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APLICATION OF RAMS AND FMEA METHODS IN SAFETY MANAGEMENT SYSTEM OF RAILWAY TRANSPORT

ZASTOSOWANIE METOD RAMS I FMEA W SYSTEMACH ZARZĄDZANIA BEZPIECZEŃSTWEM W TRANSPORCIE KOLEJOWYM

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Abstract: *This paper presents an application of the FMEA (Failure mode and effects analysis) to evaluate the operational risk in railway transport. The methodology developed by the Department of Rail Transport (KTS), including approval thresholds for risk adopted, the model forms (hazard record, FMEA form) were adopted in the Polish railways as a standard to evaluate the operational risk for operators and infrastructure managers. Reacting to the development of requirements for security management - Regulation EC No 445 of 2011 – Department of Rail Transport proposed the standard RAMS – PN – EN 50126 to oversee rail vehicles. This solution is currently being implemented in several entities building maintenance management systems (MMS) for the wagons. This article is dedicated to the people who deal with issues of safety management both in the transport of goods and people as well as the maintenance of rail vehicles.*

Keywords*: safety, risk assessment, RAMS, FMEA, monitoring of railway vehicle*

Streszczenie: *W artykule przedstawiono zastosowanie FMEA (metody analizy rodzajów i skutków oraz możliwych błędów) do oceny ryzyka operacyjnego w transporcie kolejowym. Opracowana przez Katedrę Transportu Szynowego (KTS) Politechniki Śląskiej metodyka, w tym przyjęte progi akceptacji ryzyka, wzory formularzy zostały zaadoptowane w polskim kolejnictwie jako standard do oceny ryzyka operacyjnego przez przewoźników i zarządców infrastruktury. Reagując na rozwój wymagań w zakresie zarządzania bezpieczeństwem – Rozporządzenie KE nr 445 z 2011 r. - Katedra zaproponowała wykorzystanie normy RAMS nr. PN-EN 50126 do nadzorowania pojazdów kolejowych. Rozwiązanie to jest obecnie wdrażane w kilkunastu podmiotach odpowiedzialnych za utrzymanie w ramach budowy Systemów Zarządzania Utrzymaniem (MMS) dla wagonów towarowych. Artykuł ten dedykowany jest dla osób, które zajmują się tematyką zarządzania bezpieczeństwem zarówno w przewozie towarów i osób jak i utrzymywaniem pojazdów kolejowych.*

Słowa kluczowe*: bezpieczeństwo, ocena ryzyka, RAMS, FMEA, monitorowanie pojazdów kolejowych*

1. Introduction

Upon requirements of the “Safety Directive” No 49/2004 [1-2], there has been elaborated the innovative Safety Management System-SMS. Model dedicated for railway undertakings and infrastructure managers, which has been implemented after obtaining approval from the Polish National Safety Authority(UTK). The SMS has been implemented in over 30 entities (which takes about 90% of the Polish market). The Model of Maintenance Management System(MMS) for Entities in Charge of Maintenance(ECM) has been prepared by the Railway Engineering Department(KTS) after publication of the EC Directive No 110/2008 [3-4]. Theese aforementioned models are already implemented in RU’s, MW’s and others ECM’s in Poland. The proposed innovation in those systems lies in pro-active approach towards the safety management based on rare tools in railway transport for risk assessment and supervision over the technical measures. The FMEA method was used in order to perform the operational risk assessment (nowadays it is applied allover the country). Next step was implementation of RAMS method for monitoring the following parameters: reliability, availability, maintainability and safety of the rail-vehicles.

2. Operational risk assessment with use of the FMEA method

There have been worked out two supporting tools for the proactive approach towards safety notion.
In order to meet the needs of the Safety Management System (SMS) to make the operational risk assessment, there was applied the FMEA method (i.e. Failure Mode and Effects Analysis) in the innovative way and on a scale of Poland.
It is based on the assessment of previously identified threats thanks to the special form of risk register (see Table No 1) by all the employees within the structures of certain railway undertaking.
Subsequently, the conformity assessment body in accordance with the European Commission Regulation (EC) No 352/2009 [5] is in charge of both assessment and evaluation of the particular types of risks.

Table No 1 - Form of risk register MMS/06-1

Hazard Record
‘hazard’ means a condition that could lead to an accident[1]

The register established by ....
Person responsible for keeping the register ....

Order Number	Date of filing an application	Identified hazard	Probable source of the risk appearance	Results foreseen	Entity responsible for risk	Employees (position), who reports threats	Proposed Means of safety	Remarks

[1] *In compliance with the requirements of the European Commission Regulation (EC) No 352/2009 of 24th of April, 2009*

There are applied 3 parameters for carrying out the risk assessment:
Oc – as probability of appearance,
Dt – as detection of hazard,
Sr – as Result of the hazard.
Moreover, there were also created common innovative, codified tables for process of risk evaluation, which are applied in Poland (tables from 2 to 4).
Values of probability, easiness of detection as well as results of the risk is assigned in scale of between 1 and 10 and its product constitutes level of the risk for certain type of threat.
Values deriving from the above mentioned tables, should be assigned to the particular threats and the risk level for the particular type of danger should be calculated

$$\mathbf{R_{pn}=Oc \cdot Dt \cdot Sr}$$

Table No 2 Probability of threat appearance

Probability of threat appearance: (Oc)	**Frequency of its appearance (1 occurrence/per Train-Km):**	**Scoring:**
Probability of threat appearance is negligible, practically it won't appear in reality	1/5 200 000	1
Probability of threat appearance is slight , causes of threat occur very rarely	1 / 4 500 000 1 / 3 800 000	2 3
Probability of threat is at the average level. Causes of threat appear occasionally i.e. from time to time	1 / 2 500 000 1 / 2 000 000 1/1 500 000	4 5 6
Probability of the threat appearance is high , Causes of danger occur infrequently	1 / 1 000 000 1 / 750 000	7 8
Probability of danger occurrence is seriously high . It is almost certain , that this danger will take place	1 / 500 000 1 / 100 000	9 10

Data, which are included in table No 2 constitute the proposal of author and they are related to total kilometres travelled in range of both goods and passengers by the railway carrier.
Size of the data indicated in the column No 2 of the table should depend on the volume of transport work, which has been carried out, while for the first of these values in the column No 2 has been quoted the value exceeding the size of transport work foreseen per annum.

Table No 3 Probability of threat detection

Probability of threat detection: (Dt)	**Scoring:**
Probability of detection of threat is very high. Revealing the cause of mistake is certain.	1 2
Probability of detection of threat is high. Means of control, which has been applied here could possibly allow to reveal the true cause of an error occurrence. Symptoms of the cause of an error occurrence are noticeable.	3 4
Here, exists an average likelihood of the detection of threat. Means of control, which have been here applied, could provide an opportunity to reveal the cause of an error. Moreover, symptoms indicating the possibility of threat occurrence can be set up as well as defined.	5 6
Low likelihood of danger revealing. It is very likely, that the means of control, that have been implemented here won't let to disclose the reason of an error occurrence. Determination of cause(s) of an error is very difficult.	7 8
Likelihood threat detection is insignificant. Practically it is impossible to determine the cause(s) of an error occurrence.	9 10

In the process of creating of the estimated value of probability of threat detection, it should be taken into account the best means/method of control currently in use.

Table No 4 Effect of the threat occurrence

Effect of danger occurrence (Sr)	**Scoring:**
Effects of danger occurrence have got no importance for the level of safety . Without any costs	1
Appearing of danger can be really small and lead to diminish the level of safety insignificantly (for example disturbances during traffic operation) or / and costs : in relation "2" to 10 000 Euro and in relation "3" to 50 000 Euro	2 3
Results of threat can be quite important and lead to reduction of the safety level (for instance : an incident, people got hurt etc) or / and costs : in relation "4" to 100 000 Euro , in relation "5" to 250 000 Euro , in relation "6" to 500 000 Euro	4 5 6
The danger appearance can be important and lead to significant level of security lowering (railway accident and seriously hurt people etc) or/ and costs: in relation " 7" to 750 000 Euro, in relation "8" to 1 000 000 Euro	7 8
Results of danger appearance can be very serious and lead to drastic fall of the safety level (for example serious railway accident , fatalities etc) or / and costs in position " 9" to 2 000 000 Euro , in position " 10" to 2 000 000 Euro)	9 10

Subsequently, we deal with individual risk levels assessment. We use for this the risk matrix (see table No 5). Proposed thresholds of tolerance for risk have been accepted by the railway undertakings in Poland.

Table No 5 Risk priority number table – level of risk acceptance in the railway branch

Class of risk	Evaluated Risk	Level of risk
1	$R_{pn} <= 120$	ACCEPTABLE
2	$120<R_{pn}<= 150$	TOLERABLE
3	$R_{pn} > 150$	NON ACCEPTABLE

If there is the situation of exceeding of the acceptable threat threshold, then the Assessment Body determines the scenario of behaviour against the specific risks type. A person is also assigned, who is responsible for implementation of activities of fight against certain risks.

Conformity Assessment Bodies (CABs) after completing the work they undertake in scope of accreditation are required to check again the risk level, if it is satisfactory the whole Procedure is being completed.

Otherwise, additional tasks will be put in practice. Whole process is stored on a special data form (see table No 6).

Table no 6 – Form MMS/06-2- FMEA Form

Identification of Hazards and Risk Assessment with help of FMEA method												
Current risk assessment and control measures rating								**Additional control measures**				
Order Number	Threat	Possible consequences	Existing control measures	Oc	Dt	Sr	R_{pn}	Recommended control measures	Person in charge of	Due date	Rpn
PLANNING ; DESIGN											
2.1	Poor mental or physical condition of an employee	Improper work operation	Supervisor oversight	5	5	5	125	purchase of breathalyzers and random check of employees	Department for Regular Maintenance	30 days	30
2.2	Lack of qualifica tions	Improper Execution of the Maintenance System Plans	Control of the Superiors	2	4	3	24				

Threats have been classified in conformity with processes, which had been identified within certain companies. Each threat is assigned to its area of distribution :

- Without property - own-risk
- With property **w** - common risk (in frames of the railway system)
- With property **p** - remaining risk

It allows for risk management in the specified areas, facilitates also in a substantial manner the way of risk communicating, particularly as far as the engaged parties are concerned (for ex.: other railway carriers, infrastructure managers or suppliers for instance).

3. Inspection of the technical measures with use of the PN-EN 50126 of the RAMS method

During working out of the Model of Maintenance Management System (MMS), the FMEA method was used for operational risk assessment. Legal requirements have expanded the inspection of the technical measures related demands.
For that purpose, the approach in compliance with PN-EN 50126 [6] standard has been implemented. Next, we have concentrated on monitoring the following parameters, namely: operational reliability of the rail- vehicles, their accessibility, susceptibility to maintenance and the safety of the rail-vehicles.
The wide range of indicators has been elaborated for that purpose, which one should specify for the individual railway vehicles types (see table No 6).

Table No 6 – RAMS indicators (examples)

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		
AO	Operational availability		AO=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]

System threats concern : Braking systems, wheel sets, draw gear devices, control valves for freight wagons as well as tanks destined for transport of dangerous goods. There were also worked out the patterns (see table No 6 – method of calculation) which allow to appoint the individual parameters, namely: operational reliability of the rail- vehicles, their accessibility, susceptibility to maintenance and the safety of the rail-vehicles.

Innovative algorithms can be implemented in any operating software within the structures of railway undertaking. However, if the railway undertaking does not use any kind of software for monitoring the condition of the Railway Rolling Stock a dedicated spreadsheet has been developed (see table No 7).

After the introduction of the basic data related to the operation, such as dates of certain activities connected with the maintenance or course, this spreadsheet makes possible calculation of the required parameters.

Putting into practice this popular spreadsheet enabled its distribution within the railway companies in Poland, see table No 8 for results of calculations carried out.

The presented methods are currently being analyzed by the Office of Rail Transport, State Commission for Investigation of Railway Accidents and the Department of Rail Transport and will be constantly improved in accordance with the philosophy of safety management systems and maintenance.

Operational data necessary for indicating of the package of RAMS parameters, based on the PN-EN 50126 standard guidelines.

Table no 7 Register of Maintenance Related Activities

Wagon type	Mileage [km]	Activity type:	Activity descriptio n	Failure code (ex. AVV)	System that had failes	Did the failure was related to the critical system?	Failure result (S z FMEA)	Maintenacne Workshop (MW) performing activity	Withdrawal from operation	Beginning of the activity	End of activity	Return to operation
406		P5							2000-01-01	2000-01-03	2000-01-07	2000-01-07
406		P5							2000-01-01	2000-01-01	2000-01-05	2000-01-05
406		P3							2003-01-01	2003-01-01	2003-01-03	2003-01-05
406		NA			Braking system	1	6		2004-11-11	2004-11-11	2004-11-12	2004-11-12
406		NA			Braking system	1	7		2000-09-11	2000-09-11	2000-09-18	2000-09-18

Table No 8 Examples of the calculated values of the RAMS parameters

RAMS Indicators		date	from	2000-01-01	to	2012-07-18
For type	406	Number of wagons	4			

R- Reliability		
Failure per milion km	*Mean time between failure (for repairable system)*	*Mean distance between failure (for repairable system)*
MEAN CALCULATED VALUES		
FPMK	MTBF	MDBF
[-]	[days]	[km]
37,4	156	10885
TARGET VALUS FOR INDICATORS		
200	120	8400
ACHIEVED RESULTS [%]		
535%	130%	130%

A- Availability	
Operational Availability	*Fleet Availabilty*
MEAN CALCULATED VALUES	
Ao	FA
[%]	[number of available vehicles]
89,60%	3,58
TARGET VALUS FOR INDICATORS	
95,00%	3,2
ACHIEVED RESULTS [%]	
94%	112%

S- Safety			
Mean Time Between Safety System Failure System Failure"Mean time between system failure	*Mean time between hazardous failure*	*Hazard rate*	
MEAN CALCULATED VALUES			
MTBSF	MTBHF	H(t)	H(na)
[days]	[days]	[number of failures per year]	[number of hardous failures / number of failures]
1607	1262	0,64	67%
TARGET VALUS FOR INDICATORS			
360	240	0,5	50,00%
ACHIEVED RESULTS [%]			
446%	526%	78%	75%

M-Maintainabilty			
Mean time to restore	*Mean time between maintenance*	*Mean distance between maintenance*	*Mean time to maintain*
MEAN CALCULATED VALUES			
MTTR	MTBM	MDBM	MTTM
[days]	[days]	[km]	[days]
3,9	1103	77233	3,4
TARGET VALUS FOR INDICATORS			
5,0	1068,00	74760	3,0
ACHIEVED RESULTS [%]			
130%	103%	103%	89%

Implementation of RAMS

There is many outcomes of using the RAMS analysis, one of them is the RAMS report shown in table 8. The other one is the comparisons of different parameters between types of operated wagons. For example MTBF – figure 1

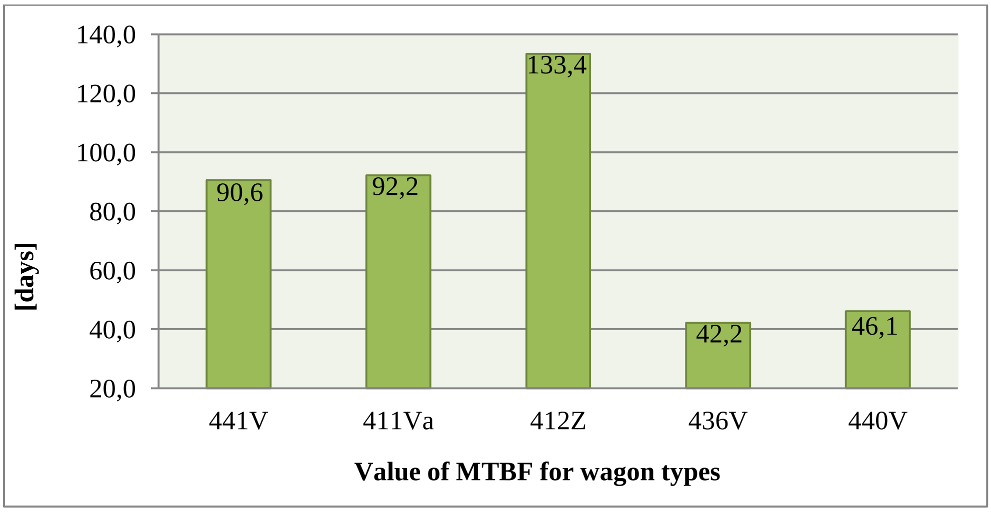

Fig.1. MTBF for selected wagon types

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

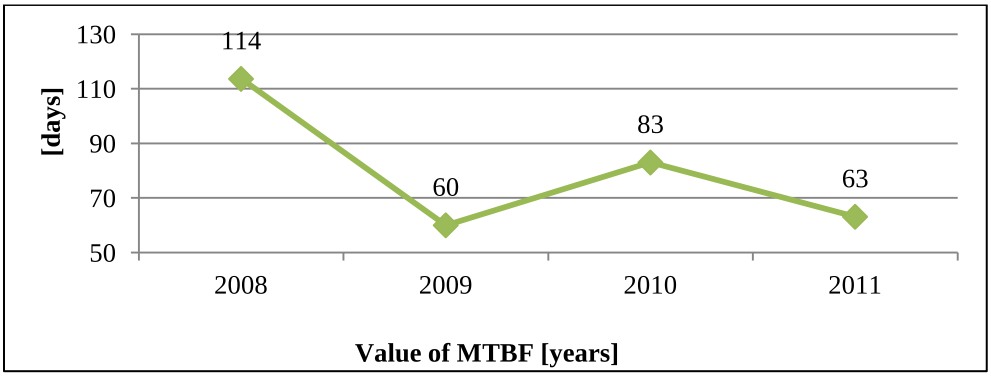

Fig.2. MTBF in sequent years

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

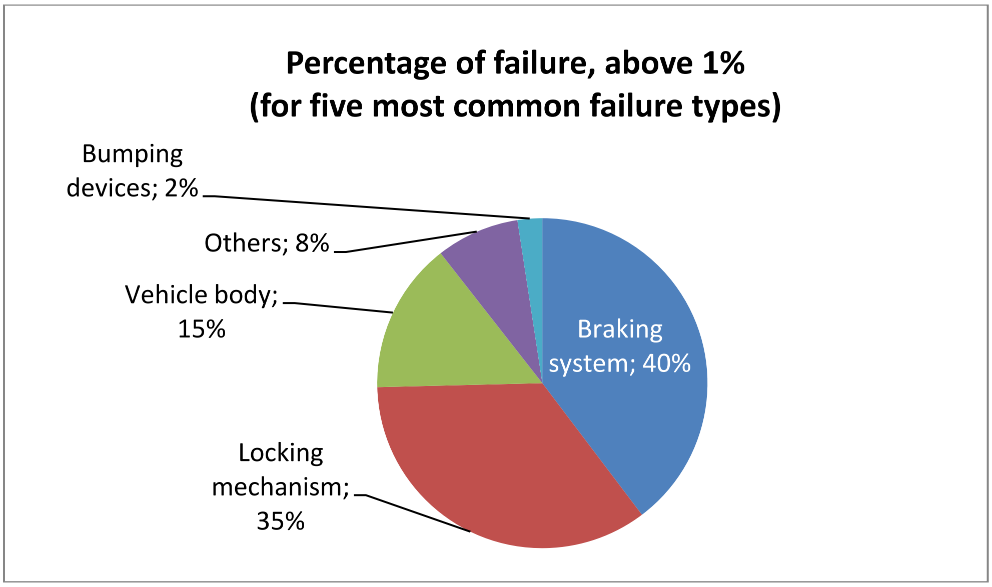

Fig.3. Percentage of failure

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

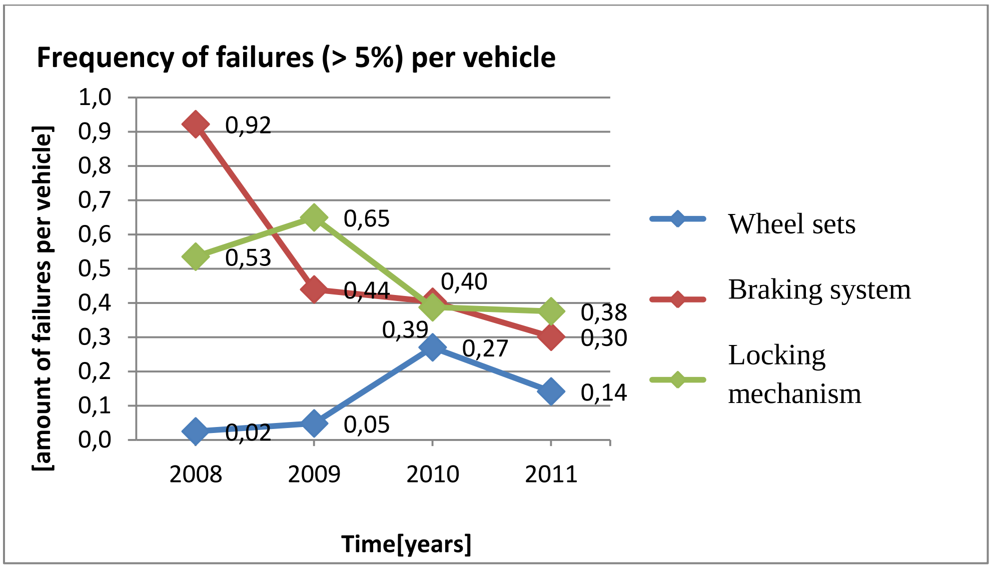

Fig.4. Amount of failure types per wagon in years

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 adres any corrective and preventive measures to the technical assets in operation.

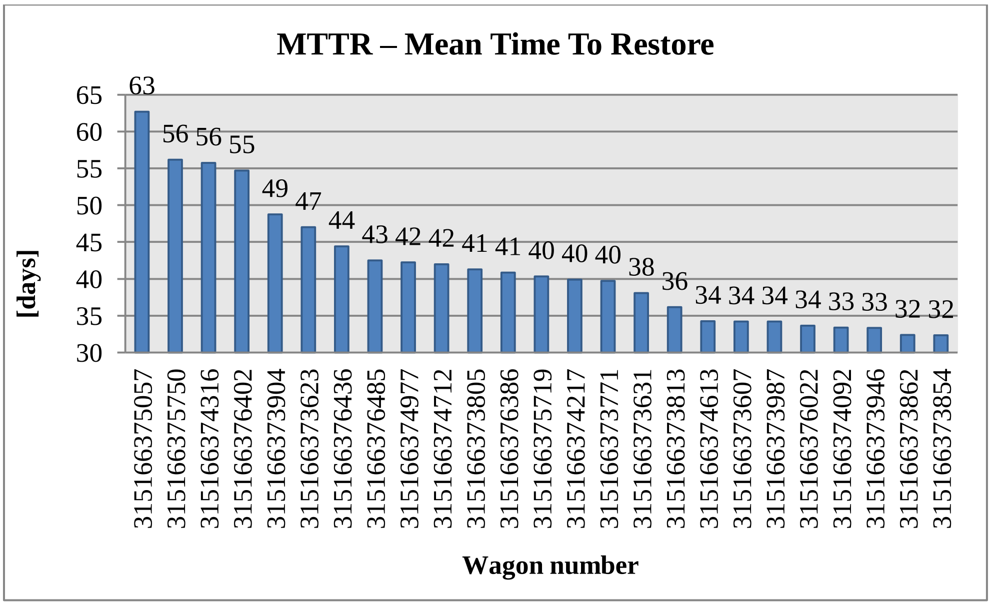

Fig.5. MTTR value per vehicle number

In figures 1-4 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.

4. Summary

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.

Currently, the largest development if process of risk management is expected in the area of common risk. At the moment, in Poland, most of the entities identify threats in this area alone.

The presented methods are currently being analysed by the Office of Rail Transport, State Commission for Investigation of Railway Accidents and the Department of Rail Transport. In addition, they are constantly improved by the railway operators in accordance with the philosophy of management systems of safety and maintenance.

1. Literature

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