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FMEA ANALYSIS OF COMBUSTION ENGINE AND ASSIGNMENT OCCURRENCE INDEX FOR RISK VALUATION

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Abstract

The need for continuous improvement of product quality, reliability and safety arises and above all a company's desire to improve its market position and customer satisfaction. These issues require product manufacturers to perform risk analyses that identify and minimize part/system failures throughout the product's life cycle. In the paper we will apply the Failure Modes and Effects Analysis (FMEA) for analysis of combustion engine failures. We analyzed 15 different types of cars in which the 2.0 TDI was equipped.

On the basis of the obtained data, we evaluated the most disturbing parts of the combustion engine and on these elements we determined the probability of occurrence of a fault which is one of the factors determining the Risk Priority Number (RPN).

Keywords: FMEA, combustion engine, occurrence, risk

1. INTRODUCTION

To minimize a project failure probability a project manager must have a process to manage project risks. This process is normally developed in the manager's head depending on his or her experience in the project. This proposal is to present a formalized risk management process that offers a tool to improve risk management.

Every process, system, or human activity is affected by risks that can have both a positive and a negative impact. Risk management is the systematic application of management policies and established practices. This process is dependent on the experience, knowledge, imagination, creativity, and capability of the team performing this analysis. Applying these procedures without being included teamwork cannot be provided to competent employees correct and thorough results of risk analysis. An important step is to choose the appropriate risk assessment method. The risk assessment based on a risk analysis assesses the severity of the estimated size of the risk and assesses the need to reduce it. Risk management is a structured sequence of logical steps where the first step is a risk analysis that examines the potential negative consequences that may result from failures in the operation of technical systems or deviations in technological processes [15, 16].

There are various methods for risk assessment. These methods are used in various steps of risk management processes, or they can also be combined. Risk assessment methods can be divided [12]:

1. According to the valuation method:
– qualitative,
– quantitative,
– semi quantitative.
2. According to sources of information:
– deductive,
– inductive.

2. PUBLISHED STANDARDS AND GUIDELINES

There are a number of published guidelines and standards for the requirements and recommended reporting format of failure mode and effects analyses. Some of the main published standards for this type of analysis include SAE J1739, AIAG FMEA-4 and MIL-STD-1629A. In addition, many industries and companies have developed their own procedures to meet the specific requirements of their products/processes. As an example, Figure 1 shows a sample Process FMEA (PFMEA) in the Automotive Industry Action Group (AIAG) FMEA-4 format [11, 12, 13, 14].

3. RISK EVALUATION METHOD

A typical failure modes and effects analysis incorporates some methods to evaluate the risk associated with the potential problems identified through the analysis. The two most common methods are Risk Priority Numbers and Criticality

Analysis. In our paper, we will apply the method Risk Priority Numbers.

Risk Priority Numbers

To use the Risk Priority Number (RPN) method to assess risk, the analysis team must:

– rate the severity of each effect of failure.
– rate the likelihood of occurrence for each cause of failure,
– rate the likelihood of prior detection for each cause of failure (i.e. the likelihood of detecting the problem before it reaches the end user or customer).

Calculate the RPN by obtaining the product of the three ratings [9,14]:

$$RPN = S \cdot O \cdot D \qquad (1)$$

Where:

S - severity,
O - occurrence,
D - detection.

The RPN can then be used to compare issues within the analysis and to prioritize problems for corrective action. This risk assessment method is commonly associated with Failure Mode and Effects Analysis (FMEA).

In an FMEA, occurrence is a ranking number associated with the likelihood that the failure mode and its associated cause will be present in the item being analysed. For System and Design FMEAs, the occurrence ranking considers the likelihood of occurrence during the design life of the product. For Process FMEAs, the occurrence ranking considers the likelihood of occurrence during production (Table 1). It is based on the criteria from the corresponding occurrence scale. The occurrence ranking has a relative meaning rather than an absolute value and is determined without regard to the severity or likelihood of detection.

Table 1. Simple assessment of the probability of occurrence of a failure in practice - subjective point of view

Likelihood of Failure	*Note*	*Criteria*	*Rank*
Very High	Certain occurrence of failures.	weekly	10
		monthly	9
High	Common failures.	6 months	8
		yearly	7
Moderate	Accidental failures with a smaller incidence.	2 years	6
		3 years	5
		5 years	4
Low	Rare occurrence of failures.	10 years	3
		15 years	2
Very Low	Unlikely occurrence of failures.	More than 15 years	1

4. ANALYZED OBJECT

The 2.0 TDI PD combustion engine consists of several parts that we can divide into fixed and mobile. Fixed parts include: crankcase, cylinder block, cylinder head, covers and oil bath. Moving parts can be divided into crank mechanism and timing mechanism. The basic parts of the crank mechanism include: piston, piston rings, piston pin, connecting rod, crankshaft, double-mass flywheel and bearings. The basic parts of the timing mechanism include: camshaft, bearings, camshaft drive, hoists, lifting rods, rocker arms, valves, valve springs. For its operation, the engine needs auxiliary equipment such as a starter system, cooling system, exhaust system (with DPF and without DPF), overfill system, lubrication system, fuel system. Figure. 1 and Figure. 2 shows the basic parts of the combustion engine [10].

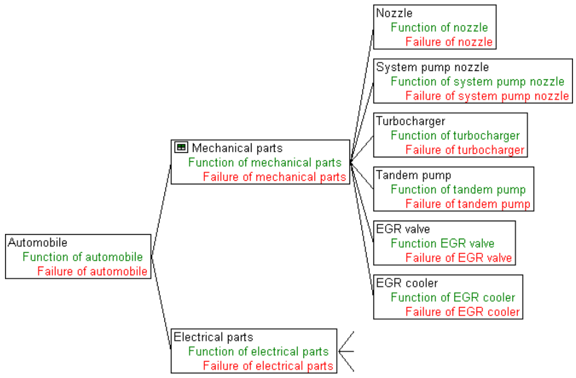

Fig. 1. View of automobile structure with the structure of functions and failures network

Fig. 2. Diesel engine 2.0 TDI

The engine is based on a 1.9 TDI PD / 96 kW engine, with an increase in volume being achieved by increasing the cylinder bore. The engine is equipped with an aluminium head with two suction and exhaust valves per cylinder, opposite suction and exhaust pipes. Other technical features include the exhaust gas recirculation cooler and the new heater system. The individual technical parameters of the engine are shown in Table 2.

Table 2. Technical parameters of engine 2.0 TDI

Identification code of engine	BKD
Basic design	Row four-cylinder
Stroke volume	1968 cm^3
Bore	81 mm
Stroke	95,5 mm
Valves per cylinder	4
Compression ratio	18:1
Max. power	103 kW at 4000 rpm
Max. torque	320 Nm at 1750 rpm to 2500 rpm
Engine control system	EDC 16 with injection pump-nozzle
Fuel	Diesel oil, min. 49
Modification of exhaust gases	Exhaust gas recirculation and oxidation catalyzer
Emission standard	EU 4

5. ANALYSE OF FAILURES BY FMEA

APIS PRO 6.5 programme was used to develop FMEA of automobile engines with criticality of nodes, including functional and failure networks.

During the operation there were failures that often lead to immobilize the vehicle. Failures were monitored for 15 engines in different vehicles under real operation (Table 3).

The reliability of a component or system can be represented in a statistical sense by the probability of a component or system performing satisfactorily at a particular time under a specified set of operating conditions. The definition of what constitutes 'satisfactory' may depend upon the nature of the system.

During operation occurred failures, which often led to the stop of the vehicle to service. These failures can be divided into:

- mechanical,
- electrical.

Furthermore, these failures on the engine can be divided into less severe and severe in terms of severity.

In the case of minor failures, the engine may continue to operate when the fault does not have a serious effect on its function.

An example may be the failure of one of the four glow plugs. As a serious failure, we can indicate, for example, a system failure in the nozzle pump system, which causes the nozzle to drop, resulting in the engine stopping and preventing it from being restarted. By analysing the resulting faults, such as the number of kilometres since the last repair, the time between failures, the number of failures for a certain number of kilometres, we can adapt the maintenance plan for the failures in order to avoid their consequences.

After plotting dependence, the line equation, whose general shape is $y = mx + b$, is displayed. Weibull's probability distribution can be transformed to the form of the linear equation:

$$F(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{2}$$

$$1 - F(x) = e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{3}$$

$$\ln(1 - F(x)) = -\left(\frac{x}{\alpha}\right)^{\beta} \tag{4}$$

$$\ln\left[\ln\left(\frac{1}{1 - F(x)}\right)\right] = \beta \ln\left(\frac{x}{\alpha}\right) \tag{5}$$

$$\ln\left[\ln\left(\frac{1}{1 - F(x)}\right)\right] = \beta \ln x - \beta \ln \alpha \tag{5}$$

Where:
F(x) - distribution function,
α - shape parameter,
β - scale parameter.

Table 3. Data collection to evaluate the probability of occurrence of failures

Engine	Electrical failure					Mechanical failure					
	Sensor intake air	Preheating	Cables preheating	Cooling liquid temperature	Boost pressure	Turbocharger	Tamdem's pumpe	Preheating	EGR valve	Injector	Cooler EGR system's
Car 1	2	1	2	1	2		1	1	1	1	1
Car 2		1	1			1				1	
Car 3	2		1		1	1	1			1	1
Car 4	1		1	2		1				3	
Car 5	1		3		1	1			1	2	
Car 6	1		3			1				1	
Car 7	1		3	2		1		1		1	1
Car 8	2		1		1	1	1			1	
Car 9			1			2		1		1	1
Car 10	1		1	2	1			1		1	
Car 11	2		2			1	1		1	1	
Car 12	1	1	1	1	1	2				1	
Car 13	1	2	1		1	1			1	1	1
Car 14	2		1	1		1			1	1	
Car 15	1	1	2		1	1	1			1	

By comparing this equation with the straight line equation, we see that the left side of the equation corresponds to y, $\ln x$ corresponds to x, β corresponds to m and $\beta \ln\alpha$ corresponds to b. Therefore, if we want to perform a linear regression, we need to use a parameter estimation. Estimation of parameter β comes directly from the slope of the line. The estimate for parameter α must be calculated:

$$\alpha = e^{-\left(\frac{x}{\beta}\right)} \tag{6}$$

The Figure 3 shows the regression curves of the 4 most conspicuous components of the explored engine to determine Weibull's probability distribution parameters.

Table 4. Determination of Weibull's probability distribution parameters

Injector	
Beta (or Shape Parameter) =	3,7915
Alpha (or Characteristic Life) =	181532,796
Turbocharger	
Beta (or Shape Parameter) =	6,4706
Alpha (or Characteristic Life) =	184795,525
Cables	
Beta (or Shape Parameter) =	2,4128
Alpha (or Characteristic Life) =	92757,9484
Sensor intake air	
Beta (or Shape Parameter) =	2,2061
Alpha (or Characteristic Life) =	94163,6958

Then Weibull's probability distribution parameters for the Injector, turbocharger, cables and sensor intake air were calculated as shown in Table 4.

Perhaps the best way to display the reliability of 4 top fault units is by using a survival graph. This line graph depicts the survival probabilities of each unit at various numbers of kilometres.

The Figure 4 allows you to read the fail-safe probability values for individual components when setting preventive maintenance every 80,000 km or every 120,000 km.

When defining the limit for preventive maintenance of these four critical components from the point 1 - Injector, the probability of occurrence of failure is 0.95.

These readings of failure probability can then serve as the basic parameters for determining the occurrence of the failure as shown in Figure 5. As an example, we can see that, in case of subtraction of point 1, the occurrence for injector 2 is achieved, which means that, according to the evaluation in the table, it falls into the category very small, which means that "This design is slightly different from earlier proven designs." This is how we can determine the occurrence for all our points of interest: turbocharger sensor intake air and cables. FMEA uses a tabular method of presenting data, meaning the content of the analysis is visually displayed in a series of worksheet rows and columns. Figure 6 is a generic worksheet with typical FMEA columns.

Then there is an initial state and as the first state is always the initial state of risk assessment and other states represent already optimized risk values using "controls." They are the methods or actions currently planned or are already in place, to reduce or eliminate the risk associated with each potential cause. Controls can be the methods to prevent or detect the cause during product development, or can be actions to detect a problem during service before it becomes catastrophic. There can be many controls for each cause.

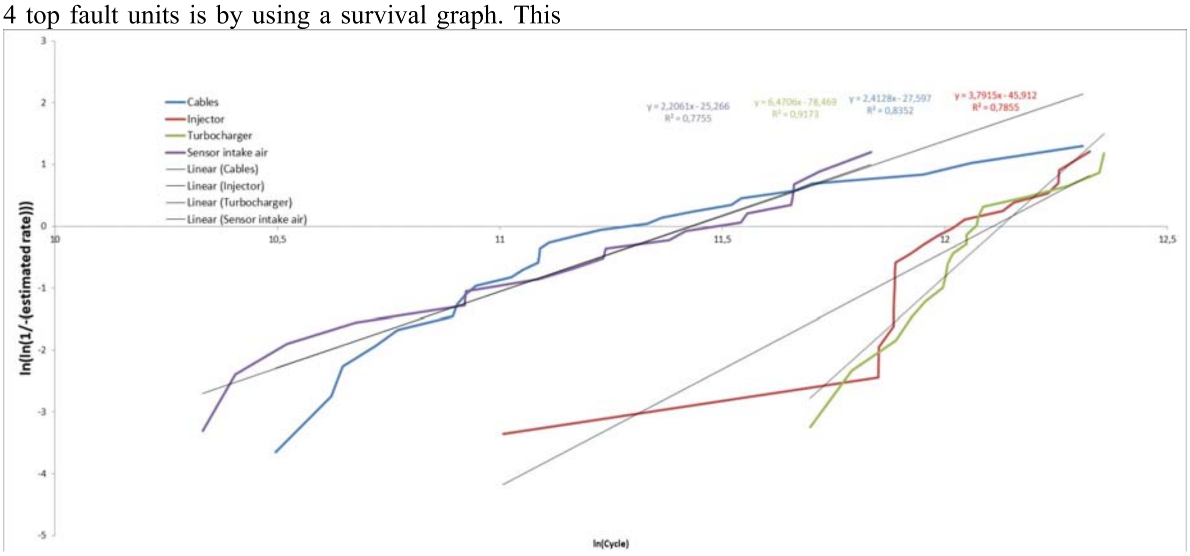

Fig. 3. Line Fit Plot for 4 top fault units

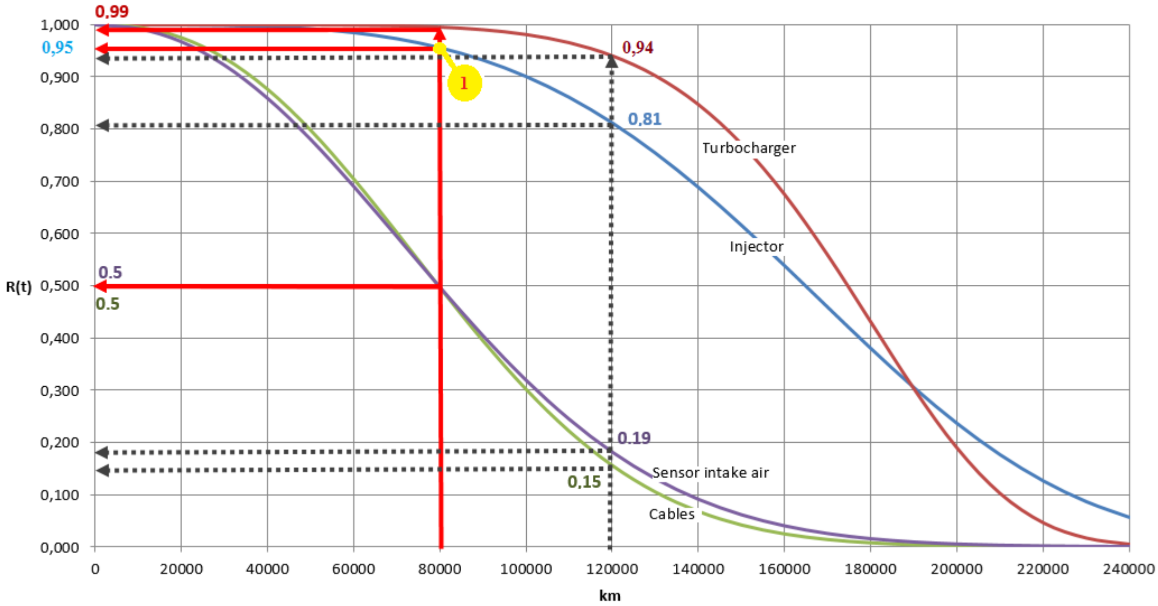

Fig. 4. Determination of service life - preventive maintenance after 80000 km and 120000 km

Occurrence	Note	Reliability	Occurrence Rating
High	This design is almost certain to cause problems	(0; 0.4)	10
		<0.4; 0.5)	9
Medium	This design is only slightly different from earlier proven designs which caused problems.	<0.5; 0.6)	8
		<0.6; 0.65)	7
Small	This design is only slightly different from earlier proven designs which failed in some cases.	<0.65; 0.7)	6
		<0.7; 0.8)	5
		<0.8; 0.9)	4
Very small	This design is only slightly different from earlier proven designs.	<0.9; 0.95)	3
		<0.95; 1)	2
Improbable	It is improbable for this failure to occur.	1	1

		Injector		Turbocharger		Cables		Sensor intake air	
Example		Reliability				Rank Occurrence			
no maintenance			10		10		10		10
long lifetime	120000	0,81	4	0,94	3	0,15	10	0,19	10
lifetime	80000	0,95	2	0,99	2	0,5	8	0,5	8

Fig. 5. Rank occurrence based on probability of occurrence of failure

6. CONCLUSION

The purpose of this paper is to locate one of three factors of the risk priority number - Occurrence of failures of combustion engine.

The Failure Modes, Effects and Criticality Analysis (FMEA / FMECA) procedure is a tool that has been adapted in many different ways for many different purposes. It can contribute to improved designs for products and processes, resulting in higher reliability, better quality, increased safety, enhanced customer satisfaction and reduced costs. The tool can also be used to establish and optimize maintenance plans for repairable systems and/or contribute to control plans and other quality assurance procedures. It provides a knowledge base of failure mode and corrective action information that can be used as a resource in future troubleshooting efforts and as a training tool for new engineers. In addition, an FMEA or FMECA is often required to comply with safety and quality requirements, such as ISO 9001, QS 9000, ISO/TS 16949, Six Sigma, FDA Good Manufacturing Practices (GMPs), Process Safety Management Act (PSM), etc.

Some benefits of performing FMEA/FMECA analysis include [7, 8]:

- contributes to improved designs for products and processes:
- higher reliability,
- better quality.
- increased safety.
- contributes to the development of control plans, testing requirements, optimum maintenance plans, reliability growth analysis and related activities.

Enhanced customer satisfaction [4, 5]:

- contributes to cost savings,
- decreases development time and re-design costs,
- decreases warranty costs,
- decreases waste, non-value added operations.

Cost benefits associated with FMEA are usually expected to come from the ability to identify failure modes earlier in the process, when they are less expensive to address. Financial benefits are also derived from the design improvements that FMEA is expected to facilitate, including reduced warranty costs, increased sales through enhanced customer satisfaction, etc.

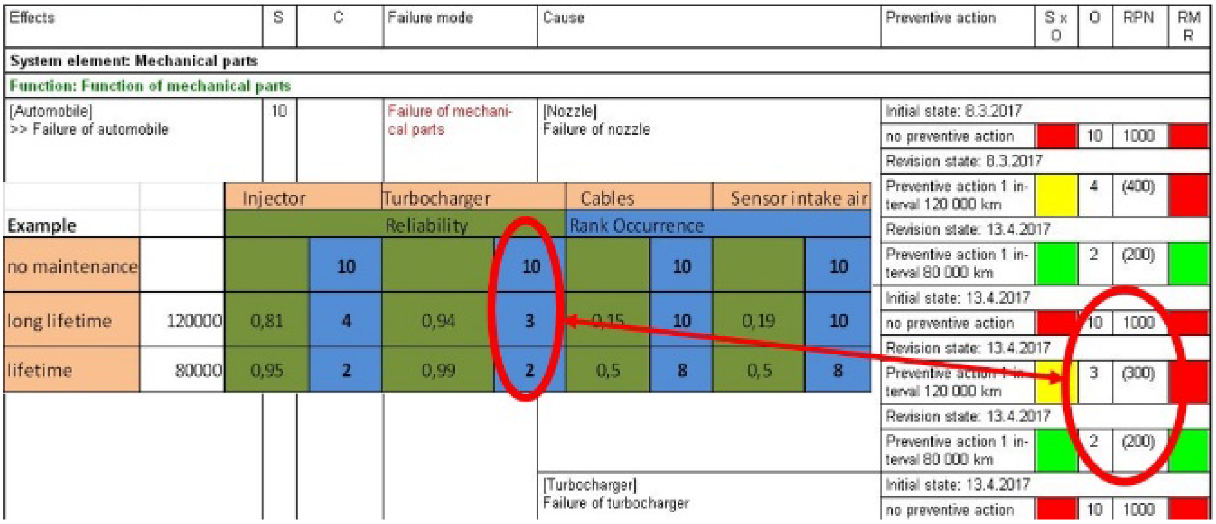

Fig. 6. Assessment of the probability of occurrence of a failure in FMEA and its impact on overall risk

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REFERENCES

1. Schmidt P, Moni V, Blata J, Cymerys D, Ripel J. Practical application of the new MMM method in non-destructive testing. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, 2014; 3(1): 451-456.
2. Galliková J, Poprocký R. Maintenance according to the technical state with use of the enterprise asset management systems, Zeszyty naukowe Instytutu Pojazdów: mechanika, ekologia, bezpieczeństwo, mechatronika, 2015; 3(103): 67-75.
3. Grenčík J. Maintenance Management: Synergy of Theory and Practice 1. vyd. - Košice: Beki Design, 2013.
4. Grenčík J, Ruman F. Proposal of new maintenance system of air brake system on semi-trailer combination aimed at increase of operational safety In: Autobusy: technika, eksploatacja, systemy transportowe, 2013; 14(3).
5. Blatnický M, Dižo J, Štauderová M. Strength analysis of a structure for attachment of a winch on SUV. Manufacturing Technology, 2017; 17(3): 291-295.
6. Blatnický M. Checks crane In: Manufacturing technology. Journal for Science, Research and Production, 2015; 15(5): 766-771.
7. Harušinec J, Maňurová M, Suchánek A. Optimalization of a brake unit in terms of control range. Manufacturing Technology, 2016; 16(5): 917-923.
8. Pačaiová H, Markuliak Š, Nagyová A. The importance of risk in management systems. Košice: BEKI Design, s.r.o, 2016.
9. Pačaiová H, Sinay J, Glatz J. Safety and risks of technical systems. Košice: Vienala Košice, 2009.
10. Vaněk P, Procházka M, Kudelová I, Helebrant F, Bílý I. Technical diagnostics implementation into production process operational experiences. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, 2014; 3(1): 607-613.
11. STN EN 16602-30-02: Space product assurance – Failure modes, effect (and criticality) analysis (FMEA/FMECA).
12. STN EN 60812: Analysis technique for system reliability – Procedure for failure mode and effect analysis (FMEA).
13. STN EN ISO 9000-1 (010320): Quality management, validity from 1. 3. 1997.
14. STN 010380: Risk management, validity from 1. 3. 2003.
15. Stuchlý V, Zvolenský P. History and Presence of Maintenance Education at the Faculty of Engineering of the University of Žilina. Řízení & údržba průmyslového podnik, 2016.
16. Pacaiova H, Grencik J, Dravecky G. Maintenance audit as a means for asset management improvement. Euromaintenance: conference proceedings: 30 May - 1 June, 2016: Athens, Greece. - Athens: EFNMS, 2016: 463-469.

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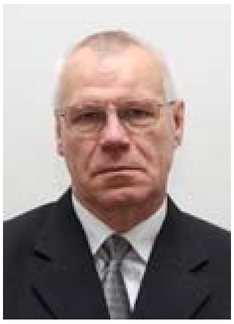

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