Factor Analysis as a Means of Filtering Rams Indicators for Railway Vehicles

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European Commission Regulation (EU) No. 445/2011 regarding the system of certification for entities in charge of maintenance (ECM) of freight wagons requires such entities to supervise the condition of wagons, without specifying the methods of supervision to be used. Each ECM should establish a Maintenance Management System (MMS), which will include the obligation to monitor the fleet of freight wagons. Monitoring railway vehicle maintenance operations should include tracking all significant technical and operational indicators. The key question is which indicators are the have the greatest impact on safety. This paper discusses some issues related to the monitoring of maintenance operations for railway vehicles. It also looks at dedicated solutions for entities in charge of the maintenance for freight wagons based on PN-EN 50126:2002 standard and RAMS indicators (Reliability, Availability, Maintainability and Safety). This paper describes factor analysis of the proposed indicators as a means of selecting those that have a decisive impact on the correctness of the process for monitoring vehicles. This paper shows an example of the implementation of the requirements of the European Commission Regulation 445/2011 [3] regarding the monitoring of the state of railway vehicles and the possibility of using the information so gained as part of a process of continuous improvement. Reducing the number of indicators will reduce the amount of data needed to calculate all the RAMS indicators, without compromising the benefits of the rail vehicle monitoring system.

Keywords: Maintenance Management System, RAMS, factor analysis.

1. INTRODUCTION

"The Council of the European Communities published Directive No 1991/440/WE on the development of the Community's railways" in 1991 initiating the liberalization of the European Rail Market. After thirteen years, the Community took a common position on rail safety publishing on 29 April 2004, Directive 2004/49/EC. The Directive requires the development and implementation of Safety Management Systems (SMS), whose main tool is the management of operational risk.

Four years later, Directive 110/2008/EC of the European Parliament and of the Council of 16 December 2008 amending Directive 2004/49/EC on safety on the Community's railways (Railway Safety Directive) first introduced the term 'Entity in Charge of Maintenance' (ECM) and a new system Maintenance Management System (MMS) associated with ECM. Finally, on 10 May 2011, Commission Regulation 445/2011 [3] established the mandatory certification of maintenance systems for freight wagons. This Regulation identifies four functions that Entity in Charge of Maintenance should include in its activities, and states that the first function must be performed on its own, while others may be delegated to other units. One of the mandatory criteria described in the Regulation is the obligation to monitor maintenance operations in order to keep or to increase the level of safety through a process of continuous improvement [7].

2. RAMS AS PART OF THE MAINTENANCE MANAGEMENT SYSTEM

Monitoring railway vehicle maintenance operations should include tracking all significant technical and operational indicators. The key question is which indicators are the have the greatest impact on safety.

Each ECM identifies and tracks such indicators to different degrees. Some companies identify basic operating parameters (down time, time to repair, elapsed time to return to service) on paper, other companies utilise computer tools to diagnose all the parameters associated with time, material resources, human resources, risk, etc.

Standard RAMS is based on IEC 61508, which stipulates safety management methods for electric, electronic, and programmable electronic control systems for industry in general. IEC 62278 is the standard for management related to R, A, M, S (*RAMS stands for Reliability, Availability, Maintainability and Safety)* and economical efficiency when developing and operating railway systems related to safety. It reflects the concepts of safety lifecycle and safety integrity level introduced in IEC 61508.

Other international standards related to safety of railways, which came into effect at about the same time as IEC 62278, are IEC 62279 (software for railway control and protection systems) and IEC 62280 (safety-related communication). Later, IEC 62425 (system safety), which stipulates documentation for certifying safety, came into effect.

Details on the concept of RAMS shown in Fig. 1 are stipulated in the standard. Here, quality of service is seen as being most important, and that quality of service is made up of RAMS for railways and other attributes. Furthermore, RAMS for railways is made up of safety and availability, which are based on reliability and maintainability plus operation and maintenance. In this way, the components of RAMS are expressed in a straightforward manner.

Standard RAMS provides details on the requirements of the Systems Assurance process during Design, Construction, Installation, Operation and Decommissioning – ie throughout the whole life cycle of the railway project. The following article endeavours to explain some of the key issues of the Standard, along with the author's interpretation during its use on a major railway project.

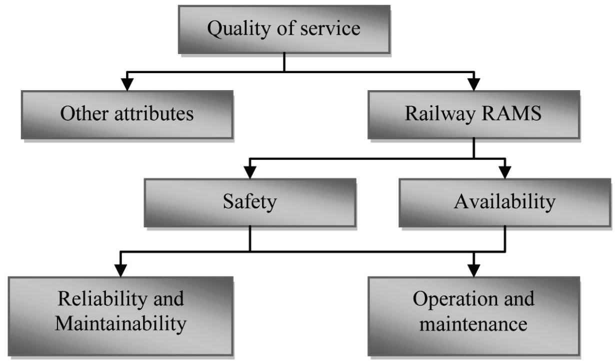

Fig. 1. The Concept of RAMS [4].

Some of the issues that are covered include:

– definitions and interpretation of the terminology used
– details of the structure of the Standard in terms of the phases throughout the life cycle of the project
– interpretation of the requirements of the Standard in so far as the design phases are concerned, including essential requirements and mandatory elements of the Standard
– general management support that is required in order to fulfil the recommendations of the Standard
– advice on the development of a Safety and Reliability Management System in order to ensure a structured approached to verifying and validating the RAMS design
– independent verification and validation in the context of Peer Review, and the key role of Auditing the process and documentation deliverables.

The aim of the Standard is to:

– enable a structured review of the management control over the RAMS design process, and
– to be aware of the RAMS application to the design of the system, taking account of: (a) the cost of system development, and (b) the ultimate cost of ownership of the system – with reference to Economic Life Cycle Costing'

The objective of the Standard is to:

– provide a consistent systems approach to the management of RAMS, and
– aim to promote co-operation between all parties

The benefits of the Standard are to:

– act as an aid to defining the interaction between the elements of RAMS throughout

the life cycle of a project
- address any conflict between the RAMS elements (see Safety and Availability below)
- specify the requirements for RAMS inputs and deliverables at each phase of the project, and
- provide a framework to demonstrate that RAMS procedural requirements are being met and sustained
- standard itself is not mandatory, and the requirements of the Standard are as such 'recommendations' – reference section on Mandatory Elements of the RAMS applies to ERTMS devices

The Standard is based upon tried and tested recommendations from the railway industry.

The Standard does not:
- define RAMS targets, or the quantification of such targets, nor
- stipulate the RAMS requirements, methodologies, techniques or solutions

The Standard, understandably gives priority to safety as opposed to RAM.

The relevant standard is EN 50126 Standard "Railway applications – The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)"- this describes four RAMS indicators.

R – Reliability – the probability that an item can perform a required function under given conditions for a given time interval;

A – Availability – the 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 subject to the required external recourses being provided;

M – Maintainability – the probability that a given 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 defined conditions, using stated procedures and resources;

S – Safety – the degree to which a system is free from unacceptable risk of causing harmful effects.

The PN-EN 50126 standard defines the following parameters:

Reliability
- MTBF – Mean time between failures,
- FPMK – Failures per million kilometers,

Availability
- A_O– operational availability,
- A_P – availability due to planned activities,
- A_N– availability due to unplanned activities

Maintainability
- MTTR – Mean time to restore for all actions,
- $MTTR_{NP}$ – Mean time to restore for planned actions,
- $MTTR_{NA}$ – Mean time to restore for unplanned actions,

Table 1.

RAMS Indicators		
Indicator	**Required data**	**Calculation method**
R – reliability		
FPMK **Number of failures per one million kilometres**	n – as number of failures D_T – stands for the number of driven kilometres during the analysed period of time	$FPMK = \frac{n \cdot 1000000}{D_T}$ [−]
A - availability		
A_O **Operational availability**		$A_O=1-[(1-A_P)+(1-A_N)]$
M - maintainability		
MTTR **Mean time to restore**	n- number of repairs N_{pi} – date of withdrawal from operation , $_i$= 1,2,.... N_{zi} - date of restoring the operation , $_i$= 1,2,...	$MTTR = \frac{\sum_{i=1}^{n}(N_{Zi}-N_{Pi})}{n}$ [days]
S - safety		
MTBHF **Mean time between hazardous failures**	$_n$- as number of failures $D_{A\ sys\ i}$ – Date of other system failures on the tracks , i=1,2,….	$MTBSF = \frac{\sum_{i=1}^{n-1}(D_{A\,sys\,i+1}-D_{A\,sys\,i})}{n-1}$[days]

– MTBM – Mean time between maintenance.

Safety

– MTBHF – Mean time between hazardous failures,
– MTBSF – Mean time between system failures.

ECMs have a choice of eleven different indicators (factors) when attempting to formulate mathematical descriptions of the proposed standard indicators. The next section describes the factor analysis of these indicators in order to identify those that are the most important. How relevant each indicator shown in Table 1.

3. IMPLEMENTATION OF RAMS

There is many outcomes of using the RAMS analysis. The other one is the comparisons of different parameters between types of operated wagons. For example MTBF – figure 2.

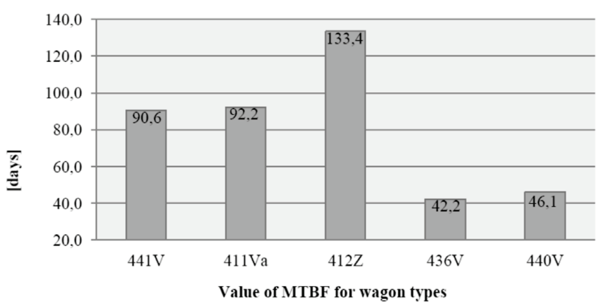

Fig. 2. MTBF for selected wagon types [9].

The method of data gathering allows these parameters to be divied between years for every vehicle and type of vehicle.

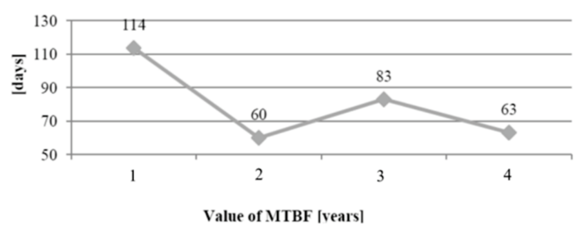

Fig. 3. MTBF in sequent years [9].

Specific types of failures can also be analysed with the use of a failure dictionary according to a specific company standard.

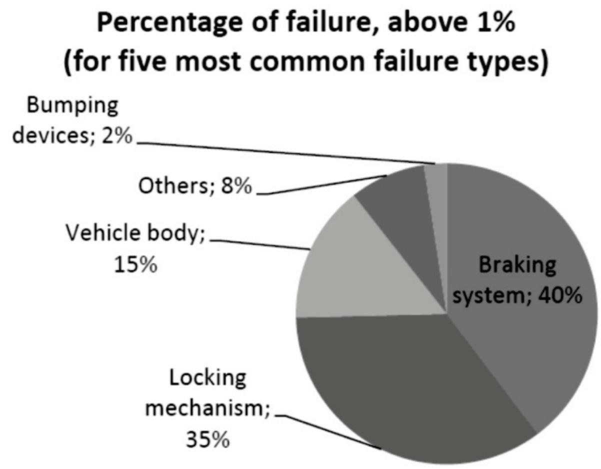

Fig. 4. Percentage of failure [9].

These failures can also be analysed according to their appearance throughout sequent years.

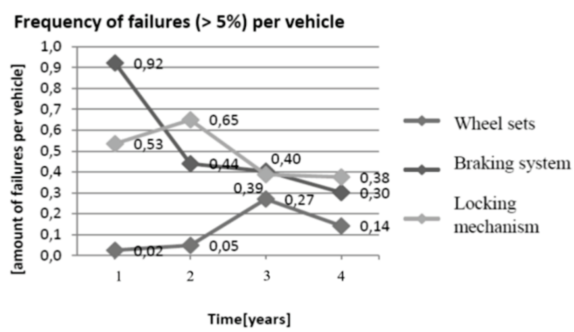

Fig. 5. Amount of failure types per wagon in years(>5% damage).

And the last type of RAMS analysis outcome is the value of a specific parameter per a specific vehicle number. Without this it would be very difficult to address any corrective and preventive measures to the technical assets in operation.

In figures 2-6 only sample parameters where shown, it was supposed to present a general idea of data collection, analysis and representation of the outcomes. When having the full picture of all RAMS parameters it is possible to manage the whole fleet of vehicles.

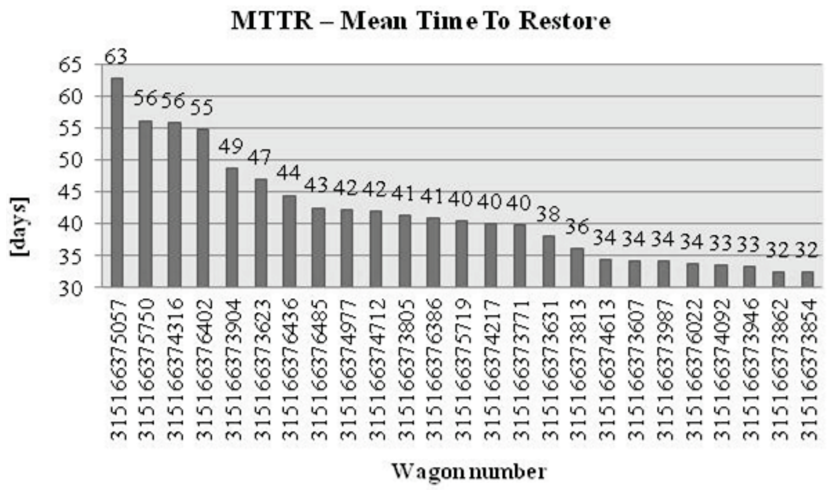

Fig. 6. MTTR value per vehicle number [9].

These methods can expand knowledge and awareness of the safety status of those involved in safety management in individual companies. This happens through the use of a single risk assessment tool that can better identify and assess common hazards between the players and prevent or reduce the effects of rail events that occur as a result of them could take place. Another aspect of improving safety is analysis of historical data of rolling stock operation. On this basis, you can at least improve the process of operation of the vehicle as well as improving new constructions after the development of appropriate solutions from with manufacturers.

4. FACTOR ANALYSIS OF RAMS INDICATORS

When attempting an analysis of complex systems we often come across the problem of having too much data, sometimes the quantity seems almost overwhelming. In such situations it can be difficult to present information in a transparent manner, and even more difficult to provide satisfactory conclusions. The conclusions of an analysis may be more useful if only most important aspects of the system are considered. To achieve this, it may be helpful to apply factor analysis.

Factor analysis is a statistical method of reducing the number of variables to be studied. When we have too much data, the analysis can help to identify the most relevant data, which best describe the system.

Using this method, we look for independent variables (from each other and the identified processes) that will adequately describe the analysed data and help to give a clear interpretation of the results.

In the process of monitoring the maintenance operations using the RAMS' eleven indicators related to the maintenance of freight wagons by an ECM have been obtained. We have calculated indicators for planned maintenance and emergency repairs. Arithmetic means of indicators which have been calculated are shown in the graphs below.

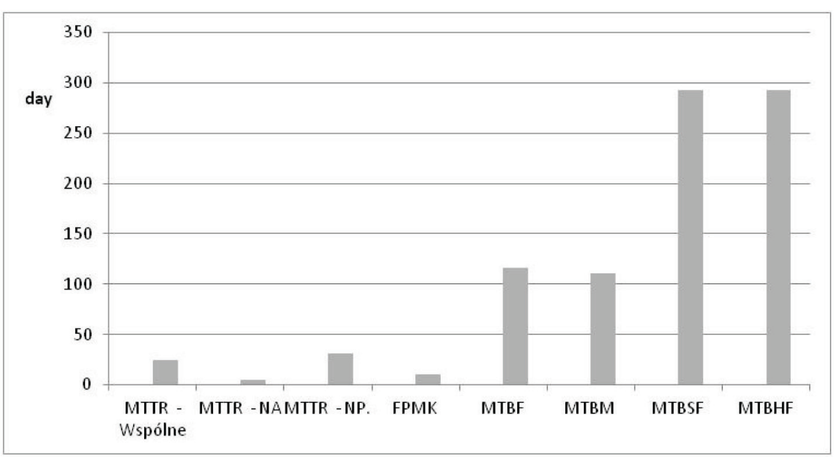

Fig. 7. Graph of RAMS indicators expressed in days.

For the purpose of factor analysis.AN (availability due to unplanned activities) and AP (availability due to planned activities) were discarded since the value of parameter A_O is calculated directly from AN and AP. The study should be larger than 0.5, if the application of factor analysis is to be justified.

From the above analysis (Table 2) we may conclude that two indicators - $MTTR_{NA}$ and MTBM can be discarded.

Table 2. Inverse Images Correlation Matrix.

	MTTR	MTTR NP	FPMK	MTBSF	A0	MTBF	MTTR NA	MTBM
MTTR	,556[a]	-,950	-,021	,059	-,096	-,532	-,723	,417
MTTR NP	-,950	,543[a]	,023	-,037	,224	,402	,660	-,378
FPMK	-,021	,023	,661[a]	-,076	-,064	,475	,022	,269
MTBSF	,059	-,037	-,076	,500 [a]	-,089	-,148	-,059	-,032
A0	-,096	,224	-,064	-,089	,723 [a]	-,133	,130	-,204
MTBF	-,532	,402	,475	-,148	-,133	,503 [a]	,358	-,137
MTTR NA	-,723	,660	,022	-,059	,130	,358	,178 [a]	-,359
MTBM	,417	-,378	,269	-,032	-,204	-,137	-,359	,232 [a]

also ignored the indicator MTBHF because test data for MTBHF were equal to the values of the indicator MTBSF.

The most common applied form of factor analysis is Principal Component Analysis. This approach entails finding the transformation of the original variables (8 indicators) for each independent variable called the principal component. In this method, we look for factors that explain the largest possible part of the variance. Looking at the principal component, we determine the eigenvalue for each original variable, that is the variance contained in this variable. For this purpose was used SPSS Statistics.

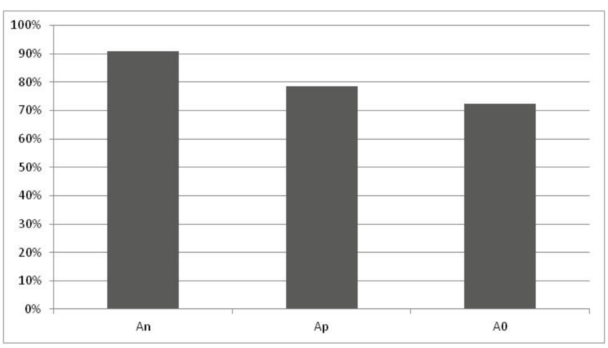

Fig. 8. Graph of RAMS indicators expressed as percentage values.

Table 2 shows the values of the correlation inverse images. The diagonal of the matrix (marked with the letter a) is occupied with measures of assessing the adequacy of the correlation matrix. It is assumed that the measure

The second step is to calculate eigenvalues. Table 3 shows the eigenvalues of the original variables, with the exception of AN, AP and MTBHF. From an analysis of Table 3 we observe that first five indicators cover the variation of almost 90% of the total sample.

Table 3. Total Variance Explained.

Component	Initial eigenvalues		
	Total	**Percentage variance**	**Cumulative percentage**
MTTR	2.803	35.043	35.043
$MTTR_{NP}$	1.601	20.018	55.062
FPMK	.981	12.258	67.320
MTBSF	.956	11.952	79.271
A0	.735	9.186	88.457
MTBF	.584	7.297	95.754
$MTTR_{NA}$	.315	3.933	99.687
MTBM	.025	.313	100.000
Component	**Extraction sums of squared loadings**		
	Total	**Percentage variance**	**Cumulative percentage**
MTTR	2.803	35.043	35.043
$MTTR_{NP}$	1.601	20.018	55.062
FPMK	.981	12.258	67.320
MTBSF	.956	11.952	79.271
A0	.735	9.186	88.457
MTBF	.584	7.297	95.754
$MTTR_{NA}$	.315	3.933	99.687
MTBM	.025	.313	100.000

The next step is to conduct a similar analysis for the obtained principal components (calculated by rejecting two indicators for which measure of adequacy is less than 0.5, and using Oblimin rotation with Kaiser normalization). The analysis shows (Table 4) that the first five indicators now describe 99% of the variance of the data examined. This implies that the last MTBF indicator may also be safely rejected.

Table 4. Total Variance Explained.

Component	Initial eigenvalues		
	Total	Percentage variance	Cumulative percentage
MTTR	2.672	44.529	44.529
$MTTR_{NP}$	1.370	22.826	67.355
FPMK	.934	15.562	82.917
MTBSF	.636	10.607	93.524
A0	.334	5.569	99.093
MTBF	.054	.907	100.000
Component	**Extraction sums of squared loadings**		
	Total	**Percentage variance**	**Cumulative percentage**
MTTR	2.672	44.529	44.529
$MTTR_{NP}$	1.370	22.826	67.355
FPMK	.934	15.562	82.917
MTBSF	.636	10.607	93.524
A0	.334	5.569	99.093
MTBF	.054	.907	100.000

The final stage of the analysis is to determine how much of the initial variance is described by first five indicators. From the analysis of Table 3 we may see that indicators MTTR, $MTTR_{NP}$, FPMK, MTBSF and A_O describe 88.45% of the variance of the original data.

5. CONCLUSIONS

This paper shows an example of the implementation of the requirements of the European Commission Regulation 445/2011 [3] regarding the monitoring of the state of railway vehicles and the possibility of using the information so gained as part of a process of continuous improvement. The method makes it possible to easily extract the most relevant indicators (MTTR, FPMK, MTBSF, Ao), and so reduce the number of indicators to be tracked and monitored. Factor analysis of the sample of variables identifies the most important indicators of RAMS, which describe nearly 90% of the total variance in this sample. Based on factor analysis, we can use five indicators:

– MTTR,
– $MTTR_{NP}$,
– FPMK,
– MTBSF,
– A_O.

Reducing the number of indicators will reduce the amount of data needed to calculate all the RAMS indicators, without compromising the benefits of the rail vehicle monitoring system.

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