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Safety management in the maintenance works on motorways through DELPHI methodology and Pareto's concepts

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Abstract

Several researchers have developed a thematic approach related with the need to improve safety management in the maintenance works on motorways in operation. The use of instruments linked to efficiency and effectiveness can be a possible solution for this challenge. The main objective of the present research is to prove the potential of identifying the main risky activities and safety measures contained in the A area curve linked to the Pareto´s concepts to show that these safety measures can reduce the risk level of the most dangerous activities. The selected methodology was a DELPHI panel formed by safety experts from different areas of road engineering. The statistic treatment was performed with the IBM SPSS Statistics 24 software. The results show that it was possible to identify the 38 most dangerous risks linked to the most dangerous activities and the 44 most efficient and effective safety measures to prevent/avoid those risks. This research concluded that (i) the risk level decreases with the adopted safety measures and (ii) the identified risk activities and the associated safety measures represent the A area from an ABC curve linked to the Pareto´s concept. These conclusions present an obvious relevance to the decisions about maintenance works on motorways.

1. INTRODUCTION

New risks are arising from the need to maintain motorways in operation combined with the traditional risks in the construction sector, exponentially increasing the hazards for both the workers and the users of these infrastructures. The use of effectiveness and efficiency tools can be one possible answer to this problem. In addition to the inherent risks associated with construction works or the activities that should be developed, the conditions related to external factors cannot be forgotten. The loss of control of vehicles caused by the different meteorological conditions, morphologic motorway factors, traffic type, pavement type and drivers' behavior are examples of some problems that should be considered when analyzing the risks that may affect the safety of workers. Different researchers have conducted several lines of approach to this thematic area. Silva et al. (2016) performed a systematic review of the relationship between effectiveness/efficiency and the management of Health and Safety (H&S) on motorways, considering the main critical factors on H&S risk analysis and revealing a lack of consistency in these topics. Hallowell et al. (2011) focused on finding the most dangerous places to work in these infrastructures. Nevertheless, the authors only took into consideration the activities of the construction phase, without the interference of other critical factors not related to H&S. Esmaieli and Hallowell (2013) analyzed the incompatibility and interference of construction activities on motorways, but once more without referring to other constraints. Finally, Silva and Rodrigues (2018) identified the main dangerous maintenance activities that can occur on operational motorways, identifying 36 activities as the 20% most dangerous. Considering the findings of the former research (Silva & Rodrigues, 2018), the main objective of this work is the identification of the 20% most dangerous risks related with the 36 identified activities and the 20% safety

measures, associated with general prevention principles that are most suitable to mitigate or eliminate risks. The second objective intends to prove the decrease in the level of risk of the most dangerous activities associated with these safety measures or general prevention principles.

2. LITERATURE REVIEW

The great variability and complexity of causes that produce work accidents on operational motorways are some of the most defying problems that health and safety professionals must deal with to ensure the safety of users and workers. To pursuit the outcome of zero serious or mortal accidents, different factors should be considered to conduct the necessary risk analysis. In addition to the inherent risks associated with the construction works or activities that should be developed, there are other conditions related to external factors that cannot be forgotten. Meteorological conditions, morphologic motorway factors, traffic type and conductors' behavior are examples of some problems that should be considered for risk analysis. However, there is an emerging challenge for all the organizations and particularly for those in the Health and Safety area. The decrease of allocated human and material resources is a reality affecting organizations, especially the ones in the areas that are not considered to be direct wealth generators. In this context, it is essential that health and safety professionals jointly with the scientific community provide an adequate response to all these problems. Previous research developed in this area is, in most of the cases, inadequate to the goals that must be achieved. Regarding these objectives, Gumpp et al. (2009) and Hu et al. (2011) developed new approaches to increase the effectiveness and efficiency of prevention measures. These approaches seek to minimize some of the main risks to the motorway workers, especially the ones associated with running over and falling from height.

Atkinson and Westwall (2010), in their research regarding the design phase and tender preparation, statistically validated an increased performance level of Occupational Safety and Health (OSH) associated with the interaction between designers and contractors. These authors also stated that a cause / effect evidence can only be verified if a statistical validated support is available. Nevertheless, this is a case study with only one enterprise and its validation cannot be generalized. This work also presents the top management commitment and the importance of safety requirements for hiring subcontractors and service providers as the main factors that influence the performance of an effective safety management system.

In another direction, Cameron & Hare (2008) remarked the need for reducing bureaucracy from the whole process of prevention planning. In this sense, the authors proposed an increase of relevant information regarding safety at work in the different documents that comprise the tender procedure, instead of the existence of an individualized Safety and Health Plan.

However, a few years later, and as result of a literature review, Zhou et al. (2013) noted the lack of consistent studies in OSH in construction works, related with the design and maintenance phases and the impact of new technologies on these areas.

Among the works previously mentioned, there are other works that were directly related with the concepts of effectiveness and efficiency. Aksorn et al. (2008) developed a methodology to assess the effectiveness of national OSH programs. This methodology was implemented in Thailand and was applied at a national level. However, it can be selected to measure the effectiveness and efficiency of safety management systems at the enterprise level. Other works deal specifically with the increase of effectiveness and efficiency of safety performance levels implemented in the construction and maintenance of highways. Esmaieli and Hallowell (2013) identified the most relevant activities through a panel of experts, suggesting an integration between a planning software tool and the concept of OSH in the planning stage. In this way, an increased danger due to interaction between activities will be avoided. Another methodology that uses a panel of experts was developed by Hallowell et al. (2011). In this case, the methodology was implemented to select the activities in highway construction that have incompatibilities with other works taking place in the same area. The activities that present a greater mismatch are construction on traffic control areas, excavation, and execution of flexible pavements.

To the best of our knowledge, there is a single work referring the incorporation of references to the existence of OSH management systems (Hallowell, 2010). The author clearly addressed and analyzed the different components needed for safety management systems. Nevertheless, it presents some risk of bias, since the study sample is represented by a single company. Other

works that should be remarked are the ones of Bonometti (2012) and Aksorn et al. (2008). These manuscripts referred the safety management systems considering only the components of accident analysis, planning, and implementation of training programs.

The new risk analysis methodologic approach proposed by Hallowell et al. (2008) revealed an interesting point of view. This approach links the catalyzing effect that risks can produce between themselves and shows the possibility of increasing OSH efficiency. An increased OSH effectiveness and efficiency in management methodologies through leadership and participation was also addressed by Bonometti (2012). The presented theory points in the direction of abandoning the traditional approach, made by procedures, and of the introduction of informal cognitive approaches. From the perspective of cost / benefit analysis, Hallowell (2010) addressed the components of workplace safety management systems in a generic way or even omitted. Except for Bonometti (2012), there is not any reference to the selection of resources and equipment to the safety area. Regarding the incorporation in the study of effectiveness and efficiency concepts and its interconnection with work safety in construction activities in motorways, only two articles provide consistency in this matter: Esmaieli and Hallowell (2013) and Hallowell (2010). Hayat et al. (2013) stated that factors related to bad visibility, high speed, low temperature, type of car occupation and type of traffic flow are relevant to the loss of control of vehicles. The scheme provided in the Figure 1 sums up the different approaches performed by the research included in this literature review.

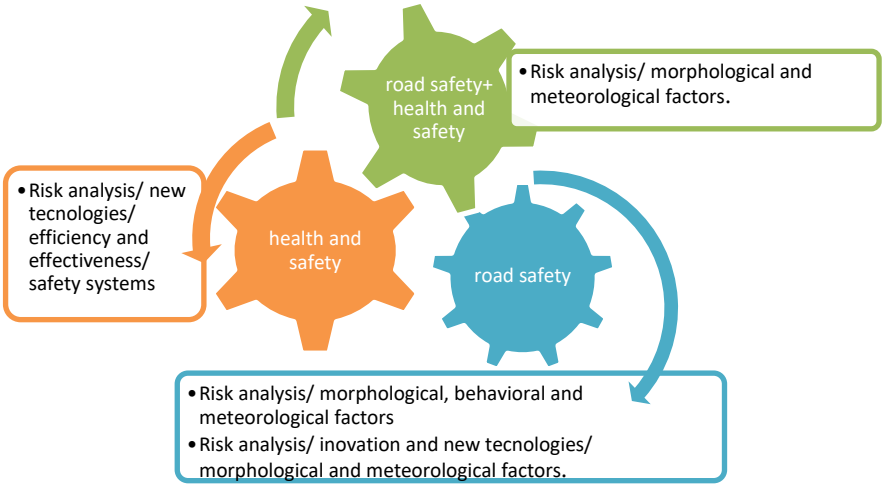

Figure 1. Research themes addressed

Based on these statements Silva and Rodrigues (2018) identified the 20% most dangerous activities and traffic factors that can increase the level of risk in maintenance operations in motorways, providing a valuable tool to identify what to do and how to do it in terms of Health and Safety. This work also proved that, besides the identification of the most relevant activities, risks and safety measures, there is a needed to identify the main internal and external factors that can make a difference at a risk level. In this sense, the current study was carried out bearing these goals in mind. Based on the work of Silva and Rodrigues (2018), the objectives of this research are the identification of the most dangerous risks and the most efficient and effective safety measures and general prevention principles that can be used for the reduction of the risk level in motorway works and the measuring of the reduction of risk in each identified activity.

3. MATERIALS AND METHODS

The research methodology implemented in this work is based on diverse items: a concept, a validated method and a computational tool. The fundamental concept is based on the Pareto's Principle, which states that 80% of events come from 20% of the possible causes (Randson & Boyd, 1997). If this Principle is applied to the topic under analysis, it means that 80% of the accidents are caused by 20% of all the activities. The next step consists in the selection of a validated method to be applied. Among the different available options, the Delphi methodology was selected. This methodology, developed by RAND Corporation after the Second World War, has the objective of achieving a feasible consensus among experts. Some authors consider this methodology as a valuable instrument to avoid conflicts among experts, to make predictions,

and to identify a hierarchy of variables with relevance to the research (Okoli & Pawlowski, 2004). Other authors consider this methodology as the most appropriate to "investigate what does not yet exist" and suitable to be applied in PhD theses (Skulmoski et al, 2007). This method requires the production of inquiries that must be answered by the experts. Okoli and Pawlowski (2004) suggested the adoption of the Kendall's coefficient, considering a minimum threshold of 0.7 to obtain consensus among the experts. When this value is not achieved, the experts receive statistical information for each question, namely the median, the average, the mode, and the 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 a consensus.

Another issue that must be carefully handled is related to the selection of the panel of experts. According to 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. In this sense, to ensure the success of the methodology, the following steps should be performed: (i) elaborate an identification matrix of experts, (ii) select the experts (iii) identify additional experts, (iv) define the experts' hierarchy level, and (v) make a formal invitation to the experts. Thirteen experts were identified through this procedure, all of them with complementary experiences in the area of Health and Safety. The experts were contacted by email. Each expert does not know the identity of the other experts. The professional areas of the experts are shown in Figure 2.

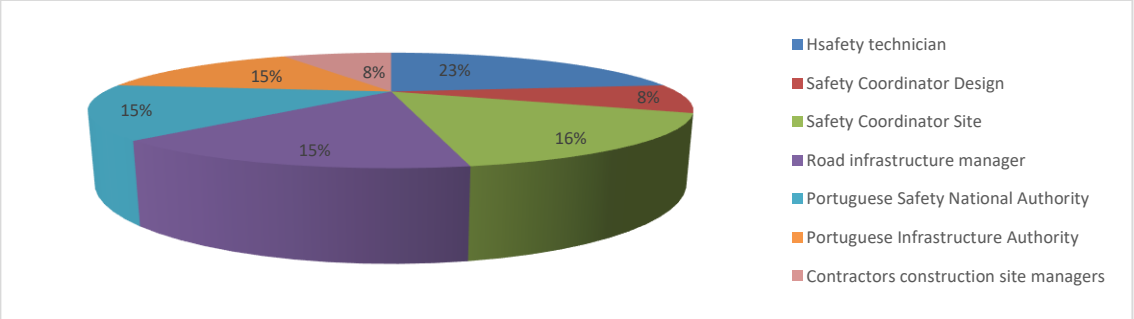

Figure 2. Experts' Areas

The members of the Delphi panel accomplish with the following requirements: minimum of 15 years of work experience in motorways safety, belonging to different professional groups and geographic areas and possessing diverse perspectives of the safety problematic. The experts where select among the members of the safety college of the national engineer's association, the national safety authorities with experience in the field, and the contractors working in this area. In this study, the initial assumptions were based on the research by Silva & Rodrigues (2018), who identified 36 activities as the 20% most dangerous. The group of experts work in a geographic area that comprehends about 51% of the Portuguese motorway network, with near 1400 Km. This ensures that the experts are familiar with motorways with all the possible characteristics in Portugal, meaning that the obtained results can be transferred to the remaining network. In the elaboration of the Delphi inquiry, questions of possible double interpretation, ambiguous, or dealing with more than one subject were avoided. The questions were made to originate direct responses, with no need to provide elaborate responses. To reach a consensus among the experts, it became necessary to carry out one round for the first inquiry and two rounds for the second one. The consensus was assessed through the achievement of a minimum Kendall's coefficient of 0.7, computed using the software IBM SPSS Statistics 24.

4. RESULTS

In the first inquiry, the Delphi panel was questioned about the influence of the possible risks on the activities, particularly related to the location of the activities. The panel was also asked to select the most efficient safety measures and general prevention principles to mitigate or eliminate those risks. In this sense, the Delphi Panel identified eight locations more prone to risks, as shown in Figure 3.

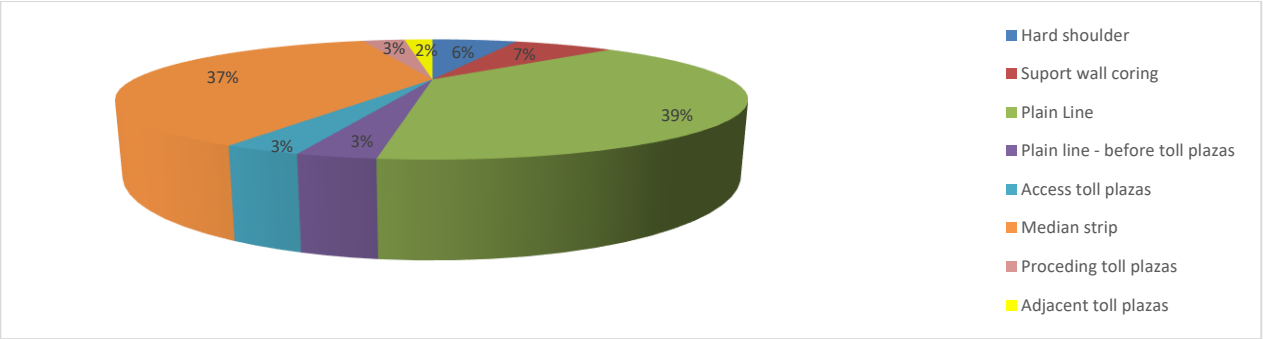

Figure 3. Location of risks

It is possible to observe that 76% of the risks are related to only two locations: plain line and median strip. The number of risks in each activity shows the distribution and importance of each one. The distribution of possible accident events associated with each type of risk can be seen in Figure 4.

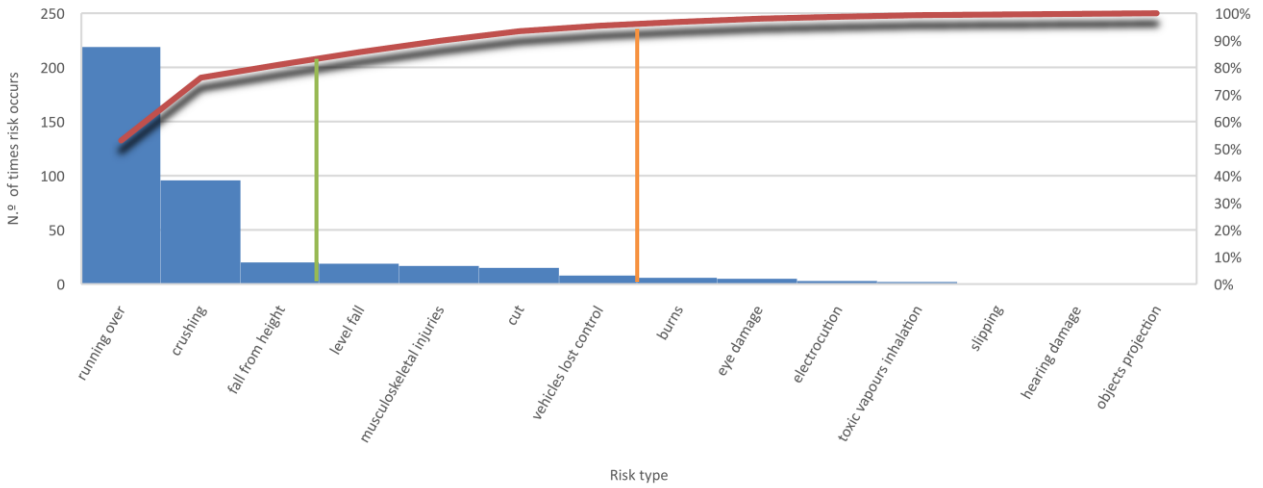

Figure 4. Pareto's distribution of risks

Figure 4 shows that 21% of the risks, specifically running over, crushing and fall from height, are associated with 81% of the possible accident events. Concerning the possible applicable safety measures, the Delphi panel identified 52 types of them. The measure that was more frequently referred by the experts is to use protecting and signaling vehicles.

The goal of the second inquiry was to find the 20% most dangerous risks related to activities previously marked as the most dangerous and identify the 20% most effective and efficient safety measures and general prevention principles associated with the same activities. The Delphi panel identified 38 risks as the most dangerous. From Table 1, it is possible to observe that 20% of the most dangerous risks are associated with almost 90% of the cases related to the risk of running over, followed by the risks of crushing and falling from height. Additionally, the members of the Delphi panel considered 44 safety measures and general prevention principles as efficient and effective. More than 25% of the suggested safety measures are related to repairs on safety guards, followed by repairs on expansion joints and emergency activities. Regarding the hierarchy of danger for each risk, the relations with each activity and with the hierarchy of the associated safety measure are presented in Table 1 (first 10 results).

Table 1. Risks and safety measures hierarchy and relationship

Rank safety measures/rank risk	Risk more dangerous/activities description	Safety measures more efficient and effective
1/1	Running over - Access to working places through electronic toll "green way" at toll plazas.	Creation of tunnels and upper passages to access the workstations
2/14,16,26	Running over – pavement ripping, and pavement works without traffic diversion (motorway with two lanes or more in the same direction).	Dragging traffic by means of authorities' vehicles
3/1,2	Running over – Access to working place through electronic toll "green way" at toll plazas.	Interdiction of crossing nonstop lanes at toll plazas
4/4,6,9,10,12,15,18,25,29,31	Running over- Motorway emergency activities in car accidents (motorway with two lanes in the same direction).	Dragging traffic by means of authorities' vehicles
5/30	Fall from heights – Working repairs on ditches and drains above support concrete walls with 2m or more.	Placing guards/nets on top of support walls.
6/7,8	Running over- Cleaning or repairing works before the toll plaza and near the new jersey median strip or in the plain lane.	Closing lanes on motorway with a protection and signaling vehicle, with a shock absorber stationed before the closing lane.
7/3,5,28	Running over - Cleaning, cutting and deforestation on the median strip, with only a new jersey.	Closing the roadside in the median strip and closing or narrowing the adjacent lane on motorway.
8/17,19,21	Running over- Expansion joints repair works on motorways with two lanes or more and narrow hard shoulder.	Closing the hard shoulder and closing or narrowing the adjacent lane on motorway.
9/14,16,26	Running over- Pavement milling and pavement works without traffic diversion (motorway with two lanes or more in the same direction).	Placing protection and signaling vehicle, with a shock absorber stationed before the closing lane.
10/23	Running over– Signaling assembly and disassembly works in construction works support on the median strip with only a new jersey	Dragging traffic by means of authorities' vehicles.

The distribution of the selected safety measures by type of activity and by location is presented in Figures 5 and Figure 6, respectively.

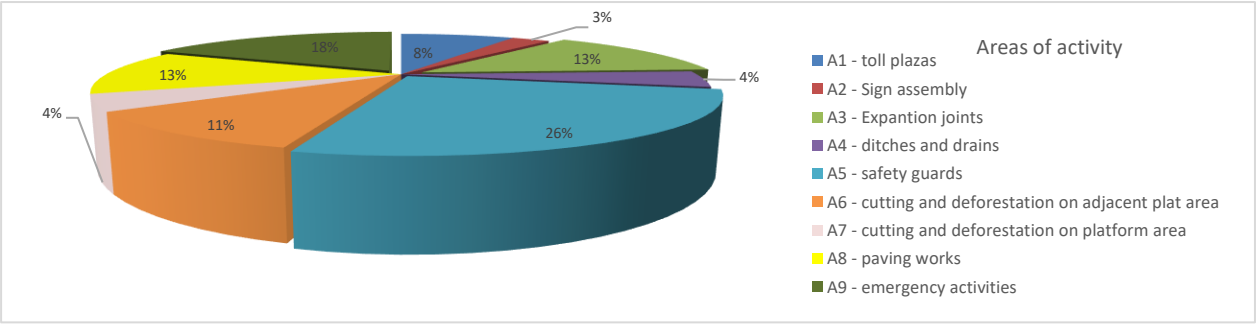

Figure 5. Safety measures by activity

From this analysis, it is possible to conclude that almost 78% of the safety measures that present a higher possibility/level of efficiency and effectiveness are associated with two locations: plain line and median strip. More than 81% of the safety measures are associated with the risk of running over, followed by the risks of crushing and falling from height. The indexation of the general prevention principles to the safety measures reveal that, for all activity areas, more than 65% of the principles associated with the most efficient and effective safety measures are linked to the domains of conception and organization, particularly in the case of the most dangerous activities.

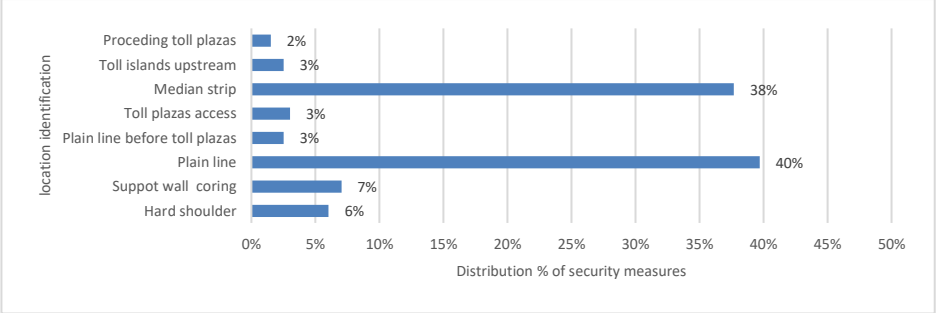

Figure 6. Safety measures by location

Overall, more than 65% of the general prevention principles are associated with the organization and/or the design of the work site or the infrastructure. The general prevention principles that were considered associated to work conception and organization can been seen on the Table 2.

Table 2. General prevention principles associated to work conception and organization

General prevention principles number	General prevention principles description
P2	Plan prevention as a coherent system that integrates technical evolution, work organization, working conditions, social relations and the influence of environmental factors.
P3	Identification of foreseeable risks in all activities of the company, establishment or service, in the design or construction of facilities, workplaces and work processes, as well as in the selection of equipment, substances and products, with a view to their elimination or, infeasible, to reduce its effects on.
P4	Integration of the assessment of the risks to the health and safety of the worker in the whole of the activities of the company, establishment or service, and to adopt appropriate measures of protection.
P5	Fighting against risks at their source to eliminate or reduce exposure and increase protection levels.
P7	Adapting work to man, regarding the design of workplaces, the choice of work equipment and working and production methods, with a view to reducing monotonous work and repetitive work and reducing psychosocial risks

Some deviations from this result were obtained when an individualized analysis by area of activity was established, while maintaining the concepts of organization and design in all areas of activity. It is also inferred that this type of general prevention principles has a higher prevalence in the area of sign assembly words, with more than 86% and safety guards, with more than 75%. The area where these principles have a lower predominance is associated with the trenches and drains, with a value close to 50%, Figure 7.

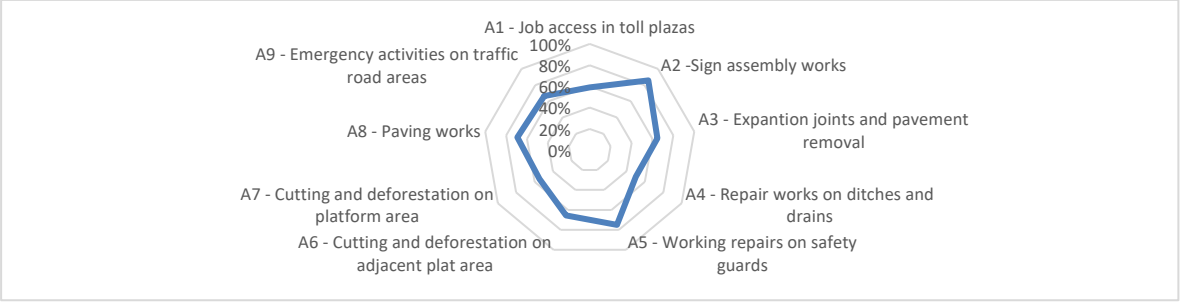

Figure 7. General prevention principles and associated to the work conception and organization

In the second inquiry and after two interactions, the Delphi panel considered that the risk level decreases with the adopted safety measures and general prevention principles for all the

evaluated situations. This was also a main objective. The decrease of the risk level in each activity can be seen in Figure 8.

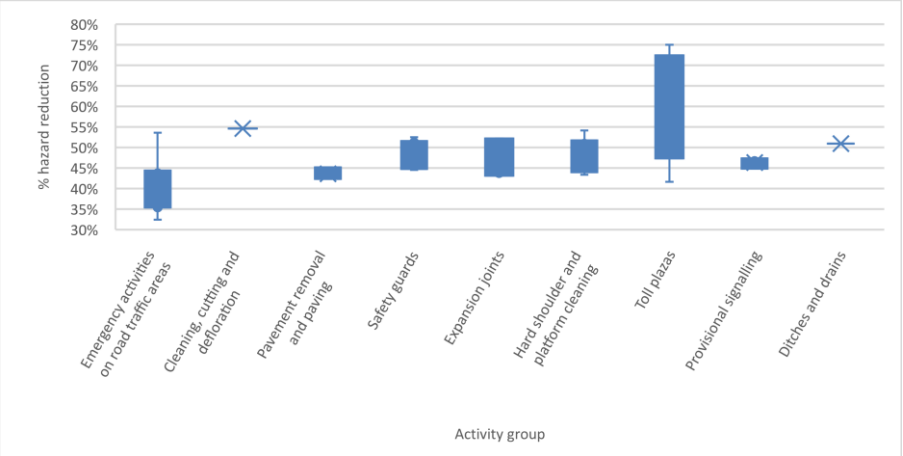

Figure. 8. Reduction of the activities risk level after the adoption of proposed safety measures

After the adoption of the safety measures, the activities that revealed the highest reductions of the risk level are related with toll plazas, followed by hard shoulder and platform cleaning and cleaning, cutting and defloration, emergency activities on road traffic areas, safety guards and by expansion joints. The activities with the smallest reductions are ditches and drains, provisional signaling and pavement removal and paving. In relation to the locations where the activities are conducted, Figure 9, shows where the safety measures associated with identified risks can be more efficient and effective.

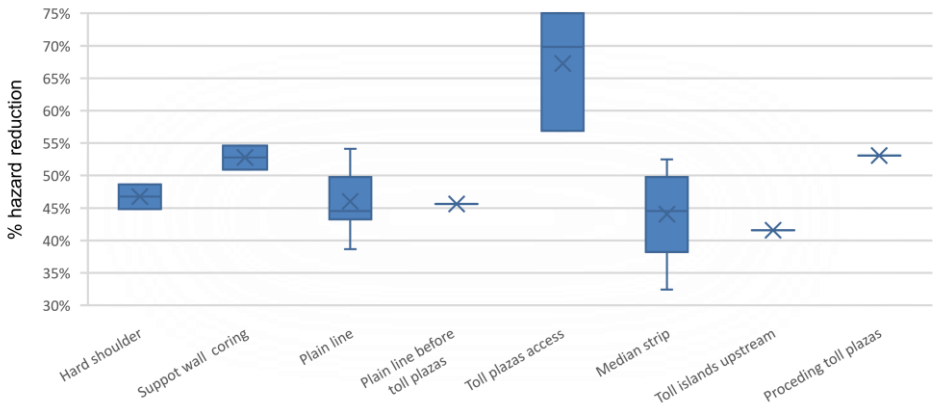

Figure. 9. Reduction of the activities risk level after the adoption of proposed safety measures

The accesses to toll plazas are the locations with the highest rate of success in the reduction of the risk level activities, followed by the coring of support walls. On the opposite side, the lowest success in the reduction of the risk level is obtained at the median strip, the plain line, and the hard shoulder.

5. DISCUSSION

The obtained results related with the risks for traffic flow are in agreement with the works of Hayat et al. (2013) and Wu et al. (2013). In both cases, extreme weather conditions are important for a possible loss of vehicle control. There is a clear consensus in the Delphi panel that the most dangerous situations are related with running over, crushing and level fall, in agreement with the results presented by Pantelidis (2011) and Hu et al. (2011). The impacts of the identified risks on the most dangerous activities are represented in Figure 10.

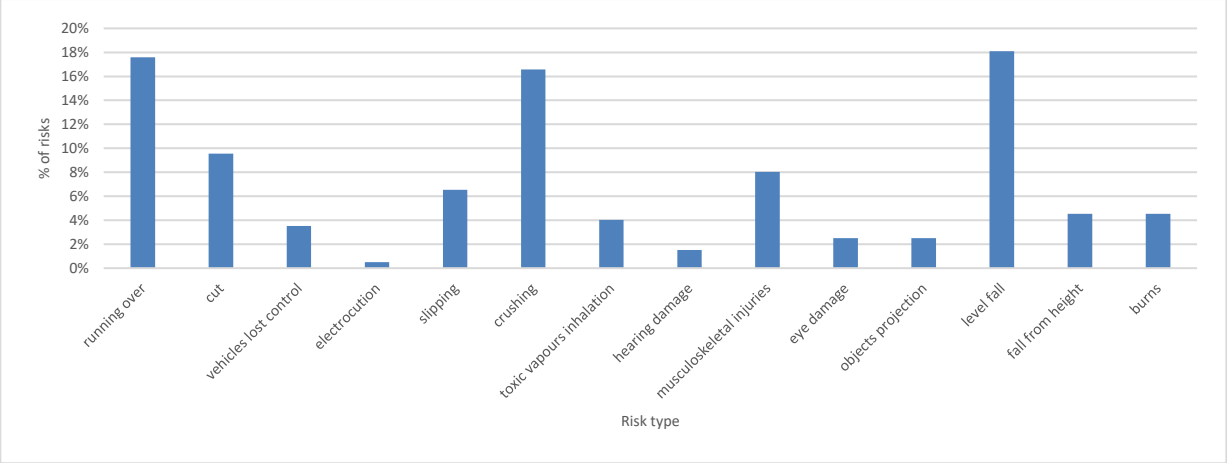

Figure 10. Risk influence on the most dangerous activities

Many of the activities concerning the risks of running over and crushing are directly linked to repairs on pavement and safety guards, access to work sites and emergency activities. In this line, Prati and Pietrantoni (2012) mentioned the difficulty of planning and implementing appropriated safety measures in the presence of psychosocial factors in the case of emergency workers.

Cameron and Hare (2008) remarked the need of safety integration on design phase taking in consideration all the different possible aspects that an operating motorway can present, such as the access to work sites and the repairs in the median strip or in plain line. In many cases, some risks could be avoided in future maintenance works if the designer produced a different type of layout at the toll plazas or had a different approach through a dialogue with maintenance contractors and owners, (Atkinson & Westwall, 2010). As an example, a different median strip layout can mostly avoid the risk of running over and crushing. All the suggested safety measures are essentially linked to the concepts related with the conception and organization of work sites. Figure 11 shows the distribution of the risks associated with the most dangerous activities by type of safety measure.

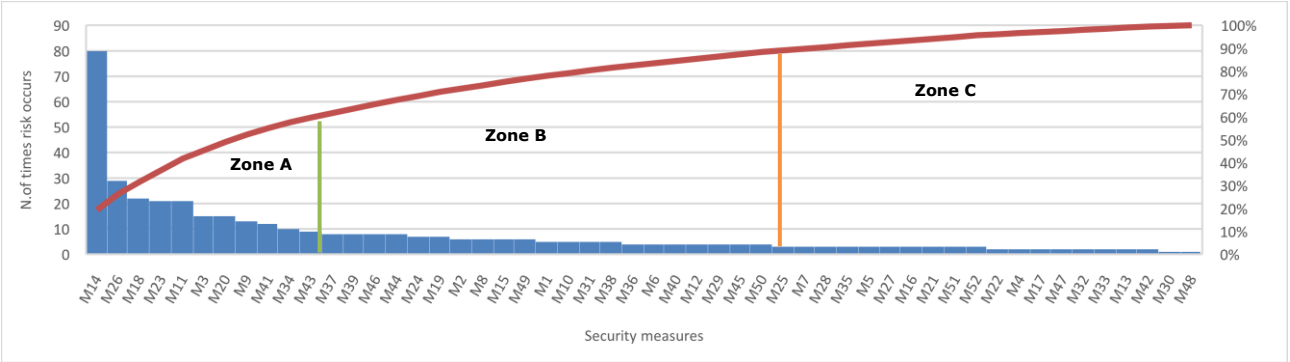

Figure 11. Safety measures and their application to the risks

It is possible to identify the A area from the ABC curve linked to the Pareto's concepts, where 21% of the safety measures are related with 60% of the possible applications.

The safety measures included in the A area are: M14 – Protection to workplace with a signaling vehicle with a shock absorber, M26 - Workers training, M18 - Distance between the protection vehicle and the workplace , M23 – Speed reduction, M11 - Closing the hard shoulder and closing or narrowing the adjacent lane on motorway, M3 - Dragging traffic by means of authorities vehicles, M20 - Delimitation of the work zone with flat cones and delimitation lines , M9 - Design of pathway rules with minimum visibility distance and vigilance, M41 - Traffic zone signaling , M34 - Sign assembly of Warning signs of work to traffic, M43 - Safety non-slip footwear.

The work planning and phasing are key concepts for the intervention in work sites. This is demonstrated by the obtained results, being one of the most important safety measures associated with general prevention principles in the areas of work conception and organization. The results also show a catalyzing effect between the risks associated with the loss of vehicle control and with maintenance works. This effect has already been noted by Hadad et al. (2007) and is one of the reasons why the experts pointed out the supervision of the work sites and the traffic dragging by the authorities, the closing of lanes where works are taking place, and the

creation of adjacent lanes as fundamental factors to avoid the risk of running over and crushing. Only safety measures M26 and M43 are not included in the referred categories. About the risk of falling from height, it can be partially solved by adopting safety guards and nets in the design conception.

The road assistance activities incorporate 27% of the application of the general prevention principles, followed by the activities of security guards with a value of 23%. This situation shows an opposite behavior of the one detected in the analysis of safety measures. This can be explained by the fact that the safety measures applicable to road assistance incorporate a greater number of general prevention principles, which is also noticeable due to the enormous danger and complexity of the tasks associated with this area. The analysis also reveals a non-uniform distribution of the general prevention principles by activity areas, as it can be seen in Figure 12, where three levels of general prevention principles are present.

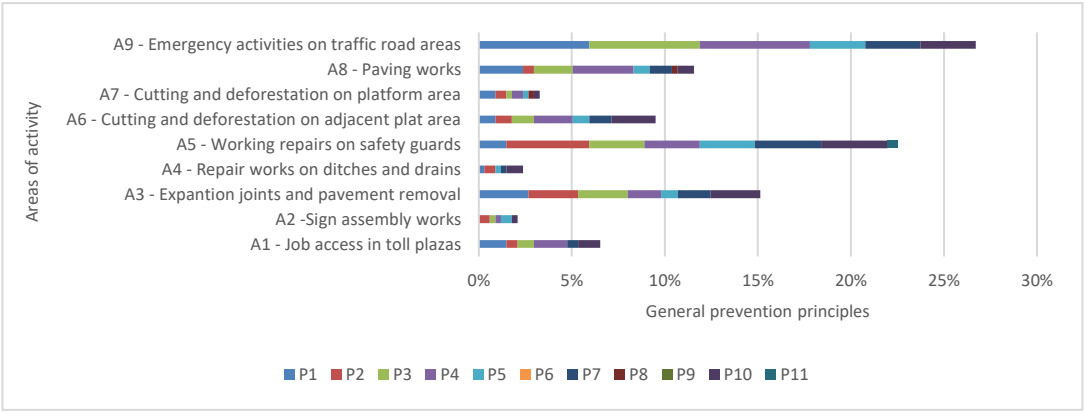

Figure 12. General prevention principles distribution associated with the most dangerous activities

Analyzing the association of the general prevention principles with the most effective and efficient safety measures, it was verified that approximately 70% of the principles are associated with the areas of design, infrastructure works, or work planning. The way these principles affect each safety measures is represented by Figure 13.

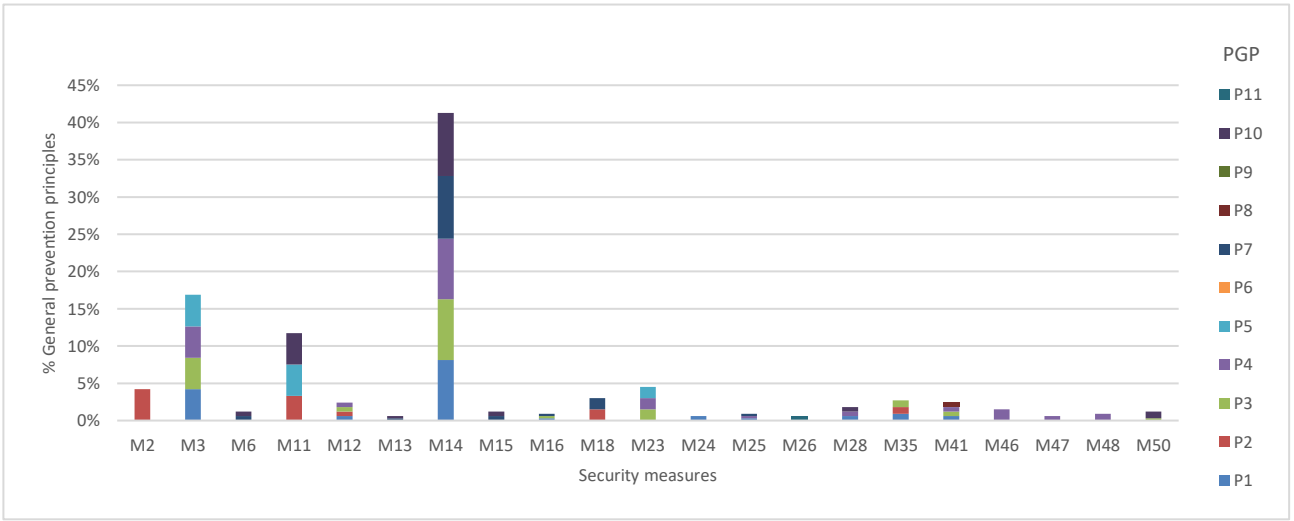

Figure 13. General prevention principles distribution associated to the safety measures

The safety measure M14 (Placement of protection vehicles and signaling) integrates a larger number of applications in the global universe in which the most effective and efficient safety measures are used. This measure reaches the value of 41% of the total applications. It is seconded by safety measures M3 (Traffic by authorities' vehicle), with 17%, and M11 (Interdiction the lane or adjacent lane or narrowing the lane or the hard shoulder), with 2%.

All these safety measures are related with the various situations of running over and crushing risk associated with the most dangerous activities. It was also verified that around 15% of the safety measures cover 56% of the situations of use of general prevention principles for risk mitigation.

From a different perspective, Figure 14 shows the relation between general prevention principles

and risks.

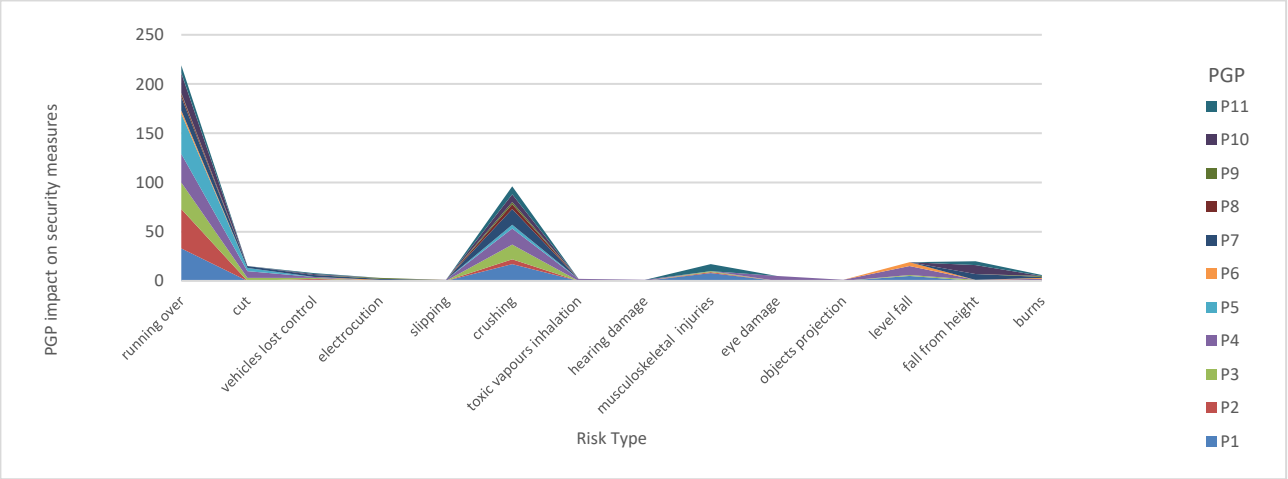

Figure 14. General prevention principles distribution associated to the risks

The analysis shows that R1 (running over) requires a greater number of combinations of general prevention principles to achieve an effective and efficient control. R6 (crushing) is also highlighted, followed by R13 (fall from height) and R12 (level fall). These results comply with the relevance of the risks in relation to the activities. It was found that the most common risks associated with the most dangerous activities are running over, crushing and falling. The results also show that only an assertive combination of general prevention principles can mitigate or eliminate the risks associated with the different activities. Concerning the number of general prevention principles required to eliminate or mitigate risks in an efficient and effective way, it was found that R1 (running over) and R6 (crushing) required the use of all these principles to achieve this goal.

6. CONCLUSIONS

The Delphi panel selected in this research to evaluate all the possible combination of risks was able to identify 20% of the most dangerous risks associated with the most dangerous activities. This represents the identification of 38 risks, consisting mainly of running over, crushing, and falling from height, occurring under adverse weather conditions.

The location of the identified risks is mainly associated with the median strip, plain line and top of sup-port concrete walls. According to the Delphi panel, these risks represent more than 80% of the most dangerous risks in all the possible situations. Concerning the relationship with the type of activities, it was possible to demonstrate that more than 30% of the identified risks are related to emergency activities. This fact was already stated by Prati and Pietrantoni (2012), who claimed that the traffic impacts on emergency workers is one of the main risks for this kind of activity. The results presented in this manuscript allowed to identify the A area from the ABC curve associated with the previously reported risks. Regarding the safety measures and their associated general prevention principles, the Delphi panel agreed on a list of 44 measures that represent 20% of the total amount of efficient and effective safety measures considered. These measures deal essentially with the supervision and traffic dragging by the authorities, the lane closing at work sites, and the implementation of safety guards and nets at the top of support concrete walls. The working area that needs a bigger combination of safety measures and general prevention principles to reach an acceptable level of efficiency and effectiveness is associated with the emergency response and the repair of safety guards, especially in the presence of running over and crushing risks.

Another relevant conclusion obtained in the present work is related with the type of safety measures and general prevention principles chosen by the experts of the Delphi panel. In their opinion, the measures and principles related with conception, planning and organization have higher efficiency and effectiveness in relation to other options. The inherent difficulty of planning emergency activities in an acceptable time and the lack of a suitable design of the infrastructure are challenges that the technical and the scientific community must address. This work demonstrated a substantial decrease, between 32% and 75%, in the hazards presented by most of the dangerous activities associated with the combination of suggested general prevention principles and safety measures.

Future research should include the quantification of risk exposure for workers, linked to the morphology of the motorway, the sinuosity of curves, grade, and the type of tunnels and viaducts. Another area that could also be pursued is the incorporation of the need for different interventions in the motorway maintenance plan, according to its age and the criteria of preventive maintenance. This research should measure the number of preventive and corrective interventions to estimate the time of exposure of the workers to the risks. Concerning new technologies, future works could include the study of the interaction between automated vehicles and the restrictions associated with interventions on the road infrastructure.

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