The Link Between Asset Risk Management and Maintenance Performance: A Study of Industrial Manufacturing Companies

DOI: 10.12776/QIP.V24I3.1477

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Received: 2020-08-24 Accepted: 2020-09-29 Published: 2020-11-30

ABSTRACT

Purpose: The purpose of this paper is to examine risk management practices and their impact on performance. Specifically, the study aimed to examine risk management practices as part of physical asset management and their impact on maintenance management and its performance.

Methodology/Approach: The empirical data were obtained from 76 manufacturing companies. Partial Least Squares Path Modeling (PLS-PM) was applied to evaluate the measurement and structural model.

Findings: The results emphasized the importance of integrating risk management practices into asset management processes in order to improve performance outcomes.

Research Limitation/Implication: This study contributes to a better understanding of how companies could achieve higher performance results by implementing risk management practices. The results of this study can help managers identify key asset risk management practices. Despite the important implications that can be derived from this study, further research that would extend the model to include additional performance measures and/or asset management dimensions would be of great importance.

Originality/Value of paper: By analyzing the interrelationships between asset risk management practices and their direct and indirect effects on maintenance performance, the study provides important insights for the development of strategies to promote the novel and important discipline of asset management.

Category: Research paper

Keywords: risk management; maintenance performance; physical assets; ISO 31000

1 INTRODUCTION

Today's global marketplace puts tremendous pressure on manufacturers to continually adapt proactive, innovative strategies to improve their manufacturing capabilities (Ahuja and Khamba, 2008). While asset availability and reliability are becoming critical issues in capital-intensive operations, the strategic importance of maintenance in such companies should be recognized (Tsang, 2002). With physical asset management that is even more profound than traditional maintenance management, companies should be able to realize their full potential and effectively achieve their business objectives. Consequently, effective management of physical assets is playing an increasingly important role in optimizing the business profitability (Maletič et al., 2018; Schuman and Brent, 2005). As a result, asset managers today face many challenges, such as the need to achieve social and environmental objectives in addition to more traditional technical and economic goals, the importance of risk management, and the need to use the best available technology in the asset management process (Thorpe, 2010). As Woodhouse (2007) noted, physical asset management represents the best sustainable mix of asset care (i.e., maintenance and risk management) and asset utilization (i.e., using the asset to achieve a business objective or performance advantage). Efficient management of existing and emerging risks of industrial technologies is therefore critical for companies (Pačaiová, Sinay and Nagyová, 2017) that want to meet the requirements of various areas of organizational management (e.g., occupational health and safety, accident prevention, critical infrastructure, transportation of hazardous materials, environmental or financial requirements) (Pačaiová, 2018). This means that risk management is an important element of any asset management system. To realize value, asset management, therefore, involves balancing the costs, opportunities and risks against the desired performance of assets to achieve organizational objectives (ISO, 2014).

Most of the earlier studies on risk management focused on Enterprise Risk Management (ERM), with the researchers'primary aim being to investigate the role of ERM in supply chain management (Olson and Wu, 2010; Wu and Olson, 2010). Another group of studies has tried to address the Risk-based thinking (RBT) in an ISO standards-compliant way (Chiarini, 2017; Pačaiová, Sinay and Nagyová, 2017). Recently, considerable efforts have been made to develop a risk-based approach to safety analysis within maintenance processes, especially in specific environments such as offshore pipeline maintenance (Li et al., 2019) or technical maintenance system optimization (Gill, 2017). Although previous studies have examined the relationship between risk management and performance implications (Callahan and Soileau, 2017; Zhang et al., 2018), several research gaps remain unexamined. Accordingly, the literature has not paid sufficient attention to the impact of risk management practices on various aspects of organizational performance (e.g., maintenance performance directly related to physical assets). The rationale for conducting this research is the need to examine the relationships between asset risk management practices and maintenance performance. Using empirical data collected from industrial companies, this study attempts to fill this gap. There is therefore a lack of understanding of the mechanisms that might explain how key elements of risk management are related to maintenance performance. Our study builds on findings from previous research investigating the relationship between risk management and performance outcomes (e.g. Callahan and Soileau, 2017), in particular by bridging the risk with maintenance management (Pačaiová and Ižaríková, 2019). We thus add a novel perspective by conceptualizing and operationalizing risk management and linking core elements of risk management to maintenance performance.

The structure of the paper is as follows: Section 2 provides an overview of the relevant literature on risk and maintenance management. Section 3 aims to illustrate a methodological framework for this study. Section 4 aims to present the data analysis, while section 5 concludes with a summary of the main findings, in particular by highlighting them from a theoretical and practical point of view and by outlining limitations and future research directions.

2 LITERATURE REVIEW

2.1 Risk Management

In the past, much has been written about risk management. Many scholars have studied ERM in companies (e.g. Hoyt and Liebenberg, 2011). This literature covers a number of approaches, including some frameworks, risk categorization, processes and mitigation strategies. In addition, International Organization for Standardization (ISO) has published ISO 31000:2009 Risk Management Principles to provide guidance on ERM implementation. A new version was recently published. ISO 31000:2018 provides more strategic guidance than ISO 31000:2009 and places more emphasis on both senior management involvement and the integration of risk management in the organization.

There are many definitions of risk and risk management. The ISO defines risk as the "impact of uncertainty on objectives". The ISO 31000:2009 definition of risk shifts the focus from the previous preoccupation with the possibility of an event (something happening) to the possibility of an effect and especially an impact on objectives (Purdy, 2010). As noted by Wu and Olson (2010), risk can include a variety of factors with potential impacts on the activities, processes and resources of any organization. The authors explained that external factors can result from economic changes, financial market developments, and threats that occur in political, legal, technological, and demographic environments. One of the recurring themes in IS0 31000 for effectiveness is that risk management must be integrated into a company's decision-making processes (Purdy, 2010). For manufacturing companies, risk management can be described as a fundamental and unchanging process and represents an iterative approach (ALARP-As Low As Reasonably Practicable) that the designer or developing engineer must consider when designing the physical asset (i.e. the machine and equipment), but also the user when managing workplace safety (Pačaiová, Markulik and Nagyová, 2016).

2.2 Maintenance Management

Maintenance management in the form of a Management System is currently not subject to any specific standard. Normally, Maintenance Management System (MMS) is associated with the software application of maintenance management (Grubb and Takang, 2003; Starr et al., 2010). The European standard for maintenance management of physical assets (European standards, 2014) describes the interaction between the requirements of the company, the physical assets and the management of its maintenance. It is based on the four main areas of the company's requirements, which are transferred to the management of physical assets through strategic analysis based on risk assessment (RBT). These four requirement areas are divided into the organizational goals, market requirements, stakeholder requirements (e.g. society, requirements of government legislation) and technologies in terms of their structure, inherent reliability, flexibility, know-how and, of course, their maintenance. The standard describes how these requirements are manifested through strategic management in the policy and objectives of physical asset management. The asset management plan must be translated into the maintenance management plan and strategies. Understanding the relationship between the organization's asset management objectives and maintenance management objectives is considered a gap in the understanding of how the maintenance management system works.

It is obvious that the decision process in maintenance applies a suitable strategy (preventive, predictive or corrective) (Al-Najjar, 2007; Bevilacqua and Braglia, 2000; Flores-Colen and de Brito, 2010). Indeed, effective and efficient maintenance processes and activities should be based on risk management (Arunraj and Maiti, 2007; Khan and Haddara, 2003). In general, there are two approaches to integrating risks into maintenance processes:

1. Maintenance planning and activities are based on unconscious decisions of maintenance personnel with high qualification and responsibility and taking into account the equipment risk (Gill, 2017; Sakai, 2010).
2. Maintenance management is based on specific concepts such as Total Productive Maintenance (TPM), Reliability Centred Maintenance (RCM) or risk-based inspection (RBI), which include risk management principles and tools (Ahuja and Khamba, 2008; Sakai, 2010).

With regard to the first approach, it should be noted that the skills are usually oriented towards quality management tools that are generally used for process assessment. For example, Failure Mode and Effects Analysis (Process FMEA: P-FMEA) aims to identify potential non-conformities and their sources (Teng and Ho, 1996). It can also be used for maintenance processes, applied to equipment (physical asset) as a process element, whose functional failure affects product quality or causes unacceptable downtime. After the analysis, Pareto analysis (the 80/20 rule) can be used for decision making in maintenance, for example, for strategy optimization, to assess which equipment with the highest risk (risk priority number RPN specification) and its failures are involved in 80% of the problems. It is a similar approach to RCM. In small companies, the maintenance personnel only decide on empirical skills that result from many years of experience and the documentation of the device manufacturer (Teng and Ho, 1996). In general, the state authority, e.g. the labor inspectorate, checks whether a documented maintenance plan exists as an accident prevention measure.

The second approach is more sophisticated and is usually based on consideration of the acceptable level of loss in an entity when a default occurs on a particular asset. In the automotive industry, there is a strong emphasis on quality (product, delivery time). Accordingly, quality management standards (e.g. IATF, 2016) are strictly required. These standards are aligned with TPM. This Japanese concept (from the 70th of the last century) is based on principles described by TPM eight pillars (Chlebus et al., 2015) and uses tools whose application minimizes the probability of failure (5S methodology). TPM prevents problems (losses) related to safety, environment, quality, ineffective management procedures, operating errors and poorly performed maintenance. This maintenance management system prevents any hazards/risks in the company that affect business objectives.

The origin of the RCM methodology is the aircraft industry in the USA. RCM is typically applied in the petrochemical, nuclear power, gas, steel and other “heavy”industries (Srikrishna, Yadava and Rao, 1996). The need for high reliability is a typical aspect of the technology, and failure of the technology has a significant impact on the activities of companies and on society and the environment. RCM uses Critical Equipment Analysis – a methodology that helps to identify usually three categories of high-risk equipment: A – high risk (prevention strategy focused on reliability and safety), B – medium risk (high availability requirement) and C – low risk (cost optimization strategy) (Hansson, Backlund and Lycke, 2003). The next step of the RCM is the implementation of FMEA for risky equipment – the priority is applied to category A and after B the optimization of the maintenance plan and strategies is considered.

RBI is a very specific concept that mainly uses quantitative risk management tools. Inspections of pressure vessels, pipelines, cranes and electrical equipment are under legal control in most European countries because the consequences of their failure have an impact on the health and/or life of people. Containers and pipelines containing dangerous goods are hazardous technologies and their risk depends on the probability of failure and scenarios (e.g. fire, explosion, toxicity) resulting from loss of containment due to specific conditions and the impact on property, society and the environment. In this case, maintenance management is the preventive approach to how the probability of failure can be minimized by an effective and efficient predictive maintenance strategy. The inspection interval is based on a quantitative risk assessment (e.g. combination of fault tree FTA and event ETA tree analysis or layer of protection analysis LOPA) and the level of

ISSN 1335-1745 (print) ISSN 1338-984X (online)

risk depends on equipment condition monitoring and failure prediction (Pačaiová, Sinay and Nagyová, 2017).

These concepts and methodologies in maintenance management can be modified in practical application through optimization and cost minimization. Why is it important to improve maintenance performance based on risk assessment? In the past TPM, Overall Equipment Effectiveness – OEE (Hedman, Subramaniyan and Almström, 2016) was used as a performance indicator, but in other concepts (also in TPM) companies now use other indicators derived from reliability management, such as MTBF (Mean Time Between Failure), MTTR (Mean Time to Recovery), MDT (Mean Down Time). The European Standard (2007) provides three main groups of Key Performance Indicators in maintenance (organizational, technical and economic), but the complexity of using performance indicators in risk management usually depends on the maintenance maturity of the organization (Tubis and Werbińska-Wojciechowska, 2017).

2.3 Risk Management and Performance

Several authors (e.g. Gordon, Loeb and Tseng, 2009; Ritchie and Brindley, 2007) have addressed the relationship between risk and performance. These studies have looked at risk mainly from a supply chain perspective. However, risk has also been a key issue for researchers in the field of maintenance and physical asset management. According to Parida and Kumar (2006), maintenance provides critical support to heavy and capital-intensive industries by keeping machinery and equipment in a safe operating condition. It is widely recognized that maintenance is a key function in maintaining the long-term viability of an organization (e.g. Al-Najjar, 2007; Maletič et al., 2014). It is argued that maintenance performance is a result of complex activities. More significantly, it is necessary to apply risk management methods when making decisions and controlling maintenance activities (Pačaiová, Glatz and Kacvinský, 2012). In addition, previous studies have also looked at risk management as part of the management of physical assets (e.g. Maletič et al., 2018; Pačaiová and Grenčík, 2014). It could also be argued that asset, risk and maintenance management are strongly interrelated. The latter implies that performance and risk are related.

3 METHODOLOGY

3.1 Data Collection Procedure

This empirical study is based on a questionnaire survey. To ensure the face validity of the questionnaire, all measured variables were reviewed by academics and experts from industry. Accordingly, a pilot study was carried out in Slovakia, taking into account a sample of 19 Slovakian enterprises from the manufacturing sector. The final survey was conducted among Slovenian manufacturing enterprises. The questionnaire with the cover letter indicating the purpose of the

ISSN 1335-1745 (print) ISSN 1338-984X (online)

study was sent to the target persons by e-mail. It was asked to address the questionnaire to employees who hold a managerial position in relation to maintenance and operational decision-making processes. The questionnaire was sent to 300 Slovenian companies in the manufacturing industry. A total of 76 usable answers were collected within the given time frame, which corresponds to a response rate of 25.3 percent. The population for this study is composed of micro (8%), small (12%), medium-sized (45.3%) and large (34.7%) enterprises.

3.2 Research Model

A research model has been developed that shows the connections between the core elements of asset risk management and maintenance performance. First, a thorough literature review was conducted, which included relevant scientific publications and international standards. In the following steps, theoretical constructs were identified. This conceptual background forms the basis for outlining the proposed research model. In accordance with the literature and relevant standards (such as ISO, 2018), four constructs of asset risk management were conceptualized and operationalized. Asset risk management measures were developed on the basis of ISO (2018), which define the "Risk Context (LV1)" in connection with organizational activities, the "Risk Identification (LV2)" (source of hazard/threat), the "Risk Analysis and Evaluation (LV3)" (steps for risk assessment) and the "Risk Treatment (LV4)". With reference to previous measurements (Maletič, Maletič and Gomišcek, 2012), the study measures maintenance performance as the unidimensional latent variable. The corresponding items for measuring asset risk management and maintenance performance are shown in Table 1. The questionnaire items for risk management were operationalised using 5-point Likert scales, where 1 means that respondents strongly disagree and 5 that they strongly agree. With regard to maintenance performance measures, respondents were asked to estimate performance aspects in line with the industry average over the last three years using a 5-point Likert scale.

We have applied Partial Least Squares Path Modeling (PLS-PM) using the R-package plspm to assess the measurement and the structural model (Sanchez, 2013). Previous studies have argued that PLS-PM is particularly suitable for small sample sizes (Chin and Newsted, 1999).

4 ANALYSIS AND RESULTS

To evaluate the PLS-PM measurement model (outer model) (Sanchez, 2013), loadings and communalities were examined. As suggested by Sanchez (2013), loadings should be above the value of 0.7. The results of the evaluation of the outer model (loadings, weights and communalities) for studied constructs are presented in Appendix. As the results show, the majority of the values exceed the loading threshold criterion of 0.7. The loadings for 4 items are between 0.6 and 0.7; however, the items have been retained in the model due to the content validity. In addition, cross-loadings were also checked with regard to the validity of the measurement model.

The following indices were used to assess the block unidimensionality: Cronbach's Alpha, Dillon-Goldstein's Rho and eigenvalues (see Table 1). The results show that Cronbach's alpha values for LV1, LV3, LV4 and LV5 were above the recommended value of 0.70 (Hair et al., 2010; Sanchez, 2013). The results show that the Cronbach alpha value for LV2 is below the recommended value, but the corresponding composite reliability is above the recommended value. The composite reliability was assessed by Dillon-Goldstein's rho. In the literature (Sanchez, 2013) the cut-off value of 0.7 is suggested to consider the corresponding block as unidimensional. The results show that the Dillon-Goldstein's rho value exceeds the cut-off point of 0.7 for all constructs. Additionally, the block is considered unidimensional if the first eigenvalue is greater than one. It appears that all indicator blocks fulfill this criterion.

Table 1 – Summary of the Results Regarding the Outer Model Assessment

	Mode	*MVs*	*Cronbach's alpha*	*Dillon-Goldstein's rho*	*AVE*	*eig.1st*	*eig.2nd*
Risk Context (LV1)	A	3	0.712	0.840	0.637	1.91	0.685
Risk Identification (LV2)	A	3	0.602	0.792	0.562	1.69	0.860
Risk Analysis and Evaluation (LV3)	A	3	0.773	0.869	0.687	2.07	0.549
Risk Treatment (LV4)	A	3	0.752	0.858	0.669	2.01	0.555
Maintenance Performance (LV5)	A	5	0.738	0.827	0.488	2.45	0.832

Notes: MVs – manifest variables (no. of items); A – reflective mode.

Furthermore, for the purpose of assessing convergent validity (Sanchez, 2013), the average variance extracted (AVE) was used to measure the amount of variance that a latent variable captures from its indicators (Sanchez, 2013). The results show that the AVE values for LV1 to LV4 are above the conventional threshold of 0.5 (Sanchez, 2013). As the AVE value for LV5 is just below the recommended value, it is also considered acceptable.

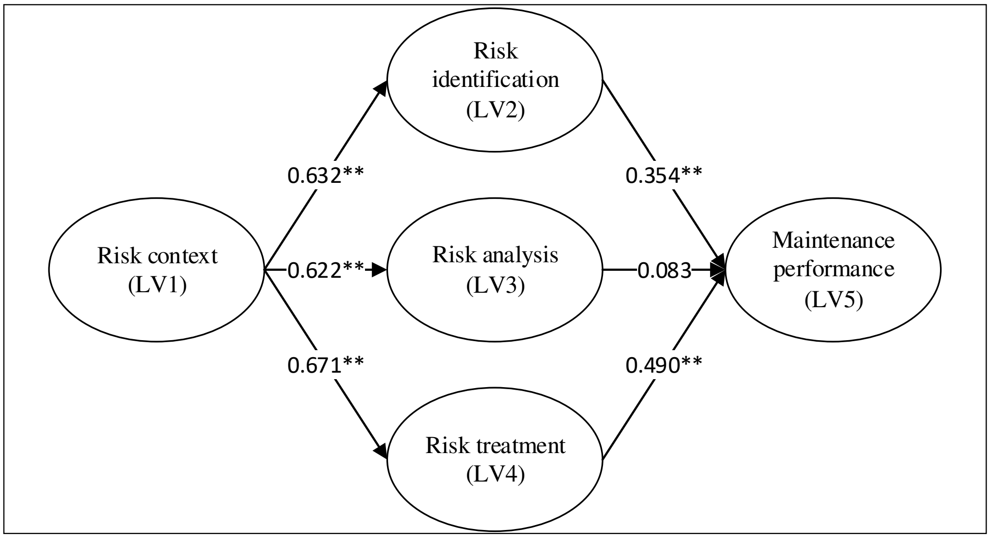
The results regarding the evaluation of the structural (inner) model are presented in Table 2. According to the results of the coefficients of determination (R^2), 50.5% of the variance of the "Maintenance Performance (LV5)" is explained by corresponding prediction variables (e.g. LV2-LV4). Furthermore, the average communality values represent the average of all squared correlations between each manifest variable and the corresponding latent variable scores in the model. As the results show, the highest value corresponds to "Risk Analysis and Evaluation (LV3)", while the lowest value corresponds to "Maintenance Performance (LV5)". The mean redundancy illustrates the percentage of variance in the endogenous block predicted from the independent latent variables. A high redundancy emphasises the ability to predict. Therefore, prediction by means of redundancy could be outlined for "Risk Treatment (LV4)". It could be interpreted that 30.1% of the variability of block LV4 is predicted by "Risk Context (LV1)".

Table 2 – Summary of the Results Regarding the Inner Model Assessment

	Type	*R^2*	*Block Communality*	*Mean Redundancy*
Risk Context (LV1)	Exogenous	0.000	0.637	0.000
Risk Identification (LV2)	Endogenous	0.399	0.562	0.224
Risk Analysis and Evaluation (LV3)	Endogenous	0.387	0.687	0.266
Risk Treatment (LV4)	Endogenous	0.450	0.669	0.301
Maintenance Performance (LV5)	Endogenous	0.505	0.488	0.247

Notes: AVE – Average Variance Extracted.

The path analysis was further performed to test the relationships between the latent variables. The results concerning the inner model are shown in Figure 1. The path coefficients represent the strength and direction of the relationships between the latent variables (Sanchez, 2013). According to the results, the "Risk Context (LV1)" has a strong direct influence on the variables LV2 to LV4 (0.632; 0.622; 0.671 and $p < 0.01$). As regards the effect on "Maintenance Performance (LV5)", "Risk Treatment (LV4)" seems to be the dominant variable (0.490, $t= 3.76$, $p < 0.01$). Regarding the indirect effect, it can be outlined that "Risk Context (LV1)" indirectly (0.500) influences "Maintenance Performance (LV5)" through "Risk Identification (LV2)", "Risk Analysis and Evaluation (LV3)" and "Risk Treatment (LV4)" influences the "Maintenance Performance (LV5)".



Notes: **statistically significant at the 0.01 level.

Figure 1 – Structural (inner) Model with Path Coefficients

5 DISCUSSION AND CONCLUSIONS

The potential links between risk management and performance outcomes have attracted considerable attention in recent years, as risk management issues have become one of the main concerns of a wide range of stakeholders in organizations. However, there are still few papers in the academic literature on asset management that specifically address the relationship between risk management and performance outcomes. Therefore, this study determines the importance of risk management and its impact on business results, particularly maintenance performance. From the perspective of theoretical explanation and empirical evaluation, this study therefore contributes to a greater clarity and understanding of the relationship between risk management practices and maintenance management. Our results support the idea of conceptualizing and operationalizing risk management within the framework of standard ISO (2018). The results of this study are consistent with theoretical arguments in the literature, which considers risk management as an important elementary form of performance measurement in maintenance (Söderholm and Norrbin, 2013). Thus, our results strengthen credence to the growing importance of integrating risk management into the asset management framework (Trindade et al., 2019). Our findings are consistent with previous findings that suggest that organizational context definition, opportunity and risk identification, monitoring and analysis are among the most important factors supporting the realization of value from physical assets (Maletič et al., 2017; Maletič et al., 2018, Maletič et al., 2019; Trindade et al., 2019).

Furthermore, as the results show, it could be argued that the most important predictors of maintenance performance are risk identification and risk treatment. Our results reinforce the belief in the growing importance of linking risk management to performance measurement (Arena and Arnaboldi, 2014). In addition, as shown in previous research (Callahan and Soileau, 2017), operational performance could be improved by a commitment to company-wide risk assessment and management. As evidenced by the results, our study revealed no direct impact of risk analysis on maintenance performance. Several plausible explanations could be delivered in this regard. The results of the risk analysis include, for example, the identified hazards and risk factors that have the potential to cause harm. These results are then incorporated into action plans (which are part of risk treatment) that bear a positive association with maintenance performance. As mentioned earlier, Risk Treatment (LV4) is the strongest predictor of maintenance performance in our model ($\beta = 0.490$, $t= 3.76$, $p < 0.01$). Therefore, although no direct effects of Risk Analysis and Evaluation (LV3)were found, possible indirect effects on maintenance performance through Risk Treatment (LV4) can be indicated.

We build on previous research and distinguish our study from the work previously published in the risk management literature in the following ways First, unlike previous studies, our study focuses on risk management in the context of asset management. Second, by looking at the importance of assessing the maintenance performance of companies (Liyanage, 2007), we examined whether and to what extent risk management activities contribute to maintenance performance (because risk mitigation, probability of failure) in asset management mainly depends on a proactive maintenance strategy). Accordingly, this study adds risk and asset management perspectives to the existing research on maintenance performance. Previous studies have mainly focused on the development of maintenance performance measurement systems (Parida et al., 2015). Finally, also in a departure from previous research that addressed risk in maintenance activities (e.g. Wijeratne, Perera and De Silva, 2014), our study proposes the empirically validated structural model, thereby expanding the literature on the benefits of integrating risk management into maintenance and asset management activities. Since asset management has become an attractive area of research, many researchers have worked in a variety of areas, such as exploring the applicability of advanced decision support techniques in different maintenance and asset management business processes (De la Fuente et al., 2018), developing the theoretical framework for physical asset management (Alhazmi, 2018), studying the performance implications of physical asset management practices (Maletič et al., 2018), developing a risk-based approach to maintenance (e.g. Arunraj and Maiti, 2007; Li et al., 2019; Pačaiová, Sinay and Nagyová, 2017) The biggest gap in this area results from neglecting the potential of integrating risk management into the physical asset management framework. The present study aims to contribute to the existing research gap by bridging the risk and asset management, especially from the performance results perspective.

The results of this study may provide additional management insights that have the potential to support the decision making process regarding the management of physical assets and maintenance. One important aspect of physical asset management is therefore to achieve the right balance between performance, costs and associated risks in pursuing business objectives. Indeed, managers should integrate risk management into the asset management plan to proactively and holistically address the underlying issues. Managers in management and operations (M&O) are advised to follow well-established frameworks (such as EFNMS-EAMC, 2012; GFMAM, 2014; IAM, 2015) and relevant European and international standards that recognize the integration of risk management into maintenance and asset management activities.

For future research we propose a combination of qualitative and quantitative studies to further investigate the proposed model. Furthermore, the proposed model may be extended to include additional performance measures and/or asset management dimensions. Future studies could also take into account some other limitations of this study. For example, given the relatively small number of companies surveyed, potential control variables could not be included without compromising statistical power. It is therefore recommended that future studies include relevant control variables and test the model with a larger sample of organizational units.

ACKNOWLEDGEMENTS

This contribution is the result of the implementation of KEGA project No. 015TUKE-4/2019 Audit management using software application according to standard ISO 9001:2015, KEGA project No. 004TUKE-4/2019 Scientific and educational centre for remote sensing with the focus on the application of e-learning approaches in education and also of the project No. APVV-19-0367 Integrated Process Safety Management Approach Framework for the Smart Enterprise.

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H.P. – supervision; H.P., D.M. – methodology; M.M., H.P. – validation; H.P., A.N. – formal analysis, review and editing; D.M., M.M. – data curation,; D.M., M.M., H.P. – conceptualization, original draft preparation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

APPENDIX

Table A1 – Questionnaire Items and Outer Model Assessment Statistics for Asset Risk Management and Maintenance Performance

	Weight	*Loading*	*Communality*	*Redundancy*
Risk context (LV1)				
Risk management approach is established in our organization.	0.410	0.822	0.676	0.000
Risk management is integral part of our physical asset management strategy.	0.454	0.850	0.7	0.000
We have a sufficient level of resources to be allocated to risk management activities.	0.387	0.716	0.512	0.000
Risk identification (LV2)				
We are using teamwork during all phases of risk identification process.	0.454	0.837	0.700	0.279
We have clearly established roles and responsibilities in relation to asset risk management activities.	0.428	0.669	0.447	0.178
We are using advanced techniques (e.g. condition monitoring) for asset risk identification.	0.455	0.733	0.538	0.214
Risk analysis and evaluation (LV3)				
We are applying risk assessment analysis for managing our physical assets.	0.384	0.786	0.618	0.239
We are using tools and techniques (e.g. FMEA) within risk assessment analysis.	0.471	0.861	0.741	0.287
We have established a process for risk evaluation (e.g. risk prioritization) of our physical assets.	0.350	0.837	0.700	0.271

	Weight	*Loading*	*Communality*	*Redundancy*
Risk treatment (LV4)				
We are applying the principles of cost/benefit analysis in developing risk actions for physical assets.	0.429	0.824	0.679	0.306
We are developing and executing the risk action plan.	0.392	0.791	0.625	0.281
We are using risk monitoring to better manage the risk action plan.	0.401	0.838	0.702	0.316
Maintenance performance (LV5)				
Efficiency of maintenance processes has increased during the last three years.	0.217	0.612	0.374	0.189
Overall Equipment Effectiveness (OEE) has increased during the last three years.	0.256	0.664	0.441	0.223
Availability of physical assets has improved during the last three years.	0.297	0.730	0.533	0.269
Mean times between failures (MTBF) have improved during the last three years.	0.339	0.786	0.617	0.312
Total maintenance costs have decreased during the last three years.	0.310	0.690	0.477	0.241

ISSN 1335-1745 (print) ISSN 1338-984X (online)