Risk Of Maintenance Resource Sharing In Transport Systems

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Abstract: The authors investigate the problem of maintenance resource sharing for transport systems in the context of operational risk assessment. The paper includes a short introduction to the maintenance problems and a discussion of maintenance resource sharing issues in transport systems' effective performance. Later, a three-parameter risk assessment ratio is introduced. It includes a probability of disruption, consequences of disruption, and a new measure characterizing maintenance resources availability. Later, the problem of maintenance resource availability is analyzed and discussed. Finally, a short case study is introduced. The presented paper gives the possibility to identify research gaps and possible future research directions connected with the optimization of maintenance problems in transportation organizations.

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1. INTRODUCTION

Risk is perceived as a natural element of transport operations. Managers, aware of this fact, are increasingly making an effort to identify potential sources of risk in various areas of their business activities. In the first instance, their attention is focused on the shipping process itself as a company's core activity. However, the quality of transport services is also strongly dependent on the supporting processes, including the efficient process of maintaining vehicles in an up-stated condition. Failure of a vehicle, just like failure of a production machine, often causes downtime in the ongoing transports. This, in turn, increases operating costs and disrupts customer service delivery [2]. At the same time, the effects of a failure cause more significant disruption to the primary process, and the accompanying costs of repairing the failure are higher than the costs incurred in maintaining vehicles in an upstate [12]. Hence, researchers and managers have a growing interest in maintenance process improvement concepts that will reduce the number of recorded failures.

Over the past few decades, maintenance strategies have gone through a significant transformation from simple corrective maintenance to more sophisticated - proactive strategies [25]. Selecting a reasonable maintenance strategy is critical and complex due to many factors that need to be considered [15]. These factors commonly include the cost of maintenance policy, required product quality, availability of spare parts, and maintenance time [26]. A literature review by [14] indicates that there has been an increasing tendency to use risk as a criterion for planning equipment maintenance tasks for many years. Also, Chemweno et al. [5] stated that the risk assessment process performs a crucial role in maintenance decision making.

Risk is defined in various ways in the known literature [3]. In recent years, it has increasingly been captured in terms of an event that, if it happens - will affect the goals achieved by the organization [6]. From the perspective of the machine/fleet maintenance process, the concept of risk is defined as the anticipated loss associated with the occurrence of a possible undesirable failure event [2].

However, today this approach is no longer sufficient. Because the superior goal of the transport system is to provide the transport service according to a specific schedule, an additional parameter should be taken into account during the risk assessment process. This parameter is the availability of supporting resources according to the resource sharing concept.

The issues of resource sharing in the context of maintenance processes planning and performance mostly regard the problem of maintenance teams sharing strategy development (e.g., [21]) or information processing (e.g., [10]).

In work [22], the authors investigated the maintenance scheduling strategy development problem by taking into account task priority, resource assign rule, resource sharing of a parallel task, and cross maintenance. The proposed solution is based on a Petri net model development. Later, in [10], the authors investigated the problem of sharing strategy development for different companies' joint use of resources. The authors introduced a simulation model and a control-theoretic model to define how resource sharing in a production network impacts the performance of stakeholders and the dynamics of the entire network. Another problem is analyzed in [4], where the authors investigated a nonlinear scheduling problem with shared resources, blending, and maintenance constraints. The analysis was performed for open-pit mining operations maintenance. In another work [24], the authors proposed a concept of resource sharing between service providers. The proposed model was developed for the maintenance processes of wind farms jack-up vessels.

However, in the context of the PN-EN 17007 standard [9], the resource sharing concept requires new methodologies and approaches for efficient and effective coordination in the technical and transportation systems. Increased interest in this problem is also associated with developing such technologies as Logistics 4.0 or the concept of intelligent supply chains. The rapid development of integration and collaboration in supply chains and new opportunities and challenges for cyber-physical systems require establishing new mechanisms for assigning available resources to request companies and managing conflicts, e.g., time delays and information and material flow disturbances. They also require adapting risk management/ assessment methods to the new operational environment.

Therefore, the article continues the authors' research presented in [27], where the fuzzy AHP. (Analytic Hierarchy Process) the method was introduced for maintenance resource sharing strategy selection. The main decision-making problem was to properly select the maintenance resources that may be shared in an organization or a supply chain to increase maintenance resources using efficiency and reduce equipment downtime. One of the selection criteria was risk. Following this, the next important issue is investigating the problem of maintenance resource availability in the context of risk assessment performance.

Therefore, the authors introduce a three-parameter risk assessment ratio. The risk measure includes two standard parameters – the probability of hazard event occurrence and its consequences. The last parameter regards maintenance resource availability. The article focuses on the possibility of estimating mainly the last parameter and presents an example of a risk assessment carried out in a selected transport company.

Thus, the paper includes a short introduction to the maintenance problems. Moreover, a short literature review of the analyzed research area is provided. The next section introduces the maintenance resource sharing problem in the performance of transportation system processes. This allows the introduction of the three-parameter risk assessment ratio with a short discussion of maintenance resource availability assessment issues. Later a short case study is presented. Finally, the presented paper gives the possibility to identify research gaps and possible future research directions connected with physical asset maintenance problems in transportation organizations.

2. MAINTENANCE RESOURCE SHARING IN TRANSPORT SYSTEMS

A transportation system is a system in which material objects are moved in time and space. Thus, the function of transportation is to execute the movement of people and goods from one place to another safely and efficiently with a minimum negative impact on the environment [11]. Following the authors of the works [11, 16], a transportation system is complex with different functional characteristics depending on the medium of movement, particular technology used, and demand for movement in the particular medium. The maintenance management of transportation systems may be defined as [20] *effective performance of transportation tasks consisting of 1) the selection of means of transport in a quantitative and structural way, 2) their operation and maintenance according to the intended specification, 3) continuous maintenance of operational readiness, by monitoring changes in the technical status and by conducting technically and economically reasonable replacement/repair of used vehicles, maintenance materials, and spare parts*.

In addition, following the European Standard EN 17007:2017 [9], *proper maintenance needs technical skills, techniques, and methods to correctly utilize assets like factories, power plants, vehicles, equipment, and machines*. Therefore, the transportation system with main operation and maintenance elements is presented in Fig. 1.

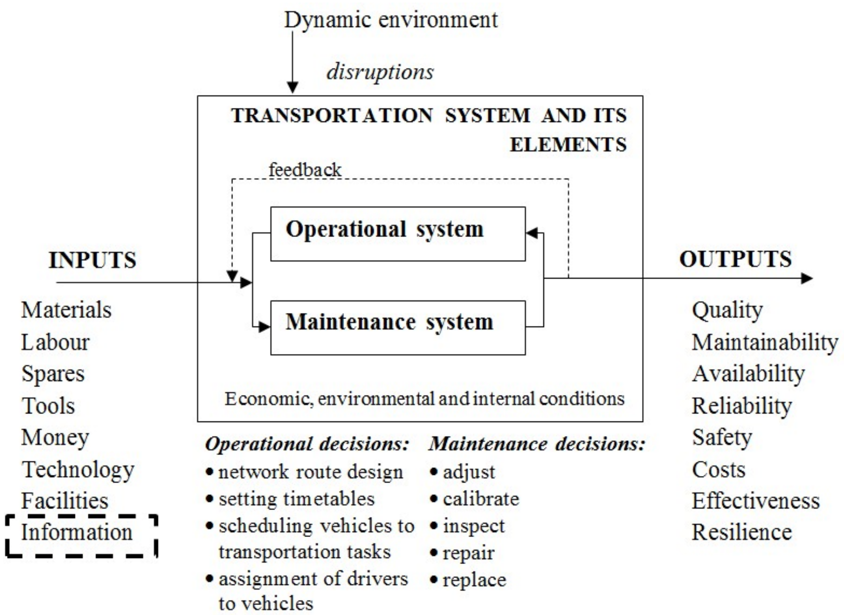

Figure 1: Transportation system and its operation and maintenance system elements. Source: Own contribution based on [9, 20]

Following this, based on the literature where the maintenance decision-making models are developed (see, e.g., [1, 7, 17]), the operation and maintenance decision-making model (OMDM) for transportation systems can be defined as a function of:

$$OMDM = \langle X_{in}, X_{out}, Y, z \rangle \quad (1)$$

where:
X_{in} – input parameters, which include:

$$X_{in} = \langle OS, MS, ES, EP \rangle \quad (2)$$

where:
O.S. – operational strategy; *M.S.* – maintenance strategy; *E.S.* – operational and maintenance structure (e.g., infrastructure, human resources, materials); *E.P.* – operational and maintenance policies (guidelines for the evaluation of maintenance processes performance); X_{out} – output parameters:

$$X_{out} = \langle PD, EA \rangle \quad (3)$$

where:
P.D. – process decision (maintenance or operational decision); *E.A.* – maintenance or operational activity; *Y* – measures of decision-making process quality; *z* – relation: $X_{in} \rightarrow X_{out}$

Based on the presented transport system model, it should be concluded that one possible area for ensuring or improving maintenance management efficiency may be sharing maintenance resources to increase maintenance resources using efficiency and reduce means of transport downtime. This sharing may apply to emergencies, where partners' resources are used to secure the continuity of services. However, the sharing of resources may also relate to the strategy of minimizing operating costs. In this situation, however, it is necessary to clearly define the rules for dividing fixed costs between the partners forming the co-shared system.

Due to the research topic covered in this paper, the researchers' attention will be focused only on the transportation means maintenance system. In this context, the primary maintenance resources that can be shared include:

- Maintenance teams/service stations – availability of maintenance service stations and accessibility of specialists who have extensive knowledge of vehicle maintenance performance. However, periodic shortages may occur during times of holidays or increased sickness periods.
- Spare parts – each company maintains a specific safety stock of strategic spare parts to ensure continuity of transportation service performance in the event of failure.
- Available fleet – in case of failure, there is a possibility to use other vehicles available in a transportation company or based on outsourcing processes.
- Maintenance documentation – internal procedures and manufacturer's guidelines for vehicle fleet maintenance performance.

Following this, a three-parameter risk assessment ratio is introduced in the next step.

3. A THREE-PARAMETER RISK ASSESSMENT RATIO

The analysis of the transportation system as a system in which resources can be shared in the global transportation system allows for a change of approach in the risk assessment performed to determine the strategy of the transportation fleet maintenance. Firstly, the risk indicator refers not to the vehicle failure itself but to the non-delivery of the offered transport service to the customer due to vehicle failure. Second, the risk is calculated based on the probability of a given adverse event and its consequences and the basis of an additional parameter: the availability of alternative resources that can take over the execution of a given task or support maintenance activities. Therefore, the estimated risk may be expressed as the product of three measures:

$$R = P \cdot S \cdot A \tag{4}$$

where: R – risk ratio; P – a measure of the probability of occurrence of an adverse event; S – a measure of the consequences of the occurrence of an adverse event failure; A – a measure characterizing available alternative resources

A plethora of studies can be found devoted to the issues of risk assessment for transport systems taking into account two main parameters – P and S. (see, e.g., [18, 23]). However, the problem is how to estimate the last parameter, which characterizes available alternative resources. This issue is challenging due to the diversity of the different assets, unpredictability of deterioration and failures, poor accessibility, and a potential lack of resources such as personnel, necessary equipment and tools, spare parts, and accessible vehicles. In addition, the literature on resource sharing in transport systems maintenance is scarce.

The measure characterizing the availability of alternative resources may be determined through a certain number of principal methods. First, a simulation model can be developed, which defines the real-life system performance and gives the possibility to perform at least a sensitivity analysis for maintenance resources availability (see, e.g., [13]). Another solution is to use the opinion of experts who assess, for example, based on a scoring method or based on linguistic variables, the availability of the company's essential maintenance resources (see, e.g., [19]). The third solution can be based on analyzing available operational data on transport system downtimes and data on necessary resources. The most critical data regard the availability of stocks, delivery times, availability of service stations (e.g., queuing systems), or maintenance teams' availability (see, e.g., [8]).

The obtained results give the possibility to propose a single aggregated measure for assessing the availability of maintenance resources. Thus, an assessment of the availability of maintenance resources may be estimated according to:

$$A = \frac{\sum_{i=1}^{n} A_i \cdot \omega_i}{\sum \omega_i} \tag{5}$$

where:
A – a measure characterizing available alternative resources; A_i – a measure characterizing available *i*th resource; ω_i – the weight assigned to the *i*th resource, where $\sum \omega_i = 1$; n – number of maintenance resources analyzed.

Therefore, the remainder of this article focuses on presenting an example of evaluating the parameter of maintenance resource availability. Based on this evaluation, an example of risk assessment for the selected transportation route is provided.

4. CASE STUDY

A case study for resource sharing potential assessment is presented for a group of companies providing passenger transport services in Poland. The conducted analysis is focused only on the problem of maintenance resources sharing potential assessment.

The analyzed group of transport companies for which it is possible to implement a sharing strategy are regional passenger transport companies operating within the so-called PKS. Group until a certain point. As the main shareholder in these companies was (and in many cases still is) the Polish State Treasury, these companies continue to cooperate in selected areas of their operations.

A characteristic element of the companies belonging to the former PKS group is their complex physical assets. Each company has its service station and maintenance teams. As vehicles are usually purchased on the second-hand market, the fleet includes various manufacturers requiring different spare parts for maintenance. As a result, there is a lack of standardization of stocked parts, which are usually purchased at the time of failure. Due to the short response times required, spare parts are purchased from suppliers offering the required lead-time rather than the best price.

The high level of competition in the regional transport market forces companies to seek opportunities to optimize maintenance costs and reduce the risk of their vehicles running out of service. Currently, the availability of operable vehicles is of particular importance, as their lack may result in the costs of lost sales, loss of customer confidence on non-serviced regular routes, as well as penalties in the case of non-serviced outsourced transport. For this reason, the Management Boards of selected companies have taken the initiative to identify the potential for sharing selected maintenance resources.

In order to analyze the resource-sharing possibility, the experts' opinions were collected. They were supposed to rate the potential for resource sharing based on a point scale. The possible ratings were: 1 - no potential for sharing; 2 - little potential for sharing, only in emergencies; 3 - potential for sharing, but periodically, in emergencies (e.g., increased demand for resources); 4 - potential for sharing based on regular cooperation; 5 - resources jointly managed; shared ownership. The results of the conducted analysis and a short explanation of the ratings given are presented in Table 1. According to (5), following the scoring assessment, measure *A* is estimated at 2.5–3.25 level (taking into account that all the maintenance resources have the same weight for transportation companies; thus, the (5) is estimated as an arithmetic mean).

According to the presented results, it should be noted that maintenance documents currently have the highest potential for sharing. This resource currently has a very high potential for sharing, thanks to digitizing documentation in most companies. An essential part of this documentation that could feed into the sharing process is exchanging good practice documents from each maintenance station. Building a joint knowledge base on the specifics of servicing different types of vehicles would make it possible to avoid the repetition of mistakes by individual companies while at the same time reducing the waste that currently occurs. Spare parts currently show the lowest potential for sharing. In addition to the arguments presented in the table, this assessment is reinforced because each company owns different types of vehicles, even from the same manufacturers. This results in very different needs for spare parts and limits their availability to other companies that do not use them.

Table 1: Potential for maintenance resource sharing for the case group of companies

Maintenance resources sharing availability		
Maintenance resource type	Points	Short discussion
Maintenance teams/service stations	2-3	The companies are located in different parts of the region, but the maximum travel time is 2.5 hours. This means that it is possible to move team members between the service stations of individual companies in an emergency. At the same time, if a vehicle fails during the service, repairs can be carried out at the nearest station based on partnership agreements.
Spare parts	2	The distance between the companies is such that transporting spare parts for regular repairs would be a high cost in the service process and, therefore, not a competitive offer to current purchasing procedures. However, when the availability of specific components is limited (which translates into an inflated price of parts) or the time to obtain them is too long, the alternative of sharing these resources may be a beneficial solution.
Available fleet	2-3	The companies do not have an extensive fleet of vehicles, and any spare capacity is usually directed to serve additional orders. Therefore, sharing this resource is only possible in crises, possibly in emergencies, but only concerning the available free capacity.
Maintenance documentation	4-5	Maintenance documentation has a high potential for sharing. Today, much of the documentation is available electronically, allowing it to be delivered quickly and cost less to the required location.

The expert evaluation results presented for parameter *A* can be used to determine the risk ratio *R*. For this purpose, the company's available operational and maintenance data should be used to assess parameter *P*. The consequences S of unwanted events were estimated based on expert opinions.

In the investigated group of companies there can be defined the following types of services:

(1) regular regional routes with low levels of competition,
(2) regular regional routes with a high level of competition,
(3) transportation of employees,
(4) regular school transport,
(5) occasional school transport,
(6) the national tourist transport,
(7) international tourist transport,
(8) regular transport of seasonal type,
(9) transportation within the framework of mass events,
(10) the transport of sports clubs,
(11) special transports (e.g., military transport).

The presented example presents a risk assessment for transport processes performed at a selected route between two cities located in the Lower Silesia region.

There were identified adverse events for the indicated route based on previous experience of drivers and company management. Based on the operational and maintenance data analysis, it was possible to identify the main adverse events that affect the transportation service performance. Adverse events were classified into adverse events in general and event-specific routes. The classification of hazard events is given in Table 2.

Table 2: Classification of hazard events in the analyzed company

GENERAL HAZARD EVENTS	
For vehicle	
OP1	Vehicle failure that makes unable to continue transport process performance
OP2	Vehicle failure that results in travel delays
OP3	Insufficient number of seats in the vehicle
OP4	Lack of proper order in the vehicle
OP5	Traffic incident that makes unable to continue transport process performance
OP6	The vehicle unsuited to the required travel conditions
For driver	
OK1	Poor health of the driver
OK2	Lack of route knowledge
OK3	Failure to follow with traffic rules
OK4	Improper behaviour towards passengers
OK5	Stop the vehicle in a place not designated as a stop
OK6	Exceeded driver's working time
OK7	No drivers that have permission to use the vehicle
For process	
OPP1	Travel delay
OPP2	Course cancellation
OPP3	A necessity for route change
HAZARD EVENTS BEING SPECIFIC TO THE ROUTE	
S1	Taking potential passengers by accelerated/delayed vehicle of the Competitor
S2	A too-small number of passengers resulting in a lack of profitability of transport

The probability of hazard event occurrence is evaluated on a point scale of 1-5. This assessment is based solely on an analysis of historical events. The company's consequences of hazard event occurrence are evaluated on a point scale of 1-4. They have been taken to losses from a financial perspective. A detailed evaluation of the given parameters is presented in Tables 3 and 4.

Table 3: The probability of hazard event occurrence definition

P_n level	Estimated likelihood	Short description
1	Very high	The threat occurred in the last month
2	High	The threat occurred in the last 3 months
3	Medium	The threat occurred in the last 6 months
4	Low	The threat occurred in the last year
5	Very low	The threat occurred once in the last two years or more

Table 4: Consequence level definition

S_n level	Estimated consequence	Short description
1	High	High financial losses
2	Medium	Medium financial losses
3	Low	Low financial losses, loss of image
4	Almost negligible	No financial losses, loss of image

Based on the conducted preliminary estimations, the risk ratio can be calculated. The obtained results are presented in Table 5.

Table 5: The summary of obtained results

Event	P_n	S_n	A_n	R_n
OP1	4	1	2.5	10.0
OP2	2	3	2.5	**15.0**
OP3	2	3	2.5	**15.0**
OP4	1	4	2.5	10.0
OP5	3	1	2.5	7.5
OP6	2	3	2.5	**15.0**
OK1	2	3	3.25	**19.5**
OK2	4	4	3.25	**52.0**
OK3	3	2	3.25	**19.5**
OK4	1	3	3.25	9.75
OK5	2	2	3.25	**13.0**
OK6	4	2	3.25	**26.0**
OK7	4	3	2.5	**30.0**
OPP1	1	3	2.5	7.5
OPP2	1	2	3.0	6.0
OPP3	4	4	3.0	**48.0**
S1	2	2	2.5	10.0
S2	1	2	2.5	5.0

Analysis of the obtained results indicates that special attention should be focused on these events, which have the lowest risk ratio value. They are, in fact, events in which incidence is high, the consequences are significant, and, at the same time, they have the lowest potential for providing maintenance resource sharing. The acceptable level of risk determined based on an interview with the management and leadership of the company was set at $R = 12.5$. This is a product of the middle of the scale adopted for the estimated three indexes (2.5 x 2 x 2.5). Following this, 10 identified hazard events obtained the acceptable level of the risk ratio. The remaining 8, with an R level below 12.5 points, require the company's intervention. These hazard events require taking action to improve the three risk assessment parameters. It is also advisable to continuously monitor basic operational parameters connected with these events' occurrence possibilities.

4. CONCLUSIONS

The article presents a concept of risk assessment in the transport system based on three parameters. A novelty in the assessment is introducing a third parameter - describing the potential for sharing maintenance resources. Therefore, the authors focused primarily on assessing the new parameter - the availability of maintenance resources shared in the system.

The greater the potential of a maintenance resource to be shared, the greater its availability in the crucial period, and thus the lower the risk of taking the vehicle out of service. The analysis of the sharing potential of selected maintenance resources in the analyzed group of transport companies is presented to confirm the adopted thesis. The presented results of the assessment procedure are the starting point for further research work aimed at assessing the risk in transport companies considering maintenance potential. The possible future research activities will be connected with fuzzy logic impelmentation with multi-criteria decision methods use.

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