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Maintenance analysis of devices powering transport telematic systems including financial outlays efficiency

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ABSTRACT

Transport telematics systems work in different exploitation conditions. As the elements responsible for the safety of the transport process they should maintain their suitability. So far it has been analyzed their reliability, however, it is also important to provide the power analysis taking into account the relations in the system. It is especially important to consider the financial investments for the maintenance of the state of the system suitability and effectiveness of the use of these funds. The paper presents an analysis of the transport telematics system power supply with special consideration of related financial outlays earmarked for repair and the effectiveness of their use.

KEYWORDS: transport telematics systems, exploitation, power supply

1. Introduction

Transport telematic systems operate under various conditions [4,9,13]. Because they are responsible for safety of transport processes they should remain in full ability [1,3,6]. One of key issues is assuring uninterrupted power supply for transport telematic systems. To date, reliability analysis of their structure was carried out by the author [11,14,15,16]. It is of paramount important for the reliability analysis to factor in relationships between elements of the system, especially power supply related. It is particularly important to recognise, secure and efficiently use financing required to maintain the system in the state of full ability. That approach was presented under subsequent items in this paper.

The reliability theory in respect of general considerations has had sound footing for many years [5,8]. For references on operating principle of power supplies see the following publications [2,10,12]. Issues related to reliability of power supply were addressed in papers [2,12,20]. Optimization problems were described in paper [17]. Redundant sources of power were elaborated on in publications [7].

2. Analysis of Power Supply Maintenance in Transport Telematics System

In order for transport telematics systems to function properly, they require that each device constituting the system is powered correctly. Power cutoff leads to full or partial system failure. Hence, usually two power supplies are used. First one is the main supply. If it fails, the redundant power supply starts running to keep the device powered up. It was illustrated in fig. 1.

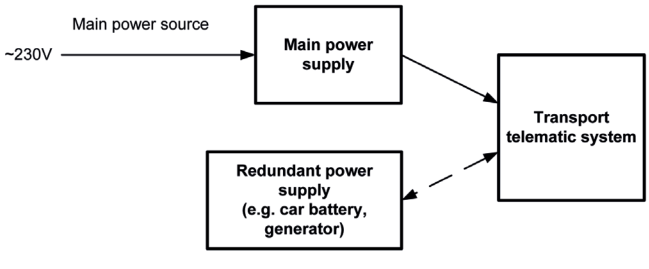

Fig.1. Main and redundant power supply

Based on analysis of transport telematics system, it may be concluded that relationships within that system - from reliability and maintenance point of view - are as per illustration in fig. 2.

In the state of full ability S_{PZ} both power sources are fully operational (both the main and redundant power supply). The state of partial operational capability Q_{NZ} is a state where only the main power supply is operational. The state of reached operational capability Q_N is a state where both power sources are not operational.

The relationship for determining probability of the system staying in the state of full operational capability R_O, partial capability Q_{NZ} and reached capability Q_N is obtained from mathematical analysis (Chapman–Kolmogorov equation).

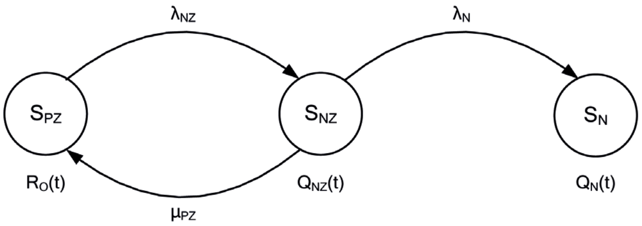

Fig.2. Relationships in the system (where: $R_O(t)$ – the function of probability of system in state of full operational capability, $Q_{NZ}(t)$ – the function of probability of system in state of partial operational capability, $Q_{NZ}(t)$ – the function of probability of system in state of reached operational capability, λ_{NZ} – transition rate from the state of full operational capability into the state of partial operational capability, μ_{PZ} – transition rate from the state of partial operational capability into the state of full operational capability, λ_N – transition rate from the state of partial operational capability into the state of reached operational capability)

The system illustrated in fig. 2 may be described by the following Chapman–Kolmogorov equations:

$$\begin{aligned} R_0'(t) &= -\lambda_{NZ} \cdot R_0(t) + \mu_{PZ} \cdot Q_{NZ}(t) \\ Q_{NZ}'(t) &= \lambda_{NZ} \cdot R_0(t) - \mu_{PZ} \cdot Q_{NZ}(t) - \lambda_N \cdot Q_{NZ}(t) \\ Q_N'(t) &= \lambda_N \cdot Q_{NZ}(t) \end{aligned} \tag{1}$$

Given the initial conditions:

$$\begin{aligned} R_0(0) &= 1 \\ Q_{NZ}(0) &= Q_N(0) = 0 \end{aligned} \tag{2}$$

Laplace transform yields the following system of linear equations:

$$\begin{aligned} s \cdot R_0^*(s) - 1 &= -\lambda_{NZ} \cdot R_0^*(s) + \mu_{PZ} \cdot Q_{NZ}^*(s) \\ s \cdot Q_{NZ}^*(s) &= \lambda_{NZ} \cdot R_0^*(s) - \mu_{PZ} \cdot Q_{NZ}^*(s) - \lambda_N \cdot Q_{NZ}^*(s) \\ s \cdot Q_N^*(s) &= \lambda_N \cdot Q_{NZ}^*(s) \end{aligned} \tag{3}$$

Through inverse transformation we get:

$$R_0(t) = \begin{bmatrix} \cos\left(\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}\cdot\frac{t}{2}\right)+ \\ +\frac{\mu_{PZ}+\lambda_N-\lambda_{NZ}}{\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}}\cdot \\ \cdot\sin\left(\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}\cdot\frac{t}{2}\right) \end{bmatrix}\cdot \\ \cdot\exp\left[-\left(\frac{\lambda_{NZ}+\mu_{PZ}+\lambda_N}{2}\right)\cdot t\right] \tag{4}$$

$$Q_{NZ}(t) = \frac{2\cdot\lambda_{NZ}}{\sqrt{2\cdot\lambda_{NZ}\cdot\lambda_N-2\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}}\cdot \\ \cdot\sin\left(\sqrt{2\cdot\lambda_{NZ}\cdot\lambda_N-2\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}\cdot\frac{t}{2}\right)\cdot \\ \cdot\exp\left[-\left(\frac{\lambda_{NZ}+\mu_{PZ}+\lambda_N}{2}\right)\cdot t\right] \tag{5}$$

$$Q_N(t) = 1-\begin{bmatrix} \cos\left(\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}\cdot\frac{t}{2}\right)+ \\ +\frac{\mu_{PZ}+\lambda_N+\lambda_{NZ}}{\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}}\cdot \\ \cdot\sin\left(\sqrt{2\cdot\lambda_{NZ}\cdot(\mu_{PZ}+\lambda_N)-4\cdot\mu_{PZ}\cdot\lambda_{NZ}-\lambda_{NZ}^2-(\mu_{PZ}+\lambda_N)^2}\cdot\frac{t}{2}\right) \end{bmatrix}\cdot \\ \cdot\exp\left[-\left(\frac{\lambda_{NZ}+\mu_{PZ}+\lambda_N}{2}\right)\cdot t\right] \tag{6}$$

3. Maintenance analysis of devices powering transport telematic systems including financing and its use

Nowadays, managing transport telematic systems focuses above all on economic side (i.e. financing required to sustain the state of full ability). Only then feasible, sound maintenance decisions may be reached. The funding provided by the users for maintaining transport telematic systems is limited, hence the necessary financial prudence. Therefore the C coefficient was introduced, which determined available financial resources allocated for repair. Therefore the relationship (4) becomes (7).

$$R_0(t) = \begin{bmatrix} \cos\left(\sqrt{2\cdot\lambda_{NZ}\cdot\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)-4\cdot\frac{1}{C\cdot t_{PZ}}\cdot\lambda_{NZ}-\lambda_{NZ}^2-\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)^2}\cdot\frac{t}{2}\right)+ \\ +\frac{\frac{1}{C\cdot t_{PZ}}+\lambda_N-\lambda_{NZ}}{\sqrt{2\cdot\lambda_{NZ}\cdot\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)-4\cdot\frac{1}{C\cdot t_{PZ}}\cdot\lambda_{NZ}-\lambda_{NZ}^2-\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)^2}}\cdot \\ \cdot\sin\left(\sqrt{2\cdot\lambda_{NZ}\cdot\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)-4\cdot\frac{1}{C\cdot t_{PZ}}\cdot\lambda_{NZ}-\lambda_{NZ}^2-\left(\frac{1}{C\cdot t_{PZ}}+\lambda_N\right)^2}\cdot\frac{t}{2}\right) \end{bmatrix}\cdot \\ \cdot\exp\left[-\left(\frac{\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}+\lambda_N}{2}\right)\cdot t\right] \tag{7}$$

In order to determine how efficiently budget for repairs was used, derivative of (7) needs to be derived for financial outlays coefficient C: $\frac{dR_0}{dC}$. The following relationship was obtained (8):

$$
\begin{aligned}
ENF(C)={}&\frac{\cos\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)+\frac{\sin\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)}{\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}}\cdot\left(\lambda_N-\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}\right)}{2\cdot C^2\cdot t_{PZ}}\cdot\\
&\cdot t\cdot\exp\left[-\left(\lambda_N+\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}\right)\cdot\frac{t}{2}\right]-\\
&-\left[\frac{t\cdot\sin\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)\cdot\left(\lambda_{NZ}+\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)}{2\cdot C^2\cdot t_{PZ}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}}+\right.\\
&+\frac{\sin\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)}{C^2\cdot t_{PZ}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}}+\\
&+\frac{\sin\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)\cdot\left(\lambda_{NZ}+\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)\cdot\left(\lambda_N-\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}\right)}{C^2\cdot t_{PZ}\cdot\left(2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}\right)^{\frac{3}{2}}}+\\
&\left.+\frac{t\cdot\cos\left(\frac{t}{2}\cdot\sqrt{2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}}\right)\cdot\left(\lambda_{NZ}+\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)\cdot\left(\lambda_N-\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}\right)}{-2\cdot C^2\cdot t_{PZ}\cdot\left(2\cdot\lambda_{NZ}\cdot\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)-\lambda_{NZ}^2-\left(\lambda_N+\frac{1}{C\cdot t_{PZ}}\right)^2-\frac{4\cdot\lambda_{NZ}}{C\cdot t_{PZ}}\right)}\right]\cdot\\
&\cdot\exp\left[-\left(\lambda_N+\lambda_{NZ}+\frac{1}{C\cdot t_{PZ}}\right)\cdot\frac{t}{2}\right]
\end{aligned}
\tag{8}
$$

The relationship (8) allows determining the value of financial outlays coefficient efficiency (FOE) as a function of financial outlays coefficient C.

Question: how does financial outlays efficiency (FOE) change relative to the financial outlays coefficient C.

Example

The following quantities were defined for the system:

- research period - 1 year: t=8760 [*h*]
- reliability of main power supply: $R_{NZ}(t)=0{,}9$
- reliability of reserve power supply: $R_N(t)=0{,}999$
- transition rate from the state of partial operational capability into the state of full ability,

$$\mu_{PZ}=\frac{1}{24}\left[\frac{1}{h}\right]$$

Respective calculations produced results presented in table 1 and in fig. 3.

Table 1. Value of the function $ENF = f(C)$

C	$ENF = f(C)$
0.5	$-27{,}561805\cdot10^{-6}$
1	$-27{,}560894\cdot10^{-6}$
2	$-27{,}559073\cdot10^{-6}$
3	$-27{,}557252\cdot10^{-6}$
4	$-27{,}555431\cdot10^{-6}$
5	$-27{,}553611\cdot10^{-6}$
6	$-27{,}551791\cdot10^{-6}$
7	$-27{,}54997\cdot10^{-6}$
8	$-27{,}54815\cdot10^{-6}$
9	$-27{,}546331\cdot10^{-6}$
10	$-27{,}544511\cdot10^{-6}$
20	$-27{,}526321\cdot10^{-6}$
30	$-27{,}506301\cdot10^{-6}$
40	$-27{,}460034\cdot10^{-6}$
50	$-27{,}319487\cdot10^{-6}$

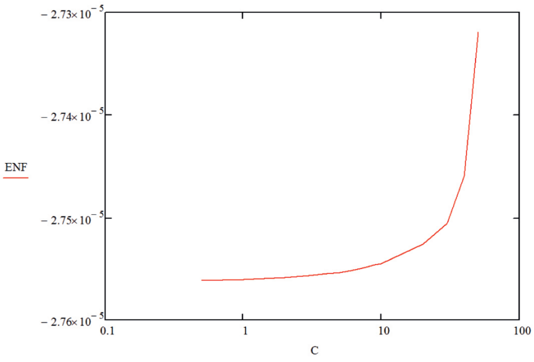

Fig.3. The relationship for financial outlays efficiency (FOE) as a function of financial outlays coefficient C

Chart in fig. 3 shows that as financial outlays coefficient C increases the financial outlays efficiency FOE decreases in non-linear fashion.

4. Conclusion

Devices powering transport telematic systems were analysed in this paper. It focused on reliability and maintenance aspects with relation to financial outlays required for repairs and efficiency of deploying that finance. Assuming three states (state of full ability R_0, state of partial operational capability Q_{NZ} and state of reached operational capability Q_N) and transitions as per fig. 2, the relationship for determining financial outlays efficiency was derived. Further research envisages computer simulation and developing an application, whereby optimal values for defined initial conditions would be determined.

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