Environmental Risk methodology applied to road Infrastructures

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Abstract

This paper addresses the issue of environmental risk associated with the development and contracts in road infrastructures culminating in the quest for reducing their environmental impact. As such, this dissertation aims to implement the risk management approach to environmental risks, minimizing the negative impact from them.

Therefore, it was sought to follow a risk management approach breaking it down into probability and significance to demonstrate not only its applicability, but that this model might play a strong assistance in the search for a better environmental performance. Thereby it was applied the methodology to a rehabilitation contract, a road infrastructure considered rural under the charge of the Municipality of Coruche. The application to the case study showed that the work of rehabilitation can improve its procedures and environmental performance, moreover, it yielded categorized risks results as well as suggested treatments.

In conclusion, it was possible to verify the usefulness of risk management methodology for it allows the rank and classification of risk, revealing the possible environmental factors and their vulnerabilities. From which you can set priorities, implement prevention, treatment and mitigation measures thus creating the basis for a possible application to larger projects.

Keywords: Environmental risk, Model of risk management, Road infrastructures, Environmental Performance

1. INTRODUCTION

Since the dawn of human civilization, man seeks security and prosperity (Johan Rockstrom et al. 2014), first with the use of natural structures and, subsequently with the development of artificial ones. In this search of prosperity, aided by advances in brain capacity, the human being realizes that must take certain actions over others in order to flourish (Peter L. Bernstein 1999).

Thus arising the concept of uncertainty associated with events, with it, came the notion of risk and the implications of this for the development of civilization are crucial (Beck 1992). This enabled an improvement in the quality of human life thus increasing life expectancy in Western cities (Edward Mcnall Burns 1975). The concept of risk becomes more prominent in society, according to (Dickinson 2001), after the rupture of several renowned companies and the integration of notions of risk in the creation of strategic plans. Risk and uncertainty are closely related, but many authors have different definitions (Samson, Reneke, and Wiecek 2009; Ropel and Gajewska 2011).Through his research (Matten 2004) states that, risk itself is not a new phenomenon and can be differentiated from the notion of danger that has always existed, for example, potential threats to health and the existence of natural disasters. On the other hand, risk comes from decisions made by man. The risk as the possibility of accidents in factories or in road traffic was already part of classic industrial societies and these risks were covered by another institutional concept – insurance. The concept of risk, its management and evaluation are applied in various areas and illustrate a clear evolution over time (David Hyett 2010; Almeida 2011). This work aims to focus on the environmental risk associated with road infrastructures, since these are of the utmost importance economically, socially and environmentally speaking (Shaw et al. 2012), as they allow quick communication between different population centers and approach business partners but, can also be the source of environmental problems such as soil occupation/degradation and habitat fragmentation (Daigle 2010).

2. OBJECTIVES

In most engineering projects, there are different stages that lead to its development. This paper deals with the object of study following a general approach on the various stages in the life cycle of a road and the implications that may arise, not only for the environment but also consequently to human health. In order to foster a better understanding of the issue and to bridge the gap in the language already used by other different areas of study in relation to risk management, is developed a methodology for assessing the environmental risk.

This methodology, which is then applied to a case study seeks to obtain an improvement of environmental practices and performance in road infrastructure. Thus, its main objectives are:

- Minimize the negative impact from risks;
- Help predict possible future risks, thus increasing the probability of achieving the objectives;
- Provide a starting point for the study of a similar project and encourage a more proactive management;
- Increase the resilience, the environmental performance and safety of the process;
- Maximize the potential opportunities, the positive impacts coming from the identified risks.

This way, seeks to contribute to better environmental management and combat the difficult in associating different environmental aspects to the risk terminology and management tools.

3. METHODOLOGY

The methodology followed on the course of this dissertation involved firstly, a survey of scientific and technical publications regarding road infrastructures and environmental risk management procedures. Secondly and reviewed in more detail, it was decided to apply the ISO 31000:2009 international standard model of the risk management process to environmental risk. In order to execute this step, definitions and legislation from APA (Environmental Portuguese Agency) as well as USEPA (United States Environmental Protection Agency) were consulted. Succeeding this, a conceptual model for the risk management process following the footsteps and recommendations proposed by the ISO standard is developed. In order to verify the applicability and adaptability as well as possible limitations and improvements to the model, this is then applied to a case study. Lastly, a discussion and conclusion are designed with regards on the results obtained and possible improvements as well as future work to enhance the environmental risk management model.

4. CONCEPTUAL MODEL

Basically, the conceptual model developed trails the structure recommended by the ISO standard.

This way, starting with the establishment of structure and context of application, the background as well as the expected outcome are presented in the form of classification grids, regarding significance, probability and combined, Table 3 Table 2 and Table 1 respectively. In the latest one a differentiation regarding the upper right part of the table can be seen, this represents the risks which should receive priority in treatment when related to all others identified. This decision is based on the high levels of probability of occurrence and/or high levels of significance to the environment.

Followed by risk identification, a phase where all relevant risk should be considered, for the ones that are not will not have a chance to be evaluated and if needed be, treated. It refers to identification in a sense that hazardous actions are contemplated and correlated to the different environmental factors. From these, five risks are selected to be analyzed and evaluated in more detail: a) raw material extraction and transportation; b) fragmentation and barrier effect creation; c) contamination of aquifers and watercourses perturbation; d) landscape destruction and construction yard creation; and e) solid waste generation. They are selected with the objective to cover a wide portion of the factors and therefore to give a better understanding of all its contents.

In the analysis stage, graphs similar to Figure 1 – refers to b) - containing the several most relevant repercussions to the environment are drawn. Throughout the scrutiny of consequences and significance for the environment, some units of measurement as noise levels, bacterial contamination and tonnage of virgin raw material extraction are proposed for the subsequently evaluation phase. Although, in some cases it can be challenging to agree and to generate a consensus around that unit of evaluation. According to (Birkmann 2006) risk can be written as a function of significance and probability, Equation 1. Given the lack of a reliable statistical base a decision was made to propose only significance evaluation intervals. Leaving the probability analysis somewhat vulnerable to debate and relying on field observations, case by case.

$$Risk = F\ (\ Probability,\ Significance\ )$$

Equation 1- Risk defined as function of probability and significance

Table 1-Combined risk classification grid

Probability ↑ / Significance →					
	1 5	2 5	3 5	4 5	5 5
	1 4	2 4	3 4	4 4	5 4
	1 3	2 3	3 3	4 3	5 3
	1 2	2 2	3 2	4 2	5 2
	1 1	2 1	3 1	4 1	5 1

Hence the evaluation phase climaxes in the comparison of the intervals suggested and the level analyzed of the risk which enables the classification of the risk.

Lastly, the final phase of the model is risk treatment, where after the evaluation phase and with the classification of the risk, mitigation and treatment measures are proposed in order to reduce the risk levels.

5. CASE STUDY

Having developed the model a case study was procured to its application. In broader terms, the structure followed is the same as the model: context definition, identification phase, analysis stage, evaluation phase and treatment suggestions.

The road infrastructure chosen is located between the municipalities of Coruche and Ponte de Sôr, in the river Sorraia watershed – sub-basin of river Tejo - a region designated as Alto Alentejo, approximately 120 km east from Lisbon. This site is chosen because of its agriculture, water usage and some spatial planning and protection Portuguese legislation relevancy. Regarding crops of rice, corn and several vineyards.

Table 2 –Classification of probability of occurrence

Occurrence	Level	Classification
Almost certain that the event does not occur	1	Very rare
Low probability of occurrence	2	Rare
It is possible to occur	3	Possible or probable
High probability of occurring an event	4	Frequent
Probability of occurrence almost certain	5	Very frequent

Although this road infrastructure does not cross any major population center this infrastructure provides access to a relevant touristic location with some significant influx of visitors during the summer months – Montargil Reservoir.

The contract is under supervision of the municipality of Coruche and it is a rehabilitation project with the length of around 7 km. The road pavement is 10 meters wide in most of its extent, except in a bridge crossing which as only 6 meters wide. One of the probable reasons for the bad shape of the pavement is the division of management between the two municipalities. Besides this, the disrespect of weight restrictions can also be one of the core problems that originated the necessity of rehabilitation.

From the characterization of the case study is initiated the environmental risk identification phase and as much as possible attempts are made in order to find similarities between the several hazards activities and environmental factors established in the model and those found in the field.

Actions as equipment and machinery maintenance, bad execution of packaging procedures of chemical substances and reagents, modifications in soil use, vehicle and equipment wash events and modification as well as possible contamination of aquifers and watercourses are considered since the implications and problems caused by these to the human health can be severe.

With that being said, four risk are chosen accordingly to the assumption that these are the more relevant for this case:

- Natural landscape destruction, with the modification in soil usage and depletion of natural resources for the rehabilitation of the infrastructure (R1);
- Contamination of watercourse and aquifers which are used for irrigation and ecosystem management purposes (R2);

Table 3 - Classification of significance

Damage	Level	Classification
Does not lead to environmental harm	1	Insignificant
May be required to apply mitigation or corrective measures in order to not originate severe environmental problems	2	Somewhat severe
Immediate mitigation and corrective measures are needed in order that life is not harmed	3	Severe
Leads to severe accidents that may not only originate human damage, limited to an area but also to the environmental	4	Very severe
Leads to very severe accidents which originate environmental damage that go beyond surrounding areas	5	Catastrophic

- Increase in road traffic and human presence in the area with the possibility of proliferation of alien species and degradation of local populations (R3);
- Asphalt and solid waste generation by removal during the rehabilitation contract (R4).

Regarding the analysis some assumptions are made in order to establish quantities of material needed to finish the contract. Assumptions as the remaining length of road that needs rehabilitation (5km), the land usage by the construction yard (2,5 hectares) and total tons of waste that will be generated by the end of the project (307 tons). Although it is expected that this will be diverted to a proper sanitary landfill, the nearest, under the management of the municipality of Coruche, is approximately 44 km away.

With the levels of impact from these activities the evaluation of the environmental risks begins:

In the case of R1, with a calculation of the average between the values of significance assigned during the previous analysis phase of the land occupation and materials extraction, one arrives at level 3 of significance. Concerning the probability analysis, this one is done under the assumption that no recycled materials are used, therefore the highest level is attributed (level 5).

Regarding R2, an additional analysis is recommended because the parameters referred in the model could not be measured accordingly. Although a more thorough visual inspection, starting 30 meters from the road was carried out, there was no equipment for the detection of micro bacterial contamination. However and attending the proximity factor of these watercourses to the infrastructure, level 3 of probability analysis is justified. About the significance analysis and having in mind the immense importance for crop growth as well as ecosystem maintenance, the level 3 is also suggested.

In the case of R3 it is recommended level 2 of significance due to the fact that this risk might need some corrective and/or mitigation measures in order to avoid its propagation and the escalation to other areas and targets. About the probability analysis and having in mind that by the end of this contract, the infrastructure will surely be in better usage conditions for road traffic than before, it is very likely that it will receive a greater affluence of vehicles. So the level 4 of probability analysis is suggested. Additionally an extra analysis is recommended due to the fact of possible alien species proliferation. This way, this fact can be verified and integrated in the analysis phase.

At the end, concerning R4 and as it is a rehabilitation contract, it is assumed that there will always be asphalt and solid waste generation and removal from the infrastructure, which leads to the highest probability level, level 5. In regards to the significance analysis, level 2 is suggested since mitigation and prevention measures might be need in order to contain the risk and not originate severe environmental damages. Having finished the evaluation phase and with that in mind, some treatment measures are proposed to attain new levels of risk.

This process should be cyclical, namely, after the implementation of the treatment an assessment of this should be made in order to evaluate the residual risks obtained from that treatment. Are those risks acceptable? Are those risks in need of mitigation still? These are the questions that this evaluation should try to answer and with that, develop new treatment and/or mitigation measures if needed be.

6. RESULTS AND DISCUSSION

After the application of the model and a visit to the construction site some results are obtained, for a more summarized visualization see Table 4.

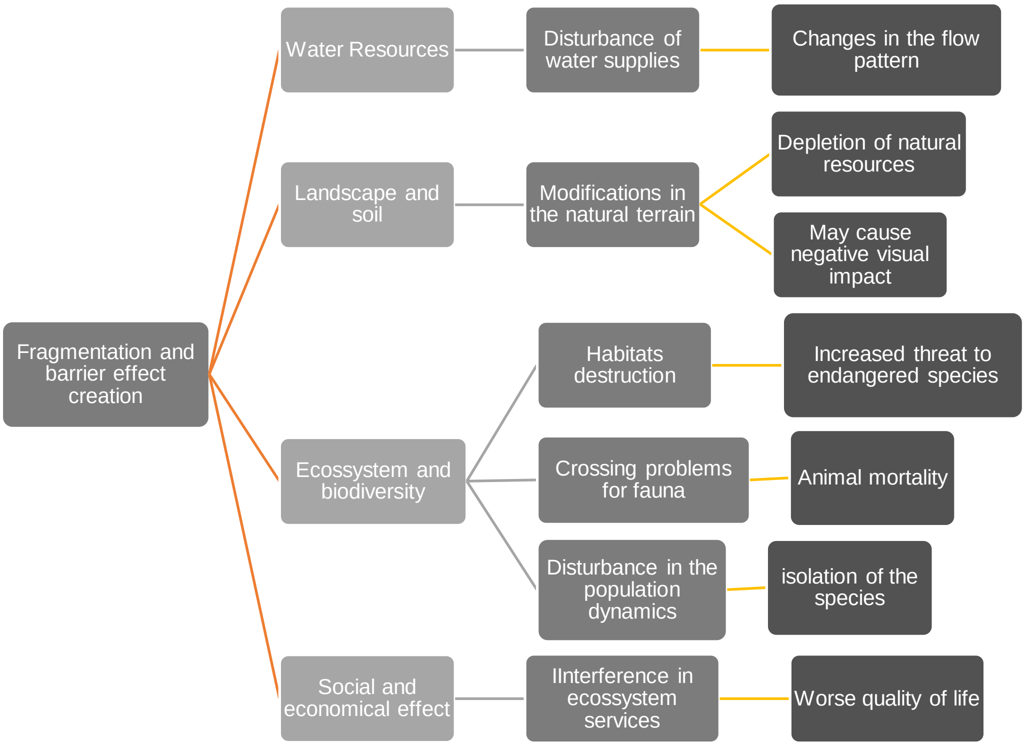

Figure 1 – Graph representing the implications to the environment of Fragmentation and barrier effect creation

As can be seen and due to a high level of probability, in conjunction with level 3 of significance, R1 is recommend to be subjected to high-priority treatment.

For R1 the main concern is to address the reduction of probability of occurrence. As such and as an alternative, the usage of bottom ash or the reutilization of other types of filling material which are not virgin material are recommended. This way, not only the reduction of probability is attained as well as the decrease for the significance analysis due to reducing the amount of material extracted. As mitigations measures, the recovery of surrounding soil and maintenance of local vegetation and fauna should be assured. With these proposals it is expected to modify the risk to levels of 4 and 2 of probability and significance respectively.

In the case of R2 it is recommend an additional analysis to confirm the ranks assigned, therefore the levels suggested are not very solid.

For the R2, is paramount the realization of an additional analysis, more complete and with a broader range of indicators. An effective preventive action can be the controlled provisioning of all the effluents created by the rehabilitation, granting this way that they are conducted to the proper treatment installations. With this, a reduction of probability is expected, meaning a drop from level 3 to level 2.

For the R3 it is proposed a reduction of the classification of probability. For which, measures that restrain access to the site are the ones that will produce more effect, however, this measure raises the question of rehabilitation itself. This way, it is recommended not only the patronage of local crop growth techniques as well as, in accordance with the Nature and Forest Conservation Institute (ICNF), the creation of a list of more affected or susceptible species of being hindered by this increased human and vehicle presence.

This can be considered both as a measure to share the responsibility of the risk and to combat the local loss of biodiversity. With these proposals a probability reduction is expected from level 4 to level 3, however measures to reduce the significance level must be investigated.

Finally for R4 and similar to R1, it is suggested a reduction of the classification of probability. Measures identical to the avoidance of deposition in landfill, the usage of waterproofing recipients and staging areas contribute to that. Preferably, this materials can be used for embankments when properly conditioned and isolated, preventing the formation of leakage in the occasion of a rainy event. With this measures a sharp decrease of the probability level is attained, from 5 to level 3 due to the minimization of the possibility of contamination and/or local infiltration. On the other hand this might not have as much impact in the significance analysis.

Table 4 – Risk assessment support, designated risk register

Risk Register				
Identification	**Analysis**			**Evaluation**
	Significance	**Probability**	**Level of risk**	
Risk 1 (R1)	3	5	3 5	High-Priority Treatment
Risk 2 (R2)	3	3	3 3	Additional analysis
Risk 3 (R3)	2	4	2 4	Treatment
Risk 4 (R4)	2	5	2 5	Treatment

Discussing the overall work, the approach of the methodology of risk assessment followed in this paper enabled the achievement of results when applied in the field. Although not all objectives are fulfilled, the model provides support in the decision making process of environmental risks and establishes a process of registry and classification of possible environmental risks. It was conceived to cover all phases of a road infrastructure life-cycle, however, it is not possible to verify its applicability to construction and/or deactivation phases due to the fact that the case study chosen is a rehabilitation contract. The adjusted model, at its core, is functional, besides a few limitations during the implementation its adaptability must be dignified.

Regarding the general quality of the results obtained, this can be contested in certain aspects due to the subjectivity and filtering done by the examiner or assessor in the field. Moreover, limitations as the lack of the temporal factor regarding noise exposition, the difficulty in adapting the calculation of soil occupation, using density as proposed in the analysis phase, and the lack of a statistical accepted base, refrain the model from achieving its prime results in a more sustained way.

7. CONCLUSIONS

The application of this risk management model to a concrete case study allows the notion of the difficulties, in adapting the risk management process to the different areas of study, to erupt. Since having risk as an object of study can be confusing in some aspects, the contribution from technical publications such as ISO standard 31000:2009 are of the utmost importance because they harmonize the way this concept can be defined, interpreted and integrated into a management system.

Although the application provided good results, some limitations and room to grow is identified. Features similar to the integration, in the analysis phase and hence in the significance evaluation, of actions, as the destruction of economic activities - such as the cultivation of vineyard, the cost of having to rely on emergency services and traffic congestions - contribute to a more robust and broad method. Besides this, the development of a statistical data base that could cope to and benefit the evaluation stage, allied with the diversification of the typology of road infrastructures studied, would greatly augment this approach.

It is expected that this model can be applied to a larger scale, as regional infrastructures for instance. Agreeing with the revision of knowledge, mitigation and prevention measures have as their main objective increase the security factor for Man, as such, it is important to pass the knowledge acquired regarding possible hazards and risk factors related with these infrastructures. It is verified that this tool increases the resilience, environmental performance and safety in developing road infrastructures besides providing an important contribute in the integration and in the dialogue between professionals from all areas that have as object of study risk.

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