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A New Approach - Use of effectiveness and efficiency concepts in the identification of activities related to occupational safety management on motorways

E. J. Silva [a], M.C. Rodrigues [b]

[a]CITTA, Faculty of Engineering, University of Porto, PT (jmarcalster@gmail.com), [b]CITTA, Faculty of Engineering, University of Porto, PT (cmr@fe.up.pt) ORCID: 0000-0002-4546-2706

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Abstract

The need to improve the safety management in the maintenance and operational works on a motorway is a request that all the organizations demand to achieve better goals on safety and in the use of resources. The use of instruments linked to efficiency and effectiveness is one possible solution to this problem. The objective of the present investigation is to prove that it is possible to identify the main activities contained in the A area of an ABC curve and linked to the Pareto´s concepts, defining this way the 20% most dangerous maintenance and operational activities on motorway works. The methodology used was a DELPHI panel formed by experts from different areas linked to safety at work on motorways. The statistic treatment was made through the informatic program IBM SPSS Statistics 24. The results show that it is possible to identify 36 main activities in maintenance and operational works, being relevant the activities related to emergency response, safety guards, expansion joints, provisional signaling and the access to working stations in toll areas. The conclusions of the study reveal that these 36 activities represent the 20% most dangerous activities in maintenance and operational works on a motorway, and show that besides the risks of the work itself, there are four crucial traffic factors to develop a correct risk analysis: weather conditions, traffic characteristics, pavement characteristics and motorway morphologic type.

1. Background

The complexity produced by multiple variables of causes in the working accidents on operational motorways is one most the defying problems that health and safety professionals must deal with in order to ensure the safety of all the users and workers involved in maintenance activities in these infrastructures. To ensure the outcome of zero serious or mortal accidents, different factors are crucial to the risk analysis that must be conducted. Besides the inherent risks associated with the construction work or the activities that must be developed, conditions related to external factors cannot be forgotten. Climatic conditions, morphologic motorway factors, traffic type and conductors' behavior are examples of some problems that should be considered when analyzing risks. Nevertheless, another type of challenges has arrived for all the organizations particularly in the Health and Safety area. The allocation decrease of human and material resources is a

reality affecting organizations and specially the areas that are not considered to be direct wealth generators. In this context, it is essential that both health and safety professionals and the scientific community can give an adequate response to all these problems. New instruments can be adopted to all these questions. For example, some researches have conducted a systematic review on the relationship between effectiveness and efficiency with the management of Occupational health and safety on motorways and with the main critical factors on Health & Safety risk analysis (Silva et al., 2016). Another research is focused in the discovery of the most dangerous places to work in these infrastructures (Hallowell et al., 2011). However, this second article only deals with construction activities on construction phase, without the interference of other external critical factors to Health and Safety. A third article is related with the incompatibility and interference of construction activities on motorways, but once more without referring other constrains (Esmaieli et al., 2013). In the case of motorways in operation, new risks are arising from the need to maintain their operation combined with the traditional risks in the construction sector, exponentially increasing the hazards for the workers and for the users of these infrastructures. Due to the lack of studies that explore a relation between motorways in operation and the maintenance and operational activities, a new approach is needed to identify the main risks that affect workers and motorway users. The use of effectiveness and efficiency tools can be one possible answer.

This context needs also to be explored by the scientific community as a research stimulus on management tools related to the effectiveness and efficiency of the human and material resources, amenable to being incorporated in the traditional instruments of Occupational Safety and Health (OSH).

In fact, this means the need to identify the main activities through multicriteria concepts as well as rationalization and optimization tools. This can help the researchers to identify what to do and how to do it, in terms of Health and Safety. Basically, this also proves that besides the identification of the most relevant activities the researchers must identify all the main internal and external factors that can make a difference at a risk level.

All in all, this research was carried out bearing these goals in mind.

2. Methodology

The research methodology is based on one concept, one validated method and one informatic tool. The fundamental concept utilized is based on the Pareto's Principle, whose basic principle states that 80% of events come from 20% of the possible causes (Randson & Boyd, 1997). This Principle adapted to our thematic states that 80% of the accidents are caused by 20% of all the activities. The first step to achieve this goal is to select the validated method that will be used in the research. Among different hypotheses, the selected method was the Delphi methodology. Besides being a validated one, developed by de RAND Corporation after the second world war, this methodology has the objective of achieving a feasible consensus among experts. Some authors (Okoli & Pawlowski, 2004), consider this methodology as a valuable instrument to avoid conflicts among experts and to make predictions, to identify a hierarchy of variables with

relevance to the research. Other authors (Skulmoski et al, 2007) consider this methodology as the most suitable to "investigate what does not yet exist" and suitable to PHD theses. This method requires the production of inquiries that must be answered by the experts. The research carried out (Okoli & Pawlowski, 2004) suggests the adoption of the Kendall's coefficient as the most suitable to be adopted by experts and of 0.7 as the minimum value to achieve consensus. When this value is not achieved, the experts receive for each question, information about the following statistics elements: median, average, mode and standard deviation. After this step, they are asked if they want to review their score. In the present research, two rounds are necessary to get the consensus. Another issue that must be carefully handled concerns the experts' choice. According to some authors (Skulmoski et al, 2007), the experts must accomplish four requirements: knowledge and experience in the area, will to participate in the research, communication skills and available time. Other requirements are needed to ensure a methodological success. The first step is to elaborate an identification matrix of experts; the second step has to do with the selection of experts. The third step refers to the with identification of additional experts and the fourth step is related the expert's hierarchy level. One last step is required to make a formal invitation to the experts. According to all these requirements, thirteen experts were identified, all of them with complementary experiences in the same area of these research. The experts are contacted by email. All the emails are confidential t\o the experts. Their areas are shown in Figure 1.

The informatic toll used to achieve the response values consensus among experts was the informatic program IBM SPSS Statistics 24.

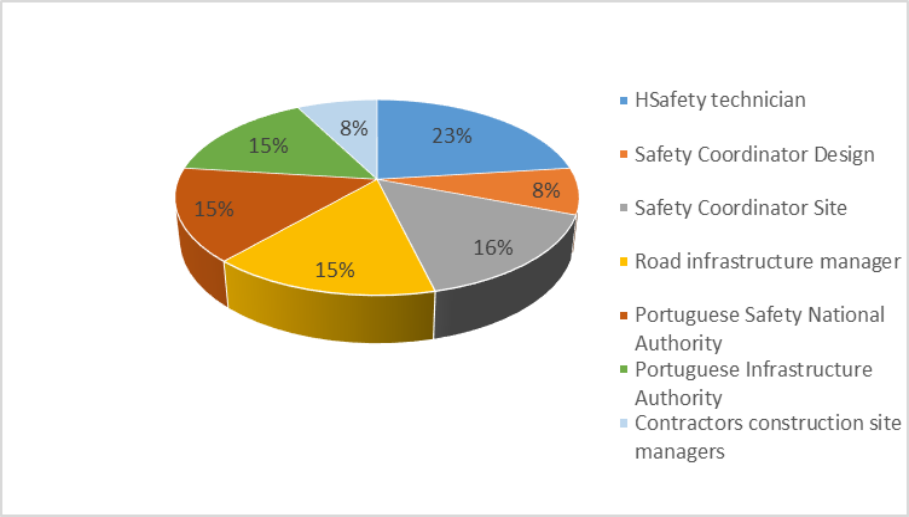

Figure 1 – Experts' Areas

3. Results

To reach a consensus among experts, it became necessary to produce and invoice two types of inquiries. The questionnaire was validated through the Delphi methodology, allowing the experts in each phase to produce initial consensus changes.

A first inquire with close questions and numeric score, which each expert could suggest for each activity and a second one with open questions, where each expert could suggest new activities

or factors. In the second inquire, each expert was questioned not only to review his score for each case where the consensus was not achieved but also to analyze the other experts' proposals.

The number of activities identified and analyzed by the experts' panel were 187 activities. Besides the inherent risks of the activities, the expert's panel considered that there are four fundamental factors that affect the risk analysis and the safety level of the selected activities. These factors are: motorway infrastructure morphology, type of pavement, climatic conditions and traffic type. After the second interaction, the experts' panel agreed in the selection of the 36 most dangerous activities and the factors that can influence their hazard level. It must be emphasized that between the first and the second interaction, only two new activities were integrated in the selected group. A simple note to explain why 36 activities were chosen instead of 37 activities. In fact, 37 activities are the real percentage of 20% of the global number of activities, but the number of draws in the 37th position, was substantial and it was decided to assume 36 activities as the percentage of 20% of the global activities. Figure 2 shows the areas and the type of activities that the Delphi panel consider as the most dangerous among that selection.

Table 1 shows in the appendix and in detail, the influence between activities and factors and the identification of the thirty-six most dangerous activities.

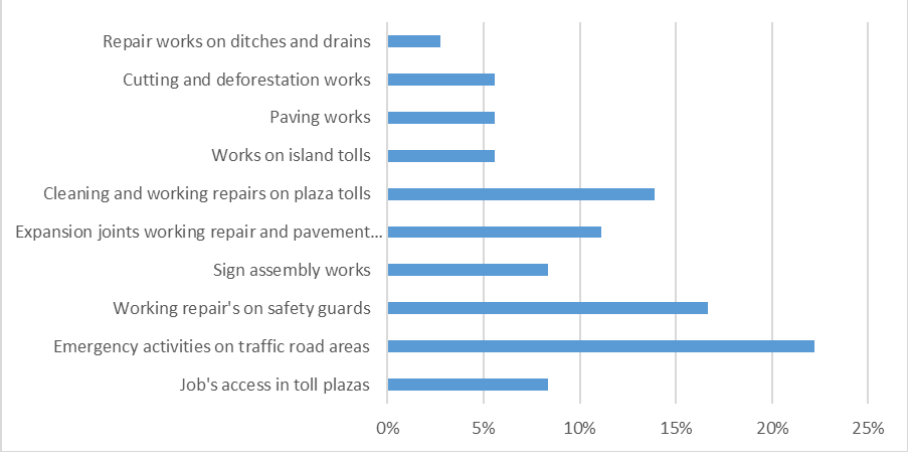

Figure 2 – Most dangerous activities

Table 1 – Relevant Activities and Factors

Hazard Level	Activities Description	Relevant Factors	Experts panel points
1	Access to working place through electronic toll "green way" on toll plazas	Light traffic, bad weather conditions and hard pavement	128
2	Motorway emergency activities in car accidents (motorway with two lanes on the same direction)	Less than 300 m curve, congested traffic, bad weather conditions and hard pavement	125
3	Cleaning works in the middle of the motorway	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	122

Hazard Level	Activities Description	Relevant Factors	Experts panel points
4	Safety rails repair on the median strip, with rails on both sides and without inner vegetal band	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	121
5	Signaling assembly and disassembly in car accidents support, by emergency team	Less than 300 m curve, congested traffic, bad weather conditions and hard pavement	120
6	Cleaning works in the middle of the motorway	Less than 300 m curve	120
7	Motorway emergency activities in car accidents (motorway with two lanes on the same direction)	Less than 300 m curve	119
8	Motorway emergency activities in car accidents (motorway with tree lanes on the same direction)	Less than 300 m curve	119
9	Motorway emergency activities in car accidents (motorway with tree lines on the same direction)	Less than 300 m curve, congested traffic, bad weather conditions and hard pavement	119
10	Safety rails repair on the median strip, with rails on both sides and without inner vegetal band	Less than 300 m curve	117
11	Access to working place through electronic toll "green way" in toll plazas	none	116
12	Signaling assembly and disassembly in working site construction, on the new jersey median strip and without safety rails	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	116
13	Safety rails repair on the motorway narrow right hard shoulder, with excavation slopes over 2m and 45 degrees/inclination and narrow hard shoulder	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	116
14	Expansion joints works, in motorways with tree lanes and narrow hard shoulder	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	115
15	Cleaning works near the new jersey median strip	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	115
16	Cleaning works before the toll plaza	Normal traffic, bad weather conditions and hard pavement	114
17	Signaling assembly and disassembly in car accidents support, by emergency team	Less than 300 m curve	114
18	Cleaning works near the new jersey median strip	Less than 300 m curve	114
19	Maintenance working repairs in island toll plaza with traffic interruption	Light traffic, bad weather conditions and hard pavement	113
20	Equipment assembly, disassembly and repair after an island toll plaza with traffic	Light traffic, bad weather conditions and hard pavement	113
21	Cleaning works near the new jersey median strip before toll plaza	Light traffic, bad weather conditions and hard pavement	113
22	Pavement works on motorways with two lanes on the same direction without traffic detour	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	113
23	Pavement works on motorways with tree lanes on the same direction without traffic detour	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	113

Hazard Level	Activities Description	Relevant Factors	Experts panel points
24	Emergency activities in car accidents on the median strip (two lanes motorway)	Less than 300 m curve congested traffic, bad weather conditions and hard pavement	113
25	Emergency activities in car accidents on the median strip (tree lanes motorway	Less than 300 m curve congested traffic, bad weather conditions and hard pavement	113
26	Expansion joints works on motorways with two lanes and narrow hard shoulder	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	112
27	Emergency activities in car accidents on the median strip (tree lanes motorway)	Less than 300 m curve	112
28	Safety rails repair on the motorway narrow right hard shoulder, with landfill slopes over 2m and 45 degrees/inclination and narrow hard shoulder	Less than 300 m curve	111
29	Cutting and deforestation works near the new jersey median strip	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	111
30	Pavement removal on motorways two lanes on the same direction without traffic detour	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	111
31	Emergency activities in car accidents on the median strip (two lanes motorway)	Less than 300 m curve	111
32	Safety rails repair on the median strip, with rails in both sides and with inner vegetal band	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	110
33	Access to working place through payment area without cancel on toll plazas	Light traffic, bad weather conditions and hard pavement	109
34	Expansion joints works, in motorways with two lanes and narrow hard shoulder	none	109
35	Drainage repair works on the top of over 2m contention walls and annex to the motorway	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	108
36	Cutting and deforestation works on the top of over 2m contention walls and annex to the motorway	Less than 300 m curve, normal traffic, bad weather conditions and hard pavement	108

4. Discussion

One of the fundamental issues addressed by this research is the relationship between the activities hazards induced by the maintenance construction works and the traffic circulation. Apart from exceptional situations, motorways as public infrastructures must always be open to traffic. This problem has been addressed in some research (Esmaieli et al., 2013), as one of the main hazards to workers and motorways users when traffic and maintenance works exist on operational motorways. The relevant question is to find out the main traffic factors and the main maintenance construction works that can cause damage to the both groups. The increase of the effectiveness and efficiency prevention measures to this problem is related to the assertive activities planning (Esmaieli et al., 2013) and these assumptions can only be achieved with a clear definition of the main hazardous construction activities or the relevant traffic factors. It has

a fundamental importance for this research, the discovery of the several factors that can induce the loss of control of vehicles, in the presence of maintenance works on the motorway. The Delphi experts panel have identified 34 of the 36 most dangerous maintenance work activities as affected by the following motorway factors: Motorway infrastructure morphology, type of pavement, traffic climatic conditions and traffic type.

For the present research and according with the identification of the most relevant activities, the subdivision of above the referred factors are as follows: motorway infrastructure morphology with or without a less 300 meters curve; three types of pavement – hard (bigger adherence and less visibility in the case of rain), rough (medium adherence and medium visibility in case of rain) and draining (less adherence and bigger visibility in case of rain); traffic climatic conditions – favorable (dry weather and good visibility) and unfavorable (rainy weather and poor visibility); traffic type – light traffic, normal traffic and congested traffic. The consensus achieved about the motorway infrastructure morphology factors stated that 8 activities are only influenced by a less 300m curve, 6 activities by a conjunction of pavement type, traffic and climatic conditions and 19 activities by a conjunction of a less 300m curve, pavement type, traffic climatic conditions and traffic type. As for the type of pavement, the achieved consensus showed that a hard pavement is the most unfavorable one for all applicable conditions. Concerning the traffic climatic conditions, the experts' panel considered that the most dangerous situations for workers and drivers are produced by unfavorable climatic conditions (poor visibility and rainy weather). As for the traffic type, the experts' panel considered that this factor is relevant in the same 25 possible referred combinations, and stated that the most unfavorable situations founded are related to the following situations: light traffic for activities in toll plazas and signage frames areas, congested traffic for emergency activities and normal traffic for all the activities.

These assumptions are all consistent with some research (Jianjun et al, 2013; Hayat et al, 2013), which stated that factors related to bad visibility, high velocity, low temperature, type of car occupation and type of traffic flow are relevant factors to the loss control of vehicles. However, another factor could be relevant for an optimized result that is not consider in this research. In effect, the number of repetition of the same working operations in the same activities on a motorway can change in some way the level of hazard exposition that the workers and drivers are subject to. This problem can only be solved by studying specific parts of a single motorway, situation that is not in the scope of this research. The types of factors versus activities can be seen in Figure 3.

Analyzing the remaining data, it is possible to see that there is a catalyzing effect that risks can produce namely between the factors associated with the loss of car control and the working maintenance risks. This effect had already been noted in a research by (Hadad et al, 2007). Another fact that is also possible to verify is the need of an intervention on the design phase, as Atkinson & Westwall (2010) suggest in his proposals, where he states there is an interaction between designers and contractors that must be followed with the intention of minimizing risks during the construction and maintenance phase of a motorway. In fact, some hazard level that has been detected can only be completely solved with another kind of options on design phase. The most paradigmatic example of this statement is the case of the toll plaza, where it's only possible to eliminate the running over risk with the construction of access tunnels or superior passages.

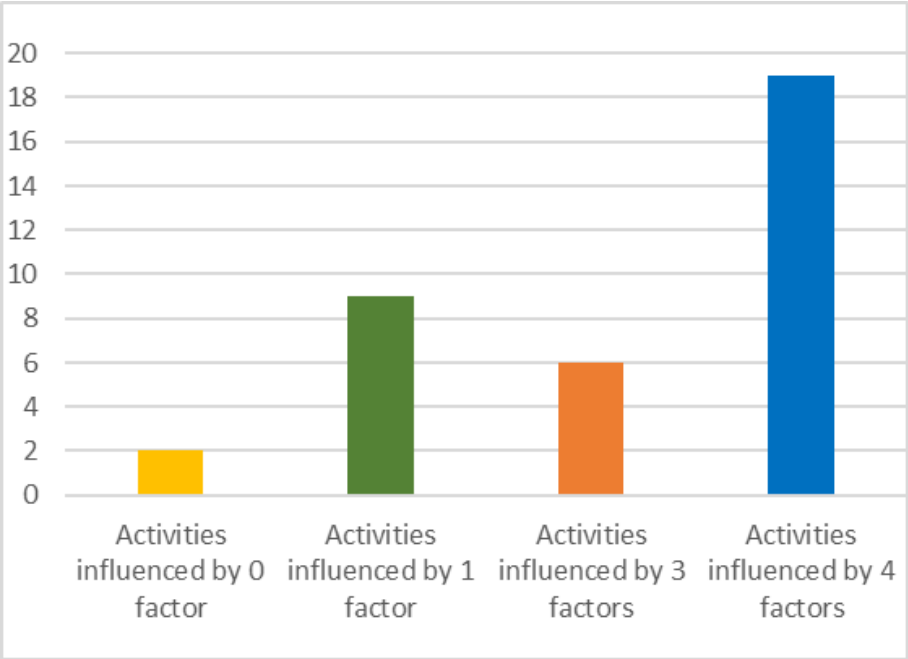

Figure 3 – The influence of factors versus activities

5. Conclusions

The research results show that almost all the scrutinized activities have at least one option factors included in the final group of the most dangerous activities. Only those included in the group of structural repairs on superior passages or support devices are not included in the final selected group. This outcome is quite conditioned by factors that are not only related to hazards from the civil works and traffic in operational motorways. As a clear example of this statement, it is possible to show the case of the emergency activities. It is a fact already stated in former researches (Prati & Pietrantoni, 2012) that the traffic impact in emergency workers is one of the main risks for this kind of activity. This conclusion is in line with the conclusions from the present research that shows that 22% of the most dangerous identified activities are connected with emergency teams' response. This group of activities is identified as the most numerous activities group in all the research. Another important conclusion that can be drawn from the analyzed data regards the type of road, traffic, weather and pavement on the motorway. More than 50% of the final selected activities are influenced by the conjunction of 4 factors and about 70% by three or more factors. This evidence proves that the global hazard level of the maintenance activities can only be properly analyzed with the incorporation of the hazards from the activities, as well as simultaneously with the hazards from the traffic and the motorway infrastructure. Another complementary conclusion came from the score level that the experts give to the same activities without the motorway and traffic factors. Only in two cases, access to working places on toll plazas and expansion joints repairs, the experts panel considered that the referred factors don't increase the dangerous level of those activities and concluded that whatever the kind of traffic, weather, pavement and/or motorway, all the risks level are the same. In all other selected activities and in 90% of the cases, every time that a factor is incorporated in the equation, the risk level increased substantially. As corollary point of the research, all the panel members agreed that the clear identification of the most dangerous activities are vital to make a correct integration of general prevention principles into the design and construction phase. This research

leads us to new challenges associated with this subject. Next steps are needed to increase effectiveness and efficiency in the level of H&S on motorways. After the identification of the 20% most dangerous activities, the next logical move is the identification of the 20% most dangerous risks, followed in the future by identification of the corresponding 20 % most efficient protection measures. This contribution aims at giving the first step on that direction.

References

Atkinson, A. & Westwall, R. (2010). The relationship between inte-grated design and construction and safety on construction projects. *Construction Management and Economics*. 28: 1007-1017. DOI: 10.1080/01446193.2010.504214.

Bergel-Hayat, R., Debbarh, M., Constantinos, A. & Yannis, G. (2013). Explaining the road accident risk: Weather effects. *Accident Analysis and Prevention*. 60: 456–465. DOI.org/10.1016/j.aap.2013.03.006.

Okoli, C. & Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & Management* 42: 15–29. Science Direct. DOI: 10.1016/j.im.2003.11.002.

Esmaieli, B. & Hallowell, M. (2013). Integration of safety risk data with highway construction schedules. *Construction Management and Economics*. 31(6): 528-541.DOI: 10.1080/01446193.2012.739288

Prati, G. & Pietrantoni, L. (2012). Predictors of safety behaviour among emergency responders on the. Journal of Risk Research. Vol. 15, No. 4. DOI:10.1080/13669877.2011.634519.

Hadad, Y., Laslo, Z. & Ben-Yair, A. (2007). Safety improvements by eliminating hazardous combinations. *Ukio Technologinis Ir Ekonominis Vystymas*. 13(2): 114-119. DOI: 10.1080/13928619.2007.9637785

Hallowell, M., Esmaieli, B. & Chinowsky, P. (2011). Safety risk interactions among highway construction work tasks. *Construction Management and Economics*. 29: 417-429. DOI: 10.1080/01446193.2011.552512.

Randson, D. & Boyd, A, (1997). The Pareto Principle and Rate Analysis. *Quality Engineering*. 10(2), 223-229. DOI: 10.1080/08982119708919129.

Skulmoski, H. & Krahn (2007). The Delphi Method for Graduate Research. *Journal of Information Technology Education* Volume 6.

Silva, J., Baptista, J. S. & Rodrigues, C. (2016). Use of effectiveness and efficiency concepts in occupational management on motorways: A systematic review. Occupational Safety and Hygiene IV – Taylor & Francis: 427-433. DOI: 10.1201/b21172-83.

Wu, J., Abdel-Aty, M., Yu, R. & Gao, Z. (2013). A novel visible network approach for freeway crash analysis. *Transportation Research*. Part C 36: 72–82. DOI: 10.1016/j.trc.2013.08.005.