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Impact of Construction Machinery and Tools on Non-Fatal Injuries in the Building Processes

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Abstract: Factors contributing to construction machines, hand tools and power tools in building multistory buildings have been investigated. 212 non-fatal injuries have been analyzed in terms of identification of type of machine and tool used, indirect cause of injury, the way in which injury has occurred, severity, injured body parts and the role of the injured worker in the work process. Research has shown that trucks and tower cranes are the riskiest machines while circular saw, grinder and drilling machine are the riskiest mechanical tools. Wheelbarrow and hammer are the riskiest hand tools. Most of the injuries happen due to the "Incorrect realization of work operation". Operators are the most injured workers considering all types of machines except tower cranes. Severity levels are higher when machines and mechanical tools are used. Hand-arm and foot-leg are the most vulnerable body parts but body-torso and other multiple injuries are right behind. "Struck by an object", "Struck against", "Caught in, under or between", "Fall to level below" and "Excessive physical strain and exhaustion of the organism" are the most probable ways for an injury to occur while using construction machinery and tools.

Keywords: construction; health and safety; machines; severities; tools

1 INTRODUCTION

Construction industry makes a significant part of the industry within the European Union (EU). Taking into consideration the total number of the EU legal entities at the end of 2008, 3.285.000 of them are construction companies, which represents 15.6% of all the companies on the EU territory. They employ 11% of the overall EU labour force. The construction industry share in the total added value within the EU amounts to 9.8% (The statistical office of the European Union - EUROSTAT).

Five years later, in 2013, out of all legal entities in the EU, 15.6% relate to construction companies which employ 9.22% of the overall EU labour force. The construction industry share in the total added value amounts to 7.97% (EUROSTAT). In the construction sector of the Republic of Serbia in 2014, the construction companies made up 8.5% of all the companies while employing 7.4% of the labour force and amounting to 6.8% in the total added value (Statistical Office of the Republic of Serbia).

In the majority of industrial countries, construction industry represents one of the most significant branches of industry, from the aspect of its influence on the gross national product. Despite being one of the most significant branches, construction industry has featured the highest injury rate in the last decades [1-10].

The International Labour Organization reveals that every year at least 60,000 deaths take place on construction sites and that in more industrialized countries from 25% to 40% of the fatal injuries at work also take place on construction sites [11]. High rate of injuries at work represents a result which requires a systematic approach and record-keeping of all potential risks which can result from badly organized building processes and work technology.

However, Hallowell and Gambatese [12] have stated that the construction industry is unique and characterized by frequent changeability of the work environment, the use of heavy equipment, as well as, at first glance, inevitable worker-hazard interactions. Charehzehi and Ahankoob [13] claim that despite mechanization, the construction industry abounds in manual work while the work environment is constantly changing, which is the reason why construction workers are the most vulnerable project members. Construction sites are workplaces that enclose a diversity of hazards to safety and health of workers and many of the activities developed within the course of the execution stage of construction projects are potentially dangerous [14].

Unfortunately, manual work will be in decrease in the future considering advantages of machine usage and automation in the civil engineering. Based on the previously mentioned it is of high importance to constantly analyse and learn about risks of machine usage, their advantages and disadvantages.

2 LITERATURE REVIEW

Nowadays it is impossible to imagine realization of construction works without using tools and mechanization. Although created to make the workers' job easier and to increase productivity, these resources also generate a wide spectrum of hazardous situations. Unlike the stationary industry where the realization of work operations is done almost identically on a daily basis, the variations of construction site conditions along with the necessity to use a large number of different tools contribute to complexity of safety conditions which quite often lead to injuries. Conte et al. [15] report that 28.24% of the injuries in the Spanish industry during the period of 11 years were caused by "being struck by objects or tools" (19.22%), "projections of fragments or particles" (6.27%), and "accidents caused by moving machinery or traffic" (2.75%). Even though the given results do not relate directly to the construction sector, they provide insight into potential risk of mechanization and tools usage.

According to HSE [16], 5% of the injuries within building construction, civil engineering and specialized construction activities were sustained due to "contact with machinery". Lipscomb, Schoenfisch and Shislov [17] indicate that 21% of the injuries treated in the US emergency departments in the construction industry happened due to tools and equipment, whereas 6% of the injuries happened due to mechanization. In addition, Lipscomb et al. [18] have concluded that nail guns were involved in 14% of the investigated injuries. Ninety percent of these injuries were the result of a carpenter being struck, most commonly by a nail puncturing a hand or fingers. The injury rate among apprentices was 3.7 per 200 000 working hours. Camino Lopez et al. [6] have reported that 8.9% of the injuries in Spain during the period of 1991-2000 were sustained due to tools, whereas 5.4% of the injuries were sustained due to construction mechanization. Ching-Wu, Chen-Chung and Sou-Sen [8] examined 1347 reports of occupational accidents and fatalities in the industry from 2000 to 2007, recorded in the occupational accident database of the Council of Labour Affairs (Executive Yuan, Taiwan), and they determined that the source of injury of 10% of all injuries was loading and transport machinery and 5% was power machinery.

Unlike tool injuries, mechanization injuries have more serious outcomes. The likelihood that an accident will have severe consequences increases when it involves vehicles [6]. Pines, Halfon and Prior [2], back in 1987, published their research on occupational accidents in construction industry in Israel and they established that mechanization, as a part of the construction industry, caused 3.6% of the injuries in 1979, and that in 1976 it was the cause of 9% of the injuries that led to permanent disability. Irumba [19] claims the three most prevalent causes of accidents in Kampala are mechanical hazards (i.e. struck by machines, vehicles, hand tools, cutting edges, etc.), being hit by falling objects and falls from height. Research that covered UK, US and Israel data for 2009, 2008 and 2007 respectively [20] showed that "contact with moving machinery" generated 6% of fatal injuries, 4% of non-fatal major injuries (resulting in permanent disability) and 4% of injuries resulting in over-3-day absence while "struck by moving vehicle" generated 12% of fatal injuries, 2% of non-fatal major injuries (resulting in permanent disability) and 1% of injuries resulting in over-3-day absence. According to this research, the sum of rates of fatal injuries caused by machinery and vehicles is just behind the rates of "falls from a height over 2 m" which are the highest among all. The same research stated that 12% of non-fatal injuries were caused by hand tools in Israel in 2007. Idoro [21] has reached the conclusion that mechanization of construction operations increases the occurrence of accidents and injuries to workers in the construction industry in Nigeria. The findings indicate that the drive by construction contractors in Nigeria towards adopting mechanized production methods is not complemented by efforts to control the hazards associated with mechanization; therefore, mechanization actually worsens the OHS performance of the industry. Analysing impact of tower cranes on fatal and non-fatal injuries in Hong Kong, Tam and Fung [22] have presented the data that there were 12 tower crane related accidents and 14 casualties in the period from 1998 to 2005.

Mechanization and tools usage implies their regular maintenance. These maintenance activities are most commonly done on the premises of the company itself, thus generating new risks which specialized workers, such as mechanics, are most often exposed to. Aneziris et al. [23] claim that almost 400 accidents take place each year in all parts of industry in the Netherlands as a result of contact with moving parts of machines and are the most frequent source of injuries in the workplace. Also they claim that most accidents occur while workers are operating machines, but many accidents have been registered for periods when machines are not operating but are under maintenance, clearing or cleaning processes. According to Cebador, Rubio-Romero and Lopez-Arquillos [24] 43.94% out of 2776 injuries caused by electricity happened while using the hand tools (31.12%) or machines (12.82%) of which 5.53% were defined as fatal or serious.

It is known that in the majority of countries employers are obliged to implement a range of activities related to workers and their safety at work, such as: risk assessment, introducing workers to risks involved as well as safety measures, theoretical and practical preparation of workers for working safely, etc. Kartam, Flood and Koushki [25] believe that only properly trained workers should be allowed to perform risky tasks, especially when using powered tools and equipment. Mitropoulos and Cupido [26] have stated another safety-related rule that the foreman should use - not to allow inexperienced workers to use power tools (e.g., circular saws). Holte and Kjestveit [27] have stated that large companies in Norway have organized training courses for using certain types of tools. Raviv, Fishbain and Shapira [28] have reached the conclusion that the largest share of failures has arisen due to human factor, that is: inattention, improper rigging, signal person error and operator error.

Interestingly, Malekitabar et al. [29] have emphasized importance of the concept of design for safety, namely, adequate planning, i.e. designing that is possible to connect with more than one fifth of fatalities caused by engineering vehicles in which cases most fatalities could have been avoided by better organization of construction sites and works.

3 METHODOLOGY

Research of risk of construction mechanization and tools usage consisted of three stages. First, collection of injury reports in cooperation with occupational health services of Autonomous Province of Vojvodina was done. After the data collection, an analysis of the data was carried out and a database was formed. Finally, a data analysis was done through the analysis of machine and tool type, cause of injury, the way in which injury has occurred, severity, injured body part and the role of the injured worker in work process. At the same time, it was analysed whether the injury occurred during their improper use or if the injury was a consequence of the operation which was associated only with the observed resource, i.e. the injury would not have occurred if the resource had not been used (for example, material takeover at the edge of the building during the use of tower crane). All injuries gathered in the database would not have happened if the specified resource (machine or tool) had not been used.

Application of databases has been intensified over the past 20 years, along with the development of computers and computer applications. The trend of their frequent application is present in the field of safety at work in the construction industry. Levitt and Samelson [30] recommend creating a database within each construction company in order to be able to identify the most problematic segments of the construction process. Kartam, Flood and Koushki [25] came to the conclusion that the creation of a national database on events which resulted in injuries would provide better management of risks of safety at work in the construction industry. Hadikusumo and Rowlinson [31] used the database for identifying potential dangers of safety at work and planning corrective measures. The database is connected with an application which provides a 3D view of a building during the construction process. Chua and Goh [32] have presented a model of causal relations with the aim of identifying the risk of safety at work. They did so by using the reports on 140 injuries which occurred in building construction. Tam, Zeng and Deng [33] have analysed a database provided by the National Bureau of Statistics of China on 1000 accidents which resulted in the death of workers in order to define causes of these accidents. Bellamy et al. [34] have formed a database with 10000 events which resulted in injuries. The created database was used when identifying and quantifying various types of risks, such as fall to a level below [35]. Marhavilas and Koulouriotis [36] have presented a hybrid model of risk quantification based upon the data on injuries which occurred over the period of 19 years.

3.1 Establishing the Database

For research purposes, a database of workplace injuries that occurred during the realization of construction works was formed. Unfortunately, present legislation does not include any obligation in terms of creating comprehensive injuries database on the state level. Further on, first step of the research was collection of all available injuries reports. The database was formed in order to define potential sources of risk, their connection with different types of works (earthworks, concrete works, carpentry works, etc.), materials, tools, machinery and labour force characteristics. In addition, injuries data provide information about the significance of these parameters and facilitate the quantification of risk parameters (probability and consequences).

The data were gathered based on work injuries reports addressed to occupational health services of Autonomous Province of Vojvodina and are related to construction companies in Vojvodina. The analysis of injury reports has shown that a certain part of the reports relates to injuries that are incurred on building sites as well as some of the reports that do not contain all the required information. The structure of the analysed injury reports is shown in Tab. 1.

Table 1 The structure of the analyzed injuries reports

Area of construction sector		Number of analyzed reports	
All construction subsectors - inside and outside the site		1158	100%
All construction subsectors- inside the site		990	85,49%
Building construction subsector – inside the site	Total	736	63,56%
	Do not include key data	17	1,47%
	Included in the database	**719**	**62,09%**

The total number of analyzed injury reports is 1158, 990 of which are related to injuries incurred on building sites in all areas of the construction industry. In addition, 736 injuries incurred in the construction of buildings, 17 of which did not contain key data (description of the injury), so it was impossible to determine the sources and causes of the injuries. For this reason a newly formed database contains the data on 719 injuries.

3.2 Database Structure

The database must contain all information relevant to the observed injury. At the same time the amount of the data must be kept to a minimum and they must be simply structured in order to allow effective implementation of the database.

The database is structured to provide information on as many parameters as are relevant to the occupational health and safety risk identification and quantification. At the same time the final database structure depends on the data available within the injury reports. The database consists of five groups of data as follows:

- Group 1 - Data on the injured worker;
- Group 2 - Data on the time when the injury occurred;
- Group 3 - Data on the type of work and work operation realized at the moment of injury;
- Group 4 - Data on the source of injury, cause of injury and the way the injury occurred and
- Group 5 - Data related to consequences of the injury (severity and injured body parts).

Each of the data groups consists of a number of subgroups that provide more accurate information about the parameters of the observed injuries. For the purpose of this research only certain data subgroups within the presented groups have been used, which will be further described in detail. In order to determine the cause of the injury the following parameters were identified based on the description of reported injuries:

- Whether these resources were direct sources of injuries (breakdown of machinery, tools);
- Whether the injury occurred during their improper use or
- Whether the injury was a consequence of the operation which was only associated with the observed resources, i.e. the injury would not have occurred if the resource had not been used (for example, material takeover at the edge of the building during the use of tower crane).

4 RESULTS AND DISCUSSION

Building process cannot be done without using mechanization and tools. Nowadays these resources are so important that their planning requires special attention in terms of both realization of works and protection at work. Upon conducting this research all resources related to injuries, thereby mechanization and tools as well, have been identified.

Special attention has been dedicated to tools in terms of being manual or mechanical. (Tab. 2) As we can see in Tab. 2 the greatest number of injuries (84 injuries which is 11.68% of 719 injuries) is connected to applying mechanization, followed by applying hand tools (66 injuries, 9.18%) and finally by applying mechanical tools (62 injuries, 8.62%) which is very close to the results of HSE [16], Perlman, Sacks and Barak [20] and twice as much as compared to the Camino Lopez et al. [6].

4.1 Type of Resource

Tab. 2 shows the number of injuries according to the type of mechanization and tool in progress at the moment of injury. Based on the table it is possible to conclude that kipper truck represents the riskiest machine on the construction site revealing 31 injuries sustained due to using this machine.

If injuries sustained by applying mechanization are taken into consideration, while using kipper truck, tower crane, excavator and concrete mixer truck (out of 20 in total whose usage was in progress when the injuries happened) 75% of the injuries took place whereby over 55% of them while using kipper truck and tower crane.

If we observe injuries sustained by applying tools (Tab. 2) while using five types of mechanical tools (out of 13 in total whose usage was in progress at the time of the injury) 70.97% of the injuries occurred, whereas using three types of hand tools (out of 19 in total) led to 69.70% of the injuries. Only the tools whose usage was in progress at the time of occurrence of at least 3 injuries are registered. It should be noted that five injuries occurred indirectly, i.e. the injured worker was implementing the work operations which are not in any way connected with the tools that caused the injury. In all five cases cause of the accident is fall of hand tools on the injured worker.

Table 2 Number and frequency of injuries by type of mechanization and tool

	Type of machine or tool	No. of injuries	Frequency
Mechanization	Kipper truck	31	36.90%
	Tower crane	18	21.43%
	Excavator	8	9.52%
	Concrete mixer truck	6	7.14%
	Jumping jack compactor	3	3.57%
	Tractor, Forklift, Loader (two injuries per machine)	6	7.14%
	Dumper truck, Water tank truck, Truck mounted crane, Wire rope hoist, Skip hoist, Truck concrete pump, Concrete pump, Bulldozer, Soil compactor-roller, Small plate compactor, Concrete factory, Plastering machine (one injury per machine)	12	14.29%
	Total	**84**	**100.00%**
Mechanical tools	Circular saw	12	19.35%
	Grinder	10	16.13%
	Drilling machine	10	16.13%
	Demolition hammer - compressor	7	11.29%
	Compressor	5	8.06%
	Rebar cutter and bender	4	6.45%
	Plaster/mortar mixer	4	6.45%
	Other	10	16.13%
	Total	**62**	**100.00%**
Hand tools	Wheelbarrow	27	40.91%
	Hammer	14	21.21%
	Handsaw	5	7.58%
	Knife	3	4.55%
	Other	17	25.76%
	Total	**66**	**100.00%**

4.2 Indirect Cause of Injury

The indirect cause of the injury is related to the characteristics of a certain work operation that caused the injury regardless of whether the injured worker was realizing the operation or the worker was injured by another worker (i.e. incorrect realization of the working operation or malfunction of tools). The detailed classification of indirect causes (Tab. 3) was formed based on the injuries analysis according to [15, 37-42] and improved by using information available from the injury reports. Tab. 3 presents 42 indirect causes divided into three groups according to whether they were associated with unsafe work and/or behaviour of workers, unsafe working conditions or unknown.

When determining the cause of injury, which was based on the data from injuries reports, all relevant information such as information about the work that was performed, information on whether the worker was properly trained, whether it was subjected to medical examination, whether the worker was properly protected as well as the data available from injury reports were considered.

Injuries which were defined to be caused by unsafe act are the sole responsibility of the workers since there are not identified reasons for which it could be argued that the injury is the responsibility of the employer. Injuries which are defined to be caused due to unsafe conditions are the sole responsibility of the employer because the employer had not fulfilled all the obligations envisaged in the current legislation. Injuries caused by unsafe act are a direct consequence of one of 12 indirect causes shown in Tab. 3.

Considering indirect source of injuring while using mechanization 54 injuries (64.29%) were sustained due to incorrect realization of work operation (32 injuries; 38.10%) and incorrect entry and exit from the machine (26.19%). During usage of hand tools 16 injuries (24.24%) were sustained due to improper use of tools and equipment, whereas 16 injuries (22.73%) occurred due to incorrect realization of work operation. In case of mechanical tools, 28 injuries, contributing to 45.16% of the injuries inflicted due to usage of this resource, occurred due to incorrect realization of work operation, whereas 23 injuries (37.10%) occurred due to improper use of tools and equipment, which amounts to 82.26% of the total number of injuries. These data indicate the significance of proper practical training of workers which should definitely include quality training for safe work while using these resources. Workers' experience can reduce the risk of using mechanization and tools to some extent, but it cannot by any means represent the measure to be relied upon.

Table 3 Number and frequency of injuries by mechanization and tools usage

Group of indirect causes	Indirect cause	Mechanization		Hand tools		Mechanical tools		Total	
		No.	%	No.	%	No.	%	No.	%
Unsafe acts	incorrect realization of work operation	32	15.09%	15	7.08%	28	13.21%	75	35.38%
	improper use of tools and equipment	0	0.00%	16	7.55%	23	10.85%	39	18.40%
	incorrect entry and exit from the machine	22	10.38%	0	0.00%	0	0.00%	22	10.38%
	failure to wear PPE	0	0.00%	9	4.25%	3	1.42%	12	5.66%
	improper handling of machinery	8	3.77%	0	0.00%	0	0.00%	8	3.77%
	overturning a vehicle	4	1.89%	0	0.00%	0	0.00%	4	1.89%
	incorrect movement, turning, blackouts	0	0,00%	1	0,47%	0	0,00%	1	0.47%
	poor housekeeping of workplace	0	0.00%	1	0.47%	0	0.00%	1	0.47%
	Indirect causes of unsafe acts without injuries: alcohol, horseplay, improper use of ladders, improperly built material								
Unsafe conditions – procedures. rules	malfunction of machinery	15	6.60%	0	0.00%	0	0.00%	15	7.08%
	use of defective or unsafe tools	0	0.00%	13	6.13%	0	0.00%	13	6.13%
	malfunction of tools	0	0.00%	6	2.38%	1	0.47%	7	3.30%
	poor housekeeping of corridors	0	0.00%	0	0.00%	5	2.36%	5	2.36%
	unsafe access ramp	0	0.00%	0	0.00%	2	0.94%	2	0.94%
	improper safety of openings	0	0.00%	0	0.00%	2	0.94%	2	0.94%
	improper storage of materials	1	0.47%	0	0.00%	1	0.47%	2	0.94%
	inadequate PPE	0	0.00%	1	0.47%	1	0.47%	2	0.94%
	improper control of internal traffic	2	0.94%	0	0.00%	0	0.00%	2	0.94%
	Indirect causes of unsafe conditions without injuries: malfunction of auxiliary equipment, use of defective or unsafe equipment, improper edge safety, improper pit safety, improper safety of trench, improper safety of working scaffolds, improper safety of scaffolds, improper marking of hazardous places, improper ladder instalation, cracking of built-in materials, poor housekeeping of access points, electrocution, improper design of internal traffic, excessive noise, exposure to radiation, insufficient ventilation, insufficient illumination, confined spaces, improperly stored explosive or hazardous materials, lack of fire protection, weather conditions								
Unsafe act		66	31.13%	54	25.47%	42	19.81%	162	76.42
Unsafe condition		18	8.49%	12	5.66%	20	9.43%	50	23.58
Total		84	39.62%	66	31.13%	62	29.25%		
		212 (100%)							

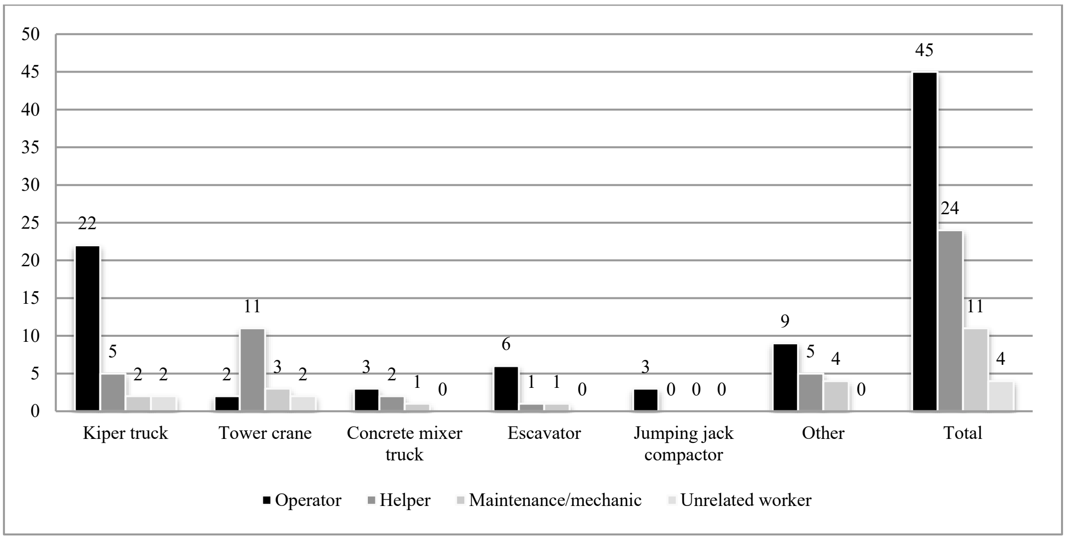

Figure 1 Number of injuries by role of injured worker in the working process of the machine observed

4.3 Workers Role

Due to the fact that exposure to a risk depends mostly on the workers position in the working process which generates the most of the hazards it was interesting to analyse whether the number of injuries varies based on the type of machine workers role. The results are presented in Fig. 1.

In 22 cases a driver of the kipper truck was injured, in 5 cases a labourer, and in 2 cases a maintenance worker and a worker unrelated to the machine work sustained injuries. It is certainly interesting that the machine which follows in the number of injuries is the tower crane, where only in 2 cases an operator sustained an injury, whereas in 11 cases a labourer, in 3 cases a maintenance worker and in 2 cases a worker who was unrelated to the machine work in progress were injured. In the cases of excavator and concrete mixer truck the most commonly injured person was the machine operator, where in the excavator cases the injuries occurred most frequently due to incorrect entry and exit from the machine, whereas in the cases of concrete mixer truck the injuries were sustained at the moment of casting concrete through the hopper. While using jumping jack compactor in all three cases the injuries were inflicted on the operator.

4.4 Experience and Age of the Injured Workers

The data on the injured worker, collected based on the information available within the application of injury at work, are extremely important for the identification of the worker risk category. The group of data on the injured worker consists of: worker's age at the moment of injury expressed in whole years, school (professional) qualification, years of service on the jobs at which the worker sustained injuries expressed in whole years and the total number of years of service expressed in whole years. It is noted that in cases when the worker had between one and two years of experience, the whole year of experience was adopted, i.e. the whole year of experience is officially recognized.

For the purpose of carrying out this research, the influence of years of age, experience and service duration on the jobs at which the worker sustained injuries expressed in intervals (recognized intervals are: 0-4 years, 5-9 years, 10-19 years, 20-29 years, 30-39 years, 40 years and more) has been analysed considering the fact that the workers with less experience were expected to have a higher injury frequency.

Considering experience of the injured workers at the tasks at which the injury was sustained in Figure 2 it is concluded that in all three cases, i.e. mechanization, hand and tools usage, number of inflicting injury is the highest in the first 4 years with the most noticeable differences in using hand tools. Interestingly, the number of injuries occurring due to using mechanization and hand tools in the first 4 years is the same even though the time of using hand tools is significantly longer comparing to mechanization usage. Additionally, in the period of 10 to 30 years of experience hand tools are less risky in comparison with mechanization and mechanical tools which suggest that it is possible that workers are less careful and rely more on the experience when using machines and power tools.

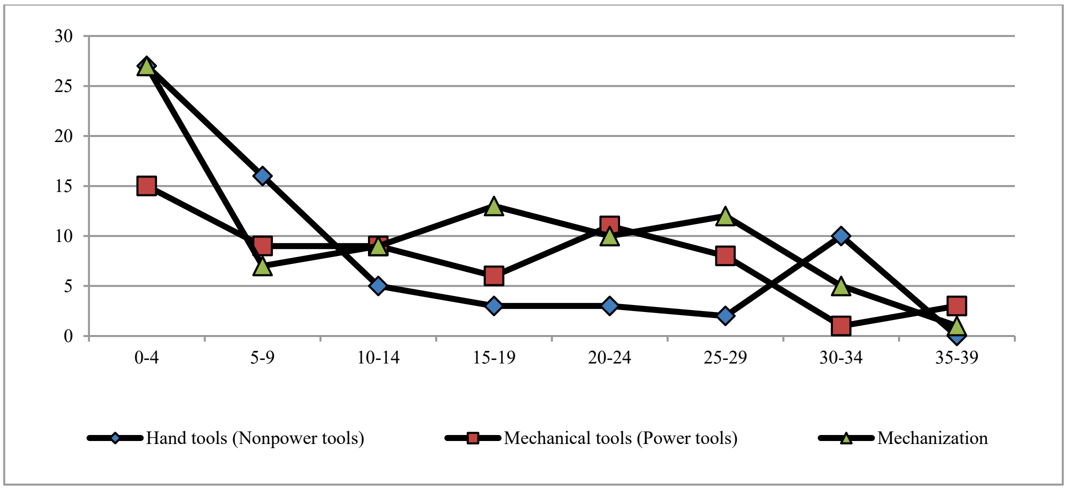

Figure 2 Number of injuries by worker's experience at work at which injury happened

4.5 Type of Construction Work

Types of works (earthworks, reinforcing works, carpentry works, etc.) are different from each other in terms of work operations (digging, cutting, grinding, masonry, etc.), required materials, tools, mechanization, auxiliary equipment, but also in necessary expertise levels of labor force for their realization. For that reason, there are different risk types and risk quantifications based on them. In order to associate causes, ways of injuring and risk quantifications with corresponding types of works, it is essential to include the data in the database on work injuries [4, 6, 43, 44].

Within applications of injury at work, which were used as the database source of information, the data on types of construction works and work operations in progress at the moment when the injury occurred are determined. This provides determining risk of different types of works and work operations. Data groups regarding types of works and work operations in progress at the moment of injuring consist of data on: the types of works in progress at the moment of injuring and the work operation being performed at the moment of injuring. Further on, every applied injury is assigned with one type of works in accordance with the data from the application of injury at work.

Within the research the works have been grouped in the following way: Operating mechanization (OM); Mechanization maintenance (MM); Reinforcing (REI); Concreting (CON); Carpentry (CAR); Masonry (MAS); Finishing (FIN); Walking without handling, working or material transfer (WAL); Preparation works and site cleaning – manual (PRE); Demolition and disassembly – manual (DEM); Erection works (ERE); Installation works - manual installation of electrical, mechanical and other equipment (INST); Loading and unloading – manual (LOA); Earthworks – manual (EAR); Transfer – manual or using manual tools, for example wheelbarrow (TRA).

Works such as loading and unloading, mechanization maintenance and mechanization handling have proven to be extremely important due to the number of injuries which occurred during their realization [45]. For that reason they have been marked as special types of works.

Walking without handling, unlike other industries with fixed workplaces, is one of the activities, which is consistently implemented within construction sites, but it cannot be described as a type of construction works. However, due to a large number of injuries occurring during walking without handling, this activity is singled out and analyzed in the same way as the other types of works [45].

The analysis of the variables resource types and types of construction works indicates that there is a dependence relationship between these two variables where the greatest number of injuries happened during "Operating mechanization", "Manual transfer" and "Finishing works" (Tab. 4). Interestingly, when using machines, "Loading and unloading" has the same accidents frequency as "Mechanization maintenance" and manual transfer which suggests that these operations must be carefully managed or replaced by other working operation. Mechanization usage caused most injuries during realization of works of "Operating mechanization" which was expected but great number of injuries happened during maintenance which corresponds to research of Aneziris et al. [23]. At the same time, hand tools caused the greatest number of injuries while realizing works of "Manual transfer" which is surprising. After detailed analysis it was concluded that all of these injuries happened while using wheelbarrow and due to the incorrect realization of work operation and poor site safety. Mechanic hand tools caused the greatest number of injuries while realizing works of "Finishing works" which was expected due to their extensive usage in these types of works.

Table 4 Number and frequency of injuries by type of tools and construction works

Resource type	Units	Type of construction works													
		OM	MM	REI	CON	CAR	MAS	FIN	WAL	PRE	DEM	LOA	EAR	TRA	Total
Mechanization	No.	**37**	11	-	6	-	-	2	2	-	-	11	4	11	84
	%	**17.45**	5.19	-	2.83	-	-	0.94	0.94	-	-	5.19	1.89	5.19	39.62
Hand tools (Non-power tools)	No.	-	1	4	3	9	3	12	1	1	2	3	-	**27**	66
	%	-	0.47	1.89	1.42	4.25	1.42	5.66	0.47	0.47	0.94	1.42	-	**12.74**	31.13
Mechanical tools (Power tools)	No.	-	5	7	6	12	4	**15**	0	1	7	2	2	1	62
	%	-	2.36	3.30	2.83	5.66	1.89	**7.08**	0.00	0.47	3.30	0.94	0.94	0.47	29.25
Total by type of construction works	No.	37	17	11	15	21	7	29	3	2	9	16	6	39	212
	%	17.45	8.02	5.19	7.08	9.91	3.30	13.68	1.42	0.94	4.25	7.55	2.83	18.40	100.00

Table 5 Number and frequency of injuries by type of mechanization and tools and way that injury has occurred

	Mechanization		Hand tools (Non-power tools)		Mechanical tools (Power tools)		Total	
	No.	Freq.	No.	Freq.	No.	Freq.	No.	Freq.
Dropping an object	4	1.89%	4	1.89%	2	0.94%	10	4.72%
Exposure to harmful substances	2	0.94%	-	-	1	0.47%	3	1.42%
Exposure to harmful environment	2	0.94%	-	-	3	1.42%	5	2.36%
Accidents occurred in traffic or transportation	5	2.36%	-	-	-	-	5	2.36%
Fragments. parts of materials	-	-	-	-	9	4.25%	9	4.25%
Falls to same level	3	1.42%	10	4.72%	1	0.47%	14	6.60%
Falls to level below	15	7.08%	1	0.47%	2	0.94%	18	8.49%
Excessive physical strain and exhaustion of the organism	5	2.36%	5	2.36%	8	3.77%	18	8.49%
Caught in. under. or between	13	6.13%	10	4.72%	7	3.30%	30	14.15%
Struck by machinery	9	4.25%	-	-	-	-	9	4.25%
Struck by	**19**	**8.96%**	**27**	**12.74%**	12	5.66%	58	27.36%
Struck against	7	3.30%	9	4.25%	**17**	**8.02%**	33	15.57%
Total	84	39.62%	66	31.13%	**62**	**29.25%**	212	100.00%

4.6 Way that Injury has Occurred

In this research an analysis of several classifications was carried, four of which were analyzed in detail. Classifications were formed specifically for the needs of the building process or the ones that can be easily applied for the same purpose. The following classifications were analyzed: Classification according to Hallowell [40], classification by Conte, Rubio and García [15], classification according to the Guidelines of the Administration of Occupational Safety and Health of the United States (OSHA) that is related to safety and health in the construction industry presented in [42] and classification according to Arandjelovic and Jovanovic [37]. Within the research a classification which is in accordance with the previous researches and which contains 12 categories of the ways of injuring shown in Tab. 5 was formed.

The Tab. 5 shows that "Struck by machinery" is not the riskiest way for an injury to occur. "Struck by" other objects (excluding machinery) and "Struck against" are the most frequent ways for injuries to occur which coincides with the research of Conte et al. [15]. It is interesting that a great number of injuries while using mechanization happened because of "Falls to level below". The main reason for this was "Incorrect entry and exit from machine".

4.7 Severity

In the literature, numerous classifications of severity of injuries have been defined. According to Great Britain's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations [46] it is necessary to report two types of injuries: serious injuries which require medical treatment of the injured person, i.e. hospitalization injury which caused the worker to be absent from work more than 7 days not counting the day on which the injury occurred. Singh, Hinze and Coble [47] have adopted the classification according to BIFSA (Building Industries Federation of South Africa) where the consequences of injuries are divided into four categories of injuries: those requiring only first aid, injuries which require hospitalization of a worker, injuries resulting in disabilities and fatal outcomes. Hallowell [40] suggests a more detailed classification of severity of injuries, with the aim of a more accurate quantification of risk, dividing them into eleven categories. According to the modified AUVA method presented in [48] severity of injuries is determined according to a five-level scale. Injuries are divided into: extremely low (negligible damages. requiring only first aid) low (minor. temporary damage. maximum 15 days of absence from work) medium (temporary damage. temporary loss of ability to work. lasting from 16 to 40 days) and high (serious or permanent damage, inability to work longer than 40 days or permanent) and death or collective (an injury resulting in death or injuries of several persons).

Relying upon the ways of classifying injuries in the research, the works mentioned above and taking into consideration the requirements of the valid legislation of the Republic of Serbia a new classification of injuries was created, encompassing six categories of injuries:

- Small injuries (injuries which required first aid and/or hospital treatment and absence from work of up to 4 days);
- Medium injuries (injuries which required hospital treatment and / or absence from work of between 4 and 13 days);
- Large (injuries which required hospital treatment and/or absence from work of 14 days minimum);
- Very large (injuries resulting in the total loss of ability to work);
- Death (occurring instantly or later on as the consequence of the injury) and
- Multiple death (an incident resulting in death of more than one worker).

The high rate of medium and large injures when using machinery and mechanical tools implies that their usage is highly risky and demands detailed and precise work planning more than planning of the adequate PPE. At the same time, most injuries caused by hand tools are minor, which suggests that use of PPE is extremely important for these resources.

Table 6 Number and frequency of injuries by type of mechanization and tools and severity

	Mechanization		**Hand tools (Non-power tools)**		**Mechanical tools (Power tools)**		**Total**	
	No.	Freq.	No.	Freq.	No.	Freq.	No.	Freq.
Small	24	11.32%	**39**	**18.40%**	17	8.02%	80	37.74%
Medium	**35**	**16.51%**	22	10.38%	**27**	**12.74%**	84	39.62%
Large	24	11.32%	5	2.36%	18	8.49%	47	22.17%
Very large	1	0.47%	-	-	-	-	1	0.47%
Total	84	39.62%	66	31.13%	62	29.25%	212	100.00%

Table 7 Number and frequency of injuries by type of mechanization and tools and injured body part

	Mechanization		**Hand tools (Non-power tools)**		**Mechanical tools (Power tools)**		**Total**	
	No.	Freq.	No.	Freq.	No.	Freq.	No.	Freq.
Head	7	3.30%	8	3.77%	2	0.94%	17	8.02%
Face	4	1.89%	-	-	-	-	4	1.89%
Eyes	2	0.94%	1	0.47%	6	2.83%	9	4.25%
Respiratory system	-	-	-	-	-	-	0	0.00%
Hands – arms	**28**	**13.21%**	**32**	**15.09%**	**38**	**17.92%**	98	46.23%
Feet – legs	20	9.43%	18	8.49%	9	4.25%	47	22.17%
Body – skin	1	0.47%	-	-	1	0.47%	2	0.94%
Body – torso	11	5.19%	3	1.42%	5	2.36%	19	8.96%
Multiple injuries	11	5.19%	4	1.89%	1	0.47%	16	7.55%
Total	84	39.62%	66	31.13%	62	29.25%	212	100.00%

4.8 Injured Body Part

Classification of injured body parts adopted in the research was specified after the analysis of international classifications adopted by international institutions such as World Health Organization presented in [49], International Labor Organization presented in [50] and certain authors who analyzed classifications particularly for the needs of construction processes, or whose classifications could be easily applied for that purpose.

These classifications are presented by Arandjelovic and Jovanovic [37], OSHA [51] and Lipscomb, Schoenfisch and Shishlov [17]. According to the analysis of the listed classifications and the analysis of information on injuries gathered from the reports on injuries at work, for the purpose of this research a new classification was created and applied within the observed data base.

The adopted classification is presented in Tab. 7.

5 CONCLUSION

Research has shown that trucks and tower cranes are the riskiest machines analysing non-fatal injuries while circular saw, grinder and drilling machine are the riskiest mechanical tools on construction sites. At the same time, wheelbarrow and hammer are the riskiest hand tools.

By analysing indirect causes it was concluded that training process should include intensive on-site work in order to prevent future mistakes. Apart from obligatory OHS trainings most injuries happened because of "Incorrect realization of work operation".

Operators are the most injured workers considering all types of machines except tower cranes. Interestingly, tower cranes' helpers, who are mostly involved in hooking and unhooking as well as binding materials and other objects, are the most injured workers in tower cranes' work processes. Frequencies of injuries are the highest when manual transfer and operating mechanization are performed. The workers with experience less than four years have greater probability to be injured.

Analysis of injuries severities has shown that severity levels are higher when machines and mechanical tools are used. Hands-arms and feet-legs are the most vulnerable body parts, which is not different comparing to the rest of construction works [45]. However, body-torso and multiple injuries are right behind according to probability to be injured, which suggests that some risks should be avoided instead treated with PPE.

Analysing the ways in which injuries have occurred, it can be concluded that "Struck by an object", "Struck against", "Caught in. under or between", "Falls to level below" and "Excessive physical strain and exhaustion of the organism" are most probable ways for an injury to occur when using construction machinery and tools.

Future research should be expanded on the whole territory of the Republic of Serbia which would enable more detailed analysis and appliance of new methods such as artificial intelligence. Unfortunately, sample of 212 injuries proved to be insufficient for any statistical analysis.

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