Modelling Accident Severity in the Construction Industry

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Abstract

A plethora of studies is found, which investigates the causes of construction accidents. However, the degree of injury severity caused to operatives by those accidents is under explored. This research empirically analysed 24,764 accident investigation reports and revealed complex interrelationships between factors that determine injury severity. Furthermore, the dynamic, interconnected nature of associations between the factors was structured using the influence modelling technique to enable inferring new insights into accident severity reduction in construction. Zero accident industry is preferred by all concerned, but it may not be achievable immediately. However, controlling the degree of injury severity can benefit workers by reducing their sufferings and builders by sustaining their reputation and turnover in projects. The findings of this study can help in this regard by informing construction organisations and OHS authorities on areas that they need to scrutinise closely and thereby enabling them correctly direct their focus and efforts to minimise fatal and sever accidents on site.

Keywords: Workplace health and safety, accident severity, influence modelling technique, accident severity model

Introduction

The construction industry is characterised by one of the worst safety performances globally. The unacceptably high accident rates in construction cause not only human sufferings but productivity losses, project delays, increased project costs and damage to the reputation of the builder (Fung et al., 2009; Gangolells et al., 2010). Because of these grave consequences, safety has ever been a hot topic for research. In this vein, causes of construction accident have been explored quite extensively by various researchers, resulting in several accident causation theories such as Domino Theory, Multiple Causation Model, Human Error Models, The Swiss Cheese Model, Accident Root Cause Tracing Model, Modified Statistical Triangle of Accident Causation Model, and Hierarchy of Causal Influences Model (Hosseinian & Torghabeh 2012). These various theories are aimed at assisting the development of safety management systems to achieve the goal of a zero accident industry. However, the reality is that construction still has one of the worst safety records despite the proliferation of safety management systems, procedures and protocols. While the march towards a zero accident industry is commendable, it is imperative to control and minimise the consequences of the already unfolding accidents. This is in alignment with the general risk management stages that the risk should be eliminated and if elimination is unachievable, the risk should be controlled / minimised to a manageable degree. Hence, the exploration of accident severity is an important aspect that can lead to significant insights and improvements for the construction industry.

Some previous studies are noted in the space of accident severity in construction. Larssen and Field (2002) studied the distribution of accident severity across various construction activities. López et al. (2011) studied the lunch time effect on accident severity. Arquillos et al. (2012) explained the connection between the mechanism of accident and accident severity. Similarly, Pinto et al. (2012)

investigated the coordinated effects of the mechanism of injury and injured body segment on accident severity. Dumrak et al. (2013) reported the bivariate relationships between accident severities and thirteen factors representing characteristics of victims, tasks carried out when accidents occurred, work environments, mechanisms of accident and the injured body part. Nonetheless, the previous research studies have largely explored linear bivariate relationships between different factors and accident severities. In reality, accident severities are resulted by the combined influence of multiple, interconnected factors. Hence, this study aims to model the complex interconnections between factors influencing accident severity in construction.

Dynamic influence modelling technique is used because of its ability to show multiple connections between factors with directions of association. The model development is underpinned by empirical evidence drawn from a very large accident database from South Australia. The paper first discusses the literature related to the study. Then, the research method involved in analysing accident data and the findings are discussed. Following that, an influence model for accident severity is developed based on the analysis findings. Finally, conclusions are drawn.

Literature Review

Accident severity is usually defined according to the degree of physical sufferings experienced by an accident victim. Different classifications/scales for accident severity can be found in literatures. Kamardeen (2009) discussed three levels of accident severity, namely fatality, permanent incapacity and temporary incapacity. The permanent incapacity resulting from an accident refers to permanently losing the potential earning ability due to the loss of a bodily organ. He provided a chart describing percentages of loss of earning potentials for different organs. The temporary incapacity refers to injuries that prevent a worker from carrying out the usual job for a limited period of time. This is essentially the temporary loss of earning to the worker due to injuries. Aneziris et al (2012), likewise, classified severity into lethal injuries, non-lethal permanent injuries and recoverable injuries. Dumrak et al (2013) used a combination of "lost days" and "hospitalisation" as the criterion to define six severity categories, namely: minor – accidents with no lost days or hospitalisation; moderate – accidents with no lost days but hospitalisation; serious – accidents with 1 to 3 lost days; severe – accidents with 4 to 10 lost days; critical – accidents with more than 10 lost days; and fatal – accidents that constituted to the demise of the victim.

An extensive review of literatures discovered ten factors as determinants of accident severity in construction and these are elaborated below.

Age of worker:

It has been reported in many studies that an increase in age of the worker is positively correlated with the degree of accident severity suffered (Dumrak et al. 2013; Arquillos et al. 2012; López et al. 2008; Salminen 2004). Moreover, Frickmann et al. (2012) and Cheng et al. (2012) argued that older workers (workers aged above 45) were involved only in few accidents compared to young and middle aged workers, but their sufferings were much severe, including fatalities, specifically for workers aged over 60.

Experience of worker:

The association between accident severities and the experience of the worker depicts an interesting pattern. Many studies have confirmed that workers with an experience of 1 to 10 years are more susceptible to severe accidents than workers with less than 1 year or more than 11 years of experience (Dumrak et al. 2013; Arquillos et al. 2012; Poon et al. 2002). Rameezdeen and Ratnasabapathy (2007) interpreted this pattern that this cohort of workers tends to believe accident won't happen to them and thus neglect hazards.

Gender:

Previous studies suggested that male workers were represented heavily in severe and fatal accidents than female workers and injuries to female workers were of mild and moderate consequences (Dumrak et al. 2013; Cheng et al. 2012; López et al. 2008; Hinze et al. 2005). This pattern was believed to be a reflection of the differences in tasks undertaken by male and female workers on construction sites.

Language background of worker:

Language background of workers has been repeatedly associated with accident severity. O'connor et al. (2005) reported that language barriers of Latino workers in the US contributed to their high accident and fatality rates. Dumrak et al. (2013) and Menzel & Gutierrez (2010) confirmed that in English spoken countries, construction workers with poor English language skills were prone to higher risks because they were not able to understand safety instructions, warnings and training.

Project size:

Previous studies confirmed that small-sized projects recorded a higher proportion of fatal and critical injuries than medium and large projects (Dumrak et al. 2013; Cheng et al. 2012; Atkinson & Westall 2010). Small projects are often undertaken by small companies, which may be less effective in managing OHS than medium and large sized companies. Dumrak et al. (2013) reported that workers from small companies who work on small projects were heavily represented in fatal and critical accidents than workers from large companies who were on large projects.

Project location:

A close association was noted between accident severity and project location. Ling et al. (2009) reported that high-rise construction in CBD areas recorded a high number of fatal accidents. Dumrak et al. (2013) discovered that projects located in the CBD, regional and outer suburbs of South Australia were represented largely in fatal accidents than inner suburb projects.

Timing of accident:

Previous studies revealed that the time of accident is associated with the degree of severity. Studies by Dumrak et al. (2013), López et al. (2011), Ling et al. (2009), Huang & Hinze (2003), and Kines (2002) detected disproportionately high fatalities between 2 and 4 pm, which are the work hours immediately after lunch.

Some researchers have reported that the climatic season and the day of the week influence accident rates. Huang & Hinze (2003) found a higher rate of accidents in summer but did not show any relationship between accident severity and season. In terms of days of the week, Arquillos et al. (2012), López et al. (2008) and Liao & Perng (2008) postulated that Mondays recorded higher accident rates. However, similar to the climatic season, no relationship between severity and the day of the week was reported. These disassociations were further confirmed by Dumrak et al. (2013).

Type of work:

The type of work undertaken by victims was found to be a key determinant of the degree of severity. The type of work can be defined by two variables: construction type and occupation type. Construction is classified largely as building works, heavy and civil engineering works, general construction and construction services. Dumrak et al. (2013) discovered that workers in the building and construction services sectors were over-represented in fatalities.

As for occupation type, Dumrak et al. (2013) and Jackson & Loomis (2002) argued that plant operators, truck drivers, electricians were highly vulnerable to fatal accidents. Unskilled workers were found to take the second place in severity after the above occupations. Moreover, Im et al. (2009) and Huang & Hinze (2003) claimed that occupation types that involve work at heights, such as roofers, painters, scaffolders and plasterers, suffered severe fall accidents while carpenters were over-represented in moderate accidents (Dumrak et al. 2013).

Mechanism of accident:

Previous studies showed that falling from a height, electrocution and equipment/vehicle related accidents were responsible for a significant portion of fatalities in construction (Dumrak et al. 2013; Arquillos et al. 2012; López et al. 2008; Tam et al. 2004). Workers being struck-by equipment, private vehicles, falling objects/materials, vertically hoisted materials, horizontally transported materials and trench cave-ins were represented in severe accidents after fatalities (Hinze et al. 2005).

Body part injured:

Past research reported that fatalities and other severe injuries were common in accidents, which involved body parts such as head, trunk, internal organs or multiple body locations/parts (Dumrak et al. 2013; Arquillos et al. 2012; Zhang et al. 2009.

Research Method

This research analysed 24,764 construction accident investigation reports by WorkCover South Australia, a state agency responsible for accident compensation under the Workers Rehabilitation and Compensation Act of 1986. Data comprised of accidents that occurred during 2002-2011 in South Australia. A typical case was characterised by factors such as: age, gender, language background, experience, construction type, time of incident, day of incident, season, mechanism of incident, project size, organisation size, body part injured, project location and lost days.

A pre-processing of the data was undertaken to filter out data points that were less-impactful on inference. The risk matrix recommended by the National Patient Safety Agency (NPSA) (2008) was based upon for this filtration. The matrix defined five levels of injury severity, with their descriptors, as follows (NPSA 2008, p6):

- Negligible - injury requiring no/minimal treatment; no time off work required/no lost days.
- Minor - injury or illness requiring minor treatment; requiring time off work (lost days) for shorter than 3 days.
- Moderate - injury or illness requiring professional treatment; requiring time off work (lost days) for 4 to 14 days.
- Major - injury leading to long term incapacity/disability; requiring time off work (lost days) for longer than 14 days.
- Catastrophic - incident leading to death, or multiple permanent incapacities or irreversible health effects.

It was decided to drop accident records that were categorised as negligible risk/severity as these are less helpful in studying the influence of the factors identified in the literature on accident severity. From the 24,764 accident records, the research therefore focused on records that had lost days or fatalities. Consequently, the data reduction resulted in 2,274 cases categorised under four different severity levels as minor, moderate, major and catastrophic. Finally, nominal scales were introduced for factors that had numerical entries for facilitating statistical analyses.

Table 1: Association between injury severity and incident characteristics

Factor	Category	Severity				Total
		Minor	Moderate	Major	Catastrophic	
Age (x2=13.585, p=0.035)	Up to 35 years	50	56	607	12	725
	Between 36 - 45	62	70	524	6	662
	More than 45 years	77	92	696	22	887
Gender	Female	26	17	60	0	103

(x2=51.049, p = 0.000)	Male	163	201	1767	40	2171
Language	Non-English	1	0	48	0	49
(x2 =9.920, p = 0.019)	English	187	216	1777	40	2220
Experience	No Experience	2	18	534	7	561
(x2=109.834, p=0.000)	Experienced	187	200	1293	33	1713
Construction type	Building construction	16	29	238	12	295
(x2 = 367.420, p = 0.000)	Non-building construction	150	144	462	10	766
	Special trade construction	2	5	223	1	231
	Other special trades	21	40	904	17	982
Body part injured	Trunk	58	90	855	1	1004
(x2=455.784, p= 0.000)	Hand	35	39	171	0	245
	Arm	9	7	132	0	148
	Foot	17	14	112	0	143
	Leg	24	31	289	1	345
	Head	7	2	28	7	44
	Eye	14	2	7	0	23
	Neck	10	16	100	1	127
	Internal	3	5	23	11	42
	Multiple	9	6	46	7	68
	Others	3	6	64	7	80
Mechanism of accident	Fall	39	49	501	2	591
(x2=232.911, p=0.000)	Struck by	53	35	194	5	287
	Caught in/between	8	10	37	2	57
	Muscular injury	60	92	865	1	1018
	Exposed to harmful substance	7	11	45	3	66
	Electric shock	1	0	4	3	8
	Vehicle accident	7	10	46	6	69
	Others	14	11	135	13	173
Location of project	Adelaide CBD and inner suburbs	71	83	1013	19	1186
(x2 =42.076, p = 0.000)	Adelaide outer suburbs	4	8	322	9	343
	Regional SA	35	50	373	12	470
Project size	Small	15	38	930	23	1006
(x2=532.042, p =0.000)	Medium	48	62	691	15	816
	Large	126	118	206	2	452
Organisation size	Small	3	24	891	22	940
(x2=748.134, p=0.000)	Medium	4	23	597	12	636
	Large	182	171	339	6	698
Season of accident	Summer	55	59	398	11	523
(x2= 14.687, p =0.100*)	Autumn	46	46	449	15	556
	Winter	42	59	502	6	609
	Spring	46	54	478	8	586
Day of accident	Monday	31	39	329	8	407
(x2 =16.245, p =0.575*)	Tuesday	34	51	348	9	442
	Wednesday	45	41	357	8	451
	Thursday	41	36	323	6	406
	Friday	23	29	320	4	376
	Saturday	6	13	93	3	115
	Sunday	9	9	57	2	77
Time of accident	Early morning	18	14	91	2	125
(x2=23.755, p=0.069*)	Morning	89	109	637	8	843
	Afternoon	51	49	524	14	638
	Evening	16	15	123	3	157
	Night	1	2	19	0	22
	Mid-night	5	4	25	1	35

In the next step, the study proceeded to investigate relationships between the four levels of injury severity and the factors that characterize accident records, using Chi-square statistics. Table 1 illustrates analysis results. Three factors (season, day and time) out of the 13 have been found not to have an association with injury severity levels (with p-values >0.05). Age and language background of the worker show moderate associations with injury severities. The above results of this study and the findings of previous research, as described in the literature review section, were analysed in a coordinated fashion in order to understand interconnections among the variables determining accident severity and their simultaneous impacts on accident outcomes. The following observations are made:

- When the size of the company that undertakes a construction project is large, injury severity tends to be low because large companies generally maintain well-established OHS management systems. Moreover, large companies often provide adequate OHS training to their workers to recognise hazards and be proactive in responding to potential risks. This in turn reduces accidents and injury severities.
- Large companies often carry out large projects that require the implementation of strict safety measures, which lead to low injury severity. On the other hand, large projects also involve large numbers of mechanical equipment, vehicles and electrical tools, which are highly conducive to severe injuries.
- Projects in remote areas are small in general and lack adequate safety measures due to a relaxed attitude of construction workers and management team. Moreover, these projects are often built by small companies whose OHS systems are not very effective. As a result, workers who meet with accidents on such projects suffer severe injuries.
- When projects involve works at heights, like in many building projects, lifting using cranes become inevitable. Workers struck by falling objects and parts of cranes reportedly suffer severe injuries. Moreover, works at heights are likely to increase falls, which are another sever injury agents.
- Most experienced workers are in the middle aged group who sometimes become overconfident with a mindset that "it won't happen to me" and misjudge danger. Because most experienced workers are involved in high risk activities and they misjudge danger, when an accident breaks-out, the severity of injury suffered by them is high. Moreover, injury severity tends to increase when the age of the worker is above 40.
- Another worker-related factor that leads to misjudgments of danger is language barrier. Non-English speaking workers who are unable to follow OHS trainings, safety instructions, and safety warnings properly misfortune with severe accidents and injuries.

Influence Model for Accident Severity

Traditionally, accidents are treated as resulting from an initiating (root cause) event in a chain of directly related failure events. This traditional approach, however, has limited applicability to complex systems where interactions among components often lead to accidents (Dulac et al. 2005). To model a real world system under investigation, influence diagrams can be utilised, which represent relationships graphically to enable decision making. With well-constructed influence diagrams, complex interactions between variables in a system can be understood.

An influence model is built with chains of cause-and-effect links where arrows indicate the direction of influence and +/- signs indicate the type of influence (Khanna et al. 2003). If a change in one variable causes a change in the same direction in the second variable, relative to the prior value, the relationship between the two variables is referred to as positive (+). In contrast, if the change in the second variable occurs in the opposite direction, the relationship is negative (-) (Mohamed & Chinda 2011).

Figure 1 illustrates the influence model for accident severity in the construction industry, which has been developed drawing from the deductions in the preceding section. The model explains how accident severity is simultaneously affected by multiple factors within a construction project and the directions of their impacts. The model also facilitates the understanding of interconnections among the factors determining accident severity.

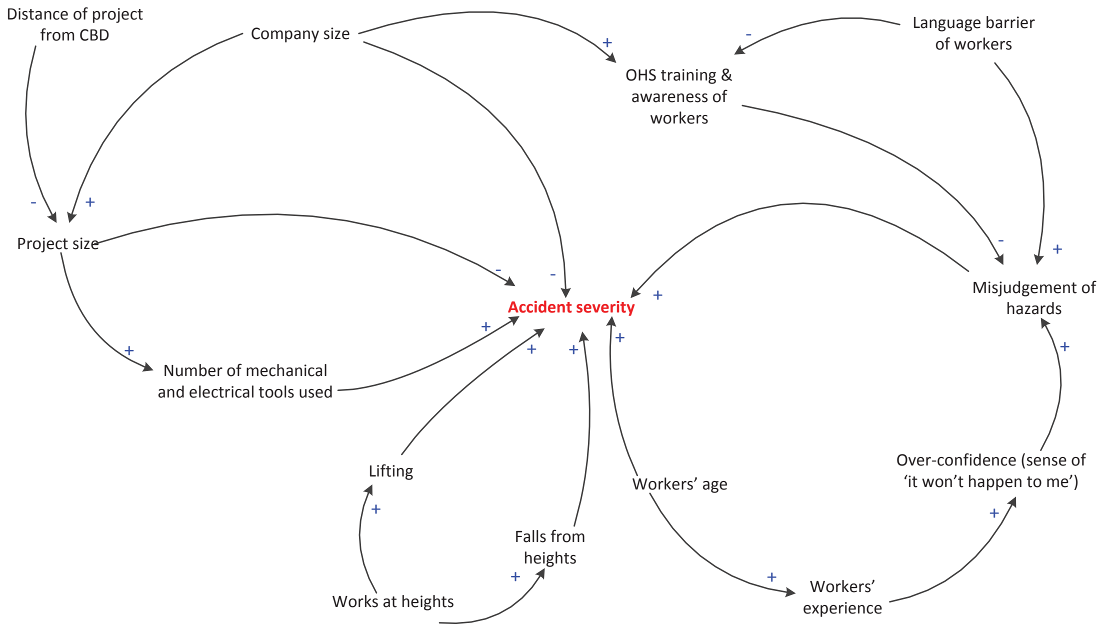

Figure 1: Influence model for accident severity

The influence model can be of significant practical use for the construction industry. It can help to identify and highlight critical factors that determine accident severity in multiple levels. Nodes in the model with multiple outward arrows or the ones that have both inward and outward arrows need to be paid more attention. For instance, works at heights is a critical factor according to the proposed model, which is capable of extending its influence on accident outcomes through multiple layers (e.g. lifting and falls). A scrutiny of the model based on this principle reveals that attempts to reduce accidents severity needs to constantly monitor the following aspects meticulously:

- Implementation of adequate safety measures in small-sized projects;
- Implementation of adequate safety measures for works at heights, crane use, and the use of mechanical and electrical equipment and vehicles in large projects;
- Availability of OHS training, safety instructions and warning signs in the native language of non-English speaking workers;
- Type of works carried out by workers of age 40 and above; and
- Close supervision of middle aged, experienced workers to ensure they follow safety instructions and do not act unsafely.

Conclusions

Through a detailed statistical analysis of 24,764 accident reports from Safe Work South Australia, this study has established the relationships between injury severities and thirteen factors that characterise the workplace, work activity, operative, nature of accident and the body part injured. An influence model, representing the multiple, simultaneous influences by these factors, was also developed to identify factors that need close attention to reduce injury severities. The findings conclude that five aspects require meticulous scrutiny and constant monitoring to reduce severe accidents on construction sites, including: small sized projects and safety implementations, non-native English speaking workers and OHS training and awareness, workers above 40 years and the type of work they undertake, unsafe behaviours of middle aged, experienced workers, and high risk activities like works at heights, crane use and utilisation of mechanical and electrical equipment and vehicles.

In a broader perspective, zero accident industry is preferred by all concerned, but it may not be achievable immediately. However, controlling the level of injury severity can benefit workers by reducing their sufferings and builders by sustaining their reputation and turnover in projects. In this regard, the findings can help Safe Work South Australia, who is the owner of the accident database used in the study, in directing/redirecting its focus for accident minimisation in the construction industry. The findings can also inform OHS policies and management systems of construction companies. Although, the study was conducted in the context of South Australia, the findings can be generalised and applied to the construction sector in other parts of Australia or even overseas that possess similar characteristics.

The study contributes to the body of knowledge in three ways, including: (1) it has established the degree of simultaneous/coordinated impact by multiple factors in construction projects on accident outcomes; (2) a new influence model has been developed to structure the simultaneous/coordinated, dynamic impacts in a manner that enables drawing of insights for effective safety management on site; and (3) the study has demonstrated the scientific approach and logical process involved in building influence models, which can offer insights for other researchers who wish to develop influence models for other construction engineering and management issues.

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