Relation between Reliability and Availability of Railway Vehicles

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Reliability, availability and their mutual relationship are very important characteristics of railway vehicles. This paper presents how to determine the influence of railway vehicle reliability on its availability, using the real worked example with real values of these characteristics, for Serbian Railway conditions. Significant importance in achieving high reliability under the conditions of maintaining characteristics with small efficiency is confirmed. That indicates an obligation of Serbian Railways to insist on high reliability of components and the system as a whole, apart from constant increase of maintenance level efficiency within modernisation of existing and purchase of new rolling stock.

***Keywords**: railway vehicle, traction vehicle, reliability, availability, reconstruction, modernisation.*

1. INTRODUCTION

Reliability, defined as probability of technical system operation without a failure within given conditions and given time interval, and availability, defined as ability of a system to perform required function at given time interval under condition that outside recourses are provided, are two extremely important characteristics of every technical system, as well as subjects of the railway vehicle. That is why reliability and availability are the theme of European norm EN 50126 [1, 4, 5], which defines processes for specifying requirements and validations of so-called RAMS characteristics (Reliability, Availability, Maintainability and Safety) of technical systems applied in railways.

Although relation between reliability and availability of railway vehicles as technical systems is complex, it is mostly analyzed to define optimal levels of reliability and availability of new or reconstructed systems related to invested financial resources.

The aim of this work is analyze the relation between reliability and availability of railway vehicles due to the fundamental statements of the norm EN 50126. Also, some calculation examples for this relation are presented, and this could be the basics of making a decision of railway vehicle reconstruction level if its reliability and mean time needed for its corrective maintenance can be estimated.

2. RELATION BETWEEN RELIABILITY AND AVAILABILITY ACCORDING TO NORM EN 50126

Definitions of all important terms used in the norm EN 50126 are given in a distinct chapter at the beginning. Definitions of basic RAMS characteristics are also given as:

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- *reliability,* defined as probability that an item can perform a required function under given conditions for a given time interval (t1, t2) - the definition is taken from the norm IEC 60050(191),
- *availability*, defined as ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external recourses are provided,
- *maintainability*, defined as probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources (IEC 60050 (191)), and
- *safety,* defined as the state of technical system freedom from unacceptable risk of harm.

Special norm items define relations between RAMS and railway service quality and also between RAMS characteristics, i.e. elements interrelation. Railway RAMS is realised through application of: established engineering concepts, methods, tools and techniques in the system life cycle and it is an important parameter of railway quality of service (Fig.1).

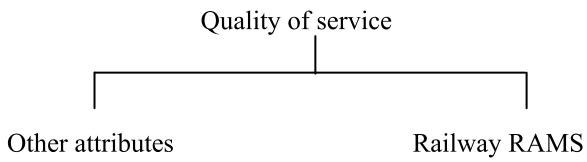

Fig. 1 Quality of service and Railway RAMS

Interrelation between RAMS elements of technical systems (reliability, availability, maintainability and safety) is shown in Fig.2. It can be seen from the Figure that safety and availability are output RAMS characteristics, depending on RAMS characteristics that are inherent to railway technical system (reliability and maintainability). In the relation of an influence on safety and availability, let it be that operation and maintenance conditions are at the same level as reliability and maintainability.

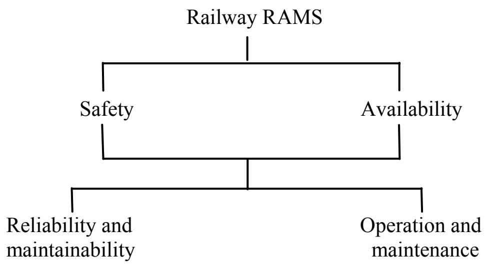

Figure 2. Interrelation between Railway RAMS elements

Special norm item shows and defines processes of identifying factors that influence railway systems RAMS characteristics. Those factors and their influences are input data for RAMS requirements specification for a system.

Three types of sources, or failure factors, influence Railway RAMS systems:

- failure sources happen in the system in any phase of life cycle, and are connected to its construction (system conditions connected with its characteristics),
- failure sources connected with system exploitation (operating conditions), and
- failure sources connected with its maintenance (maintenance conditions).

Those sources of system failure, i.e. factors that influence railway RAMS, also have an influence on each other. This norm gives detailed scheme of relations between some influential factors (Fig. 3). Beside this, it is necessary to introduce new factors specific for each railway itself.

Safety and availability are RAMS characteristics of higher level, if compared with reliability and maintainability (see schemes in Fig. 1 and 2). In scheme in Fig. 3 reliability is not explicitly shown, and is given through a group of internal failures in technical system, which includes regular and random errors that influence safety and availability through system characteristics. Hence, characteristics of safety and availability depend on characteristics of system reliability, so it is important to determine their interrelation in the earlier phase of system life cycle.

Formulas for availability calculation of railway vehicles are indirectly given in the norm EN 50126. Particularly, availability definition, given in norm EN 50126 was taken from the norm IEC 60050 (191) [2] where three types of availability are given, depending on what is considered to be mean delay time. So, there are defined:

a) Inherent availability:

$$A_{\mathrm{i}}=\frac{MUT}{MUT+MDT_{\mathrm{cm}}}=\frac{MTBF}{MTBF+MDT_{\mathrm{cm}}},$$

b) Technical availability:

$$A_{\mathrm{t}}=\frac{MUT}{MUT+MDT_{\mathrm{cm}}+MDT_{\mathrm{pm}}},$$

c) Operation availability:

$$A_{\mathrm{o}}=\frac{MUT}{MUT+MDT_{\mathrm{cm}}+MDT_{\mathrm{pm}}+MDT_{\mathrm{log+ad}}},$$

where:

MUT – mean up time,
$MTBF$ – mean time between failures,
MDT_{cm} – mean down time due to corrective maintenance,
MDT_{pm} – mean down time due to preventive maintenance,
$MDT_{\mathrm{log+ad}}$ – mean down time due to logistic and/or administrative reasons.

Previous equations for calculation of availability show that availability increase can be influenced by:

- reliability increase,
- decrease of repair frequency within maintenance (preventive and corrective) and
- system down time decrease (MDT_{pm} , MDT_{cm} i $MDT_{\mathrm{log+ad}}$).

From previous equations it can be concluded that influence of reliability on availability differs according to availability type. Own availability level significantly depends on reliability of technical system that was built in during development and manufacture, and it is important for the manufacturer. However, the influence of manufacturer on availability and reliability is decreasing if operational availability is observed, which is important to a user. Those influences of manufacturer, user, or carrier on availability have different directions and are shown in Fig.4. Average availability levels of modern railway vehicles, for all three types of availability, are also shown in the same figure [3].

3. RELIABILITY AND AVAILABILITY RELATIONSHIPS OF RAILWAY VEHICLES

Relation between reliability and availability of railway vehicles is basically the same as of other complex technical systems. The difference is in display of analysis results of that relation, taking into consideration the fact that reliability of railway vehicles is mostly expressed through mean failure for 10^5 or 10^6 km of running distance and rarely through mean time between failures (*MTBF*). That is the reason to analyse the influence of reliability on availability with variation of reliability expressed through mean failure at 10^5 km of running distance.

In order to input reliability R, which is expressed as number of failure at 10^5 km of running distance, in calculation of availability, it is necessary to set an equation for mean up time (*MUT*) that depends on: reliability R [No of failure /10^5 km], mean down time *MDT* [day], which differs according to the type of availability that we want to calculate, and running distance within a year S [10^5 km], which is calculated as multiplication of unit running distance for reliability evaluation of 10^5 km. Accordingly, annual mean up time of the vehicle is as follows:

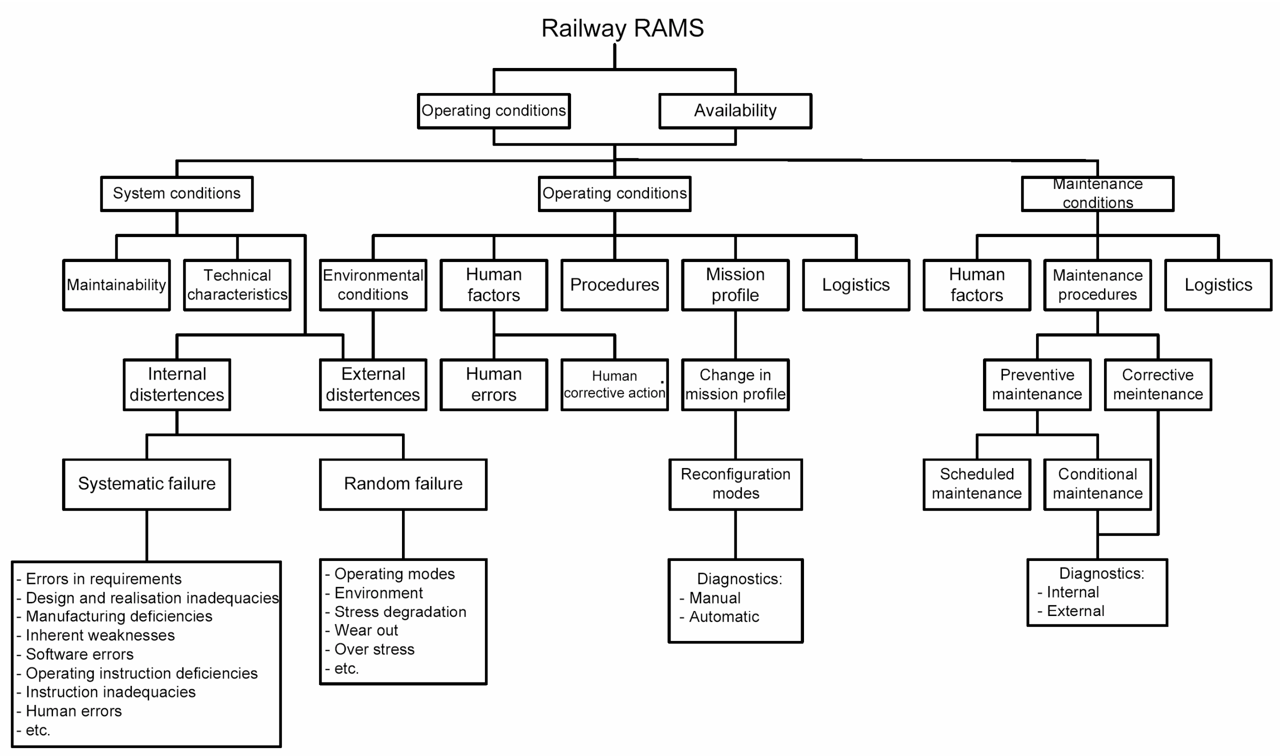

Figure 3. Factors influencing Railway RAMS

$$MUT = \frac{365 - S \cdot R \cdot MDT}{S \cdot R} ,$$

and availability is:

$$A = \frac{365 - S \cdot R \cdot MDT}{365} = 1 - \frac{S \cdot R \cdot MDT}{365} .$$

The final equation of availability calculation used to analyze the influence of reliability ton availability, is a well-known equation, where behind minus sign stands relation of total down time and total observed time (in this case 365 days).

The linear dependence of reliability and availability is obtained, as it was expected. A diagram that presents dependence of availability on reliability for several different values of mean down time (MDT) is created for railway traction vehicle and a real value of annual running time $S = 2$ ($2 \cdot 10^5$ km) (Fig. 5).

Diagram in Fig. 5 shows that, apart from significant influence of reliability, there is also great influence of mean down time on availability, so it is necessary to mention the existence of additional considerably complex connection between reliability and mean down time. Namely, for complex technical systems with large number of different failures, there is large dissipation of down time round mean value because of different duration time of corrective repairs for different types of failures.

Accordingly, significant reliability decrease for some system components can influence an increase of mean down time.

However, disregarding what was previously said, the diagram clearly shows significant influence of mean down time on availability for low reliability values. Accordingly, efficient maintenance is extremely important for low availability system. Maintenance should provide short mean down time, and increase availability in that way, although it is clear that mean down time doesn't depend only on efficiency of maintenance system but also on built in design system characteristics, i.e. convenience for maintenance. In that way, for example, for the same reliability R, an increase of mean down time for one day, decreases vehicle availability by 0.055 (5.5%), which means that from 100 traction vehicles in rolling stock fleet, each day more than 5 traction vehicles will be less in traffic.

Diagram also shows one drastic example of railway traction vehicle with low reliability R = 30 failure/10^5 km (such low reliability can be seen at electric

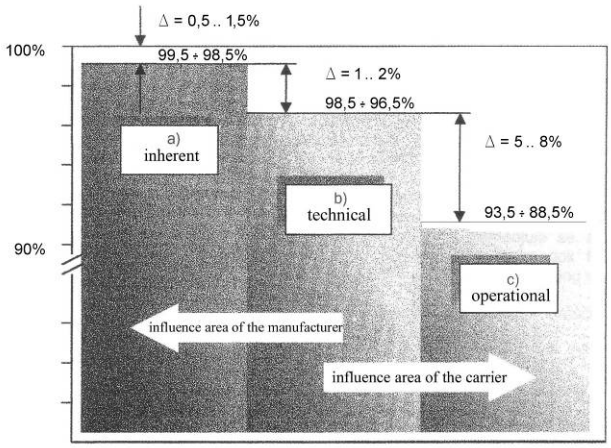

Fig. 4 Availability types and average availability levels of modern railway vehicles

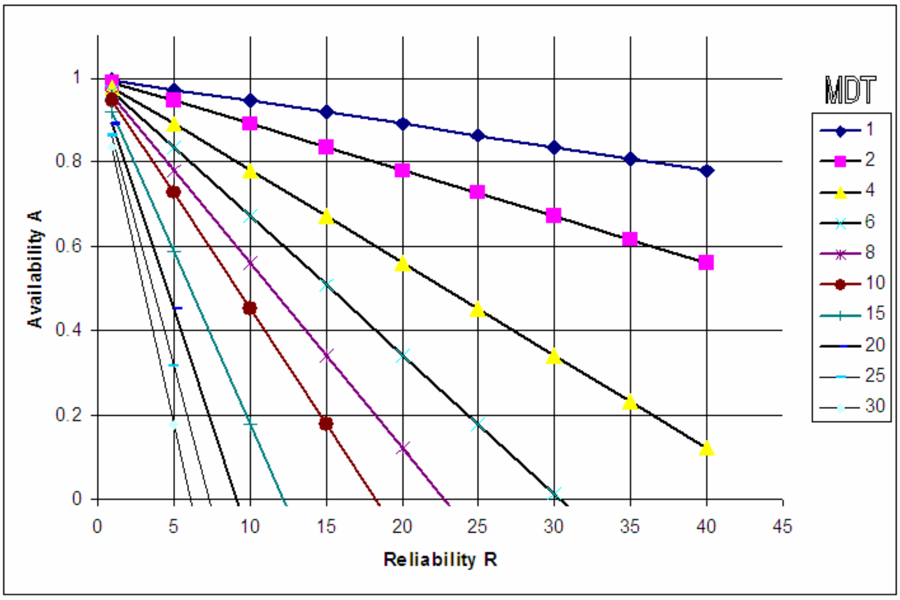

Figure 5. Dependence of availability (*A*) from reliability (*R*) for different values of mean down time (*MDT*)

locomotive series JŽ 461, see diagram[1] in Fig. 6) and mean down time *MDT* = 6 days, which implies to considerably inefficient maintenance. Availability for that case is close to zero, which practically means that locomotives are repaired, but they fail as soon as they are released in traffic, so these locomotives are not running at all. On the other hand, if reliability is significantly improved[2] to $R = 3$ failure/10^5 km, even if maintenance is still inefficient (MDT = 6), relatively high availability of A = 0,901 is achieved, i.e. over 90% of locomotives in traffic.

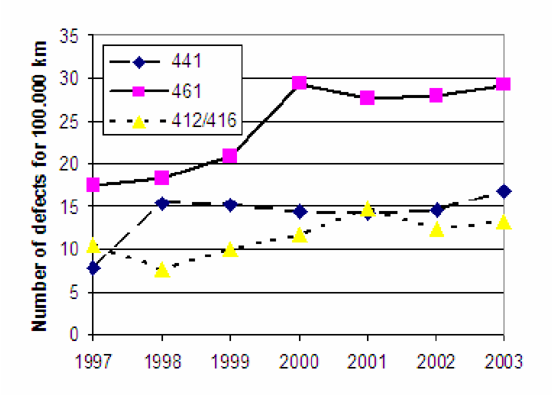

Figure 6. Number of defects for 100,000 km of running distance of electric traction vehicles "Serbian Railway" in period from 1997 to 2003

Due to the consideration given above, it can be concluded that in the reconstruction of existing and buying new railway vehicles, high reliability of components and whole vehicles are ultimative.

[1] Regarding diagram in Fig.6, it should be mentioned that term defect, in addopted and regulated terms on Serbian Railways [6], means failure, which has as a consequence a need to replace vehicle or failure that causes delay of passenger train for longer than 30 min or freight train longer than 60 min.

[2] To the value of agreed reliability for modernisation of electric locomotives series JŽ 461

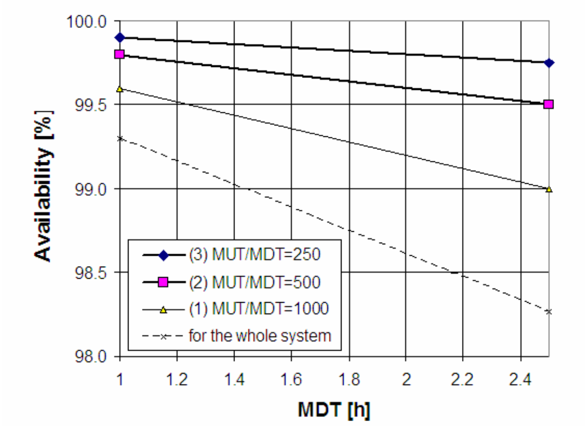

Fig. 7 Dependence of availability on mean down time for subsystems that have different ratio *MUT/MDT* and for the whole system

Railway vehicles manufacturers have been dealing with the problem of providing high reliability for years. There is an example of company SIEMENS, which takes number of measures to increase reliability during development of its multiple unit sets with the goal to increase their availability [3], and all according to European norm EN 50126. Those measures are often forced and are the consequence of implementation of new concepts and technologies in modern multiply unit sets,

- providing the same function on several modules with the same type, which provides maintaining of system function even if one of the modules completely fails (application of parallel connection, i.e. redundancies, or quasi-parallel connection, or partial redundancy);
- connecting vehicle diagnostic system with all components and sub-systems in train communication network (TCN), and

- providing of high modularity and unification, which, thanks to significant reduction of spare parts, should reduce maintenance costs.

SIEMENS also creates analyses of availability dependence on mean down time for components and system as a whole. Fig. 7 shows theoretic example [3] for system that has three subsystems (straight lines 1-3) with different ration of mean utilisation time and mean down time for each subsystem (MUT / MDT = 250, 500 and 1000). Diagram shows significant influence of previously discussed ratio to total availability. Company SIEMENS gives high values of 98% for iherent and 96% for technical availability in its technical description of diesel multiple-unit set DESIRO.

4. CONCLUSIONS

On the basis of defined procedure and carried outglobal analysis of ratio between availability and reliability of railway vehicles, the following conclusions are:

1. Created dependence diagram of availability on reliability and mean down time $A = f(R, MDT)$, for Serbian Railway conditions, in real value ranges for R and MDT, can be useful in making decisions about a level of reconstruction of the existing railway stock and about suppliers` offer for purchase of new stock. Before making decision about reconstruction level or modernisation, the analysis of how reliability of different solutions influences system availability has to be performed. This is one of the basic criteria for evaluation of the quality of the chosen solution, and it is always used together with reconstruction or modernisation (development and series production) cost analysis. Decisions of reconstruction and modernisation level are always difficult, and are usually made within making technical part of a bidding documentation, when optimal solution has to bi chosen with the best possible ratio price-efficiency.
2. For real estimation of the influence of reliability on availability in operation and maintenance conditions on Serbian Railways, it is necessary to collect suitable data from operation and maintenance and do calculations of reliability and availability for all series of rolling stock owned by Serbian Railway. Initialisation, defining and realising these activities could be done within realisation of already permitted research-developing project “Increasing maintenance efficiency of Serbian Railway rolling stock” and it would be very useful for further application of the norm EN 50126 in Serbian Railway.

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ОДНОС ПОУЗДАНОСТИ И РАСПОЛОЖИВОСТИ ЖЕЛЕЗНИЧКИХ ВОЗИЛА

Душан Милутиновић, Војкан Лучанин

Поузданост и расположивост железничких возила су значајне карактеристике због чега је врло важно утврђивање и њиховог међусобног односа. У раду је дат приказ могућности одређивања утицаја поузданости железничког возила на његову расположивост на примеру који узима у обзир реалне вредности тих карактеристика за услове “Железница Србије”. Потврђен је велики значај остварења високе поузданости возних средстава у условима њиховог одржавања са малом ефикасношћу. То, са своје стране, упућује на обавезу “Железница Србије” да, поред сталног подизања нивоа ефикасности одржавања, приликом модернизације постојећих и набавке нових возних средстава инсистира на високој поузданости компонената и система у целини.