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INTEGRATION OF OCCUPATIONAL SAFETY ANALYSIS IN CONSTRUCTION PROJECTS

Construction is world over thought to be a very hazardous industry. According to the International Labour Organization, it accounts for 30-40% of the world`s fatal injuries and non-fatal injuries occur most frequently than in other industries. Many different approaches to safety should be considered and implemented in order to reduce on-site safety risks and to achieve the goal of less or zero injuries. One of the key steps to achieve adequate safety levels at the construction phase of the project consists in safety risk analysis in pre-construction phase. The paper deals with the approaches to occupational safety risks analysis in construction and introduces the methodology of safety hazards identification and evaluation of risk levels for all identified hazards. The methodology was applied in the project of Shopping Centre Aupark in Košice. In this application the specific nature of construction process, uniqueness of construction site workplace, two degree decomposition of construction safety hazards and their synergy effects are considered.

1. Introduction

The construction industry as important one in the world economy employs around 180 million people, or 7% of global employment [1]. Even though it has a world reputation for the quality, it is a generally risky business; it remains one of the most dirty, difficult and dangerous with poor working conditions. According to the International Labour Organization, it accounts for 30-40% of the world`s fatal injuries. One hundred thousand workers are killed on sites every year – one person killed every five minutes. It is caused by many reasons [2]: high – risk nature of construction work, low knowledge and a lack of trade risk awareness of tradesmen, building terms decreasing, high proportions of unskilled and temporary workers, low demands on site facility according to law, complicated contractor system with big amount of subcontractors, thin exercitation of safety protection equipments by reason of the building costs

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increasing, absence or malfunction of safety management system especially in small construction companies and tradesmen etc. Besides causing human tragedy, the accidents delay project progress, increase costs, and damage the reputation of the contractors [3]. However, almost all injuries are predictable and preventable. Many different approaches to safety should be implemented to achieve the goal of fewer injuries. The most effective way to improve safety performance should be preventing accidents and reducing uncertainty before their happen. Thus, occupational risk analysis is a foundation upon which safety management is built and risk assessment is a critical task which forms a part of safety management systems.

2. Occupational safety in building design and construction

The construction is a project based industry existing in a dynamic and changing environment [4]. Almost all production processes within the construction come through different, more difficult conditions as in other industries. Most construction sites are small without sufficient storage spaces and spaces for auxiliary works. In the site, different tradesmen have to work close together within limited spaces. Due to diversification of activities, the large number of subcontractors is common within the construction site [5]. With higher numbers of subcontracting, the chances of accidents occurrence become more frequent.

Traditionally, the construction workers safety used to be an exclusive responsibility of the contractors who employ them. Almost nobody used to suppose that the work environment during the construction phase depends on the previous planning and on considerations for safety in the planning phase. The demands for safety were not required to be incorporated into contracts and tendering materials. Among designers and owners was unusual to see it as their responsibility to consider the workers safety. They used to make rarely decisions pertaining to construction worker safety. They were declaring their responsibility only for the final product and no for means and methods affecting the workers safety. But the ideal situation for the construction workers safety is to make this an important parameter for the planners and designers of the conceptual and preliminary design phase. The work environment in the site depends on the previous planning and on considerations for occupational safety in the planning phase. This served as the basis for the **EU Council Directive – Construction Sites Directive 92/57/EEC** concerning minimum demands for health and safety at temporary construction sites, where the role of the building planner (owner, architect and consultant) is emphasized as having the responsibility for workers safety during the building design in pre-construction phase. An approach for anticipating, evaluating, and minimizing or removing the hazards prior to initiating work is hereby promoted. The EU member states, as well as Slovakia, adopted the mentioned directive (Government Regulation 510/2001 and then Government Regulation 396/2006) requiring architects and design engineers to implement design for construction safety. In around 10 years since it was implemented, many EU countries have experienced significant reductions in construction sites accident rates. The directive initiated two important points. The first is a concept of health and safety based on a new chain of responsibility including the owner „Safety Coordinator for design and Coordinator for Construction" and the second is presented by new document **„Health and safety plan"**. Following the Directive (Article 4) [6], the owner shall take account of the general principles of prevention during various stages of designing and preparing the project, particularly when architectural, technical and organizational aspects are being decided, in order to plan the various items or stages of work which are to take place simultaneously or in succession and when estimating the period required for completing such work or work stages. Prior to the beginning of construction works, the owner shall complete the Health and Safety Plan **which notably manage the identified occupational safety hazards of individual project**. Thus, construction safety is not now considered as the responsibility of the contractor, as it was traditionally. The owners and designers are included through design and planning phase of the project in order to ensure that hazards are eliminated and workers are protected. The owner should also ensure that safety standards are being met on site.

3. The occupational safety risk analysis in construction

The process of occupational safety risk analysis generally includes three main stages [7]: **identification** – choosing specific activity and breaking it down into sequence of stages and identification of all possible hazards that may cause some accidents at the workstation during activity performance; **assessment** – evaluation of relative risk levels for all identified hazards; **action** – controlling the risk by taking sufficient measures to reduce or eliminate it.

Carter and Smith [8] indicated that current hazard identification levels in construction projects are not ideal. Significant barriers to improving hazard identification involve: knowledge and information barriers (lack of information sharing across projects; lack of resources on smaller projects, e.g. industry publications, full-time safety department; subjective nature of hazard identification and risk assessment; reliance upon tacit knowledge) and process and procedure barriers (lack of a standardized approach; undefined structures for tasks and hazards).

Assessment of risk level associated with the hazards on site is an essential component in the process of risk management, which is a process of estimating the magnitude of risk and deciding whether the risk is tolerable or not. Many different methodologies for occupational risk assessment are available (e.g.

PHA, EA, HAZOP, FMEA, Event tree analysis, Check-lists, What-if). Their output data can be qualitative, such as recommendations, or quantitative in the form of an index of risk level [9].

As an example, Gangolells et.al. [10] introduced a systematic process-oriented approach for dealing with potential safety risks at the pre-construction stage serving as an assessment tool for measuring the safety risk level of construction projects. The first step is to make an inventory of construction activities and stages (earthworks, foundations, structures, roofs, partitions etc.). A big number of stages and activities could be considered in such initial review. The second step is to make an inventory of common safety hazards related to the construction activities. Such review could use reports of accidents that have yet occurred in any construction sites. In order to asses the construction safety risks, the development of corresponding indicators, formulation of significance limits, and determination of the overall safety risk level of a construction project is required. In order to determine the significance rating of a safety risk (risk level) in a particular construction stage, a risk is the combination of the probability of occurrence of a hazardous event and the severity of the injury or ill health that can be caused by the event. The probability refers to the chance of a potential event (e.g. number of events per day), severity represents the potential outcome of an event (e.g. money or loss of days per event) and exposure describes the duration of potential contact with a potentially hazardous situation (e.g. days).

However, unlike other industries, it is not easy to undertake risk assessment on construction site, due to its complexity and diversity in job tasks, climatic conditions and work environments, as well as the work nature of construction industry is quickly changing and workforce is highly dynamic; [11] the production environment changes in time and place, and work crews change frequently. The workplace changes daily and the type of work varies greatly. Moreover, workers commonly endanger other workers, who may be performing a different activity at a different location. The standard occupational safety risk analysis method is not designed to reveal these dangers. It focuses on production activities in isolation, at predetermined workstations. These are the reasons why in construction is needed the different approach to identify hazards and risks and prevent accidents. Ophir Rozenfeld et.al. [11] introduced in their research an improved technique called Construction Job Safety Analysis, in which the job risk analysis is performed independently of any specific considerations of time and place.

4. The occupational safety risk analysis in construction

From construction safety hazards identification point of view, following structure could be applied [12]: **group of hazards** – set of hazards referring to some construction aspect; **specific hazards (I level decomposition)** – set of hazards referring to some group of hazards (it is presented in Tab. 1); **construction activity hazards (II level decomposition)** – set of particular hazards referring to particular construction activities and to their performance conditions (it is presented in Tab. 2).

As the sites develop with progress of work hence the working environment is altering hour by hour. The time plays an important role in the analysis of construction safety hazards and their synergies during construction. That is why the group of hazards referring to particular construction stages or activities (HA) e.g. masonry, facing tiling, concreting etc. is not just one in the composition of potential construction safety hazards. The other three groups of hazards are significant in decomposition of construction safety hazards. The mentioned four groups of hazards are simply presented in Fig. 1 and in Tab. 1.

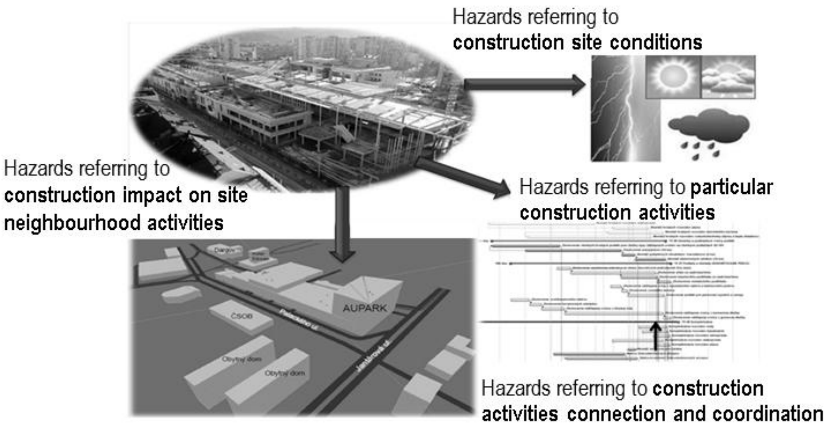

Fig. 1. Groups of construction safety hazards [13]

Table 1. Decomposition of construction safety hazards (I level decomposition) [12]

Groups of hazards	**Specific hazards (I level decomposition)**
Hazards referring to particular construction stages or activities **(HA)**	earth works; concreting works; masonry; assembly works; works in height and over the free depth; demolition and reconstruction works; machines and equipments
Hazards referring to construction site conditions **(HS)**	construction site conditions; intra-site transport; weather conditions; works in extra dangerous conditions
Hazards referring to construction impact on site neighbourhood **(HN)**	public threat; traffic restrictions; dense area
Hazards referring to construction activities connection and coordination **(HC)**	time relativity of activities; activities performed together; activities performed in current-time

The specific hazards qualified in Tab.1 can be then decomposed (II level decomposition). So the broad range of hazards is created. Second level hazards express specifically the events that may occur. Within each specific hazard usually expose together more hazards of II level decomposition. For example the hazards connected with weather conditions (in group of hazards referring to construction site conditions) could be represented by: unfavoured work in extremely high or low temperature, insufficient water taking, bad visibility in terms of rain, hazardous work in fog, slip on wet floor, fall on frozen floor etc. The difference among them consists in probability of occurrence of a hazardous event and in severity of injury that can be caused by the event. The example of II level decomposition is presented in Tab. 2.

Table 2. Decomposition of construction safety hazards (II level decomposition) [12]

Specific hazards (I level decomposition)	**Construction activity hazards (II level decomposition)**
Earth works hazards	insufficient assurance of excavations against landslip; insufficient control of sheeting; shelters sheeting release; landslip into shelter; worker landing-up; fall into open excavations; dangerous enters into excavations; work within the grasp of machines; insufficient marking of underground utilities etc.

From their exposure during construction point of view, the mentioned groups of hazards can be characterised by this means:

1. **Hazards referring to particular construction stages or activities (HA)** – their exposures are just at the moment of particular activities performance. It is necessary to know the construction schedule in order to be prepared to these hazards. Within the particular stages or activities can cumulate various hazards of different risk level. All the same the manipulation with material connected with the activity performance may present some hazard. Furthermore, the construction activities could involve hazardous operations, such as contact with hazardous materials and loading, unloading and storage of materials and site movements of vehicles and pedestrians.
2. **Hazards referring to construction site conditions (HS)** – come on force during all construction time. But their risk levels oscillate. The biggest are in the phase of frame work (earthworks, foundations, framework concreting, roofing etc.) where the activities are performed in the exterior. In phase of completion works (partitions, installations, flooring etc.) which are performed in the building interior, the amount of hazards may be lesser, even though the accident probability can be bigger because of more tradesmen working in almost each building part.
3. **Hazards referring to construction impact on site neighbourhood (HN)** – come on force similarly during all construction time and their

risk levels oscillate too. The significant are for example in earthwork because of excavated soil removal by the public road or in assembly production when the load carried by the crane can present the danger for people being around site. Unfortunately not only the construction workers themselves suffer injuries and deaths. Many people not employed in the industry were killed because of construction related activities.

4. **Hazards referring to construction activities connection and coordination (HC)** – hazards consist in relativities and joins between the particular work activities. The biggest are in the case of more activities performance in parallel, the exposure is multiplied as each activity is characterised by various hazards referring to its performance.

Regarding the synergism of time and space, in construction safety risk analysis these two variables are continuous, interacting. That is because the construction may be characterised as the set of activities which interlock, are in progress at continual place and in continual time. In construction risk analysis **from time point of view**, the construction could be divided to particular construction phases (preparatory works, framework, completing works etc.), to stages (earthworks, foundation, framework, roofing, partitions etc.), or simply to time periods and **from space point of view**, the building space (after framework finish, it is building interior), the site, and the site neighbourhood could be considered. In Figure 2 is presented one possibility of construction safety risks levels expression by three parameters: time, space and the risk level. The time is characterized by aggregated construction stages (E&F – earthworks and foundation, F&R – framework and roofing, IW – inside works, C – completions) and space, with risk exposure, is characterised by the site neighbourhood, the site and the building space (e.g. building interior where construction activities are performed). The risk levels are in interval from 0 (neither risk that not even exist) to 5 (unacceptable risk). It is made following the considerations presented in particular construction safety risks group appointment and upon their distribution in time of the building process time.

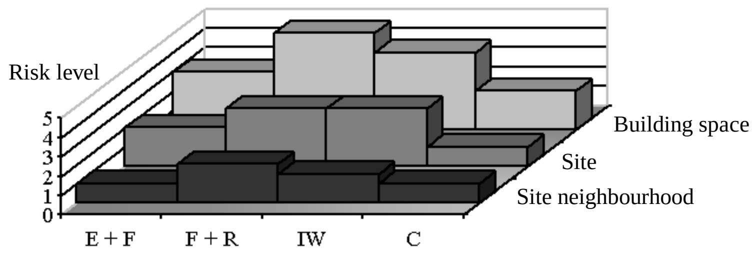

Fig. 2. The construction safety risks levels expression [12]

5. Case study: occupational safety risks analysis in construction of Aupark Shopping Centre in Košice

5.1. Aupark Shopping Centre in Košice

On the basis of considerations presented in the previous parts of the paper we have made the analysis of occupational construction safety risks in construction of Aupark Shopping Centre in Košice (Fig. 3). The methodology and results of the analysis are presented in this part of the paper.

The construction of a multifunctional complex Aupark Košice in the City centre consists of a shopping and entertainment building and an office building. The Developer has started the construction in January 2010. As soon as at the end of 2011, it will provide with new services, shops, entertainment and office space. The shopping building consisting of 7 dilatation blocks has three above ground floors, 2 underground floors and almost 34 000 square meters. It will offer 1 100 parking spaces in the underground garages. The office building is going to be 11 storied. The developer estimates the total construction costs at 93 million EUR. In order to provide for the smoothness of traffic in the city centre, the company will also build a modern four-way road at the Liberators` Square. The framework of the building is a monolithic reinforced concrete structure. It is combination o structural walls and poles. One of the most significant contractors constructing the centre is an internationally well known building company having one of its divisions in Eastern Slovakia. Two hundreds workers are being at the site in average and six tower cranes are serving. Approximately 40 354 m^3 of concrete, 139 141 m^2 of system forms and 5 429 t of structural is planned to be used in construction.

Fig. 3. Visualisation of Aupark Shopping Centre in Košice [14]

5.2. Identification of occupational safety hazards

The safety risks analysis was made by the group of experts consisting of safety specialist from the company constructing the Aupark centre, few Civil engineering students and the authors of the paper. It has been made on the basis of the building design and construction schedule. The analysis has been made in consideration of two meaningful aspects: time and space. From time point of view, the total construction process has been divided into ten specific phases: earthworks, foundations, under framework, framework, roofing, indoor works (partitions and energy, water, sewage, gaz and air-condition distributions), indoor surfacing (flooring etc.), indoor completions (painting, floor surfaces), facilities completions (sanitary, electricity, gaz etc.) and facade. From space point of view we considered three specific spaces: building space (indoor), construction site (exterior) and site neighbourhood. In these three spaces have been reflected three before mentioned groups of hazards (chapter 4): HA in building space, HS in construction site, and HN in site neighbourhood. Within the ten presented specific phases of construction process a big number of hazards (all possible loss-of-control incidents that may occur) have been identified. The identified hazards relate to construction activities being made, to construction site conditions, and to site neighbourhood during particular construction phase works performance. All hazards were collected to form of catalogue lists. Thus, we have collected 30 **catalogue lists of occupational safety hazards**; 3 for each specific phase of construction time (pertaining to 3 groups of hazards: HA, HS and HN). In the Table 3 are presented amounts of identified hazards and sources of these hazards.

Table 3. Amounts and sources of identified occupational safety hazards

Construction phases	**Group of hazards**	**Amount of hazards**	**Sources of hazards**
Earthworks (EW)	HA	26	soilcrete sealing wall; shaft excavating; soil transport; pump wells and dead wells making
	HS	20	atmospheric electricity; hand roads cleaning; pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; night work; external site; intra site roads transport
	HN	14	extra site transport of soil; hands road cleaning; road cleaning machines; earthworks machines; pedestrian and machines transport out of site; noise and dust; night work; excavating; site entries and exits
Foundations (FO)	HA	16	foundations (piles) construction; Forming, reinforcing and concreting of base plate, sewer pipes installation
	HS	14	atmospheric electricity; pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; night works; external site; intra site roads transport
	HN	11	extra site transport; road cleaning machines; pedestrian and machines transport out of site; noise and dust, night work, site entries and exits

Table 3 (cd.)

Construction phases	**Group of hazards**	**Amount of hazards**	**Sources of hazards**
Under framework (UF)	HA	39	forming, reinforcing and concreting of poles, walls, ceiling, elevator shaft and ramps; assembly of prefabricated stairways
	HS	19	atmospheric electricity; pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; night work; external site; intra site roads transport
	HN	11	extra site transport of soil; road cleaning machines; pedestrian, machines and trucks transport out of site; noise and dust, night work, site entries and exits
Framework (F)	HA	49	forming, reinforcing and concreting of poles, walls, elevator shaft and ceilings; assembly of prefabricated stairways; assembly of steel pylons and girders
	HS	19	atmospheric electricity; pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; night work; external site; intra site roads transport
	HN	13	road cleaning machines;, pedestrian, machines and trucks transport out of site; noise and dust; night work; site entries and exits; scaffolding; tower cranes
Roofing (R)	HA	27	green and other roofs constructing; steel structures assembly
	HS	17	atmospheric electricity; pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; external site; intra site roads transport
	HN	9	hand roads cleaning; pedestrian, machines and trucks transport out of site; noise and dust; site entries and exits; scaffolding; tower cranes; roof structures products
Indoor works (IW)	HA	15	automatic roller doors installation; wickets installation; water distributions installation, sewer lines installation; power lines installation; gas lines installation; central heating installation; air-conditioning lines installation
	HS	6	pedestrians (workers) movement; dangerous holes; going to heights
	HN	5	pedestrians, machines and trucks transport out of site; noise and dust; site entries and exits; tower cranes
Indoor surfacing (IS)	HA	25	flooring; escalators installation; moving pavements installation; electric lifts installation
	HS	6	pedestrians (workers) movement; dangerous holes; going to heights
	HN	5	[edestrians, machines and trucks transport out of site; noise and dust; site entries and exits; tower cranes

Table 3 (cd.)

Construction phases	**Group of hazards**	**Amount of hazards**	**Sources of hazards**
Indoor completions (IC)	HA	25	fanlights installation; gypsum partitions assembly; lower ceilings assembly; concrete screeding on floors; paintings, swabs and facings; pavage; doors installations; cleaning
	HS	6	pedestrians (workers) movement; dangerous holes; going to heights
	HN	5	pedestrians, machines and trucks transport out of site; noise and dust; site entries and exits; building lifts
Facilities completions (FC)	HA	28	power, gaz, water, air-conditioning; sewer lines completion; lifts machine rooms installation; sanitary installation
	HS	6	pedestrians (workers) movement; dangerous holes; going to heights
	HN	5	pedestrians, machines and trucks transport out of site; noise and dust; site entries and exits; building lifts
Facade (FA)	HA	21	facing, glazing and painting
	HS	16	pedestrians (workers) movement; dangerous holes; going to heights; weather conditions; external site; intra site roads transport
	HN	8	pedestrians, machines and trucks transport out of site; noise and dust; site entries and exits; building lifts; façade products; scaffolding

The **hazards referring to construction activities connections and coordination (HC)** must have been identified differently. It has been done on the basis of construction schedule. More accuracy in the construction schedule execution is the assumption for better hazards identification. The construction of five floored shopping part of the building is divided into six working areas. The sky, office part of the building, is constructed as one working area. The most significant occupational safety risks exposures are in the phase of completing works, after roofing finish. In this phase of construction is not rare that many construction works are made together, in parallel, regarding the time as well as regarding to space. Many construction workers often collide in constrained spaces or they use shared equipments or storage accommodations eventually storage spaces. That is why the probability of injury occurrence is bigger. The best way to avoid such safety hazards consists in elimination of construction works performance at the same time and in the same space in parallel. Sometimes, mainly in completion phases it is almost impossible. Among the most effective measures to eliminate such safety hazards belong: better work organization, change of workers amount, extension or shortening of construction activities, technological breaks etc.

In evaluation of risk levels for identified hazards referring to construction activities connection and coordination is necessary to remember that some connections do not involve danger but other connections could be substantial from hazards exposure point of view.

5.3. Evaluation of risk levels for identified hazards

The second step of occupational safety risks analysis (safety risks assessment) was seeking to determine the expected risks levels for all hazards identified in previous one (no 5.2). The risk levels were estimated as the combination of three factors: **the probability (P)** – the likelihood of occurrence of loss-of-control event, **the severity (S)** – the expected degree of severity of accident scenario and **the subjective opinion (O)** of the experts group. The information was collected by means of a survey that was conducted through face to face workshop participated by the experts. The safety specialist from the construction company was considered as the most appropriate source for practical information about potential loss-of-control event. He, more than anybody, is aware of the overall circumstances on site; the composition of activities on site and their nature, the number of workers involved, organizational conditions, etc. We determined a scale for probability, severity and the subjective opinion from 1 to 5. The descriptive interpretation of particular values can be found in Tab. 4. Then risk significance ratings, **risk levels (RL)**, for all identified hazards were defined as composition of three values: probability, severity and the subjective opinion of the experts.

Table 4. Scales for probability, severity and the subjective opinion

Value	Probability	Severity	Subjective opinion
1	random	injury without disablement	negligible effect to risk level
2	improbable	injury with disablement	little effect to risk level
3	probable	injury with hospitalization	bigger, considerable effect to risk level
4	highly probable	injury with persistent effects	big and meaningful effect to risk level
5	permanent	fatal injury	various meaningful and negative effects to risk level and implications

The resulting risk level from 0 to 3 designates the risk which could be neglected; the risk level from 3 to 10 designates the potential risk, it is necessary to pay attention; the risk level from 10 to 50 designates that some safety arrangements are essential; the risks in interval from 50 to 100 are high and immediate safety arrangements must be done; and in case of risk level bigger than 100, the work must be stroke. The results of assessment are in Tab. 5.

Table 5. The results from occupational safety risks assessment

Construction phases		HA	HS	HN
Earthworks (EW)	average RL	15	21	19
	max RL	**48**	**40**	**48**
Foundations (FO)	average RL	19	20	21
	max RL	**36**	**40**	**48**
Under framework (UF)	average RL	16	21	16
	max RL	**36**	**40**	**48**
Framework (F)	average RL	16	17	20
	max RL	**36**	**40**	**48**
Roofing (R)	average RL	16	17	24
	max RL	**36**	**40**	**48**
Indoor works (IW)	average RL	11	11	10
	max RL	**27**	**12**	**16**
Indoor surfacing (IS)	average RL	13	10	10
	max RL	**32**	**12**	**16**
Indoor completions (IC)	average RL	10	10	10
	max RL	**16**	**12**	**16**
Facilities completions (FC)	average RL	11	10	10
	max RL	**32**	**12**	**16**
Facade (FA)	average RL	14	15	25
	max RL	**48**	**36**	**45**

Besides such tabular expression, the results from risk assessment could be figured by the type of time-spatial map, which is presented in Fig. 4. The contractor can easy understand the levels of safety risks affecting construction in particular construction phase (from earthworks to facade) and in particular space (building space, site or site neighbourhood).

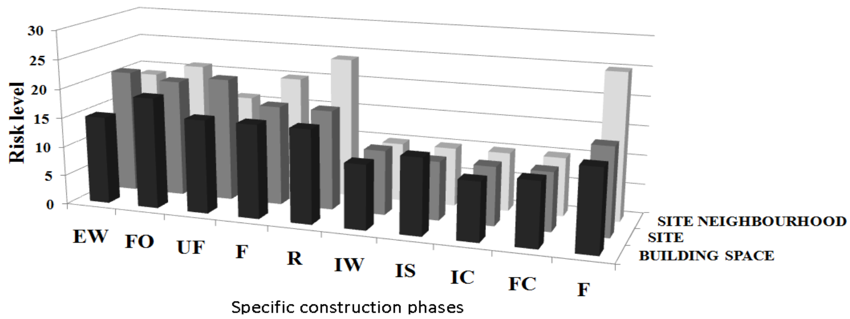

Fig. 4. Expression of safety risks significance ratings by time-spatial map

6. Conclusion

Proactive hazards identification and risks elimination is always safer and more cost-effective than reactive hazard management. Designers, architects, engineers and contractors have a big influence on the health and safety of site workers. Since the adoption of the Government Regulation 510/2001 (transposition of EU Directive), Slovakian building designers are required to consider health and safety in their designs. Full occupational safety risk analysis of a construction project should be covered in health and safety plan a of construction project. Designers fall short of satisfying this obligation and most contractors often neglect the proper implementation of health and safety plans. They see these health and safety plans as merely a burdensome requirement that they must fulfil in order to avoid government fines. In this paper is presented the approaches to occupational safety risks analysis in construction and the methodology is applied on construction of Aupark Centre in Košice.

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