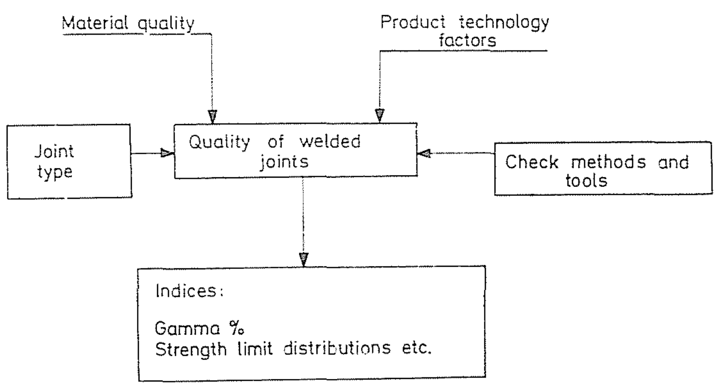

Fig. 3. **Main factors affecting quality of welded connections**

brittle failure, cracking, etc. In general, four limiting states are considered, but other criteriare a also possible:

— strength (the rate of structure failure);

— rigidity (the rate of inadmissible elastic or plastic deformation preventing the structure from normal operation);

— fatigue (the rate of structure breakdown);

— loss of stability.

Practically, probabilities of getting into the listed limiting states are seldom confrontable. In general, the limiting state the most likely to occur in the given situation has to be selected. Besides, for most of the technical systems of elements to be characterized at a high confidence correlation between limiting states may be neglected without introducing an error beyond the calculation accuracy [5].

In this case, probability of faultless service in case of a sudden failure is

$$P_h = \prod_{i=1}^{k} P_i$$

where P_i — probability of faultless working according to the ith limiting state;

k — number of limiting states.

Reliability evaluation methods for welded structures, the mathematical facilities for sudden failure greatly differ with the load type (Fig. 4).

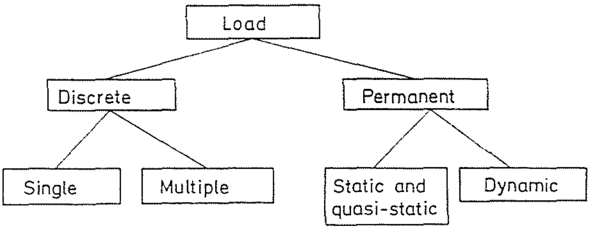

Fig. 4. Load types on welded structures

Gradual failure of welded structures means operable state loss due to fatigue. Wear, on the other hand, cannot be considered as a typical failure, except corrosion wear due to the aggressive surrounding.

Reliability forecasting methods

Road vehicles in use are subject to random load effects under a wide range of service conditions. Appreciation of either particular or complex reliability parameters requires to know the distribution of various load (stress) types, but also the vehicle resistance to damaging processes. Forecasting accuracy most depends on our knowledge of the vehicle resistance and of the expected stresses [6].

Applicability of the method of "design for reliability" for structural parts of vehicles still under development requires to assume a given stress state distribution, or to accept test results obtained on other vehicles. Nevertheless caution is recommended, expecially concerning the specific vehicle characteristics, i.e. with a view to differences between the tested and the designed vehicle [7].

Remind that the method of overall service life forecasting, relying on the cumulative damage theory, often requires utmost complex examinations, to be performed in laboratory on special fatigue testers, and under service conditions. In creating a new product or developing, updating an earlier product, timely evaluation of tests involves serious inconvenients. This is why ever new, accelerated reliability forecast methods are developed and adapted to the vehicle manufacture.

For complex systems, acceleration of the tests with increasing stresses hits difficulties because of the different failure mechanisms of component parts.

From among forecasting at nominal stresses, that of so-called individual forecast will be considered, applying the method of statistic classification (mathematical pattern recognition) to determine the reliability characteristics (Fig. 5).

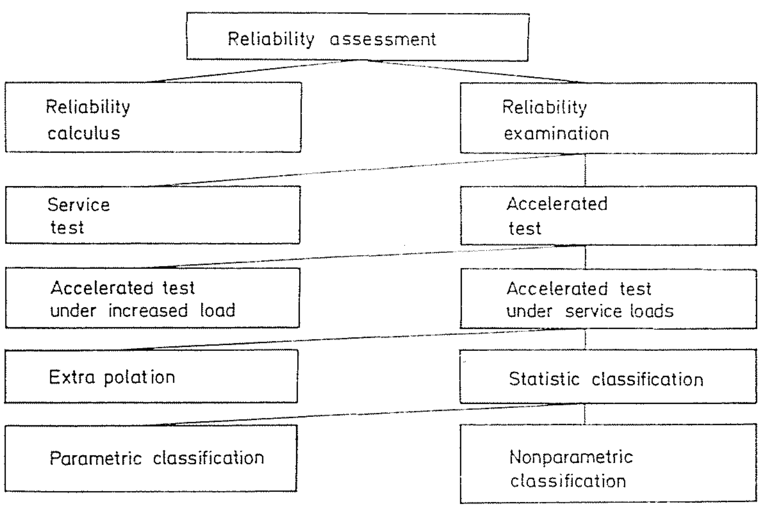

Fig. 5. Reliability prediction methods

Reliability prediction by pattern recognition (8)

Pattern recognition (statistic classification) are called certain mathematical-statistical methods of concluding from a number n of known variables on another — unknown — variable. There are also other possibilities, e.g. regression analysis (linear, nonlinear), and othe) methods of decision theory. These, however, assume the statistical model of the tested phenomenon to be known (joint density function, correlations, etc.). In concrete practical cases, for a multidimensional model, these statistical characteristics are not available, imposing to apply so-called non-parametric models, e.g. pattern recognition.

In the method of pattern recognition, a series of data for known structures, the so-called "archieve", rather than characteristics of the statistic model, are indicated. Computer methods of pattern recognition draw conclusions from archive data, "experience" on an unknown structure to be tested.

Forecast of reliability characteristics by pattern recognition methods relies on the comparison of characteristics of the equipment to be tested, and of equipment of a reliability known from previous tests. Expected life-time reliability of the tested equipment is assumed to behave rather similarly between two systems exhibiting identical or rather similar characteristics during a sufficient period $|t_e|$.

If the technical state of an equipment at a given time can be described by a set of numbers $\xi_1, \xi_2, \ldots, \xi_n$ where ξ_1 is a state characteristic of the equipment, then it can be characterized by a point of an n-dimensional space (state vector). Vectors describing particular specimens of a given equipment type will be differently located in space.

n-dimensional vectors characterizing systems of known history, hence of point sets, are compiled in an archive. Also within the archive, similar systems will be expressed by close-lying spatial points. Identical systems will have an identical point, and considering the rate of similarity as distance, the closer two multidimensional spatial points lie, the more similar the corresponding systems are.

Archives of data for known equipment are of the form:
where $\bar{x}_i$ is a realization of vector ξ describing the technical condition of the systems, $i = 1, 2, \ldots, N$, N being the number of known systems of the same type;

a_{ij} — parameter of the technical condition of the equipment, $j = 1, 2, \ldots, n$;
n — number of state parameters (n-dimensional state vector);
δ_i — rating of the state of the ith equipment.

State vector components will be recorded at times $t = 0, t_1, t_2, \ldots, t_M$.
Major steps of reliability prediction by pattern recognition are:

1. Measurement: Recording of technical characteristics (e.g. recording operation and stillstand times for part systems and the complete vehicle);
2. Sampling: Definition of failure criteria, computation of reliability characteristics; compilation of the available data set in an archive;
3. Pointing out essentials: Definition of the criterion of similarity based on premary causes, componerts of failure;
4. Decision: Comparison of a newly tested equipment to all known ones in the archives, and selecting the most similar one.
5. Prediction: Classification based on the behaviour of te most similar known equipment.

Method of prediction by pattern recognition in vehicle engineering

Published results on pattern recognition have in common to concern cases where the tested system is well characterizable by the timely development of its physical characteristics. Thereby the sate vector underlying similarity can be defined from technical considerations on the given product.

However, complex systems raise difficulties. While e.g. all information on the operation of electronic parts or instruments can be described by a set of electrical parameters, parameters the most affecting the life-times of road vehicles cannot always be selected. Even if physical characteristics of a given item are accessible to measurement, statistical data for assessing the reliability parameters are usually missing.

In lack of observation on the physical characteristics, the idea arises to make observations on the product itself, advisably decomposed into functions of its critical subsystems, assigning them the timely development of reliability characteristics. Thereby any structure can be individually characterized where failure information recorded to the level of main parts is available [9], such as test drives, evaluated service data.

Let the state of an arbitrary main unit of the given vehicle type be described by the timely development of its reliability characteristics.

The selected reliability characteristics describe intensity of damages of a given part, part system, seriousness of damages, and general niveau of service activity.

Availability of a system collecting failure data from earlier life-time examinations or servicing data entering into the above reliability parameters for the given product is the main point. Structure of the tested item will be described by convenient codes for connections, hierarchy of parts, part systems, the so-called construction matrix. Thereby weak points of the system are about mapped and quantified.

Thereby the problem is reduced to the recording of changes of several typical parameters — failure intensities of certain part systems of the structure.

In possession of observed state vector values for the equipment to be appreciated for a given time interval, and of the timely development of a high number of the equipment state during its life for observed state characteristic values, the newly tested equipment can be classified according to its expected lifetime, provided it will be exposed to identical or proven similar static and dynamic stresses (similar service conditions).

Economy advantages of reliability prediction by pattern recognition

Vehicle reliability analysis may contribute to the reduction of total costs spent on vehicle traffic, to a reasonable distribution of expenditures on production and up-to-date vehicle maintenance, coordination of new constructions, and of the production of spare parts, reduction of the number and seriousness of traffic casualties, etc.

Reliability prediction by pattern recognition yield a faster, less data demanding, cheaper solution of the given problems — determination of an economical lifetime, assessment of the expected total service costs, prediction of the demand in spare parts, assessment of exploitability, etc.

Accelerated reliability forecast method of statistic classification relying on pattern recognition permits to quantify reliability characteristics of the product without special tests, based on service data. Thereby export-oriented technical development may introduce measures to increase reliability and to enhance exportability.

Summary

Interpretation of some fundamental concepts of the theory of reliability in vehicle engineering is presented. Reliability analyses of welded vehicles are of a high significance. Reliability characteristics can be predicted by pattern recognition.

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Prof. Dr. Pál MICHELBERGER
Tamás FARKAS
Dr. György BARTA
H-1521, Budapest