Predicting accident susceptibility: a logistic regression analysis of underground coal mine workers

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Synopsis

This study examined the group differences in accident susceptibility among underground coal mine workers accounting for their personal and workplace characteristics. A logistic regression model was used for this purpose. Data were collected from five underground coal mines for a period of four years. The case study results revealed that different age and experience groups of workers bear no significant differences in their accident susceptibility; however, the workplace location and occupation groups show significant differences in their risk of injuries. It is inferred based on the logistic model results that among the three occupation groups, the face workers are more susceptible towards accidents/injuries compared to the haulage and other workers.

Key Words: Mine Safety, Accident Susceptibility, Group Differences, and Logistic Regression.

Introduction

The history of research into individual liability to accidents is long and troubled (Iverson and Erwin[1997]). Some researchers studied the distribution and risk of accidents, and concluded that various groups of individuals displayed differences in susceptibility to accidents (Peters[1989]; Bhattacherjee[1991]). Other investigators sought to characterize the accident-prone individuals either by comparing the individual characteristics of workers involved and non-involved in accidents, or by evaluating the degree of association between individual characteristics and accident involvement (Shaw and Sichel[1971], Hansen[1988], Dhalback[1991]; Dhar *et al.*[1997]). However, studies on accident proneness have attracted a significant amount of controversy. Debate has occurred over the effects of various personal factors towards accident occurrences (Shaw and Sichel[1971]; Guilford[1973]). Equally important has been the criticism of their causal attributions which researchers make frequently on the basis of bivariate relationships, without controlling for the effect of work environment (Hadden *et al.*[1964]; McKenna[1983]; Hansen[1989]; Sutherland and Cooper[1991]). According to Iverson and Erwin[1997], accident researchers should broaden the study of individual characteristics to include the work-environmental factors which may affect the risk of injury.

The literature on mine accident causation revealed several personal and work-environmental factors affecting the occurrences of injuries to underground coal mine workers (Root[1981]; Bennett[1982]; Bennett and Passmore[1986]; Peters and Schaffer[1986]; Phiri[1989]; Kenny[1993]). The interesting notion about these investigations is that the variables studied were generally common in most of the cases which included: miner's age, experience, occupation, workplace location and mine. The early research studies on the quantitative analyses of accidents/injuries categorized these variables into suitable groups/classes and concluded about the differences in accident susceptibility among different groups of workers through classification tables and aggregate statistics (Pfleider and Krug[1973]; Zebetakis and Zalar[1982]). Later on studies were conducted to assess the relationships of mine and miners' characteristics with severity of injuries (Bennett[1982]; Bennett and Passmore[1986]; Phiri[1989]; Maiti *et al.*[1999]). These studies clearly demonstrated the differences in accident/injury susceptibility among different groups/classes of workers. However, they lacked in two aspects. First, the majority of these studies included only the injured miners into their analysis ignoring the effect of uninjured miners' population. Second, some studies although they considered the uninjured miners' distribution, however, they addressed only their bivariate relationships. To address the issues of accident proneness taking into consideration the injured and uninjured workers population, Maiti and Bhattacherjee[1999] investigated the risk of

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occupational injuries among underground coal mine workers through the multinomial logit analysis. As an alternative approach, the logistic model was explored in this study to evaluate the differences in accident susceptibility to various groups/classes of underground workers controlling for both their personnel and workplace characteristics. A group of underground coal mines operating under a company was chosen to conduct this investigation.

Logistic model

The logistic regression analysis presents a unique complement to multivariate regression in its ability to utilize binary dependent variable (Hair *et al.*[1995]). To understand the effects of the independent variables more fully, the logistic model is investigated in this study where the dependent variable considered is degree of injury and independent variables are the personnel and workplace characteristics of the miners.

Dependent variable

The degree of injury was categorized as fatal, serious, reportable and no injury. However, as there were only a few fatalities that occurred in the case study mines during the study period, the fatal and serious injuries were merged into a single category as severe injury.

Independent variables

The independent variables were miners' age, total mining experience, occupation, workplace location and specific mine, which were coded as dummy variables. A description of the categories of these variables with indicator coding scheme is presented in Table I. Table I reveals that three dummy variables (X_1, X_2, and X_3) were used to represent the age variable. The variable X_1 was coded as '1' for all the miners in the age group of 30–40 years (AGE1), and '0' otherwise; the variable X_2 was coded as '1' for all the miners in the age group of 40–50 years (AGE2), and '0' otherwise. Likewise, the variable X_3 was coded as '1' for all the miners of 50–60 years old (AGE3) or '0' otherwise. The reference category for these three dummy variables is the miners in the age group of 18–30 years (AGE0). Similarly, for all other independent variables, (k-1) dummy variables were created where k is the number of categories of each independent variable. For example, the occupation variable has three categories namely, face workers, haulage workers and other workers. The face workers are identified as those workers who are working within 30 metres of the face. The haulage workers are mainly involved in the transportation of coal by conveyors and they are generally working outby the face. The other workers such as general labourers and maintenance workers perform various supportive functions in the mine. The occupation variable was measured by the two dummy variables X_6 and X_7.

Model

The logistic model allows one to estimate the probability γ ($0 < \gamma < 1$) of an injury/injuries among a group of coal mine workers with given characteristics such as age, experience, occupation, and workplace location. In order to understand the modelling process, a binary variable was used. A binary variable Z is defined as follows:

$Z = 1$ if a miner had an accident that resulted in an injury of a given degree

$Z = 0$ if a miner did not have an accident during the study period.

The covariates and the probability parameter γ in terms of independent variables of a logistic model are defined as follows (Cox[1970]):

$$\gamma(\underline{X}) = \Pr(Z = 1/\underline{X}) = \exp(\underline{\beta}'\underline{X})/(1 + \exp(\underline{\beta}'\underline{X})) \quad [1]$$

which is the logistic equation, where

$\underline{X} = (1, X_1, X_2, \ldots\ldots\ldots\ldots, X_p)'$ is the covariate vector and

$\underline{\beta} = (\beta_0, \beta_1, \ldots\ldots\ldots\ldots\ldots\ldots, \beta_p)'$ is the corresponding parameter vector.

Based on the categories of the degree of injury, three cases were considered in this study. The Cases A, B and C dealt with injury versus no injury, severe versus no injury and reportable versus no injury respectively. Three binary variables for the degree of injury were generated in this model. First, the degree of injury was coded as '1' for all injured miners and '0' for uninjured miners (Case A). Second, the variable was coded as '1' for an injury resulting in a fatality or serious bodily injury and '0' for no injury (Case B). Third, the variable was coded as '1' if a reportable injury occurred and '0' for no injury (Case C). Following the established coding scheme (Table I) of the variables, the logistic model for all the case specifications is specified as follows:

$$\text{Probability of an injury of a given degree} = f\,(\text{age, experience, occupation, workplace location and mine}) \quad [2]$$

Table I

Description of independent variables used in logistic regression analysis

Variables and category description		**Indicator covariates used in logistic regression**			
Personnel-level variables					
Age	(years)	X_1	X_2	X_3	
AGE0	18–30(RC)	0	0	0	
AGE1	30–40	1	0	0	
AGE2	40–50	0	1	0	
AGE3	50–60	0	0	1	
Total Mining Experience	(years)	X_4	X_5		
EXP0	0–10(RC)	0	0		
EXP1	10–20	1	0		
EXP2	≥ 20	0	1		
Occupation		X_6	X_7		
OCCU0	Face workers(RC)	0	0		
OCCU1	Haulage workers	1	0		
OCCU2	Other workers	0	1		
Workplace-level variables					
Location		X_8			
LOCAT0	Face(RC)	0			
LOCAT1	Outby-face	0			
Mine		X_9	X_{10}	X_{11}	X_{12}
MINE0	Mine 1(RC)	0	0	0	0
MINE1	Mine 2	1	0	0	0
MINE2	Mine 3	0	1	0	0
MINE3	Mine 4	0	0	1	0
MINE4	Mine 5	0	0	0	1

(RC) indicates reference category

The logistic regression equation for this study can be expressed as:

$$P(X_1, X_2, \ldots\ldots\ldots\ldots, X_{12}) = 1/\left(1 + \exp^{-}\left(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12}\right)\right) \quad [3]$$

where X_1, X_2 and X_3 = dummy variates for the age categories,
X_4 and X_5 = dummy variates for the total mining experience categories,
X_6 and X_7 = dummy variates for the occupation categories,
X_8 = dummy variate for the location categories, and
X_9, X_{10}, X_{11} and X_{12} = dummy variates for the mine categories.
β_1, βb_2, β_3,....β_{12} = corresponding parameters of X_i, for i = 1, 2, ..., 12.

The β parameters of the logistic model were estimated by the maximum likelihood method suggested by Cox[1970]. The test that the β coefficients are zero or not were performed based on Wald Statistic, which follows a chi-square distribution (SPSS manual[1993]).

Case study

Data

Four-year data were collected from a group of five underground coal mines. The mines operate six days a week, three shifts per day for coal production. The mining method practised in these five mines is mainly bord-and-pillar working. During the 4-year period, the average annual production from all the mines was 1.15 million tons with an average underground employment of 6281 workers. The data included records for both the injured and uninjured miners during the study period. Among the 6281 underground workers, the injured and uninjured workers were 459 and 5822 respectively.

Before an application of the logistic model to the injury data, an accident data analysis based on the variables identified in this study was conducted through cross-classification tables to identify the pattern of injuries. Injury statistics of the mines based on the cross-classification of the variables of interest namely, mine, occupation, location, age and experience are presented in Tables II through VI. Table II shows that among the five mines studied, the Mine 2 encountered the highest number of injuries (32.2%) followed by Mines 4 and 5. For all the mines, the face workers experienced the maximum number of injuries; and the overall average of the face worker injuries is 47.1% of the total injuries. Location-wise, the injury trend shows that a majority of the injuries occurred at the outby-face location. For example, Table III reveals that the outby- face accounted for 69.2% of the total injuries at Mine 1. Table IV presents the cross-tabulation of injuries based on the mines and the age-groups of workers. It is revealed from Table IV that workers at the age-group of 30–40 years experienced a maximum number of injuries in all the mines except in Mine 3 where workers of 40–50 years old encountered the highest number of injuries (38.2%). The experience categories show that at Mines 2, 3 and 5, workers of 10–20 years of experience encountered more injuries; whereas, at Mines 1 and 4, the least experienced group (0–10 years) shows the highest injury figures (Table V). Table VI shows the frequency of injuries based on the variables occupation and location of accidents. 57.4% of the total face worker injuries occurred in the face and the remaining 42.6% occurred at the outby-face location. The fact that a significant percentage of face worker injuries occurred at the outby-face location led to a detailed examination of the injury data as well as follow up discussions with the mines management. It was revealed that the major reasons were the following: (i) assignment of some jobs to face workers at the outby-face location, and (ii) travelling/walking from pit bottom to the working places which results in slip/fall injuries. Certainly, these work practices are common in the coal mines of India, which may not be observed world-wide.

Table II

Frequency of injuries based on mine and occupation of workers and their cross-tabulation

Occupation Mine	Freq. (%)	Face workers 216 (47.10)	Haulage workers 107 (23.30)	Other workers 136 (29.60)
Mine 1	65 (14.20)	31 (47.70)	17 (26.20)	17 (26.20)
Mine 2	148 (32.20)	64 (43.20)	43 (29.10)	41 (27.70)
Mine 3	55 (12.00)	24 (43.60)	12 (21.80)	19 (34.50)
Mine 4	103 (22.40)	44 (42.70)	25 (24.30)	34 (33.00)
Mine 5	88 (19.20)	53 (60.20)	10 (11.40)	25 (28.40)

Figures in brackets indicate percentage of injuries

Table III

Frequency of injuries based on mine and location and their cross-tabulation

Location Mine	Freq. (%)	Face 147 (32.00)	Outby-face 312 (68.00)
Mine 1		20 (30.80)	45 (69.20)
Mine 2		52 (35.10)	96 (64.90)
Mine 3		13 (23.60)	42 (76.40)
Mine 4		33 (32.00)	70 (68.00)
Mine 5		29 (33.00)	59 (67.00)

Figures in brackets indicate percentage of injuries

Table IV

Frequency of injuries based on mine and age of workers and their cross-tabulation

Age Mine	Freq. (%)	18–30 years 89 (19.40)	30–40 years 153 (33.30)	40–50 years 127 (27.70)	50–60 years 90 (19.60)
Mine 1		18 (27.70)	26 (40.00)	15 (23.10)	6 (9.20)
Mine 2		35 (23.60)	41 (27.70)	37 (25.00)	35 (23.60)
Mine 3		5 (9.10)	15 (27.30)	21 (38.20)	14 (25.50)
Mine 4		19 (18.40)	35 (34.00)	27 (26.20)	22 (21.40)
Mine 5		12 (13.60)	36 (36.00)	27 (30.70)	13 (14.80)

Figures in brackets indicate percentage of injuries

Table V

Frequency of injuries based on mine and experience of workers and their cross-tabulation

Experience	0–10 years	10–20 years	>20 years
Mine Freq. (%)	**158 (34.40)**	**181 (39.40)**	**120 (26.10)**
Mine 1	31 (47.70)	24 (36.90)	10 (15.40)
Mine 2	50 (33.80)	57 (38.50)	41 (27.70)
Mine 3	15 (27.30)	23 (41.80)	17 (30.90)
Mine 4	41 (39.80)	33 (32.00)	29 (28.20)
Mine 5	21 (23.90)	44 (50.00)	23 (26.10)

Figures in brackets indicate percentage of injuries

Table VI

Cross-tabulation of injuries based on location and occupation of workers

Occupation Location	Face workers	Haulage workers	Other workers
Face	124 (57.40)	8 (7.50)	15 (11.00)
Outby-face	92 (42.60)	99 (92.50)	121 (89.00)

Figures in brackets indicate percentage of injuries

Although Tables II through VI showed a substantial variability in injury frequencies for the different group of workers; however, they are based on the injured workers population. In order to get a true picture of the injury patterns, it is necessary to incorporate the uninjured workers population into the analysis. Table VII presents the injury rate (IR) of the worker-groups based on age, experience, occupation, location and mine, where IR is defined as the number of injuries per 1000 person employed in a specific category during the 4-year period. The injury rates for the all injury case indicate that the oldest group of workers (50–60 years) shows a fairly high injury rate compared to the younger workers (Table VII). A similar trend was also observed for the severe and reportable injury cases. However, the injury rates for the workers in the age-groups of 18–30, 30–40, and 40–50 years show that they are almost the same in all the cases of injuries. The injury rates for the experience categories show that the least and the most experienced work-groups are more injury prone. The occupation categories indicate that the haulage workers have higher injury rates than the face and other workers. The location variable categories reveal that in all the three cases, the injury rates at the outby-face location are higher than the face location. The Mine variable categories depict that Mine 2 has the highest injury rates in all the cases.

Though the results presented in Table VII indicate that some variables exhibit interesting patterns of injuries; however, they are based on the bivariate aggregate statistics. The significance of the differences in injury rates cannot be established from this Table in relation to the occurrence of an injury of a given degree. To address this issue, the logistic model is investigated in establishing the significant differences between the categories of the various variables in a multivariate situation.

Logistic Model Results

The Statistical Package for Social Sciences (SPSS) was used for the logistic model runs (SPSS Inc.[1993]). The β_j parameters expressed in Equation [3] were estimated using the SPSS LOGISTIC routine. Table VIII presents the logistic coefficients (β) for the three case specifications namely, injury versus no injury (Case A), severe versus no injury (Case B) and reportable versus no injury (Case C). The significant parameters are indicated by an asterisk at 0.05 probability level of significance. From Table VIII, it is seen that none of the age groups are statistically significant for the Cases A, B and C. Similarly, none of the total mining experience groups are significant. The occupation categories show that the haulage and other workers are significantly differing from the face workers in the occurrence of injuries for all the three cases. The workplace location categories are also significantly related to the occurrence of injuries for all the three case specifications. Finally, the mine categories show that for the cases A and C, the Mines 2, 4 and 5 are significantly related to the occurrences of injuries while Mine 3 is insignificant. For the case B, none of the mine categories are significant in the occurrence of severe injuries.

The logistic model results were utilized to predict the susceptibility of an injury/injuries of a given degree to various groups of underground coal mine workers accounting for their personnel and workplace characteristics. The estimated β-parameter value of any category of a variable represents the strength and pattern of relationship of this particular category with respect to the reference category of the variable. A positive value of β of a particular category indicates that the workers of this group are more susceptible

Table VII

Injury rates with respect to age, experience, occupation, location and mine during the 4-year period

Variables and category		All injury	Severe injury	Reportable injury
Personnel-level variables				
Age				
AGE0	18–30	67.78	8.38	59.41
AGE1	30–40	70.31	9.65	60.66
AGE2	40–50	70.10	8.21	61.88
AGE3	50–60	92.13	15.53	76.60
Total mining experience				
EXP0	0–10	74.13	10.72	63.40
EXP1	10–20	62.89	7.30	55.59
EXP2	>20	94.59	14.31	80.29
Occupation				
OCCU0	Face workers	75.56	8.87	74.40
OCCU1	Haulage workers	100.19	14.98	85.20
OCCU2	Other workers	51.92	8.78	43.15
Workplace-level varibles				
Location				
LOCAT0	Face	56.84	5.80	51.04
LOCAT1	Outby-face	84.44	12.72	71.72
Mine				
MINE0	Mine 1	46.23	10.67	35.56
MINE1	Mine 2	113.06	12.99	100.08
MINE2	Mine 3	56.94	9.32	47.62
MINE3	Mine 4	72.33	9.13	63.20
MINE4	Mine 5	74.83	7.65	67.18

Table VIII

The logistic model coefficients (β_s) for various case specifications

Variables and category	Case specifications	Injury versus no injury (Case A)	Severe versus no injury (Case B)	Reportable versus no injury (Case C)
Personnel-level variables				
Age				
AGE0	18–30(RC)	(0)	(0)	(0)
AGE1	30–40	0.227	0.313	0.211
AGE2	40–50	0.069	0.068	0.062
AGE3	50–60	0.018	0.337	-0.035
Total mining experience				
EXP0	0–10(RC)	(0)	(0)	(0)
EXP1	10–20	-0.132	-0.480	-0.087
EXP2	>20	0.298	0.165	0.306
Occupation				
OCCU0	Face workers(RC)	(0)	(0)	(0)
OCCU1	Haulage workers	-3.382*	-4.879*	-3.643*
OCCU2	Other workers	-4.031*	-5.360*	-4.319*
Workplace-level variables				
Location				
LOCAT0	Face(RC)	(0)	(0)	(0)
LOCAT1	Outby-face	3.916*	5.823*	4.121*
Mine				
MINE0	Mine 1(RC)	(0)	(0)	(0)
MINE1	Mine 2	0.961*	-0.007	1.180*
MINE2	Mine 3	0.159	-0.529	0.322
MINE3	Mine 4	0.427*	-0.209	0.577*
MINE4	Mine 5	0.377*	-0.654	0.577*
Intercept		-3.311*	-4.893*	-3.578*

(RC) indicates reference category
*indicates significant categories at 0.05 probability level

towards injury compared to their reference group; whereas, the negative value of β indicates the opposite. For example, for the Case A the estimated β parameter values for the age-groups AGE1, AGE2 and AGE3 are positive with respect to the reference age-group AGE0 which indicate that injury risk increases in these age groups compared to the reference category (Table VIII). Similarly, for the experience categories the estimated β values for the 10–20 years of experienced workers (EXP1) are negative for all the cases with respect to the least experienced workers (EXP0) indicating that workers of 10–20 years of experience are less susceptible towards injury when compared to the least experienced worker-group. However, as none of the age and the total mining experience categories are significantly related to the occurrence of an injury/injuries, the chances of injuries for these categories are the same compared to their reference categories. Hence, it can be concluded that for the case study mines the various age and experience groups have almost equal susceptibility to accidents.

Regarding the occupation variable for the Case A, the estimated β parameter values for the haulage and other workers are –3.38 and –4.03 respectively, which indicate that the haulage and other workers are less susceptible towards injury compared to the face workers at the case study mines. This finding contradicts the earlier result presented in Table VII that the haulage workers are more injury prone compared to the face workers. However, it can be argued that in contrast to the bivariate aggregate statistics the multivariate logistic model coefficients provide a more guarded assessment of the injury patterns. For the Cases B and C, it is also revealed from Table VIII that among the three occupation categories the face workers are more susceptible towards severe and reportable injuries. Face workers are generally engaged in most hazardous jobs in a mine. Focused management attention should be given to reduce the susceptibility of the face worker injuries in the mines studied. Table VIII also reveals that the chances of injuries are more at the outby-face location compared to the face location for all the three cases. This result contradicts the conventional wisdom that the face is the most accident-prone location. Discussions with the mines' safety personnel and further investigation divulged that the possible reasons are the following: (i) wet or slippery mine floor due to inadequate drainage system causing slip and fall injuries of the miners at the outby-face location during travel/transportation, (ii) frequent changing of allocation of jobs to the workers at the outby-face location, and (iii) tendency of the workers to underestimate the potential dangers in performing tasks away from the face area (Bhattacherjee *et al.*[1997]). Table VIII also reveals that for the Case A, the β parameter values for the Mines 2, 3, 4 and 5 are positive with respect to the Mine 1 indicating that the workers in these mines are more susceptible towards accidents compared to the Mine 1. Further, the estimated β value for the Mine 2 is quite high compared to that of the Mines 3, 4 and 5. Hence it can be inferred that the Mine 2 workers are more prone to accidents which warrant immediate management attention. For the reportable injuries (Case C), the result also shows the similar trend. However, for the severe injuries (Case B) none of the estimated β parameters are significant which indicates that for all practical purposes the workers at all the mines have similar chances of severe injuries.

Conclusions

The applicability of the logistic model for predicting accident susceptibility was demonstrated through a case study. The model utilized individual records of injured and uninjured miners. The results revealed that the variables occupation and workplace location show distinct relationships with the degree of injury indicating significant differences in accident susceptibility among the groups representing the variable categories. Of these relationships, the occupation categories showed that the face workers are the most accident prone job occupants than the haulage and other workers. However, the workplace location categories showed that the outby-face location is more susceptible to accidents. This finding is due to certain work practices followed in the coal mines of India which may not be applicable to the coal mining environment of some other countries such as South Africa.

The variables age and experience do not show any significant relationship with degree of injury indicating that miners of different age and experience groups are equally liable to accident occurrences. The revealing fact that the variables age and experience did not have any significant effect on accident/injury occurrences indicates the important role of other factors such as work environment, management and supervision, and psychological (human behavioural) factors such as risk-taking behaviour, emotional instability, and unsafe practices of the workers in accident causation. Even though the total mining experience did not have any effect on severity of injuries, it may be worthwhile to incorporate the task specific experience which might have an effect on accident/injury occurrences of the workers. However, it was not investigated in this study due to unavailability of reliable data from the mines.

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The South African Institute of Mining and Metallurgy
Founded in 1894

OBITUARY

		Date of Election	Date Deceased
M G Atmore	Honorary Life Fellow	9 March 1956	25 June 2001
A Ball	Fellow	21 November 1975	16 June 2001
G J Bernfeld	Retired Fellow	6 March 1973	4 April 2001
D W Butcher	Member	5 September 1974	25 December 2000
H A Hall	Retired Fellow	8 May 1953	21 March 2001
G Hitchcock	Retired Fellow	4 April 1972	January 2001
C J Tainton	Associate	23 March 1970	23 February 2001
T Zadkin	Retired Fellow	23 August 1950	24 March 2001