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A MONTE CARLO SIMULATION METHOD FOR RISK MANAGEMENT IN ROAD PAVEMENT MAINTENANCE PROJECTS

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Abstract

Road pavement management and maintenance are responsible for a considerable amount of resources and energy consumption, with limited options to forecast due to the fact that projects have different sizes, are taking place in regions with various types of soil, landforms or types of distress.

The objective of this paper is to offer a solution for risk management using Monte Carlo simulation by taking into consideration three key aspects for the management of any project: costs, time, quality and the most important road parameter, that may cause the failure of the project - type of road distress. As a module of PAV3M maintenance and management project, Risk3M application uses the Pavement Condition Index (PCI) and the Long-Term Pavement Performance Program (LTPP) in order to identify and classify risk based on the type of road distress, using a scale from 1 (very poor) to 5 (very good). The impact on costs (Rc), on risks depending on the time span (Rt) and on the overall quality of the project (R_q) where classified in a scale from 1 to 5. This paper uses Monte Carlo simulation procedures with evaluation of risk scales and type of road distress (PCI) and specifications of correlations between the simulated variables (Rc, Rt, R_q).

Key words: risk assessment, road management and maintenance system, road distress, quality

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1. Introduction

Road pavement management and maintenance system (PMMS) are especially important, as they are responsible for offering value to community and at the same time determining complex projects that may involve risk on different stages and aspects. It is crucial in this case for a project to be based on models and methods that allow managers to identify and quantify risks and costs, taken into consideration that a road pavement project is usually a large one, involving a lot of resources and having a big time span. Every PMMS system PMS offers several module related to: an evaluation of optimal pavement performance, evaluation of the most efficient allocation of resources given budget constraints, analysis of data and resources and database management. Cost elements are predictable and a risk factor from construction, maintenance and rehabilitation process. User costs consist on vehicle operating costs due to deteriorated pavement roughness and delay expected during maintenance and rehabilitation process (Austroads, 2017; Dumitrescu et al., 2014).

"Value is a function of risk and return. Every decision either increases, preserves, or erodes value" (Patchin and Mark, 2012).Taking this quote from the Deloitte (2012) we put value as the main driven that transforms a project into a successful one. This becomes an important issue in road pavement projects that are usually characterized by a large quantity of resources involved, a considerable amount of time invested and a variety of factors that may lead to risks

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and in the end the failure of the project if those risks are disregarded or not assessed.

The risk management approach is widely used to identify and/or avoid potential costs and consider a proactive management in a project that may be able to correctly size the risks and adapt funds and resources according to necessities within the limited budget of a project. "Risk impact assessment is the process of assessing the probabilities and consequences of risk events if they are realized" (MITRE, 2017).

Risk management represents the process of identifying risk, assessing and taking steps to reduce it to an acceptable level (Stoneburner et al., 2002). The results of risk assessment are used to prioritize and set the risk importance, its frequency of occurrence and possible ways to asses and allocate resources needed through a project life-cycle.

The main steps in risk assessment plan includes: risk identification, developing assessment criteria, assess risks, determine risk interactions, and prioritize risks and in a situation where all the above steps and successfully completed respond to risks (Patchin and Mark, 2012). On a broader approach risk assessment needs to be integrated in the context of continuous communication and consultation that will help establish the context, asses risk and risk treatment and in the end monitor and review the chosen alternatives (Fig. 1). Based on effort, time and cost of implementation, risk assessments can be categorized by short-term, mid-term and long-term and assign a certain level of importance. The implementation of any plan is usually prioritized based on its importance to the project. Assessed risks can be reduced in several ways: avoid the risk, transfer the risk, reduce the threat, reduce the vulnerabilities, reduce the possible impacts, detect unwanted events, react and recover from them.

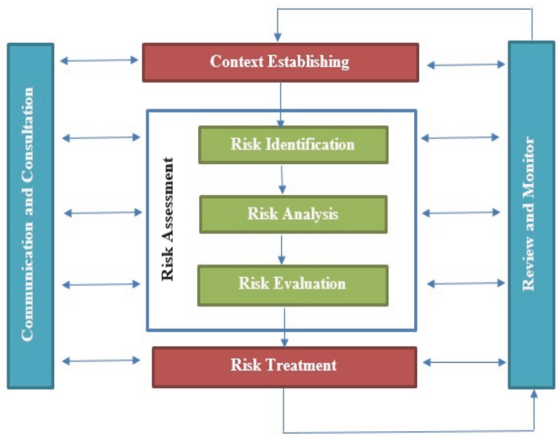

Fig. 1. Process Flow Diagram for Assessing Risks (Adapted upon Patchin and Mark, 2012)

The main goal of this paper is to present a solution for risk assessment in road pavement projects, using Monte Carlo simulation and a risk scale prioritization for the parameters analysed, as an alternative to the evaluation of risks using discrete variables. The method take into analysis the main parameters that influence a project in general– costs, time and quality, based on Life-Cycle Cost Analysis (LCCA) method, most suitable solution for road maintenance in our country Based on the impact a certain risk may have on them we used scale of prioritization (from 1 to 5) for each one of these factors. Besides the above mentioned risk scales in pavement management projects, during the maintenance process it is also important to detect and analyse the types of road distress. Road distress will be taking into consideration as a specific parameter for road pavement construction and maintenance projects and measured using a scale from low to high and a computed using PCI (Benta et al., 2017).

The literature review reveals different approaches in dealing with risks and road pavement projects, taking in consideration the complexity of such projects, the variety of factors that may be involved (factors that may lead to risks and uncertainty) and their interactions. Authors use models that identify and compute costs of the project, use simulation or risk prioritization approaches in order to determine ways of dealing with risk in complex projects that involve lots of resource and time, like the ones for road pavement.

One of the most notable projects is Life-Cycle Cost Analysis (LCCA) in Pavement Design conducted by The Federal Highway Administration in 10 states of US as an analysis tool to quantify the differential costs of alternative investment options for a given project, especially transportation and road investment decisions. It uses a model that includes all possible inputs, like real costs for initial construction, rehabilitation and maintenance into the analysis and weighs the probability of occurrence of each in order to determine future costs for risk pavement management (Walls and Smith, 1998). A typical LCCA involves the following steps: an initial strategy and decision in establishing parameters and alternatives that are to be taken into consideration by the LCCA, estimate costs for each alternative, compare alternatives by using common metrics like Net Present Value (NPV) or Benefit-Cost Ratio (B/C) and analyse the results using usually a sensitivity analysis or re-evaluate alternatives (Walls and Smith, 1998).

LCCA have been developed during the last years and even computer programs have been created in order to assist managers in using LCCA as an option for decision support. Babashamsi et al. (2016) analyze the alternatives of LCCA and the existing decision support tools or software packages based on it. They offer a wide analysis taken into consideration the LCCA state of practice in USA, Europe and Canada and emphasize on the conclusion that differences in inputs can considerably influence the results and the analysis confidence and in the end, the chosen alternative.

Risk assessment and management is a complex an important aspect. Fang and Marle (2011) present a model of simulation-based risk network that identifies asses and analyses the risks using a network framework. It uses nodes to represent nodes and edges to represent the cause and effect of potential interaction between risks, in order for the model to be able to re-evaluate and prioritize risks. It uses matrix-based and simulation-based approaches. Its limitation comes from not fully identify the complex interactions, as the effect of some interactions are influenced by other interactions. It emphasizes the need of evaluating risks from more than one point of view and taking into consideration more than one factor that influences a complex project, whether it is a in the area of constructions or a road pavement project.

Another interesting approach is a study of risk management in highway construction by using a risk priority matrix, which consider that a risks have a major impact in aspects like cost, time and quality when working in projects like highway or road construction. Risk is a "choice in an environment rather than a fate", emphasizing the idea that it is an aspect that may be predicted and modelled. The authors used a questionnaire addressed to contractor firms to identify the factors that may lead to risks, their severity and the frequency of occurrence. A risk priority matrix was developed in order to manage and overcome the risk impact in construction projects (Abhinaya and Nidhu, 2017).

A more complex case of simulation, using in particular the Monte-Carlo method of costs simulation using Monte Carlo in order to improve the risk analysis procedures used by highway agencies in many US states, most of them based on the Life-Cycle Cost-Analysis (LCCA) model. The main disadvantage of the traditional approach was the use of discrete variables, which failed in representing the complexity of pavement projects where the majority of the initial parameters were uncertain (Herbold, 2000). Risk was in this case an ignored aspect. In most of the cases the information that could have improved decisions was not present due to the fact that the computed variables were not evaluating any real risk. The study proposed a probabilistic approach were the uncertain variables like initial cost, future rehabilitation cots, discount rate or year of rehabilitation were modelled with probability distributions and used into a Monte Carlo simulation experiment. A random sampling is used to compute NPV and the result is calculated as a probability distribution. The study was applied in 10 US States by highway agencies and allowed agencies to model scenarios for risk analysis when determining the pavement costs.

The study of Monte Carlo method for road pavement projects calculations is presented by Chou (2011). It emphasizes the disadvantage of using traditional deterministic approach when estimating risk in complex projects like the ones of road pavement and presents streamlining Monte Carlo procedures in a model that uses historical construction projects as case studies data in order to create a cost distribution for initial project allocation. The author presents self-developed algorithms that compute costs results with a superior simulation accuracy and errors rates that falls into acceptable ranges allowing managers that work into road construction project to easily model uncertainty.

Mills et al. (2012) use Monte Carlo simulation in order to identify and model the propagation of transverse cracks in road pavements. The study develops a framework in which uncertainty can be explicitly presented. The study aims to investigate how hierarchical Markov-chain Monte Carlo simulation may be used to estimate and predict the spread of transverse cracks and by taking their associated uncertainty into consideration, as an aspect necessary in order to deal with risks in a road pavement management system. It focuses in determining pavement distresses as main factor that may influence a project and its outcome.

Taking all these studies into consideration, our approach will try to use the advantage of Monte Carlo simulation technique on a risk prioritization matrix that will model the key aspects of a road pavement project - costs, time and quality in combination with the main natural aspect that may influence a road pavement project - the type of road distress.

2. Methodology

Road pavement projects are characterized by the diversity of situations, dimensions of projects and budgets. A certain risk may have a different impact on two projects depending on other parameters like time, a limited budget or the overall quality of a project. That is why a risk analysis for road pavement needs to take into consideration a complex mixture of parameters that influence it. Another aspect that needs consideration is the size of a project which leads to a difficult way of homogenously computing a certain risk. For example, a given type of road distress may lead to an amount of resources that can have a different impact on projects with different budgets or time spans. A project with a bigger budget may allocate easier the necessary resources, which leads to a lower level of impact the distress has on the project, compared to a project with less resources for which the same type and size of a distress may lead to a bigger impact. The same logic applies to projects with tighter deadlines versus projects with a bigger time span. Therefore, the present study takes into consideration a risk scale prioritization instead of discrete values for the parameters involved.

Risk scale prioritization is used in decision-making analytical techniques or prospect theory. In this case, it will be used to determine how resources should be managed in order for a budget to be adapted as to cover the potential risks and for the project to achieve its goals. Any potential risk that is overlooked may lead to an exceeded budget or a failure in complying with performance and quality of road pavement.

The proposed method of simulation is part of the Risk3M application, included in the PAV3M platform, supported by Grant Project Partnerships PCCA2013 "Intelligent management, monitoring and maintenance of pavements and roads using modern imaging techniques-PAV3M". The main objective of PAV3M is the integration of road pavement imaging technology with a risk management application for road management and maintenance using visual inspection projects.

Similar solution, which used specialized vehicle and shapefile maps produced from ArcView, ArcGIS or AutoCAD or GIS/GPS facilities are focused on: condition assessments, asset valuation, analysis of maintenance strategies, multi-year budgeting, queries and reporting, cloud based application and free tech support. We mention several of related platforms: iWorQ Internet mapping utilizes a visual distress survey, SMEC Pavement Management System (PMS) as planning tool for modeling pavement and surface deterioration due to the effects of traffic and environmental ageing and determine long-term maintenance funding requirements, a Dot NET solution PAVER™ v7.0. for maintenance and GIS/ GPS capabilities (with PAVER FieldInspector™ and PAVER ImageInspector™ takes advantage of state-of-the-art pavement image data collection methods using specialized vehicles traveling, Street Saver, SMEC Software aso. (Hamdi et al., 2017; iWorQ, 2018; PAVER 2018; SMEC, 2018). PAV3M is a web based platform that includes a module for image processing and analysis (IPA) that collects information about road distress through a mobile specialized camera and sensors mounted on a non-specialized vehicle. The information collected in this way is transmitted through a Management and Maintenance module (MM) to the RISK3M module for road pavement risk management (Rusu et al., 2012; Rusu et al., 2015).

The information collected through the PAV3M system into the RISK3M module is used as a data source for the present Monte Carlo simulation experiment. Risk management analysis factors and prioritization was describing in detail in another paper (Rusu et al., 2015).

The Risk3M application uses the Pavement Condition Index (PCI) and the Long-Term Pavement Performance Program (LTPP) in order to identify and classify risk based on the type of road distress (Benta et al., 2017). PCI is used to measure the pavement surface condition using a scale from 1 (very poor) to 5 (very good) and LPTT offers descriptions and measuring methods for all types of distresses in pavement (Miller and Bellinger, 2014). From the image processing and analysis (IPA) module all images which are collecting from the road are processed (using pre-processing and post-processing algorithms) and transformed in suitable information related to risk classification parameters.

In IPA module and RISK3M application we use same classification of distress: cracking, potholes, ravelling, patching, rutting, and edge failure, a classification determined by (Miller and Bellinger, 2003). For each one of these distresses the module determines the risk level which has a scale from low to high, a description which gives more information about the risk involved and the PCI value (Benta et al., 2017). We exemplify part of the table by defining risk for the patching road type distress, one of the most frequent issues in road maintenance:

- Risk is low, when patch has low severity distress of any type including rutting<6 mm and pumping is not evident; PCI=3
- Risk is medium, when patch has moderate severity distress of any type or rutting from 6 mm to 12 mm and pumping is not evident; PCI=2.
- Risk is high if patch has high severity distress of any type including rutting>12 mm, or the patch has additional different patch material within it; also pumping may be evident and PCI=1.

The type and level of distress represents one parameter taken into consideration when conducting the Monte Carlo simulation. The other parameters are represented by costs, time schedule and quality. For these parameters we use a scale from 1 (very low impact on a considered factor) to 5 (very high impact on a factor) to calculate the levels of risk impact.

The impact on costs (Rc) is determined by increased costs that lead to an exceeded budget (B_O) compared to the initial budget (BI), where $B_F = B_I + B_O$ (Table 1).

Table 1. The impact on costs (*Rc*) in exceeded budget (B_O)

Rc	*Budget*
5	$25\%B_I < B_O$
4	$20\%B_I < B_O < 25\% B_I$
3	$15\%B_I < B_O < 20\% B_I$
2	$10\%B_I < B_O < 15\% B_I$
1	$5\%B_I < B_O < 10\% B_I$

The impact on risks depending on the time span (R_t) includes one or more changes in the initial project parameters that may extend the initial allocated time of project to a certain time delay which gives the impact for risk management (Table 2).

Table 2. The impact on risks depending on the time span (R_t)

R_t	**Time span**
5	delay greater than 2 years
4	delay greater than 1 year
3	delay between 6 to 12 months
2	delay between 3 to 6 months
1	delay smaller than 3 months

The impact on the overall quality of the project (R_Q) outcome involves risks associated with general performance standards for road construction and maintenance projects (Table 3).

A vector of risk prioritizations results and it is used to calculate the global impact (*Ig*) as a function of maximum from risk prioritization computed for the impact on costs final budget level (R_c), prioritization of risks depending on the project time span level (R_t) and quality risk (R_Q) factors (Eq. 1).

$$Ig = Max\{R_C, R_t, R_Q\} \quad (1)$$

Table 3. The impact on overall quality of the project (R_Q)

R_Q	**Overall quality of the project**
5	Risk that has a major impact on the system so the final outcome (in terms of performance, efficiency or quality) is inadmissible. Usually such a situation leads to cancellation of the project
4	Risk having an impact on the system so the final outcome is below the minimum allowable.
3	Risk having an impact on the system so the final outcome is below the proposed targets, but above the accepted lower limit.
2	Risk having an impact on the system so the final outcome is below the proposed targets but significantly above the accepted lower limit.
1	Risk that has a negligible impact on the final outcome but regular monitoring is recommended.

This vector is used for analysis and forecast risk scenario because at this point until the moment of the PAV3M platform and module development we did not have historical data structured on the types and categories of analyzed risk.

3. Monte Carlo simulation results

Monte Carlo simulations are used to model probability of different outputs in an experiment that cannot be easily predicted due to uncertain parameters or variables that influence a certain process. It is widely used in financial, costs, project management and any other forecasting analysis that may deal with uncertainty and risk. According to Liesenfeld and Richard (2001) Monte Carlo simulation methods are used to evaluate expectations of functions with random variables whenever no analytical expressions are available. The experiment consists in generating random numbers from the relevant distribution and associate them with parameters of the model that depend on a certain random probability. We then compute the model using the selected parameters by random means. A Monte Carlo simulation uses thousands of simulation experiments to determine and compute the model, each time using a random selected variable. The method uses this large amount of experiments to determine a more relevant arithmetic mean across the considered distribution.

Taking into consideration the scales presented in the previous section, we have created a simulation model that takes as inputs the following parameters: the type of distress, the level of risk determined by taking into consideration the measurements made for each distress case, the PCI index and the scales for determining the Impact on costs (R_C), time (R_t) and overall quality of the project (R_Q). The parameters follow a discrete distribution. The output of the model will be the global impact factor of the project (*Ig*) as a function of maximum $Ig=Max\{R_C, R_t, R_Q\}$ and by taking into consideration that the *Ig* and PCI have an inverse correlation of -0.7915. We have then created 50 scenarios of risk analysis by type of distress, level of risk and scales for risk prioritization computed for the impact on costs (R_c), prioritization of risks depending on the project time span level (R_t) and quality risk (R_Q). The result is a matrix of scenarios presented in Table 4.

Table 4. Matrix of scenarios

Type of distress	***Risk***	***PCI***	R_C	R_t	R_Q
Patching	Moderate	2	3	3	2
Edge Failure	Low	3	2	1	2
Potholes	Low	3	2	4	3
Patching	Moderate	2	3	1	2
Cracking	Moderate	2	2	4	2

Pavement Condition Index has several scale depending on modalities of evaluation and measurements accuracy. For instance we have 5 points scale: Excellent 8 - 10, Very smooth 6 - 8, Good Smooth with a few bumps or depressions 4 - 6 , Fair, Comfortable with intermittent bumps or depressions 2 - 4, Poor Uncomfortable with frequent bumps or depressions 0 - 2 Very Poor Uncomfortable with constant bumps or depression (Michels, 2017) or 7 level rating of PCI or 7 level rating of PCI 85-100 - Excellent; 70-85 -Very good, 55-70 Good,40-55 Fair, 25-40 Poor, 10-25 Very poor, 00-10 Failed (Karim et al, 2017). In our study we have classified all risk factors from 1 to 5 as others risk factors in order to have same hierarchy. PCI factor has influence in R_C and R_t. If PCI is low (0, 1, 2), R_C could increase from 2 to 3 or 4 even 5. Also, if $R_t = 5$ or 4 PCI could decrease and the maintenance of road could involve additional costs, and if R_t has low value PCI could remain at initial evaluation. As a conclusion between PCI and R_C respectively R_t there is an inversely proportional dependence, but R_C could be influenced by R_t not only by PCI. We have used this matrix in a Monte Carlo simulation procedure that determines a random number from 1 to 50 and associate this number with a certain road project scenario. Each experiment computes the Ig based on parameters of a randomly determined scenario that include the type of distress, risk value, PCI value, the scales of risk depending on costs, time and quality. The table below shows the first five results out of 5000 simulations experiments. For each scenario the global impact was computed as described above and marked with colored bars ranging from green for projects with the global impact lower than 2, yellow for the projects with the global impact equal to three and red for the ones above 4 considered with high risk (Table 5).

The experiment uses the determined *Ig* parameter to indicate the probability of a project to be successful - when *Ig* is lower or equal to 2, a project may be completed with reasonable adjustments of time and budget when *Ig* is equal to 3. A project with *Ig* equal to 4 is a project that needs a considerable amount of changes in the budget and time span, influencing it considerably in order to be finished. The Ig equal to 5 indicates a project that cannot be finished given the considered budget and time span.

Table 5. Monte Carlo simulation experiment planning

Experiment no	***Random no - Scenario chosen***	***Type of distress***	***Risk***	***PCI***	R_C	R_t	R_Q	*Ig*
1	39	Potholes	low	3	2	2	2	2
2	8	Edge Failure	low	3	1	3	1	3
3	29	Edge Failure	high	1	4	3	1	4
4	16	Potholes	moderate	2	3	3	2	3
5	50	Ravelling	low	3	2	2	1	2
6	30	Rutting	low	3	1	3	2	3
7	34	Ravelling	moderate	2	3	4	2	4

The simulation experiment was performed using a Microsoft Office Excel spreadsheet and Risk AMP Add-On which is connected to the PAV3M database. The results summary is presented in table 6 and the histogram in Fig. 2. The average value after 5000 simulations is 3.272 which leads to a confidence interval of [3.235; 3.286] that was calculated taken into consideration an alpha value of 0.05 as a maximum error value.

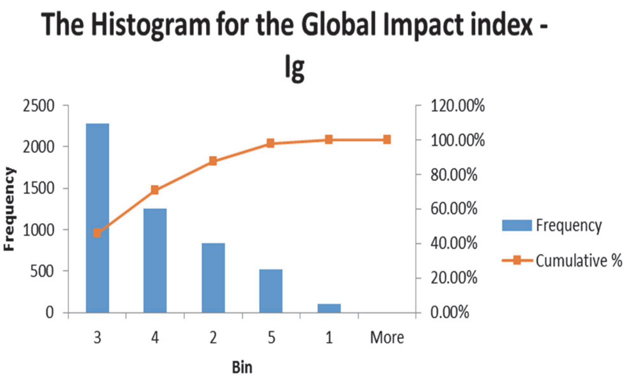

Fig. 2. Histogram of simulated *Ig* index

Table 6. Risk analysis by type of distress

Results Summary			
Mean	***3.272***	***Standard Deviation***	***0.9156***
Number of Trials	5000	Variance	0.84
		Skewness	0.09
Minimum	1	Kurtosis	2.75
Maximum	5		
Median	3	Confidence	0.025
Range	4	**Confidence interval**	**3.235**
			3.286

The Pareto analysis on the histogram presents the distribution of the simulation results through the series, showing that values 3 is the most frequent result of the simulation, meaning that projects may usually deal with considerable project adjustments needed in order for the project to be successful.

Considering that a project is successful and delivered on time when *Ig* is below or equal to 2 and a project may be finished with reasonable budget and time adjustments when *Ig* is equal to 3, we have determined with a 95% of certainty that the probability for a project to be successful is 17.78% and 44.72% to be finished with reasonable adjustments.

We have then considered each type of distress and computed the probability of the project to be successful given the simulation results. We have kept the same metrics of considering a successful project as one with the Ig lower or equal to 2 and a project that may be finished with accepted limits and adjustments one that has the Ig equal to 3.

- **Cracking** - we have determined that there is a probability of 13.32% for a project to experience cracking and out of this percentage there is a probability of 43%, and 72% for the project to be delivered successfully
- **Edge failure** - there is a probability of 28.14% for a project to experience an edge failure and when this situation is considered there is a probability of only 11.94% for the project to be delivered successfully and a percentage of 40.59% to be finished with accepted limits and adjustments.
- **Patching** - there is a 16.52% probability for the project to experience patching as a distress but in this case the simulation experiment offers a more optimistic result - a 62.71% of the projects may be delivered successfully and a 24.37% of those projects will be delivered with adjustments.
- **Potholes** - we have determined that there is a probability of 18.56% for a project to have potholes as type of distress and out of this case 90.19% may be completed successfully and a 9.81% with adjustments above the accepted limit of the project. In this case there were no situation that involved potholes and the possibility of the project to not be completed.
- **Ravelling** - is the type of distress with the lowest percentage of occurrence 8.08%. Out of these projects almost half of them may be delivered successfully - 48.51% and a percentage of 12.58% with adjustments that may allow the project to be completed.
- **Rutting** - for this type of distress there is a 15.38% probability of occurrence during a road pavement project and a 62.58% probability of the project to be delivered successfully and 12.58% percentage for the project to be completed with adjustments.

We have presented risk scenarios using all kinds of distress that may appear on a road. The reality confirms that there are roads in our country where over 100-150 km are found almost all these distresses. Images acquired and processed by the IPA module from PAV3M show that the most common distress encountered are: Patching, Edge Failure, Potholes, Rutting and Cracking. Unfortunately, some regional or county roads present distress that exceed the maximum rating of (Miller and Bellinger, 2014) classification.

Another risk analysis included in RISK3M has developed the principle of predicting the reference class using a k-NN algorithm for analyzing and classifying the risk data. How the k-NN algorithm uses similar existing data to achieve an object ranking that is impartial. In the present case, as we did not have a history of analyzing the pathways previously included in the maintenance activity, we considered the overall PCI classification for a portion of the road. This classification was the only one available at the date of the present conducted simulation analysis.

In this case, the reference class used was broad enough to have a statistical significance, but not sufficiently narrow to be truly comparable to the project considered "new unknown", the project for which the reference class was projected. In this method the results are expressed in%, which represents the probability of finalizing the projects over time or the probability of delay compared to the reference class. As the reference was synthetically expressed (at the level of the road, not at the analyzed portion), the results obtained with the k-NN method and those obtained with the Monte Carlo method differ. These differences are due to the fact that for the k-NN method there was no historical data at the level of detail images purchased.

4. Conclusions

Risk identification and assessment is a complex aspect of a project in general and for a road pavement project in particular, considering the amount of time and resources involved. Its impact on costs and the project development is essential and risk management methods may do the difference between a successful project and one that may need to be aborted.

This paper presents an efficient method for risk prioritization and resource management involving the examination of a series of simulation experiments. Important factors such as costs, time, quality and the impact of risks on them are used to determine degrees on which a project should efficiently adjust its budget.

Further improving of the method will be made by taking into consideration factors like weather and temperature, as factors that may be identified and interact with distresses and influence their type, severity and occurrence.

Another research direction is the comparative analysis of the two Monte Carlo and k-NN methods for a set of images collected from the field using the IPA module. If these data become classification criteria for historical projects, then k-NN and Monte Carlo can be compared with more accuracy from the point of view of the effectiveness of maintenance prediction. As the classification of projects using factors like weather and temperature has not been achieved so far, both methods can provide unexplored solutions to date.

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References

Abhinaya K., Nidhu S., (2017), Risk management in highway construction using risk priority matrix and SPSS software, *SSRG International Journal of Civil Engineering*, **4**, Special Issue, 7-11.

Austroads, (2017), Guide to pavement technology: part 4F: bituminous binders, AGPT04F-17, Austroads, Sydney, NSW, On line at: https://austroads.com.au/.

Babashamsi P., Yusoff N.I.M., Ceylan H., Nor N.G.M., Jenatabadi H.S., (2016), Evaluation of pavement life cycle cost analysis: Review and analysis, *International Journal of Pavement Research and Technology*, **9**, 241-254.

Benta D., Jecan S., Rusu L., Dines, O., (2017) Business Process Analysis for Risk Management in PAV3M, *Environmental Engineering and Management Journal*, **16**, 949-956.

Chou J.S., (2011), Cost simulation in an item-based project involving construction engineering, *International Journal of Project Management*, **29**, 706-717.

Dumitrescu L., Maxineasa S.G., Simion I.M., Taranu N., Andrei R., Gavrilescu M., (2014), Evaluation of the environmental impact of road pavements from a Life Cycle perspective, *Environmental Engineering and Management Journal*, **13**, 449-455.

Fang C., Marle F., (2011), A Simulation-Based Risk Network Model for Decision Support in Project Risk Management. Decision Support Systems, On line at: https://hal.archives-ouvertes.fr/hal-01207061/document.

Hamdi I., Sigit P., Hadiwardoyo L., Correia A.G, Pereira P., (2017), New optimization strategies of pavement maintenance: A case study for national road network in Indonesia using integrated road management system, AIP Conference Proceedings 1855, On line at: https://doi.org/10.1063/1.4985511.

Herbold K., (2000), Using Monte Carlo simulation for pavement cost analysis, *Public Roads*, **64**, 2-6.

iWorq, (2018), Pavement Management System Software, On line at: https://iworq.com/pavement-management-system-software/.

Karim F.M.A., Rubasi K.A.H., Saleh A.A., (2016), The Road Pavement Condition Index (PCI) evaluation and maintenance: A case study of Yemen, *Organization, Technology and Management in Construction*, **8**, 1446-1455.

Liesenfeld R., Richard J.F., (2001), Monte Carlo Methods and Bayesian Computation: Importance Sampling, *International Encyclopedia of the Social and Behavioral Sciences*, 10000-10004.

Michels D.J., (2017), Pavement Condition Index and Cost of Ownership Analysis on Preventative Maintenance Projects in Kentucky, On line at: http://hawaiiasphalt.org/wp/wp-content/uploads/PCI-101.pdf.

Miller J., Bellinger W., (2003), Distress identification manual for the long-term pavement performance program, Washington D.C.: Federal Highway Administration Report FHWA-RD-03-031.

Miller J., Bellinger W., (2014), Distress Identification Manual for Long Term Pavement Performance Program, Washington D.C.: United States Federal Highway Administration. Office of Infrastructure Research and Development.

Mills L., Attoh-Okine N., McNeil S., (2012), Hierarchical Markov Chain Monte Carlo Simulation for modeling transverse cracks in highway pavements, *Journal of Transportation Engineering*, **138**, 700-705.

MITRE, (2017), Risk Impact Assessment and Prioritization, On line at: https://www.mitre.org/publications/systems-engineering-guide/acquisition-systems-engineering/risk-management/risk-impact-assessment-and-prioritization.

Patchin C., Mark C., (2012), Risk Assessment in Practice. On line at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Governance-Risk-Compliance/dttl-grc-riskassessmentinpractice: Deloitte and Touche LLP.

PAVER, (2018), Pavement Management Software, On line at: =http://www.paver.colostate.edu/.

Rusu L., Benţa D., Podean M., Arba R., (2012), Web based pavement maintenance and monitoring system, *Procedia Technology*, **23**, 74-83.

Rusu L., Sitar-Taut D., Jecan S., (2015), An integrated solution for pavement management and monitoring systems, *Procedia Economics and Finance*, **27**, 14-21.

SMEC, (2018), On line at: http://www.smecsoftware.com.au.

Stoneburner G., Goguen A., Feringa A., (2002), Risk Management Guide for Information Technology System, National Institute of Standards and Technology, Special Publication 800-30, On line at: https://www.archives.gov/files/era/recompete/sp800-30.pdf.

Walls J., Smith, M., (1998), Life-Cycle Cost Analysis in Pavement Design Federal Highway Administration, Report no. FHWA-SA-98-079, Washington D.C., USA.