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Occupational Risk Index for the Assessment of Risk in Construction Work by Activity

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Abstract

The concern for occupational health and safety in construction work is reflected in the many preventive measures taken. However, examples of the systematic assessment of project alternatives aimed at minimizing occupational hazards are rare. This paper proposes a measure of occupational safety (Occupational Risk Index, ORI) that is based solely on the project design and resulting construction process and is a function of the activities carried out and their specific occupational risk (probability and consequences of occurrence). The ORI can thus be used as an indicator to feed multi-criteria decision-analysis tools. The proposal is illustrated with a simple example in which two alternatives (one precast and the other constructed *in situ*) are prioritized in terms of occupational safety, and certain aspects related to redesign are briefly addressed. With the ORI, occupational safety goes from having a passive influence (application to projects that have already been designed) to an active one (influence on the design concept itself) in the design stage of construction projects. The research is based on an analysis of the applicable legislation and interviews with experts.

Keywords: Risk management; Safety; Construction management; Assessment; Occupational Health; Occupational Safety; Design.

Introduction

Occupational safety is one of the most important social aspects of construction work. However, unlike other issues addressed in the decision-making stage of project

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management, it is usually considered only after completion of the design (Seo and Choi, 2008).

In this paper, we combine multi-criteria analysis methodologies for decision-making in project management with an assessment of the occupational risks inherent in certain construction activities. The aim is to enable the consideration of occupational safety criteria from the very start of the design process.

To this end, first, the main risks associated with different construction activities are analyzed. Next, an Occupational Risk Index (ORI) for construction work is defined, calculated as the sum total of the workload for the risk activity weighted by its relative risk. The workload for each risk activity is calculated as the total number of working hours spent on it. The relative risk of each activity is calculated based on the probability of occurrence of the risk and the likely severity of its consequences. This is followed by a brief discussion of different methodologies for supporting decision-making in the context of project management. The discussion shows how application of the ORI would integrate occupational safety criteria into the selection of design alternatives for construction work. An example of how to obtain the ORI for two different construction alternatives is presented at the end of the paper.

Main Occupational Risks Associated with Construction Activities

The methodology used in this study falls within the framework of generally accepted risk management schemes (Perry and Hayes, 1985; Cooper and Chapman, 1987; Tah and Carr, 2001; Ahmed et al., 2007) and consists of the following steps: establishing the context, identifying the risks, analyzing the risks, evaluating the risks, and treating the risks. Therefore, once the occupational health and safety context has been established for a given construction project, finding and grouping the relevant risks posed by the different construction activities is the next step toward developing a model. To this end, this study first analyzed relevant European and Spanish legislation, technical guides, and other supporting documents applicable to the health and safety of construction site workers. An initial round of interviews was then conducted with three panelists (health and safety experts). Finally, three additional panelists reviewed the resulting list of risks and activities. All six panelists qualified as experts according to the criteria suggested by Hallowell and Gambatese (2010). Moreover, one had extraordinary expertise, having been informed of and investigated most construction accidents occurring in Catalonia (a region of Spain with a population of 7.6 million and an area of 32,000 km^2) over the last 40 years.

As a result of this process, it was concluded that the main health and safety risks found in construction work and its associated activities to be included in this methodology were as follows (Risk - Activity):

1. Falls to lower levels – Work at heights or depths of more than 2 meters.
2. Direct or indirect electrical contact – Electrical work, work in proximity to power lines, and work with electrical equipment under wet conditions:
    2a. Electrical work on overhead power lines or other unprotected live elements (work in the hazardous area).
    2b. Work in proximity to overhead power lines or other unprotected live elements.
    2c. Work in proximity to live underground power lines.
    2d. Work with electrical equipment under wet conditions.
3. Burns caused by fire or explosion due to a ruptured pipeline - Work close to fuel pipelines.
4. Gas inhalation – Work near gas pipelines.
5. Entrapment and subsequent suffocation due to a landslide – Earthmoving, excavation, shafts, underground work and tunnels.

6. Particle projection and accidental explosion – Blasting for excavation, shafts, underground work and tunnels.
7. Decompression sickness – Work under hyperbaric conditions.
8. Collision with or entrapment by a moving load due to its movement or detachment – Mechanical load-handling.
9. Blows to upper and lower limbs – Manual load-handling.
10. Collision with or running over by heavy equipment or heavy goods vehicles – Work with heavy equipment or heavy goods vehicles.
11. Cuts, blunt trauma and other injuries due to light equipment – Work with light equipment.
12. Burns – Welding.
13. Injury due to the impact of falling objects and projectiles – Manual, mechanical or explosive demolition; shot-hole drilling prior to the blasting of a cut slope and the subsequent cleanup and field survey.
14. Acute dust and toxin poisoning – Manual, mechanical or explosive demolition of structures or buildings in general and of hospitals, factories, slaughterhouses or any other place that may contain toxic substances in particular.
15. Suffocation or poisoning in confined spaces – Work in confined spaces.
16. Drowning – Work in areas at risk of flooding.
17. Collision with or running over by vehicles unrelated to the construction work – Work in areas with traffic unrelated to construction work.
18. Traffic accident – Transport of equipment and materials to the construction site.
19. Structural risk or macro risk – Complex operations or structures.
20. Same-level falls – All types of work.
21. Heat stroke, cold-related injuries and sunburn – Outdoor work under adverse weather conditions.
22. General increase in accident probability – Night work or work in reduced visibility conditions.

The following occupational diseases were also taken into consideration in the analysis:

23. Back injuries – Manual load-handling.
24. Joint and bone diseases – Work involving exposure to mechanical vibrations.
25. Deafness – Work involving noise exposure.
26. Decompression illness – Work under hyperbaric conditions.
27. Illnesses caused by asbestos – Work involving possible exposure to asbestos.
28. Illnesses caused by ionizing radiation – Work with equipment that generates ionizing radiation.
29. Silicosis – Work that produces high concentrations of silica dust.

The legislation, technical guides and other documents used to assemble the above list and classify the risks are listed in the “Supplemental data” section of the online publication.

The final methodology takes into account the risks associated with activities 1 to 19 above. The risks associated with 20, 21 and 22 have not been included for the following reasons:

- (20) Same-level falls – All types of work.

  Same-level falls can occur in any activity involving the movement of people and materials. They are mainly due to a lack of order and cleanliness and also to human behavioral factors and personal issues that are difficult to control. For these reasons, the methodology does not consider this risk.
- (21) Heat stroke, cold-related injuries and sunburn – Outdoor work under adverse weather conditions.

  The environmental conditions of a workplace (temperature, wind speed, humidity and radiation), along with the intensity of the work and the clothing used, can pose a risk to workers’ health known as heat stress. Heat stress can be caused by heat or cold, and certain individual characteristics can increase the risk. Because of the variability of the weather, the inability to accurately forecast it well in advance, and the influence of personal conditions on the occurrence of the risk, the methodology does not take this risk into account.

- (22) General increase in accident probability – Night work or work in reduced visibility conditions.

  The consequences of a night accident are the same as those of the same accident during the day. However, the night accident may be more likely to occur due to the overall lack of visibility at the construction site. Even when floodlights are provided, there are dark areas where risks may not be perceived as well as in daylight conditions. As the exact increase in the probability of the occurrence of accidents due to night work is unknown, this factor cannot be assessed.

Because it is not possible to assess the likelihood of contracting an occupational disease from exposure to a single instance of construction work, occupational diseases (risks 23 to 29) were likewise excluded from the final methodology. Most of these diseases are not the result of a single exposure to the cause, but rather of prolonged exposure, and they are moreover influenced by the personal characteristics of each worker.

Definition of the Occupational Risk Index (ORI)

The ORI is a measure of the risk involved in a given construction project that depends on the volume and type of activities performed (equations [1] and [2]). It is calculated as the total amount of work to be devoted to each risk activity (*i*), weighted by the importance of the associated risk (W_i, obtained as stated below):

$$ORI_i = W_i \cdot person - hours_i \qquad [1]$$

$$ORI = \sum ORL_i \qquad [2]$$

This indicator depends on the activities and scale of the construction project and can thus be calculated as soon as the project has been defined. Other authors (Seo and Choi, 2008; Sun et al., 2008; Rajendran and Gambatese, 2009) have studied the safety of construction projects based on the different health and safety measures or strategies used by the contractor. The methodology described in this paper assumes that the contractor will take all the health and safety measures specified in the project design and required by law and focuses instead on the construction project's design. It can thus be calculated prior to the contract's award, making it possible to compare different design alternatives. Indeed, the specific objective of the ORI is to introduce the concept of occupational safety at the design level.

Tam et al. (2002) applied multi-criteria methodologies to decision-making on health and safety strategies. They too took the design as a starting point, but not as a concept that could be influenced to improve working conditions. Akintoye and MacLeod (1997) studied risk management in construction projects. While they did not consider the possibility of influencing the design to improve occupational conditions, they did note one aspect that we consider relevant: the lack of familiarity of construction industry professionals with risk analysis methodologies. This notwithstanding, in an in-depth 1996 study of risk management in the construction industry, Jaselskis et al. suggested that occupational risk management expertise can be found among construction industry professionals. However, the individuals who have it are generally involved in the project management, rather than design, team.

Some authors (Armengou et al., 2012) have applied the concept of occupational safety to the process of selecting alternatives. However, due to the lack of an occupational safety index or similar indicator, they had to assign a safety level to each alternative without the use of a tried-and-true method.

The Appendix describes a method for calculating the person-hours spent on each activity that can also be used by non-experts in health and safety. It is worth noting that the calculation includes the person-hours spent by both direct and subcontracted employees on all risk activities. It also includes those spent on the rerouting of services or any necessary modification work carried out by utility companies, fuel companies, etc., due to the execution of the work.

The following step corresponds to the risk analysis (Perry and Hayes, 1985; Ahmed et al., 2007). In order to assign a relative importance to each risk activity (W_i), a qualitative assessment was conducted of the most probable severity or consequence of a potential accident, and a numerical value was assigned (Table 1). Likewise, a qualitative assessment was conducted and a numerical value assigned to the probability of an accident happening given the risk activity (Table 2). The importance of each type of risk was obtained by multiplying the accident's consequences by its probability. The ratings used for risk calculation in Tables 1 and 2 have been adapted from Fine (1971), with some adjustments. The economic consequences are not shown in Table 1, as they are obviously not the focus of the research. The lowest probability rating (a virtually impossible sequence that has never happened, rating 0.1) was also excluded, both because it was not considered significant for the aim of the study and because the next highest rating (which has also never happened but is conceivable) has a very similar meaning. The consequence ratings are much higher than the probability ratings because an extremely severe risk with a low probability of occurrence should be given more weight than a probable minor injury.

The assessment of the likelihood and consequences of each risk was calculated as the average of the assessments made by three occupational health and safety specialists who qualified as experts according to the criteria established by Hallowell and Gambatese (2010). An initial round of assessments was conducted with an extraordinarily experienced expert. A second round was conducted with two other experts, who were aware of the answers from Round 1. A third and final round was conducted, once again, with the extraordinarily experienced expert, who reviewed the answers from Round 2. As a result of the third round, an assessment of the consequences of Risk 5 in the case of underground work and tunneling was discarded because it did not reflect current technology and safety measures in construction work. For the remaining assessments, a consensus was reached, and the deviation was bounded. Table 3 shows the resulting values (C: numerical assessment of the consequences; P: numerical assessment of their probability; and PxC: product of these values or "weight"), as well as the "standardized weight," calculated by dividing the weight of each risk by the highest possible weight (1000).

However, the probability of occurrence of an accident and of certain consequences can vary depending on how technologically developed a given region or company is and the approach taken to preventive measures. The probability assessment shown in Table 3 is a guidance value and may not apply in all cases. It is up to the local health and safety experts to determine whether these coefficients are applicable to their region given its technology and safety management practices and, if not, to assess the new probability of occurrence of an accident for each risk. To that end, we recommend following the Delphi method as presented by Hallowell and Gambatese (2010).

Table 1. Qualitative and numerical ratings for the most probable consequence of a potential accident

Table 2. Qualitative and numerical ratings for the probability of occurrence of an accident

Table 3. Relative risk of each activity

Occupational Safety Integration at the Project Level

When the evaluation of project alternatives takes into account the cost of construction, waste generation, energy consumption, the recyclability of materials, etc., the occupational safety of each alternative should also be considered.

The alternatives are usually assessed using multi-criteria decision-analysis tools. This involves integrating all aspects affecting a decision into the construction project's management:

- Stakeholders: property owner, constructor, users, the environment, neighbors, etc. This point also includes all points of view: economic, social, functional, environmental and that of future generations.
- Project components: materials, cost, time, risk, etc.
- Entire life cycle: from planning to demolition at the end of life.

Numerous examples can be found of how this approach is applied in different fields (Ormazábal et al., 2008; Armengou et al., 2012; etc.), although it may be less common in the social field, probably due to the false belief that the indicators are subjective or cannot be measured. The approach usually involves considering the different requirements that each alternative must meet, assigning them a relative importance, and calculating the value of each alternative according to the requirements.

Pons and Aguado (2012) analyzed the alternatives for school building projects in accordance with three kinds of requirements: economic, environmental and social. The set of social requirements was assigned a relative weight of 20%, the set of environmental requirements a relative weight of 30%, and the set of economic requirements a relative weight of 50%. Within the social requirements, safety was assigned a relative weight of 65%. These weights were assigned in two seminars by experts from different organizations on the basis of current and near-future administrative priorities. The authors then assigned points to obtain the value of the occupational safety indicator for each alternative.

The ORI enables greater objectivity in the measure of the occupational safety of each alternative. Given the set of alternatives and their respective ORIs, the alternative with the lowest ORI will be the most valuable alternative with regard to occupational safety, while the alternative with the highest ORI will be the least valuable. Hence, while all construction projects should comply with current occupational safety requirements, those involving greater risk due to the types of activities carried out will be at a disadvantage.

Practical Steps to Apply the Methodology

The ORI can be obtained for the different alternatives for a specific project by means of the following steps. These steps correspond to the ones presented in Ahmed et al. (2007):

Step 1 (establishing the context): Assess whether the coefficients in Table 3 are applicable to the project. If so, step 3 can be omitted.

Step 2 (identifying risks): For each alternative, identify the activities within the construction project that could potentially involve each risk.

Step 3 (analyzing risks): Local health and safety experts should assign the consequences and, especially, the probability of occurrence of each risk identified in Step 2 according to the region's degree of technological development and the preventive measures taken.

Step 4 (evaluating risks): For each activity determined in Step 2, ascertain the person-hours required for the project, following the guidelines provided in the Appendix. Apply the ORI formulae (equations [1] and [2]) to each alternative.

Step 5 (treating risks): Draw conclusions, prioritize alternatives, redesign, choose the best alternative, etc.

Example of Application

The following simple example shows how the ORI is obtained, how to interpret the results, and how to use them to redesign. The length limit of the paper prevented us from including a more complex example. Nonetheless, in our opinion, a simple example is sufficient to highlight the main aspects. The case consists of a decision between *in situ* and precast solutions for three drains – OD1, OD2 and OD3 –to be used as small passages for a residential road. Figure 1 shows the precast solution, while Figure 2 shows the *in situ* solution. The differential aspects of these solutions will be compared from the point of view of occupational safety.

Figure 1. Drains with precast concrete arch

Figure 2. Drains with *in situ* concrete arches

The drains have a total length of 150 m, meaning that 60 precast concrete elements or 12 assembly and dismantling operations for a falsework of more than 12 meters are required. A working day is defined as 8 hours.

A team of 4 people working 10 days is needed to build the precast segments in the factory. A tenth of the time is spent on manual load-handling and a fourth of the time on mechanical load-handling. The workers in the factory do not have to work at heights of over 2 meters. The precast factory has its own concrete plant adjacent to the factory. Eight 2-hour round trips are needed to transport the steel reinforcing bars. Thirty 6-hour round trips are needed to transport the precast voussoirs by road. Three workers (1 crane operator and 2 assemblers) must assemble the 60 precast voussoirs in 6 days.

Completion of the 12 assembly and dismantling operations requires 24 days of work by 3 people plus a crane operator. A third of the 3 workers' time is spent on scaffolding, and a sixth of their time on the falsework (during the assembly and dismantling). It is assumed that a tenth of their time will be spent on manual load-handling and a fifth on mechanical load-handling. The concrete mixer must make 70 round trips lasting 40 minutes each. Eight 2-hour round trips are needed to transport the steel reinforcing bars.

Table 4 shows the results of applying Table 3 and the expressions [1] and [2] to these values.

Table 4. Occupational Risk Index (ORI) for each alternative

The ORI of the precast alternative is lower than the ORI of the *in situ* alternative, which shows that the manufactured solution is safer than the *in situ* one. The activities with the highest ORI for the precast alternative are the transport of precast pieces (ORI=16.20) and work in an area at risk of flooding (ORI=8.64). The first risk mainly depends on the distance from the factory to the construction site; hence, a closer precast factory should be found, if possible, in order to reduce the ORI of the alternative or the pieces should be precast on site. The second risk depends on the time spent in the area at risk of flooding. It is thus essential for most of the activities to be performed outside that area, although, in this case, that could be difficult. Another way of improving the safety for this risk would be to set up an efficient early-warning system to decrease the probability of occurrence of the accident. For the *in situ* alternative, the highest ORIs were obtained for the risk of drowning and the risk of falls to lower levels.

Conclusion

Both construction industry professionals and academics (teachers and researchers) are sensitive to occupational safety in construction work. Classic project management tools (continuous improvement, alternatives analysis, risk management, communication management, motivation, etc.) apply to occupational safety. However, we found no evidence that occupational safety criteria were taken into account during the design phase of projects. To some degree, in the construction industry, occupational safety can thus be said to be a passive rather than active concern.

In this paper, we proposed an Occupational Risk Index (ORI) that depends solely on the occupational activities carried out as part of the construction work. The ORI can be calculated during the design stage and, thus, prior to the award of the contract.

The paper also shows how to integrate the ORI in multi-criteria decision-making methods through the evaluation of alternatives. The use of the ORI as an indicator for evaluating the alternatives in a project enables the consideration of occupational safety from the start of the design, thereby ensuring that concern for workers' occupational safety is an active component of both the project's design and management.

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Appendix. Guide to the Calculation of Hours Spent on Each Activity

The hours spent by all workers on the following activities due to the execution of the work should be considered as follows.

Note: All distances and other values included in the Appendix are based on European and Spanish legislation and are provided for guidance purposes. Values defined in other legislation can be used instead.

1. Falls to lower levels – Work at heights or depths of more than 2 meters

Person-hours spent at a height of over 2 meters, including both work in which it is possible to fall from a given height and work in which it is possible to fall to a given depth, should be considered. The height is measured from the surface on which the worker is located to the lower level where the worker's fall would be broken if there were no protection.

2. Direct or indirect electrical contact – Electrical work, work in proximity to power lines, and work with electrical equipment under wet conditions:

2a. Direct or indirect electrical contact - Electrical work on overhead power lines or other unprotected live elements (work in the hazardous area)

The person-hours of qualified workers performing electrical work required for the construction project should be considered. Electrical work is work carried out in the hazardous area bounded by the distance D_{HAZ} to the live overhead power line or unprotected live elements (Table 5 and Figure 3).

Table 5. Hazardousarea delimited by the distance to the overhead power line or unprotected live element. Source: Spanish Royal Decree 614/2001.

Figure 3. Hazardous area for live work with and without a physical barrier. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico*.

2b. Direct or indirect electrical contact – Work in proximity to overhead power lines or other unprotected live elements

Person-hours spent in proximity to overhead power lines or other unprotected live elements should be considered. The area of proximity is bounded on the inside by the distance D_{HAZ} to the power line or unprotected live element and on the outside by the distance D_{PROX-1} or D_{PROX-2} (Table 6). Work is considered to be performed in proximity when the work area and area of proximity overlap. If the work area can be precisely delimited, then the area of proximity is defined by the outer distance D_{PROX-1}.If the work area cannot be precisely delimited, or if it is unknown whether it will be possible to delimit it, the area of proximity is defined using the outer distance D_{PROX-2} (Figures 4 and 5).

Table 6. Distances delimiting the inner and outer boundaries of the area of proximity to an overhead power line or unprotected live element. Source: Spanish Royal Decree 614/2001.

Figure 4. Activities for which the work area can be precisely defined. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico*.

Figure 5. Activities for which the work area cannot be precisely defined. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico.*

2c. Direct or indirect electrical contact - Work in proximity to live underground power lines

Person-hours spent on earthmoving or other activities susceptible to reaching and damaging a live underground power line should be considered. These include the activities carried out at a distance of 1 meter or less from the power line. The distance is measured from the outer diameter of the line.

2d. Direct or indirect electrical contact - Work with electrical equipment under wet conditions

Person-hours spent using mobile and semi-mobile electric concrete mixers.

3. **Burns caused by fire or explosion – Due to the rupture of a pipeline in work close to fuel pipelines**

Person-hours spent on earthmoving or other activities susceptible to reaching and damaging live underground fuel pipelines should be considered. These include activities carried out at a distance of 1 meter or less from the pipeline. The distance is measured from the outer diameter of the pipe.

4. **Gas inhalation – Work near gas pipelines**

Person-hours spent on earthmoving or other activities susceptible to reaching and damaging underground gas pipelines should be considered. These include activities carried out at a distance of 1 meter or less from the pipeline. The distance is measured from the outer diameter of the pipe.

5. **Entrapment and subsequent suffocation due to a landslide – Earthmoving, excavation, shafts, underground works and tunnels**

Person-hours spent on earthmoving, excavation, shafts with or without casing, underground work, and tunnels built using traditional methods, explosives, roadheader machines, and tunneling machines under normobaric conditions that reach a depth equal to or greater than 0.80 meters in ordinary soil and 1.30 meters in solid soil should be considered. In case of doubt about the soil type, work that reaches a depth equal to or greater than 0.80 meters should be considered.

6. Particle projection and accidental explosion – Blasting for excavation, shafts, underground work and tunnels

Person-hours spent on the handling of explosives and blasting for excavation, shafts, underground work and tunnels should be considered.

7. Decompression sickness – Work under hyperbaric conditions

Person-hours spent on work under hyperbaric conditions, whether in the air or in an underwater environment, should be considered.

8. Collision with or entrapment by a moving load due to its movement or detachment – Mechanical load-handling

Person-hours of the workers to be present during the mechanical load-handling, understood as handling performed by means other than human effort, should be considered. Where this information is not known, the person-hours of the mechanical load-handling operator (e.g. crane operator) should be considered instead. The key is to use the same measuring criterion for all the alternatives compared.

9. Blows to upper and lower limbs – Manual load-handling

Person-hours spent on manual load-handling, understood as handling carried out exclusively by human effort, should be considered.

10. Collision with or running over by heavy equipment or heavy goods vehicles – Work with heavy equipment or heavy goods vehicles

Person-hours spent by workers using heavy equipment or heavy goods vehicles should be considered.

11. Cuts, blunt trauma and other injuries due to light equipment – Work with light equipment

Person-hours of workers using the following light equipment should be considered: angle grinders, manual circular saws, road cutters, post-stressing equipment, rail cutters, chainsaws, ram or plate compactors, and circular or diamond table saws.

12. Burns– Welding

Person- hours spent performing any kind of welding should be considered.

13. Impact injury from falling objects or projectiles – Manual, mechanical or explosive demolition; shot-hole drilling prior to the blasting of a cut slope and subsequent cleanup and field survey

Person-hours spent on manual, mechanical or explosive demolition should be considered. Person-hours spent drilling shot holes prior to the blasting of a cut slope and the subsequent cleanup and field survey should also be considered.

14. Acute dust and toxin poisoning – Manual, mechanical or explosive demolition of structures or buildings in general and of hospitals, factories, slaughterhouses or any other place that may contain toxic substances in particular

Person-hours spent on the manual, mechanical or explosive demolition of any building or structure should be considered due to the risk of dust poisoning. Furthermore, person-hours spent on the manual, mechanical or explosive demolition of hospitals, factories, slaughterhouses or any other building or structure that may contain toxic substances should be considered due to the risk of toxin poisoning.

15. Suffocation or poisoning in confined spaces – Work in confined spaces

Person-hours spent in the following places and on the following activities should be considered:

- Sewage systems
- Chambers, manholes and service galleries for gas, electricity, telecommunication, etc., installations

- Welding in confined spaces
- Blasting in confined spaces
- Application of solvent-based paint in confined spaces
- Maintenance and changing of the cutters on tunnel-boring machines under normobaric conditions

16. Drowning – Work in areas at risk of flooding

Person-hours spent in areas at risk of flooding, either outdoors, such as in a river bed, or in enclosed areas, such as in a sewage system, should be considered.

17. Collision with or running over by vehicles unrelated to the construction work – Work in areas with traffic unrelated to the construction work

Person-hours spent in areas that overlap, or may eventually overlap, with areas with traffic unrelated to the construction project should be considered.

18. Traffic accident – Transport of elements to the construction site

Person-hours spent transporting elements from the factory to the construction site should be considered.

19. Structural risk or macro risk–Complex operations or structures

This is the risk of accident due to the failure of an auxiliary element or the structure during construction. It is caused by errors in the design, execution or management of the structure under construction rather than by a lack of health and safety measures. Some examples of structures and operations entailing structural risk are: maneuvers on launched bridges, large cranes moving heavy loads, pile construction with climbing formwork, post-stressed concrete operations, large falsework, self-launching centerings, etc.

This risk includes the person-hours spent in workplaces where, were an accident involving the macro risk to occur (e.g. collapse of the structure or auxiliary element), it would harm the workers. For example, in a viaduct built with falsework, the macro risk would be the failure of the falsework. Therefore, all person-hours spent in the falsework or in places that would collapse were the falsework to fail would need to be considered.

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Table 1. Qualitative and numerical ratings for the most probable consequence of a potential accident

Consequences	
Classification	**Rating**
Minor injury (minor cuts, bruises and bumps)	1
Non-serious disabling injury	5
Extremely serious injury (amputation, permanent disability)	15
Fatality	25
Multiple fatalities	50
Catastrophe, numerous fatalities	100

Table 2. Qualitative and numerical ratings of the probability of the occurrence of an accident

Probability	
Classification	**Rating**
Has never happened but is conceivable	0.5
Remotely possible	1
Unusual sequence	3
Quite possible, not unusual	6
Most likely and expected result should the hazard event occur	10

Table 3. Relative risk of each activity

	Risk – Activity	Rating		Weight	Standardized weight
1	**Falls to lower levels–Work at heights or depths of more than 2 meters**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Winch	20.0	1.0	20.0	0.020
	Conventional formwork	23.3	4.5	105.0	0.105
	Self-climbing formwork for piles or dams	50.0	3.0	150.0	0.150
	Sliding formwork	20.0	1.0	20.0	0.020
	Centering (during assembly and dismantling only)	20.0	3.0	60.0	0.060
	Self-launching centering (during assembly and dismantling only)	20.0	3.0	60.0	0.060
	Trestle scaffold (up to 3 meters high)	15.0	3.0	45.0	0.045
	Mast-climbing work platform	20.8	1.0	20.8	0.021
	Steel tube scaffold	21.7	4.5	97.5	0.098
	Mobile scaffold and mobile work platforms	20.0	3.0	60.0	0.060
	Hanging scaffold	31.7	4.5	142.5	0.143
	Work platform for the maintenance or changing of the cutters on a tunnel-boring machine	15.0	3.0	45.0	0.045
	Non-mobile work platforms and concrete-pouring work platforms	10.0	3.0	30.0	0.030
	Placement of concrete slabs and reinforcement-laying and concrete-pouring work on the deck of a bridge	20.0	3.0	60.0	0.060
	Hollow spaces (mainly in buildings)	25.0	3.0	75.0	0.075
	Outside openings in facades	20.0	3.0	60.0	0.060
	Work on decks	21.7	3.0	65.0	0.065
	Ditches	10.0	1.3	13.3	0,013
	Cut and fill batters	15.0	3.0	45.0	0.045
	Shafts	20.0	1.0	20.0	0.020
	Work inside floating caissons	15.0	3.0	45.0	0.045
	Manual demolition	20.0	6.0	120.0	0.120

2	**Direct or indirect electrical contact– Electrical work, work in proximity to power lines, and work with electrical equipment under wet conditions**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Electrical work on overhead power lines or other unprotected live elements (work in the hazardous area)	22.5	3.0	67.5	0.068
	Works in proximity to overhead power lines or other unprotected live elements	20.0	4.5	90.0	0.090
	Work in proximity to live underground power lines	20.0	4.5	90.0	0.090
	Work with mobile and semi-mobile electric concrete mixers	15.0	3.0	45.0	0.045
3	**Burns caused by fire or explosion due to the rupture of a pipeline – Work close to fuel pipelines**	20.0	3.0	60.0	0.060
4	**Gas inhalation – Work close to gas pipelines**	20.0	3.0	60.0	0.060
5	**Entrapment and subsequent suffocation due to a landslide – Earthmoving, excavation, shafts, underground work and tunnels**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Earthmoving and open-cast mining	20.0	3.0	60.0	0.060
	Shafts with casing and simultaneous formwork	20.0	1.0	20.0	0.020
	Shafts without casing (mainly used in mines)	20.0	3.0	60.0	0.060
	Underground work and tunneling performed with traditional methods, explosives, roadheader machines, or tunneling machines under normobaric conditions during the maintenance and changing of the cutters	20.0	3.0	60.0	0.060
6	**Particle projection and accidental explosion –Blasting for excavation, shafts, underground work and tunnels**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Particle projection over workers	15.0	3.0	45.0	0.045
	Accidental explosion	25.0	1.0	25.0	0.025
7	**Decompression sickness – Work under hyperbaric conditions**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Maintenance and changing of cutters during tunneling under hyperbaric conditions; divers in maritime construction work	15.0	1.0	15.0	0.015
8	**Collision with or entrapment by a moving load due to its movement or detachment–Mechanical load-handling**	**C**	**P**	**CxP**	**CxP/max(CxP)**

	Cranes and self-propelled industrial trucks	21.7	3.0	65.0	0.065
	Winches	15.0	3.0	45.0	0.045
	Placement of floating caissons	15.0	3.0	45.0	0.045
	Other means of mechanical load-handling	20.0	1.0	20.0	0.020
9	**Blows to upper and lower limbs –Manual load-handling**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Materials and auxiliary elements	7.0	6.0	42.0	0.042
	Beams	10.0	6.0	60.0	0.060
	Installation of reinforcing bars	7.0	3.0	21.0	0.021
10	**Collision with or running over by heavy equipment or heavy goods vehicles–Work with heavy equipment or heavy goods vehicle**	22.5	3.0	67.5	0.068
11	**Cuts, blunt trauma and other injuries due to light equipment –Work with light equipment**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Angle grinder	10.0	6.0	60.0	0.060
	Manual circular saw	11.7	6.0	70.0	0.070
	Road cutter	10.0	6.0	60.0	0.060
	Post-stressing equipment	15.0	3.0	45.0	0.045
	Rail cutter	15.0	3.0	45.0	0.045
	Chainsaw	10.0	6.0	60.0	0.060
	Ram or plate compactor	5.0	3.0	15.0	0.015
	Circular or diamond table saw	15.0	4.5	67.5	0.068
12	**Burns – Welding**	7.0	1.0	7.0	0.007
13	**Impact injury from falling objects and projectiles –Manual, mechanical or explosive demolition; shot-hole drilling prior to the blasting of a cut slope and subsequent cleanup and field survey**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Manual demolition and rubble removal	20.0	6.0	120.0	0.120
	Mechanical demolition and rubble removal	7.0	6.0	42.0	0.042
	Demolition by explosives and rubble removal	7.0	6.0	42.0	0.042
	Shot-hole drilling prior to the blasting of a cut slope and subsequent cleanup and field survey	20.0	6.0	120.0	0.120

14	**Acute dust and toxin poisoning–Manual, mechanical or explosive demolition of structures or buildings in general and of hospitals, factories, slaughterhouses or any other place that may contain toxic substances in particular**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	General demolitions	5.0	3.0	15.0	0.015
	Demolition of hospitals, factories, slaughterhouses or any other place that may contain toxic substances	15.0	3.0	45.0	0.045
15	**Suffocation or poisoning in confined spaces–Work in confined spaces**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Welding in confined spaces	15.0	3.0	45.0	0.045
	Work in sewage systems (suffocation)	20.0	2.0	40.0	0.040
	Work in sewage systems (poisoning due to inhalation or ingestion; infections)	7.0	3.0	21.0	0.021
	Work in chambers, manholes and service galleries for gas, electricity, telecommunication, etc., installations	15.0	4.5	67.5	0.068
	Blasting in confined spaces	20.0	3.0	60.0	0.060
	Maintenance and changing of the cutters on tunnel-boring machines under normobaric conditions	20.0	0.5	10.0	0.010
	Application of solvent-based paint in confined spaces	7.0	3.0	21.0	0.021
16	**Drowning–Work in areas at risk of flooding**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Work in wastewater systems, river beds, streams, etc.	20.0	3.0	60.0	0.060
17	**Collision with or running over by vehicles unrelated to the construction work–Work in areas with traffic unrelated to the construction work**	21.7	2.7	57.8	0.058
18	**Traffic accident – Transport of elements to the construction site[ii]**	**C**	**P**	**CxP**	**CxP/max(CxP)**
	Precast pieces	20.0	4.5	90.0	0.090
	Concrete	10.0	4.0	40.0	0.040
	Steel (structural and reinforcing bars)	10.0	3.0	30.0	0.030
19	**Structural risk or macro risk–Complex operations or structures[iii]**	50.0	1.0	50.0	0.050

[i] The assessment of the probability of the occurrence of drowning was obtained from accidents occurring in the region of Catalonia and, thus, is valid for that region. For application in other regions, a new assessment should be performed, according to the hydrographic conditions.

[ii] The assessment of the consequences and probability depends on the material transported. The health and safety expert should assess the probability and consequences for the transportation of other materials.

[iii] The assessment of the probability depends on the type of work or activity. The health and safety expert should assess the probability of the occurrence of the structural accident using Table 2. The probability indicated in the table is for guidance purposes only.

Table 4. Occupational Risk Index (ORI) for the two alternatives

	Risk – Activity	Standardized weight	Precast		In situ	
1	**Falls to lower levels – Work at heights or depths of more than 2 meters**	**W**	**Exposure (hours)**	**WxE**	**Exposure (hours)**	**WxE**
	Centering (during assembly and dismantling only)	0.060	-	-	96	5.76
	Steel tube scaffold	0.098	-	-	192	18.82
8	**Collision with or entrapment by a moving load due to its movement or detachment – Mechanical load-handling**	**W**	-	-	-	-
	Crane in the construction site	0.065	94	6.24	115.2	7.49
	Crane in the precast factory [i]	0.065	80	5.20	-	-
9	**Blows to upper and lower limbs – Manual load-handling**	**W**	-	-	-	-
	Materials and auxiliary elements [i]	0.042	32	1.34	57.6	2.42
16	**Drowning – Work in areas at risk of flooding**	**W**	-	-	-	-
	Work in wastewater systems, river beds, streams, etc.	0.060	144	8.64	768	46.08
18	**Traffic accident – Transport of elements to the construction site**					
	Precast pieces	0.090	180	16.20	-	-
	Concrete	0.040	-	-	46.7	1.87
	Steel	0.030	16	0.48	16	0.48
			$ORI_{prefab.}$=	**38.10**	**$ORI_{\textit{in situ}}$=**	**82.92**

[i] The probability of occurrence of an accident in the precast factory could be lower than the probability in Table 3 assigned for construction work. This is because in factories the working conditions are much more constant over time and, therefore, controlled than at a construction

site, where the activities, conditions, etc., are constantly changing. Hence, the ORI value for the precast alternative obtained in the example is an upper bound. As the upper bound of the ORI value for the precast alternative is lower than the ORI value for the *in situ* alternative, we can say that the "real" ORI value for the precast alternative is lower than the ORI value for the *in situ* alternative ($ORI_{prefab.} \leq ORI_{prefab.\ upper\ bound} < ORI_{in\ situ}$).

Table 5. Hazardous area delimited by the distance to the overhead power line or unprotected live element. Source: Spanish Royal Decree 614/2001.

Rated voltage of the installation(kV)	D_{HAZ} (cm)
≤1	50
3	62
6	62
10	65
15	66
20	72
30	82
45	98
66	120
110	160
132	180
220	260
380	390

Table 6. Distances delimiting the inner and outer boundaries of the area of proximity to an overhead power line or unprotected live element. Source: Spanish Royal Decree 614/2001.

Rated voltage of the installation (kV)	D_{HAZ} (cm)	D_{PROX-1} (cm)	D_{PROX-2} (cm)
≤1	50	70	300
3	62	112	300
6	62	112	300
10	65	115	300
15	66	116	300
20	72	122	300
30	82	132	300
45	98	148	300
66	120	170	300
110	160	210	500
132	180	330	500
220	260	410	500
380	390	540	700

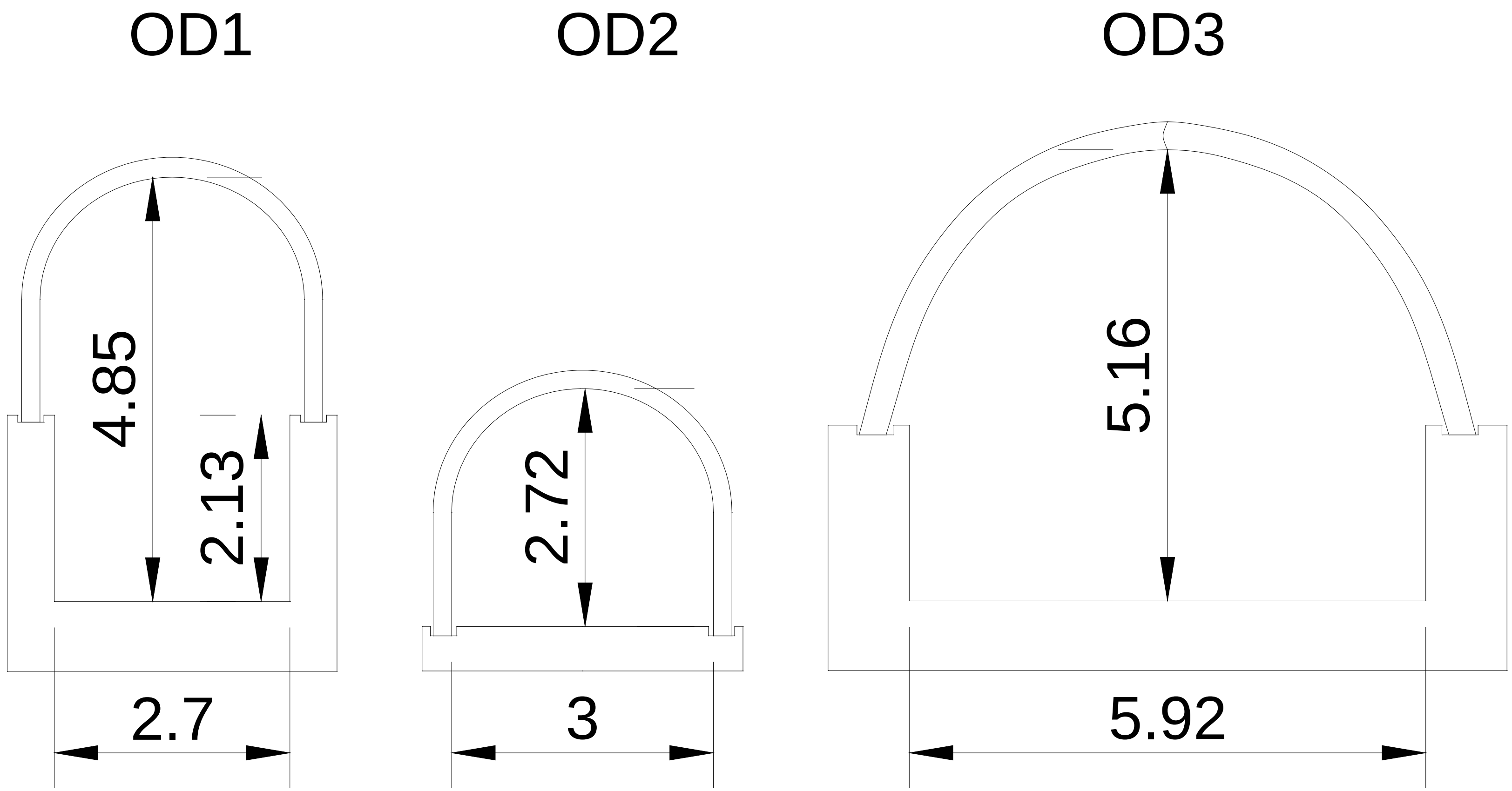

Figure 1. Drains with precast concrete arch

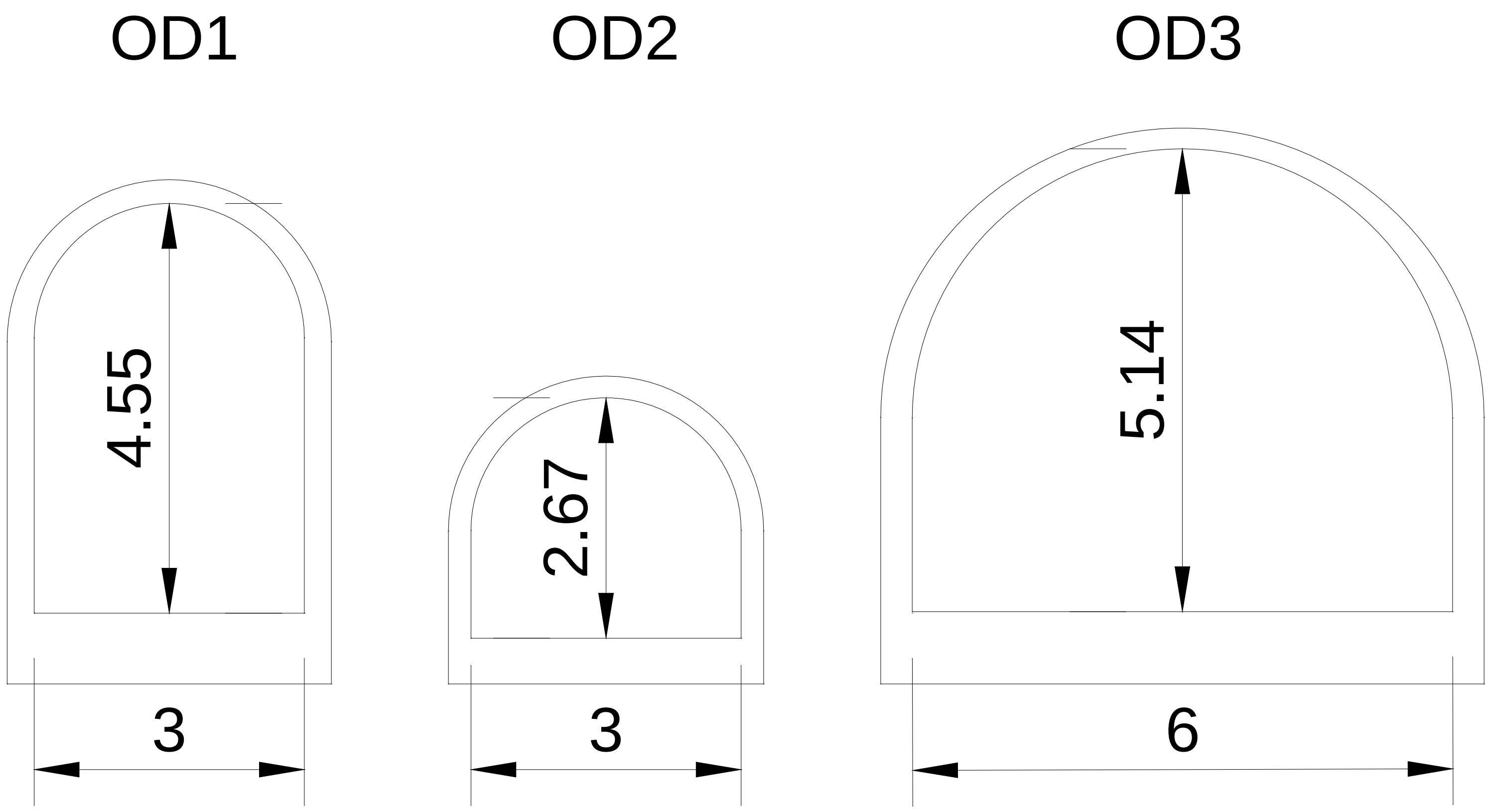

Figure 2. Drains with *in situ* concrete arches

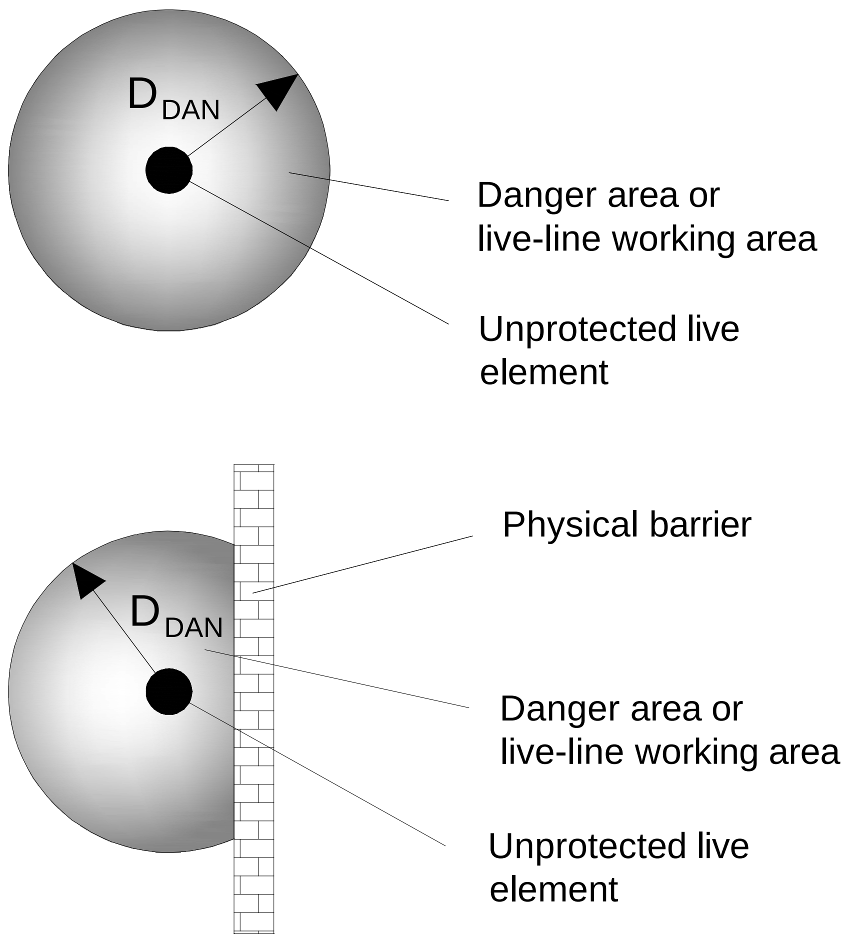

Figure 3. Hazardous area for live work with and without a physical barrier. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico*.

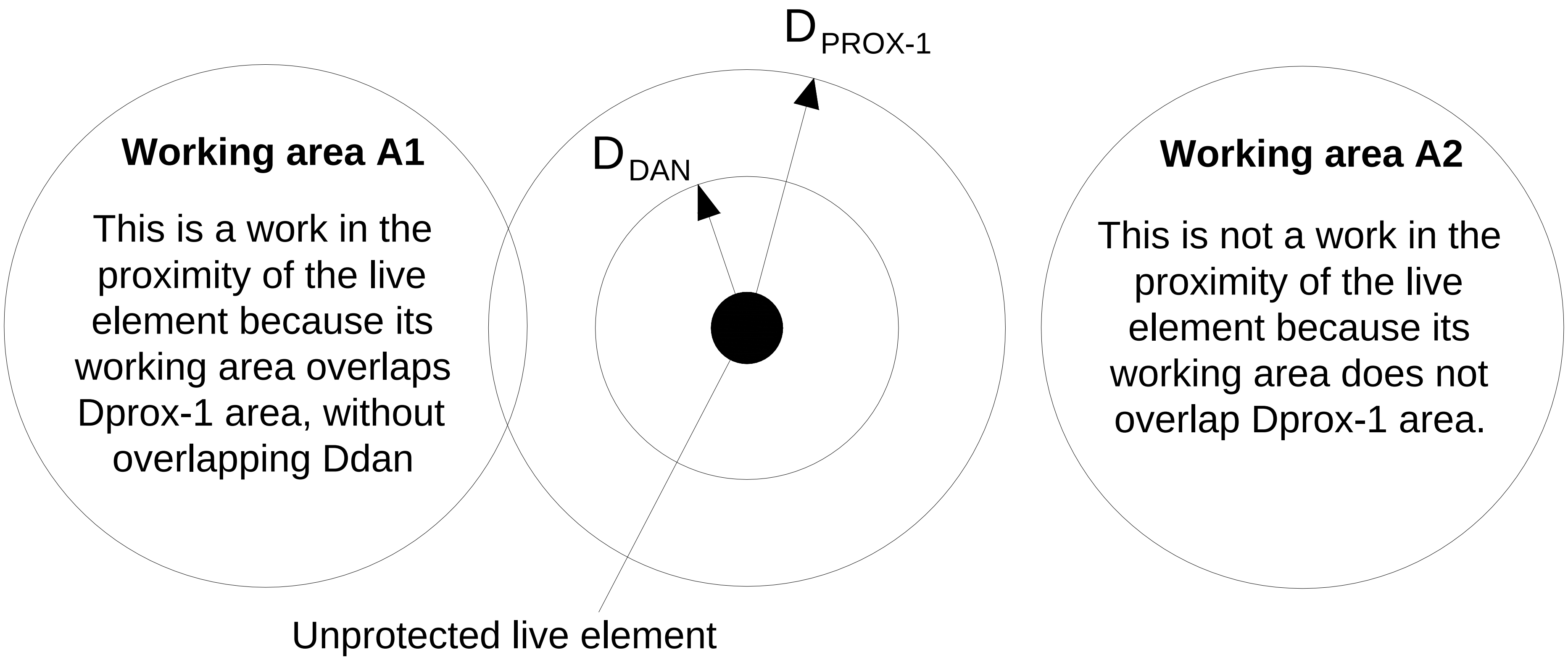

Figure 4. Activities for which the work area can be precisely defined. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico*.

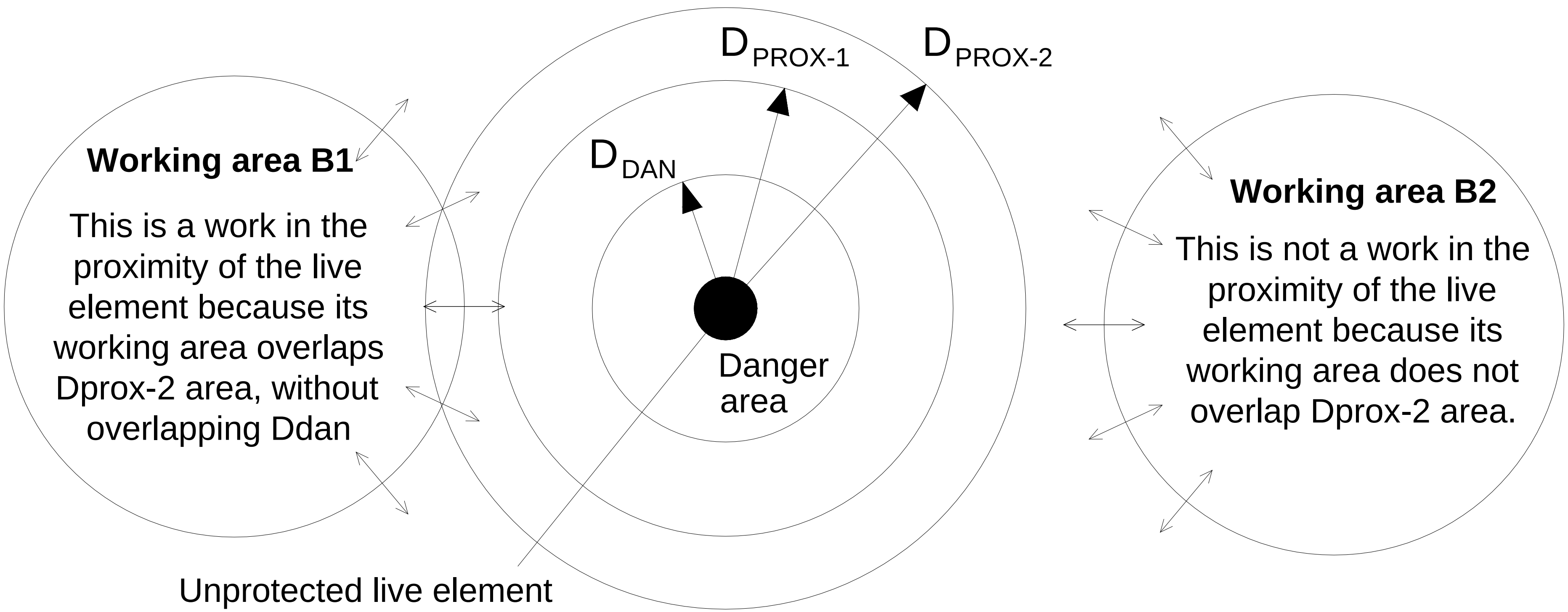

Figure 5. Activities for which the work area cannot be precisely defined. Source: *Guía técnica para la evaluación y prevención del riesgo eléctrico.*