Development and test of a sociotechnical model for accident/injury occurrences in underground coalmines

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Synopsis

Mine accidents/injuries are complex and generally characterized by several factors, from technical to social characteristics. In this paper, a sociotechnical model for work injury in mines was developed and tested through structural equation modelling with application to case study mines in India. In total 14 variables were considered in this study. Most of the variables are not directly quantifiable. Instruments were developed to quantify them through a questionnaire survey. Underground mineworkers were randomly selected for the survey. Responses of 300 participants were used for the analysis. The analysis was conducted in three parts. Firstly, high-low plots were constructed to explore the variations in responses to the questionnaires by the accident involved (AG) and non-involved (NAG) workers. Secondly, a t-test was conducted to see whether the responses were significantly different for the two groups or not. The chi-square results showed significant differences of responses among the two groups. Finally, how these differences can cause accidents/injuries in mines was hypothesized and evaluated using structural equation modelling. The measurement model of the Linear Structural Relations (LISREL) program was used to identify the latent constructs of the sociotechnical model. The structural model of LISREL was used to estimate the interrelationships among the constructs. The case study results showed that there is a sequential interaction among the sociotechnical factors leading to accidents/injuries in mines. Work hazards induce more job stress in the workers while social support mitigates the same. Job stress and safety environment predict the workers' job involvement. A worker who is more job-involved exhibits better safety performance, which in turn reduces work injury. The safety environment is shown to have a direct mitigating effect on work-related injury. The findings of this study clearly revealed that job stress and safety environment are the two key factors influencing work-related injuries in mines that need to be addressed properly through effective safety programmes.

Introduction

Mining is considered one of toughest and most hazardous occupations. The underground mine-workers have to work in severe working conditions in narrow openings with substantial heat and humidity, heavy noise and vibration, poor illumination, airborne dust and noxious gases. These physical hazards pose a serious problem in managing the safety and health risks of mine workers. As a result, accidents/injuries are prevalent across all commodities in underground mining. In India, the hazardous nature of coalmine operations can easily be depicted from the national statistics of mine accidents and injuries. For example, in Indian coalmines the number of fatalities and serious body injuries in 1999 and 2000 were 138, 134 and 593, 441, respectively. Similarly, the fatality and serious body injury rates per 1 000 persons employed for the years 1999 and 2000 are 0.28, 0.27 and 1.27, 0.90, respectively. For non-coalmines, the number of fatalities and serious body injuries in 1999 and 2000 were 70, 41 and 225, 136 and their rates were 0.43, 0.25 and 1.38, 0.84, respectively (DGMS Statistics, 2000). Although the 20th century has experienced a considerable amount of success in coalmine safety, the safety problems in the Indian coalmining industry were being mainly addressed in terms of frequency of fatalities and serious injuries. The reduction of these fatalities and serious injuries was achieved through reactive measures of hazard control (Bhattacharjee and Maiti, 2000). Further, the workers face differential risks of injuries due to their different job occupations (Maiti and Bhattacherjee, 1999).

The basic causes of high injury rates are unsafe conditions, unsafe acts, or both. Unsafe behaviour is said to both directly and indirectly contribute to 90% of all workplace accidents and incidents. Unsafe conditions may arise through insufficient mine design, unanticipated geological conditions, inadequately maintained equipment, inadequate supervision, or a combination of these factors (Bhattacherjee, 1991). Unsafe acts mainly

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arise through human behaviour. There is a popular notion that employees' unsafe acts are the primary causes of workplace accidents, but a number of authors suggest a perspective that highlights influences from operating and social systems (Brown *et al.*, 2000). Identification of these factors may play an important role in accident mitigation.

The literature review revealed that on the international level, several studies were conducted along this line (Kenny, 1993; Peters, 1989; Phiri, 1989; Bennett and Passmore, 1986). However, on the national level, a few studies have been reported so far (Ahuja, 1997; Sharan, 1994; Verma, 1991). The studies generally deal with accident/injury rates in terms of frequency or severity of injuries. Mines are compared based on their frequency rates per 1 000 persons employed or per lakh manshifts worked. These approaches seem to be inadequate to reflect the safety performance of the mines, as they do not consider the individual miner's responsibilities in accident/injury occurrences. Bhattacherjee *et al.* (1997) and Maiti *et al.* (1997) used a two-way classification table to evaluate the risk of injuries to the miners. According to their studies, the haulage workers are the most accident-prone work group, followed by loaders; slip and fall was the major contributory cause of accident/injury occurrences. These studies, although they provided some useful insight towards safety improvement, were based on aggregate frequency rates and the differences in accident/injury risk for the various work groups were not statistically validated. The unanswered question was whether the differences were merely random variations or whether they are significantly related. Statistical modelling will help answer this by providing an index of difference with a suitable significance level. This index can also capture the multivariate relationships of multiple factors.

Maiti *et al.* (1999) and Maiti and Bhattacherjee (1999) conducted studies with the application of rigorous statistical models such as logit and multinomial logit models. These studies evaluated the risk of injuries among underground coal workers by accounting for their individual and workplace level characteristics. These studies clearly demonstrated the need for differential training requirements for different groups of workers with their different risk to injuries.

Bhattacherjee *et al.* (2000) and Ghosh *et al.* (1998) investigated the system dynamics model to capture the complex dynamics behaviour of the mine safety system involving the feedback process such as safety programmes and direct management actions.

In a nutshell, several investigators have researched perspectives of workplace safety in mines. Many factors are highlighted, from technical to social and behavioural and their interrelationships. However, while these multiple factors were addressed, either they were not studied or studied separately. Furthermore, no single study published so far has accounted for sociotechnical context of work injures in mines. In this paper an attempts is made to develop and test a sociotechnical model of work injures in mines, incorporating these structural relationships.

A sociotechnical model of causal relationships

A sociotechnical model of causal predictions was developed using a balanced set of indicators. The sociotechnical system (STS) represent a broad area of organizational study that examines the interactions, synergies, and disconnects between the social or human factors and the technical work factors, such as layout, process design, equipment, information, and so forth. The model describes that a mixture of social factors, technical factors, and organizational conditions drives employee beliefs, attitudes, learning and other outcomes like safety performance and work injuries. Figure 1 depicts the sociotechnical models of work injuries in mines. In total, six constructs, namely work hazards, safety environment, social support, job stress, job involvement, and safety performance, were measured along with work injury; their dependent and independent relationships are captured through a structural framework.

The model is viewed with two sets of variables. One set represents dependent variables, which are viewed to be dependent of one or more dependent or independent variables such as work injury and safety performance. The other set is independent of the other variables considered such as work hazards, social support and safety environment. Short definitions of the variables (constructs), together with a description of their interrelationships with work injuries, are as follows:

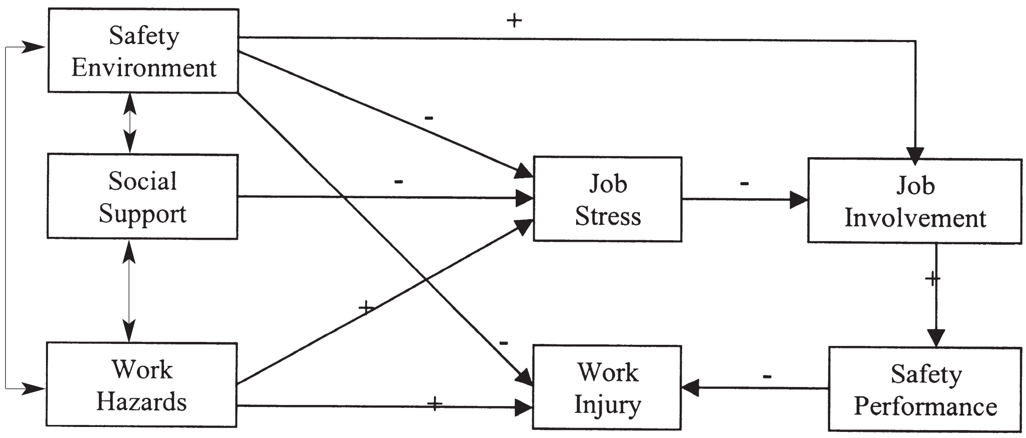

Figure 1—Preliminary path diagram of sociotechnical model

Dependent variables

Work injury

Work injury represents direct quantitative evidence of an employee's safety performance. It also measures the injury severity, which is an indirect measure of the cost of an accident (Bennett and Passmore, 1986; Phiri, 1989). A more severe injury extracts greater costs from a mining operation than a less severe injury through worker's compensation payments, reduced production rates and social costs such as longer periods of physical rehabilitation for severe injuries (Maiti and Bhattacherjee, 1999). In this study, work injury was measured on a dichotomous scale such as injured or not injured.

Safety performance rating

Measures of safety performance are necessary for all industrial organizations. While an employee's safety performance is usually revealed by measuring the results (frequency of injuries/illness), it does not always reveal the true safety behaviour of the victims. One universally accepted and mostly used measure of employee's safety performance is supervisor rating. The supervisor rating was assumed to be appropriate for assessing safety performance of the workers as it was assessed by the immediate supervisors who have direct control over the employees through direct observation and supervision.

Job involvement

Job involvement indicates the degree to which the workers are concerned about their work for improving safety and productivity. It can be hypothesized that workers who are more involved in their jobs show good safety practices, which eventually lead to fewer accident/injury occurrences. Peters (1989) stated that although the rate of absenteeism in the mining industry varies, most sources suggested that it is high relative to other industries. Goodman and Graver (1988) examined the effect of absenteeism on accidents. His central premise was that lack of familiarity leads to more dangerous conditions that, in the absence of compensatory changes in the level of care taken by a miner, would contribute to a higher rate of accident.

Job stress

Job stress, defined in the present study as work attributes that pose threats or risks to an employee, results from a poor person-environment fit (Rahim *et al.*, 1996). The indices of role conflict and ambiguity developed by Kahn, Wolfe, Quinn, Snoak, and Rosenthal (1964) have been used in a number of studies to measure stress. In this study, job stress was measured through a questionnaire survey in which questions regarding role conflict, ambiguity, and role overload were incorporated.

Independent variables

Safety environment

Safety environment represents the organization's safety policies and practices prevailing at the mine site, including training. Safety training is important in that workers who are aware of safety issues and well trained for the tasks they are to perform, may avoid injury on a dangerous job, whilst untrained and careless workers may be injured under the safest possible conditions. Prior research suggests that although training has a major role to play in accident/injury reduction, it is very difficulty to evaluate its effect in a short span of time (Phiri, 1989; DeMichiei *et al.*, 1982). However, DeMichiei *et al.* (1982) stated that new miners in high accident rate mines were less informed on how to do their jobs than new miners in low accident rate mines. Bhattacherjee *et al.* (1997) found that the training given to miners are mostly classroom oriented and on-the-job training and specific tasks training is to be implemented to improve the safety of workers. Mineworkers have considerable autonomy in determining their own work practices and managing their workplaces. Moreover, as a result of legislative restrictions, the worker needs to follow certain work practices. Proper safety practices lead to fewer accidents/injuries in mines. Safety equipment availability and maintenance have immediate effects on safety performance and they are usually not good in high accident rate mines (DeMichiei *et al.*, 1982; Pfeifer, 1976).

Social support

Management-worker interaction includes variables such as overall labour relations climate, management concern for labour, and labour supports for safety disciplinary actions. A considerable amount of evidence is accumulating to suggest that there is a significant positive relationship between poor management-worker interaction and work injuries. Gaertner *et al.*'s (1987) analysis indicated that the injury rate in companies with a negative labour relations climate is almost double that of the rate in companies with a positive climate. DeMechiei *et al.*'s (1982) study showed that management at high accident rate mines is less interested in the welfare of workers both on and off the job than management at low accident rate mines. Pfeifer *et al.*'s (1976) analysis suggested that supervisors in low accident rate mines 'more often show real concern for workers' welfare'. Their results are based on the perception of underground hourly employees. National Academy of Science studies showed that at all the low accident rate mines the union generally supported the company's enforcement of safety rules. DeMichiei *et al.*'s (1982) questionnaire results suggested that section supervisors in low accident rate mines received more support from safety personnel when reprimanding miners for unsafe acts.

Co-worker support is defined as the degree of consideration expressed by co-workers. Sander *et al.*'s (1976) and DeMicheie *et al.*'s (1982) questionnaire results suggested a negative relationship between co-worker support and work injuries. Bell (1987) reported that injury rates at an underground silver mine were significantly lower following the institution of organization development.

Supervisory support is the degree of consideration expressed by the immediate supervisor for the subordinates (Michaels and Spector, 1982) and it has a negative relationship with work injury.

Work hazards

Work hazards have a very substantial role to play in accident/injury occurrences in mines (Carter, 1998). Several variables of work hazards have been implicated in the occurrence of work injuries (Frone, 1998). Hazards do not always result in accident or injuries, but they lurk in work environments, waiting for the right combination of circumstances to come together (Brown *et al.*, 2000). The work hazards have been measured in this study through physical hazards and production pressure. Physical hazards represent the extent to which individuals are exposed to dangerous equipment, unsafe working conditions and poor environmental conditions. Dawson *et al.* (1983) defined physical hazards as the degree to which employees are exposed to harmful working conditions. Prior research supports a positive relation between physical hazards and work injuries (Hansen, 1989; Harrell, 1990; Savery and Wooden, 1994; McDonald, 1995; Frone, 1998). The National Academy of Science (1982) stated that a management that plans to increase production could also plan to improve safety. Pfeifer's (1976) study suggests that in comparison with supervisors in high-accident mines, supervisors in low-accident mines are significantly less inclined to push hard for production or to cut corners on safety. Sander (1976) states that production pressure appears to lead to an increase in disabling injuries, which in turn results in a decrease in production.

Method

Sample

The setting for this study was two neighbouring underground coalmines within a large public sector organization in the eastern part of India. The mines comprised a total of 1 000 underground workers who were directly involved in production. The data were randomly collected from 300 underground mineworkers who participated in this study. The mines were selected because work injuries of these mines are high. One mine was declared an accident prone mine. Of the participants, 50 per cent had injury records, 48 per cent were loaders who worked at the coal face, loading coal into tubs, 12 per cent from coal preparation, 14 per cent from transport, 6 per cent from a support gang, 7 per cent from the engineering department, and the rest involved in other work. On average, the participants were 37.34 (SD= 9.01) years old, and held their current job for 14.58 (SD= 9.25) years.

Instruments

Measures used in this research were miners' job involvement, safety training, safety practice, safety equipment availability and maintenance, co-worker support, supervisory support, management-worker interaction, job stress, physical hazards, production pressure, safety performance rating, and work injury. The safety performance of each respondent was obtained from supervisors' ratings. The supervisors were asked to rate the participants based on their overall safety performance. The remaining indicators, except injury, were measured through a questionnaire-based survey. The number of scale items, sample question, means, and standard deviations of each of the ten indicators are shown in Table I. The injury was measured through a dichotomous variable (1= injury, 0= no injury) obtained from each respondent's personnel records.

Reliability and validity of the collected data

A multi-item survey measure was administered to the participants during their working hours. A three-point Likert-type scale format was used to measure the participants' responses on each item of the three constructs. Initially, a factor analysis was done to explore the factor loadings of each of the items to the construct (factor) of interest. A loading of 0.3 or more was considered significant (Brown *et al.*, 2000), and items with factor loading less than 0.3 were discarded. Then item correlations of the remaining items were examined, and items with low (<0.3) correlations were deleted. Finally, the items which met the factor loading and item correlation criteria were considered as significant indicators of the construct. The internal consistency reliability of each of the constructs was measured based on Cronbach's alpha. An acceptable alpha value is 0.7 or greater but 0.6 is occasionally acceptable, especially for an exploratory study (Nunually 1978). For example, job involvement was measured from 19 items. A factor analysis revealed that four items showed a factor loading of <0.3 and were discarded. The item correlations of the remaining 13 items suggested deletion of another 2 items. Finally, 13 items were considered as the significant indicators of the variable, negative affectivity. Cronbach's alpha was 0.84.

Similarly, the safety training, safety practice, and safety equipment availability and maintenance were treated through

Table I

Construct scale items, means, and standard deviations (item format for managerial subjects)

Construct	No. of questions	Sample question	Construct reliability
Job involvement	13	Do you feel uneasy when your work remains incomplete?	0.84
Safety training	6	Do you feel training given to you is effective?	0.66
Safety practice	19	Does shortfirer give warning before blasting?	0.80
Safety equipment availability and maintenance	8	Are required amount of helmets, boots and cap lamps available in your mine?	0.72
Job stress	8	Do you think your work is difficult and arduous?	0.67
Co-worker support	5	Does an extremely friendly atmosphere prevail amongst the workers in this mine?	0.64
Supervisory support	7	Do supervisors instruct and guide their subordinates?	0.71
Management-worker interaction	10	Does management support your decisions concerning safety?	0.84
Physical hazards	12	Are loose chunks of coal at the roof and side wall of this mine seen frequently?	0.65
Production pressure	4	Have you ever been pressurized to deliver production targets to the detriment of safety?	0.80

factor loadings and item correlations. Two items for safety training, eight items for safety practice and one item for safety equipment availability and maintenance were discarded. Finally, safety training, safety practice, and safety equipment availability and maintenance were measured by 6, 19 and 8 questions, respectively. The Cronbach's alphas were 0.66, 0.80, and 0.72, respectively.

Supervisory support is the degree of consideration expressed by the immediate supervisor for the subordinates (Michaels and Spector, 1982). Supervisory support was measured through 7 items. A factor analysis revealed that all the items showed a factor loading of ≥0.3 and the item correlations were ≥0.3. Finally, all the items were considered as significant indicators of supervisory support. Cronbach's alpha was 0.71. Similarly, the management-worker interaction, and co-worker support were treated through factor loadings and item correlations. Four items for management-worker interaction, and two items for co-worker support were discarded. Finally, the management-worker interaction, and co-worker support were measured by 10 and 5 questions, respectively. The Cronbach's alphas were 0.84, and 0.64, respectively.

Job stress, physical hazards, and production pressure were measured through 12, 16, and 4 items. Four items each for job stress and co-worker support were discarded. Finally, job stress, physical hazards, and production pressure were measured by 8, 12 and 4 questions, respectively. The Cronbach's alphas were 0.67, 0.65 and 0.80, respectively.

Hypothesis

Sociotechnical factors like social support, safety environment and work hazards predict employees job stress, which in turn dictate their job involvement. A highly job involved worker will exhibit better safety performance. Better safety performance in turn reduces work injury to the mineworkers. Therefore, it can be hypothesized in this study that job stress is negatively correlated with safety environment and social support and positively correlated with work hazards. Job stress, on the other hand, negatively affects job involvement, which has a positive influence on safety environment. Safety performance is hypothesized to be positively affected by job involvement and has a negative effect on work injury. Further, it is assumed that work injury is also directly caused by safety environment and work hazards. All these hypotheses are tested through structural equation modelling.

Analysis

The analysis of this study was conducted in three phases. Firstly, high-low plots of the sociotechnical variables were done using SPSS 10 (SPSS 1999) to explore the variations in responses to the different questionnaires by the accident and non-accident group of workers. The accident group of workers are those who experienced injuries over the last five years as workers of the mines. Workers who did not face any accident during the last five years of employment are termed the non-accident group. The last five years is taken as a reference time that is believed to portray the present safety levels of the mines studied. These high-low plots depict the major weak links of the two groups of workers for their safety in mines. Secondly, a t-test was conducted to see whether the variations in their responses are random or if there is a significant difference between the two groups. Finally, how these differences can ensure accident/injury in mines through hypothesis testing was evaluated using structural equation modelling. The unique features of the structural equation modelling are that it can portray the complex structural framework of the sociotechnical safety system, analyse them simultaneously, and evaluate the pattern and strength of relationships of the factors with work injuries.

Result

High–low plots

High-low plots show how several values of one variable relate to one value of another variable. Typically, each variable value on the horizontal axis has several corresponding values on the vertical axis. High-low plots of the different variables are shown in Figure 2. The X-axis represents the raw score of all the respondents for specific variable and the Y-axis represents the number of respondents from the accident group (AG) and non-accident group (NAG).

For example, the minimum and maximum score of the variable safety practice are 19 and 57 and it is seen from the plot that AG workers are mostly concentrated at the low scoring zone and NAG workers are mostly concentrated at the high scoring zone. Similarly, for the variables safety equipment availability and maintenance, safety training, co-worker support, supervisory support, management worker interaction, and job involvement, it is also seen from the plots that AG workers are mostly concentrated at the low scoring zone and NAG workers are mostly concentrated at the high scoring zone. It implies that most of the accident group (AG) of workers are dissatisfied with their existing safety training, safety equipment availability and maintenance, have a poor relationship with supervisors and management, low safety practices, and poor involvement during work compared with the non-accident group (NAG) of workers.

But AG workers are mostly concentrated at the low performance rating zone and NAG workers are mostly concentrated at the high performance rating zone which reveals that the safety performance of the AG workers is mostly poorer than that of the NAG workers.

Figure 2 also shows that AG workers are mostly concentrated at the high scoring zone and NAG workers are mostly concentrated at the low scoring zone for the job stress, physical hazards, and production pressure. It is revealed that the AG felt more job stresses, production pressure, and hazards than the NAG. Their means and mean differences have been located on the respective high-low plot. Whether the mean differences of the respective variables are statistically significant or not were determined through t-test.

T-test

The t-values, standard deviations, and 2-tailed significances to test the equality of factor means of different variables for NAG and AG workers are shown in Table II. It is seen from the t-test that, except for co-workers support, all other observed variables, namely job involvement, safety training,

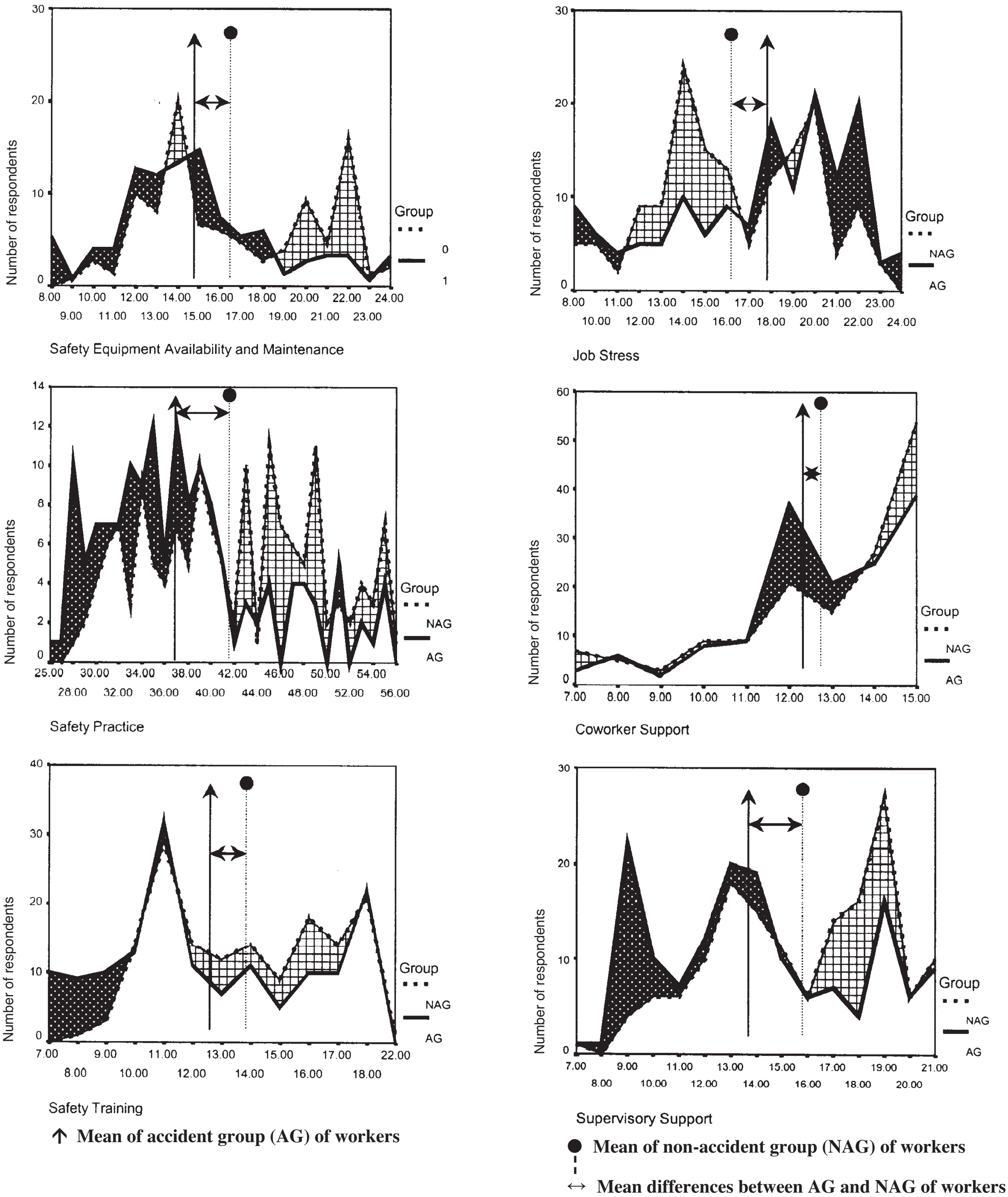

Figure 2—High-low plots for AG and NAG workers

safety practice, safety equipment availability and maintenance, supervisory support, management worker interaction, job stress, physical hazards, production pressure, and safety performance, emerged as significant factors. The null hypothesis for the equality of factors means is rejected in each case, which indicates that mean scores of the NAG and AG workers are significantly different for these sociotechnical factors. This suggests that sociotechnical factors play a significant role in accident involvement.

The factor safety performance of the workers administered by their respective supervisors reveals that safety performance of the AG workers is significantly poorer than that of NAG workers. The t-test also implies that there are significant differences of the mean scores of all the factors between AG and NAG workers. These factors must have multivariate relationships with each other for the occurrences of accident/injures in the mine. To find out the multivariate relationships among the factors, structural equation modelling was done.

Structural equation modelling

The postulated hypothesis was tested using the Linear Structural Relations computer program (LISREL 8.30,) developed by Joreskog and Sorbom (1998). The analysis was performed in two parts: first, a measurement model was used to determine whether the latent variables were defined appropriately and were measured consistently; and a correlation matrix of the latent constructs was generated. The

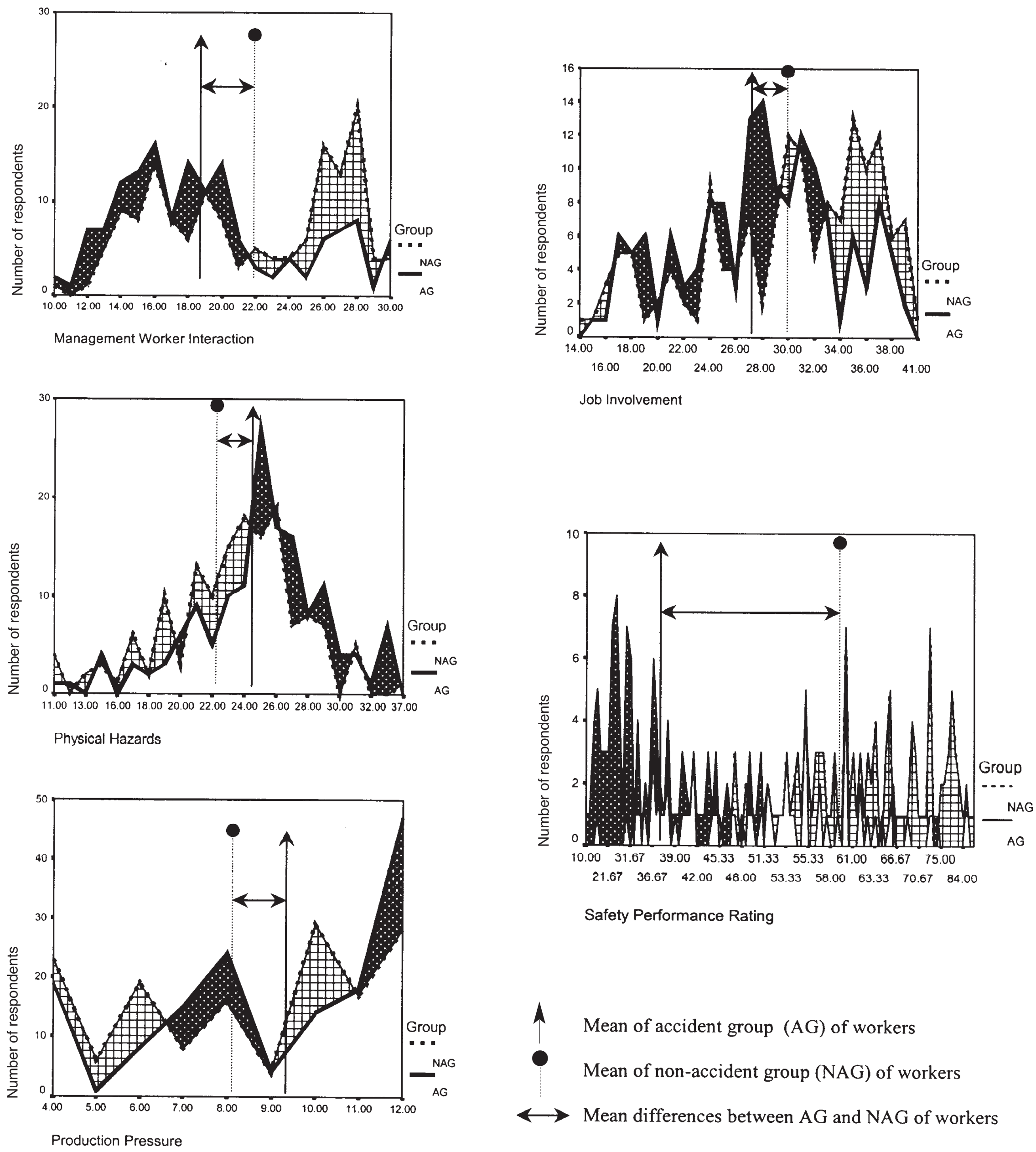

Figure 2—High-low plots for AG and NAG workers (continued)

Table II

Comparison of accident and non-accident groups for equality of factor means

Variables	Mean NAG	Mean AG	Mean difference	SD NAG	SD AG	t-value	2-Tail Significance
*Co-worker support	12.93	12.79	0.15	2.32	2.02	0.58	0.560
Job involvement	29.96	27.96	2.00	6.64	5.91	2.75	0.006
Job stress	16.29	17.36	-1.07	3.62	4.27	-2.35	0.020
Management-worker interaction	21.62	19.09	2.53	5.40	5.18	4.14	0.000
Physical hazards	23.27	24.93	-1.65	4.38	4.20	-3.34	0.001
Production pressure	8.46	9.03	-0.63	2.83	2.78	-1.96	0.052
Safety performance rating	58.23	37.45	20.78	15.45	18.06	10.71	0.000
Safety equipment availability and maintenance	16.66	14.81	1.85	3.92	3.74	4.19	0.000
Safety practices	41.81	37.52	4.29	7.36	7.08	5.15	0.000
Safety training	13.83	12.61	1.22	2.92	3.48	3.29	0.001
Supervisory support	15.75	14.07	1.69	3.37	3.79	4.07	0.000

* mean difference is not statistically significant

Table III

Descriptive statistics and interrelationship amongst constructs

Construct	Mean	SD	Correlations 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Work injury	0.50	0.50	1.00													
Rat 1	52.54	20.73	-0.35**	1.00												
Rat 2	47.84	19.74	-0.53**	0.60**	1.00											
Rat 3	48.26	19.68	-0.57**	0.63**	0.72**	1.00										
Job involvement	28.96	6.36	-0.16**	0.12	0.16**	0.12	1.00									
Safety training	13.22	3.27	-0.19**	0.06	0.20**	0.15**	0.25**	1.00								
Safety practice	39.67	7.53	-0.29**	0.06	0.18**	0.11	0.50**	0.52**	1.00							
S_Equip_A_M	15.73	3.93	-0.24**	0.04	0.12*	0.05	0.52**	0.36**	0.65**	1.00						
Job stress	16.82	3.99	0.14*	0.01	-0.11	-0.06	-0.50**	-0.54**	-0.60**	-0.46**	1.00					
Co_W_Sprt	12.86	2.18	-0.03	0.01	0.07	-0.03	0.11	0.29**	0.44**	0.31**	0.30**	1.00				
Sup_Sprt	14.91	3.68	-0.23**	0.05	0.16**	0.15*	0.54**	0.62**	0.70**	0.52**	-0.64**	0.29**	1.00			
M_W_Int	20.36	5.44	-0.23**	0.03	0.15*	0.08	0.57**	0.53**	0.80**	0.67**	-0.66**	0.39**	0.81**	1.00		
Prod_Pr	24.10	4.36	0.19**	-0.01	-0.09	-0.07	-0.34**	-0.17**	-0.50**	-0.51**	0.46**	-0.21**	-0.42**	-0.51**	1.00	
Phy_Hrz	8.78	2.82	0.11	0.04	-0.04	-0.01	-0.38**	-0.27**	-0.40**	-0.38**	0.38**	-0.10	-0.50**	-0.45**	0.44**	1.00

* P<0.05
**P<0.01

Legend: S_Equip_A_M = Safety equipment availability and maintenance, Co_W_Sprt = Co worker support, Sup_Sprt= Supervisory support, M_W_Int = Management worker interaction, Prod_Pr = Production pressure, Phy_Hrz=Physical hazards

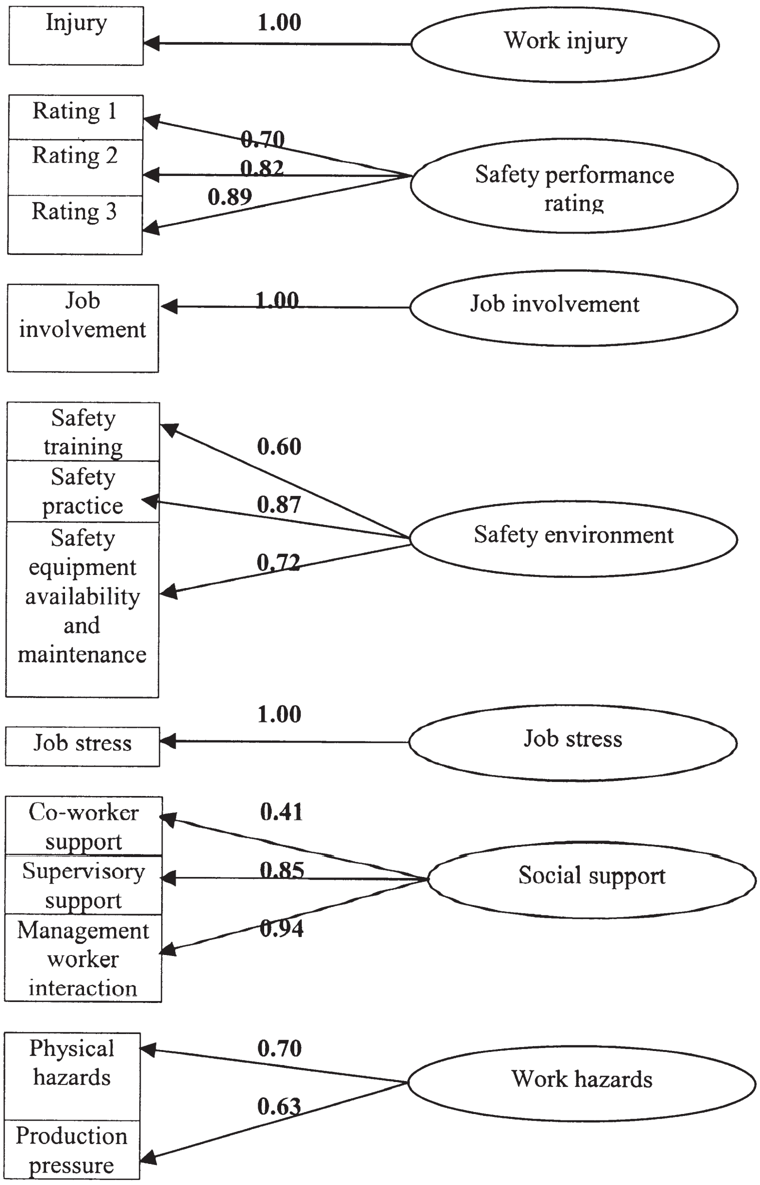

Figure 3—Baseline measurement model

input data for the measurement model run was the correlation matrix of 14 variables collected from case study mines presented in Table III. Finally, a structural model was developed and tested to identify the interrelationships among the variables, with a set of simultaneous equations. The final structural model run was completed on a revised accident model (Figure 4). The input data for the structural model were the correlations among the constructs that were generated through the measurement model.

Measurement model

The latent variables (safety environment, job stress, social support, job involvement, work hazards, safety performance, and work injury) are viewed as important factors causing accidents in mines and are measured through different indicator variables as shown in Figure 3. Safety performance rating was measured through three performance ratings given by three supervisors. Safety environment was measured through safety training, safety practice, and safety equipment availability and maintenance. Co-worker support, supervisory support, and management-worker interaction measured the latent variable social support, whereas work hazards was measured through physical hazards and production pressure. The relationships between the indicators and latent variables are estimated by factor loading through the measurement model. The estimates of factor loading and their t-values are shown in Figure 3.

Test of overall fit of measurement model

Joreskog and Sorbom (1989) recommended three indices to judge the fit of the path analytic model to the data. These are chi-square, the goodness of fit index (GFI) and the root mean square residual (RMR). The chi-square was used as a measure of fit of the hypothesized model to the actual covariance data; the lower the chi-square value, the better the fit. Ideally, the chi-square should be small and non-significant, the GFI, between 0.90 and 1.00, and the RMR, small relative to the size of the diagonal elements in the correlation matrix (Hansen, 1989). However, for the RMR, no threshold level can be established. Researchers can assess the practical significance of the magnitude of the RMR in light of overall objectives and the observed/actual covariance or correlation (Bagozzi, 1988). The goodness of fit indices for this measurement model are shown in Table IV. Table IV shows that the model is a good fit. The chi-square statistics is 219.52 with 55 degrees of freedom. The chi-square statistic was not significant, indicating that the model fit s the data. The GFI is the preferred statistic in assessing the fit of the path model to the data, as it measures the relative amount of variance and covariance accounted for by the model (Joreskog and Sorbom, 1989; Hansen, 1989; Hair *et al.*, 1995). The value of goodness of fit index for the measurement model is 0.90, indicating an acceptable fit of the model. The RMR in this model is the average residual correlation, as the correlation matrix was used for the analysis. The RMR for the measurement model is 0.05, which is equal to its threshold value ($p \leq 0.05$). These statistics indicate that the proposed measurement model is a good fit to the data. Parameters estimates with their t-values, for the measurement model, are shown in Table V.

Test of overall fit of structural model

The goodness of fit indices for this structural model are shown in Table VI. Table VI shows that the model is a good fit. The chi-square statistic is 48.71 with 11 degrees of freedom. The chi-square statistic was not significant, indicating that the model fits the data. The GFI for the structural model is 0.96, indicating a very good fit with the model. The RMR in this structural model is 0.03, which is smaller than its threshold value ($p \leq 0.05$). These statistics indicate that the proposed structural model is a very good fit to the data. Parameter estimates with their t-values, for the structural model, are shown in Table VII.

Result of structural model run

The final model with only the significant paths is shown in Figure 4. In the sociotechnical model (Figure 4), out of three exogenous variables, social support shows significantly negative relationship with job stress and work hazards shows significantly positive relationship with job stress, whereas the variable safety environment is not statistically related with job stress. But, safety environment has a significant negative relationship with work injury. Job involvement is affected negatively by job stress and positively by safety environment, respectively. The safety performance has a significant negative relationship with work injury and is positively affected by job involvement.

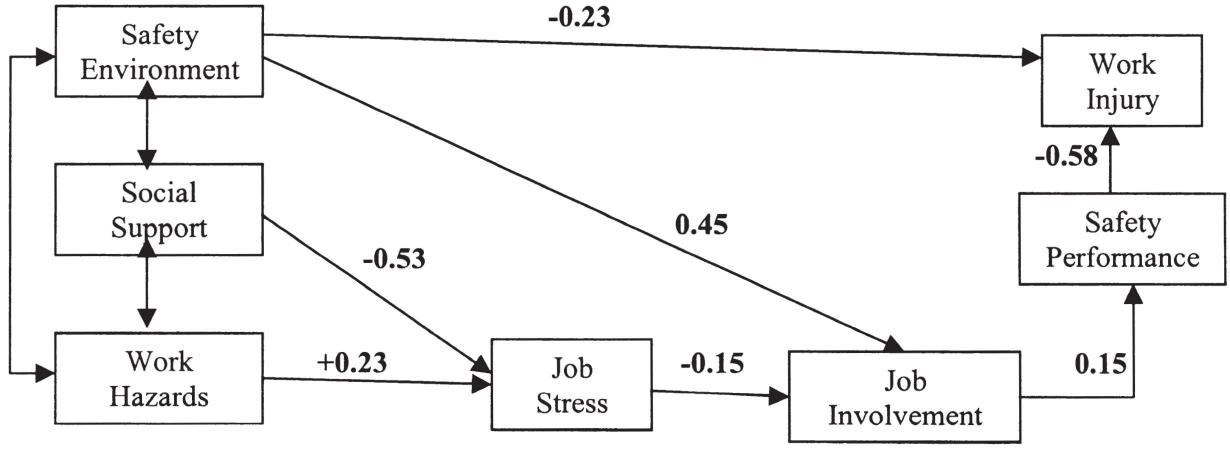

Figure 4—Final path diagram of sociotechnical model

Table IV

Goodness of fit indices for the measurement model

Chi-square with 55 degrees of freedom	= 219.52
Goodness of Fit Index (GFI)	= 0.90
Adjusted Goodness of Fit Index (AGFI)	= 0.82
Root Mean Square Residual (RMR)	= 0.049
Normed Fit Index (NFI)	= 0.90
Relative Fit Index (RFI)	= 0.84

Table V

Parameter estimates with their t-values, for the measurement model

Parameter	Estimates	t-value
$\lambda_{1\,1}$	1.0	--------
$\lambda_{2\,2}$	0.70	16.81*
$\lambda_{3\,2}$	-0.82	24.63*
$\lambda_{4\,2}$	0.89	24.28*
$\lambda_{5\,3}$	1.00	--------
$\lambda_{6\,4}$	0.60	19.68*
$\lambda_{7\,4}$	0.87	23.14*
$\lambda_{8\,4}$	0.72	22.85*
$\lambda_{9\,5}$	1.00	--------
$\lambda_{10\,6}$	0.41	14.16*
$\lambda_{11\,6}$	0.85	24.96*
$\lambda_{12\,6}$	0.94	25.33*
$\lambda_{13\,7}$	0.70	13.45*
$\lambda_{14\,7}$	0.63	13.78*

* indicates 0.01 probability level of significance

Table VI

Goodness of fit indices for the structural model

Chi-square with 11 degrees of freedom	= 48.71
Goodness of Fit Index (GFI)	= 0.96
Adjusted Goodness of Fit Index (AGFI)	= 0.89
Root Mean Square Residual (RMR)	= 0.03
Normed Fit Index (NFI)	= 0.97
Relative Fit Index (RFI)	= 0.95
Expected Cross Validation Index (ECVI)	= 0.28
Square multiple correlations for structural equations:	
Safety performance	= 0.02
Work injury	= 0.42
Job involvement	= 0.33
Job stress	=0.53

Table VII

Parameters estimates with their t-values, for the final structural model

Parameter	Estimates	t-value
$\gamma_{1\,1}$	-0.23	-5.28**
$\gamma_{3\,1}$	0.45	6.79**
$\gamma_{4\,2}$	-0.53	-8.50**
$\gamma_{4\,3}$	0.23	3.65**
$\beta_{1\,2}$	-0.58	-13.26**
$\beta_{2\,3}$	0.15	2.61*
$\beta_{3\,4}$	-0.15	-2.29*
$\psi_{1\,1}$	0.56	12.17**
$\psi_{2\,2}$	0.98	12.17**
$\psi_{3\,3}$	0.67	12.17**
$\psi_{4\,4}$	0.47	12.17**

* indicates 0.05 probability level of significance
** indicates 0.01 probability level of significance

The results show some interesting patterns of relationship between work injury and other causal variables. Among the three exogenous latent variables, social support shows a highly significant negative relationship with job stress (-0.53), which in turn effects job involvement (-0.15). Job involvement has a positive relationship with safety performance (0.15) and safety performance bears a very strong negative relationship with work injury (-0.58). The results also show that safety environment has a direct negative causal relationship with work injury (-0.23) and a positive relationship with job involvement (0.45). The variable work hazard positively affects job stress (0.23).

Discussion

Many factors are responsible for occupational injuries in mines. In this study an attempt was made to identify such causal factors and to evaluate their effects on work injuries in mines. Extensive literature reviews revealed that factors behind mine injuries can be categorized into the following groups: (1) demographics (2) personality (3) social support (4) safety environment (5) job stress, and (6) work hazards. However, the majority of studies was mostly directed towards quantifying accident data according to frequency and frequency rate and identifying curative approaches through various avenues. But few researchers have shown an interest in investigating the multivariate relationships of several factors affecting mine safety using multivariate analysis.

The beauty of multivariate analysis, namely structural equation modelling applied in this study, is that it can handle several variables at a time and has the ability to estimate their relationships in a structural framework. Hence, the overall safety system of the mine can be evaluated, which helps management to understand the lacuna of their existing safety promotional activities through (i) proper understanding of the causes of accident/injury in the mines, and (ii) identifying the required actions necessary to activate the sociotechnical system towards better safety. Therefore, unlike previous studies, the present study considered 14 variables of work injuries, which are mainly based on social and technical factors, and analysed them simultaneously. Finally, the sociotechnical causal model was developed in a structural framework, which is almost non-existent in prior mine safety studies.

The case study results supported the hypothesis that social support predicts employees' job stress, which in turn dictates their job involvement. This finding indicates that an increase in an social support will result in a decrease in job stress perceived by the workers. The construct social support is measured through co-worker support, supervisory support, and management-worker interaction. Hence workers perceiving poor support from the surroundings of the workplace i.e. from supervisors, and co-workers, and also from mine management, feel more job stress. So care must be taken to identify these workers and appropriate training should be given to overcome this situation. Face to face counselling, and encouragement for more intensive participation of these workers in the safety matters will definitely help in this regard.

The construct, safety environment, does not, have any direct relationship with job stress for the mines studied. Safety environment was measured through safety training, safety practice, and safety equipment availability and maintenance. Out of these three observed variables, safety practice has stronger factor loading than safety environment.

On the other hand, the persons dissatisfied with their working conditions (work hazards) have a positive relationship with job stress and highly stressed persons are less involved in their work. The results also indicate that a positive safety environment improves the workers' job involvement. This is obvious as it was measured through safety training, safety practice, and safety equipment availability and maintenance. These positive enforcing variables create a healthy working environment and the workers feel comfortable with the availability and use of these very requirements for their safety in mines.

As expected, job stress reduces workers' job involvement. The model shows that job involvement is the only direct predictor of safety performance, and better safety performance yields less injury. So, the root cause lies in less job involvement, which is again predicted by job stress and safety environment. Safety environment also directly affects work injury. Therefore, safety environment and job stress are the two key variables of work injury for the mines studied. Identification of these highly job stressed individuals, understanding their existing problems, and rectifying them through classroom teaching is required for the case study mines so that they can overcome the existing unhealthy conditions by developing good relationships with co-workers, supervisors, and mine management. Keeping up a good safety environment through proper checking of the working conditions with technical persons, providing adequate training, both psychological counselling and on the job task training, and allocating jobs properly (right person to right job) must improve the existing safety status of the mines.

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