THE ANALYSIS OF FATAL ACCIDENTS IN INDIAN COAL MINES

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Abstract

This paper describes the analysis of fatal accidents of Indian coal mines from April 1989 to March 1998. It is found that Indian mines have considerably higher accident and fatality rates compared to those in USA and South Africa, respectively. While open cast mines are generally known to be safer than underground mines, the Indian open cast mines are shown to be at least as hazardous to the workers as the Indian underground mines. Analysis of the accident rates is made via a few regression models involving the effects of working shifts, the various companies, the types of mine, manshift and production. The accident-prone combinations of mine type and company are identified for follow-up action. The break-up of the accidents by cause is also studied.

Key words: Linear models, Generalised Linear Models, Analysis of Variance, Poisson Process, Accident rate, Fatality rate.

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1 Introduction

Coal is an important mineral in India. Besides being the main source of fuel in power plants, it is also used in household cooking throughout the country. The coal industry employs over 600,000 miners and other workers. Safety in the Indian coal mines is therefore a very important issue. However, there has been no significant statistical analysis of the safety records of Indian coal mines.

The fatal accident rates in India and US during the period 1989-97 are shown in Table 1. The data for the US mines are taken from the *Work Time Quarterly Reports* of Mine Safety and Health Administration, the US Department of Labour (http://www.msha.gov/STATS/PART50/WQ/1978/ wq78c105.htm), while the data for the Indian mines are taken from the *Fatal Accident Register* and *Annual Performance Report* of Coal India Limited (CIL).

Table 1. Fatal accident rates in US and India, 1989-97 [2]

	Accidents per million tons of production per year		Accidents per million manhours per year	
Year	India	USA	India	USA
1989	0.722	0.077	0.112	0.05
1990	0.638	0.071	0.105	0.04
1991	0.587	0.068	0.103	0.04
1992	0.644	0.060	0.118	0.04
1993	0.541	0.055	0.103	0.04
1994	0.484	0.049	0.099	0.04
1995	0.468	0.050	0.103	0.04
1996	0.383	0.040	0.089	0.04
1997	0.380	0.030	0.091	0.03

A cursory glance at the above table reveals that the yearly accident rates (standardized by production) in India is consistently higher than the corresponding rate in the USA by a factor of about ten. Differences in the levels of productivity is not the only explanation for this discrepancy, since the yearly accident rates (standardized by manhours) is also consistently higher in India than in USA by a factor of two to three. Thus, there seems to be a wide scope for improvement in the safety practices in India.

This paper presents an analysis of the fatal coal mine accidents in India, and attempts to identify a few problem areas for safety.

All matters relating to the mining, processing and marketing of coal in India is overseen by CIL, which is an umbrella organisation. There are eight subsidiaries or regional companies working under CIL. These are Eastern Coalfields Limited (ECL), Bharat Coking Coal Limited (BCCL), Central Coalfields Limited (CCL), Northern Coalfields Limited (NCL), Western Coalfields Limited (WCL), South-Eastern Coalfields Limited (SECL), Mahanadi Coalfields Limited (MCL) and North-Eastern Collieries (NEC). The companies have different number of active mines, amount of production and the number of manshifts in a given year. The companies also have largely exclusive managements, although some amount of

[2] The U.S. production data, originally given in short tons, have been converted to tons. The Indian yearly figures are for the period starting from the month of April of the reported year till the month of March of the following year.

coordination is achieved through a common board of directors. Some of the companies have mostly underground mines, while the majority of mines in other companies are open cast. NCL has no underground mine.

There are two broad categories of mines in India: Open Cast and Underground. The accident records classify the location of accident as underground, open cast and surface. While the first two categories represent accidents occurring inside the two types of mines, respectively, the third category represents mining-related accidents occurring above the surface in the vicinity of either type of mine. Accordingly, for the present analysis, we use a variable named 'type' which can have three possible values: underground (ug), opencast (oc) and surface (su).

In the cases of accidents occurring in underground or open cast mines the production/manpower *in that category* for the relevant period has been used for standardization. In the case of accidents occurring on the surface, scaling has been done using the *total* production/manpower for that company in the relevant period.

In the following sections, attempts have been made to answer several questions of general interest. In Section 2, we examine whether the inter-accident times are exponentially distributed, so that a Poisson process model of the incidence of accidents may be used. In Section 3 we check whether the widely believed hypothesis that open cast mines are safer than underground mines (see Murty and Panda, 1988, pp. 127–132, and Melinkov and Chesnokov, 1969, pp. 21–22) is valid in the Indian context. We compare the safety records of the eight companies in Section 4. We examine the effects of the working shift and month of the year on the incidence of accidents in Sections 5 and 6, respectively. Thus, in Sections 3–6, we consider the effects of four categorical variables, taking one variable at a time. In Section 7 we look for a single regression model that incorporates all these variables, starting with a model similar to that used by Lawrence and Marsh (1984). In this section we look for the partial effects of each factor mentioned above in the presence of the other factors. In Section 8 we fit an exponential regression model for the inter-accident times. In Section 9 we identify the major causes of the accidents. We provide some concluding remarks in Section 10.

Data on the date and time of an accident, the corresponding working shift, cause of accident and the age of the victims were obtained from the *Fatal Accident Register* of CIL. Data for the period April, 1989 to March, 1998 have been used for the current analysis. The *Annual Performance Reports* of CIL were the source for data on companywise yearly production and the total number of manshifts. The production and manshift figures of MCL for the year 1989-90 to 1991-92 were not available.

2 Distribution of inter-accident times

Cox and Lewis (1966) had used a plot of the cumulative number of accidents against the number of days, while analyzing the coal mine *disasters* (accidents involving at least 10 deaths) in Britain. A similar plot for all the fatal accidents in Indian coal mines during the period April 1989 to March 1998 is given in Figure 1. The figure shows, in addition to the total accident counts, the accident counts for underground and open cast mines as well as surface accident counts. All the plots are somewhat linear, with a hint of concavity in the case of the total number of accidents (bottom right plot). This is in contrast with Figure 1.1 of Cox and Lewis (1966), which is clearly concave, exhibiting the effect of safer modes of production and better safety practices in recent times. The lack of concavity in the plots

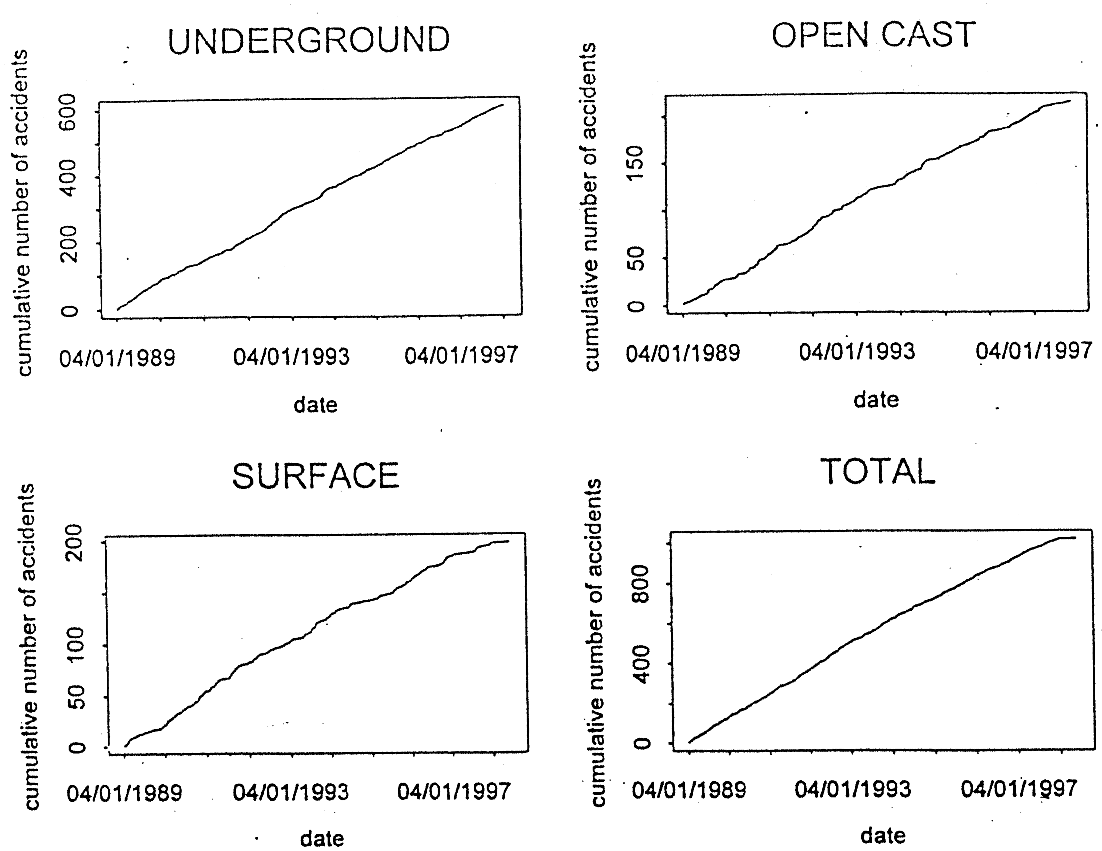

Figure 1: Plots of cumulative number of Indian coal mine accidents against date

of Figure 1 would indicate that a similar reduction in the rate of accidents has not taken place in India, and that there is ample room for improvement.

For a confirmation of the assumption of independent and identically distributed (i.i.d.) inter-accident times we tested the renewal process assumption against the alternative of monotonic trend (see Ascher & Feingold, 1984, p.74 and 80). For this purpose, we used Proschan's (1963) modification (for observations with ties) of Mann's U-statistic. The p-values of the test in the cases of underground, open cast, surface and total count are 0.26, 0.31, 0.23 and 0.06, respectively. Thus, there is no reason to reject the hypothesis of i.i.d. inter-accident times. Therefore, it is meaningful to look for a suitable distribution of these times, which we do in this section. It would also be meaningful to treat the number of accidents in various years as samples from a distribution, while fitting regression models for the accident count (see Section 7).

The simplest known probability distribution for the inter-arrival times of temporal events is the exponential distribution. This distribution was considered by Jarrett (1979) for the intervals in between coal mine *disasters* (accidents involving at least 10 deaths) in Britain. If the time in between accidents has the exponential distribution then the pattern of consecutive accidents can be adequately described by a homogeneous Poisson process. The latter model would make the data amenable to a formal test of equality of two such processes which we may use in Sections 3–6. Furthermore, the Poisson process formulation would imply that the number of accidents in a given time follows the Poisson distribution. This fact would have important implications on the choice of the regression models to be developed in Sections 7 and 8.

We use an omnibus test to check whether the inter-accident times are exponential. We do this for every combination company and type, except for two combinations for which there is no data. The test is based on the so called Gini's statistic and is discussed by Gail and Gatswirth (1978).

Consider an ordered sample $t_{(0)} = 0$ and $t_{(1)} \leq t_{(2)} \leq \ldots \leq t_{(n)}$ of size n. The statistic is

$$G_n = \frac{\sum_{i=1}^{n-1} iW_{i+1}}{(n-1)\sum_{i=1}^{n} W_i}$$

where,

$$W_i = (n-i+1)(t_{(i)} - t_{(i-1)}), i = 1, \ldots, n$$

are the scaled spacings. The distribution of G_n under H_0 has been obtained and tabulated for n=3,4,...,20 by Gail and Gastwirth (1978). For n larger than 20, the distribution of $\sqrt{12(n-1)}(G_n - 0.5)$ is reasonably approximated by the standard normal distribution.

The values of the G-statistic computed with the corresponding sample size are given in Table 2. The subscripts ug, oc and su stand for underground, open cast and surface accidents respectively.

Table 2: Values of the Gini statistic for various type-company combinations

	n	G_{ug}	n	G_{oc}	n	G_{su}
ECL	162	0.500	21	0.446	37	0.493
BCCL	203	0.521	40	0.560	48	0.484
CCL	53	0.518	55	0.499	48	0.518
NCL	NA	-	25	0.527	8	0.516
WCL	92	0.521	24	0.534	14	0.540
SECL	101	0.482	33	0.439	30	0.573
MCL	10	0.637	12	0.590	16	0.444
NEC	10	0.651	3	0.396	0	-

The null hypothesis is accepted at 95% level in all the cases, i.e., *all* the inter-accident times follow the exponential distribution.

The insignificance of the statistics may have been due to the lack of power of the (non-parametric) test and the shortage of data in some cases. Hence, we had also carried out parametric tests of exponentiality within the Gamma and Weibull families of distributions, by checking whether the shape parameter in each case is equal to 1. The results confirm the findings reported above. We refer the reader to Mandal and Sengupta (1999) for a detailed report of these tests as well as the Q-Q plots for checking exponentiality in each case.

3 Are open cast mines safer?

Each of the companies has two technologically different types of mines, namely underground and open cast. Only the NCL does not have any underground mine. All companies have some accidents occurring outside the mine, which are classified under "surface accidents".

It is generally believed that open cast mines are safer than underground mines (see Melinkov and Chesnokov, 1969, pp. 21–22). In the case of USA, the MSHA data suggest that during the period 1989 to 1997, the number of accidents in underground mines per million tons of production per year was on the average 3.8 times higher than the corresponding rate in open cast mines. This discrepancy is partially due to the greater productivity of open cast mines. It is also due in part to the lesser risk to the miners in open cast mines. This is illustrated by the fact that the number of accidents per million manhours per year in the underground mines is 2.1 times higher than the corresponding rate in the open cast mines, after averaging over the yearly figures for the period 1989 to 1997 in the USA.

In the case of Indian mines, the yearly number of accidents per million tons of production for underground, open cast and surface happen to be 1.236, 0.144 and 0.102, respectively. The rate is 0.526 when all the types are combined. (Here, pooled data for all the years from April 1989 to March 1998 and all the eight companies have been used.) This suggests that for a fixed amount of production, accidents are about 8.5 times more frequent in underground mines than in open cast mines. The factor is much larger than the corresponding factor in the US. This may be because of drastically less productivity of underground mines compared to the open cast mines in India and/or greater safety of workers in open cast mines compared to the underground mines in India.

If the latter of these two confounded factors is significant, its effect should be reflected in the rate of accidents in India, scaled by manshift. The yearly number of accidents per million manshifts for underground, open cast and surface are 0.687, 0.579 and 0.160, respectively. The rate is 0.822 when all the types are combined. (Once again, pooled data for all the years from April 1989 to March 1998 and all the eight companies have been used.) It is clear that the number of accidents per million manshifts in open cast and underground mines are comparable. Therefore, for a given worker, working in an open cast mine is not less hazardous. This is quite remarkable, in view of the perceived safety of open cast mines in general and the US records in particular.

As a clarification, we note that all the 'surface' accidents in India occur in the vicinity of the mine. Unlike in the US, there is no remote facility which caters to over-the-surface processing or maintenance of equipment for a collection of mines. Thus, in an underground mine in India, the 'underground' accident count excludes the 'surface' accidents which correspond to the same manshift figures. The 'open cast' accident counts similarly exclude the surface accidents associated with the common manshift figures. This is why we compared the *ratio* of accident rates in underground and open cast mines in India and USA, rather than comparing the rates themselves.

4 Are all companies equally safe?

4.1 Summary statistics

Having observed the relatively higher rate of accidents in the Indian coal mines, we now turn to the comparison of safety records of the eight companies working under CIL. It may be recalled that these companies have their mines in non-overlapping sectors in India, and the price of coal is also fixed by CIL centrally. Thus, there is little scope of competition among these companies. The following table shows the number of accidents for all the companies during the period April 1989 to March 1998.

Table 3. Number of fatal accidents in Indian coal mines for the years 1989 to 1997

Company	Number of accidents in underground mines	Number of accidents in open cast mines	Number of surface accidents	Total number of accidents
ECL	159	21	37	217
BCCL	199	40	48	287
CCL	48	55	48	151
NCL	NA	25	8	33
WCL	86	24	14	124
SECL	100	33	30	163
MCL	10	12	13	35
NEC	10	3	0	13
TOTAL	612	213	198	1023

Note that NEC has the smallest number of accidents. This is misleading, however, because NEC is the smallest of the companies, both in terms of production and manpower. The number of accidents per million ton production for all the companies during the period March 1989 to April 1998 are given in the table below.

Table 4. Number of accidents per million ton production in Indian coal mines

Company	Underground	Open cast	Surface	Total
ECL	1.297	0.203	0.166	0.970
BCCL	1.995	0.268	0.194	1.167
CCL	1.270	0.220	0.173	0.530
NCL	NA	0.087	0.024	0.112
WCL	0.104	0.083	0.062	0.152
SECL	0.723	0.090	0.060	0.331
MCL	0.793	0.074	0.080	0.198
NEC	3.267	0.582	0.000	1.582
Total	1.236	0.144	0.102	0.526

It is clear that the number of accidents in NEC is very high compared to its size. Among the larger companies, BCCL, ECL and CCL seem to be more accident-prone in relation to their productivity. If one analyses the composition of the above figures, it is clear that most of the accidents in BCCL, ECL and CCL occur in underground mines.

From the worker's point of view, however, the most important consideration is the number of accidents per million manshifts. The following table gives the number of accidents per million manshift for all the companies during the period March 1989 to April 1998.

Table 5. Number of accidents per million manshifts in Indian coal mines

Company	Underground	Open cast	Surface	Total
ECL	0.559	0.451	0.112	0.667
BCCL	0.938	0.606	0.172	1.034
CCL	0.567	0.517	0.262	0.801
NCL	NA	0.715	0.200	0.916
WCL	0.071	0.308	0.089	0.219
SECL	0.607	0.711	0.139	0.767
MCL	0.543	0.925	0.489	1.207
NEC	1.366	2.023	0.000	1.476
Total	0.687	0.579	0.160	0.822

On this count, BCCL, MCL and NEC appear to be more hazardous. MCL has a remarkably larger number of accidents per million manshifts in the surface. The open cast mines of SECL, NCL and MCL, apart from NEC, seem to be more hazardous than most other companies. The underground mines of BCCL and NEC stand apart from the underground mines of the other companies because of their high rate of accidents.

4.2 A formal test

Dewanji (1999) proposed a test of homogeneity of a group of nonhomogeneious Poisson processes which may be adapted to the present context. Suppose that there are $(r+1)$ groups and let $\lambda_j(t)$ denote the expected count per unit "volume" for an observation at time t in the jth group, for $j = 0, 1, \ldots, r$. The equality of these $\lambda_j(t)$'s over different j is to be tested without assuming any specific model for them. The null hypothesis is

$H_0 : \lambda_0(t) = \lambda_1(t) = \ldots = \lambda_r(t) = \lambda(t)$, say, for all t.

Let $t_1 < t_2 \ldots < t_k$ be the different observation times. Also, let n_{ij} denote the count for a volume a_{ij} observed at time t_i and in the jth group, for $i = 1, 2, \ldots, k$ and $j = 0, 1, \ldots r$. Write $\lambda_{ij} = \lambda_j(t_i)$. Then, n_{ij} has the Poisson distribution with mean $a_{ij}\lambda_{ij}$, for $i = 1, \ldots, k$ and $j = 1, \ldots, r$.

Note that, under H_0,

$$\lambda_{i0} = \lambda_{i1} = \ldots = \lambda_{ir} = \lambda_i, \text{ say, for } i = 1, \ldots, k.$$

The conditional expectations and variances are

$$\begin{aligned} E(n_{ij}|n_{i.}) &= n_{i.}\frac{a_{ij}}{a_{i.}} = e_{ij} \\ Var(n_{ij}|n_{i.}) &= n_{i.}\frac{a_{ij}}{a_{i.}}(1 - \frac{a_{ij}}{a_{i.}}) = V_{jj(i)}, \text{ say,} \\ \text{and } Cov(n_{ij}, n_{ij'}|n_{i.}) &= -n_{i.}\frac{a_{ij}a_{ij'}}{a_{i.}^2}, \text{ for } j \neq j' \\ &= V_{jj'(i)}, \text{ say.} \end{aligned}$$

where $a_{i.} = \sum_{j=0}^{r} a_{ij}$ and $n_{i.} = \sum_{j=0}^{r} n_{ij}$

Consider the vector $d_i^T = (d_{i0}, d_{i1}, \ldots, d_{ir})$, where $d_{ij} = n_{ij} - e_{ij}$ is the difference between observed and expected counts in the $(i, j)^{th}$ cell. Note that, given $n_{i.}$, the random vector d_i has zero expectation and variance-covariance matrix given by V_i, the $(j, j')^{th}$ entry of which is $V_{jj'(i)}$. Let

$$d = \textstyle\sum_1^k d_i \text{ and } V = \sum_1^k V_i.$$

The test of homogeneity proposed by Dewanji (1999) is based on an asymptotic $\chi^2_{(r)}$ distribution for $d^T V^- d$, where V^- is a generalized inverse of V.

We assume that the number of accidents per year for each company follows Poisson distribution (separately for underground, open cast and surface). There are $r + 1 = 8$ companies and $k = 9$ observation times (i.e. years). The observed values of the test statistics with the corresponding p-values are given below. Production and manshift, are taken as the 'volume' in two cases, respectively.

Table 6. Values of Dewanji's test statistics with their corresponding p-values

	production		manshift	
	$d^T V^{-1} d$	p-values	$d^T V^{-1} d$	p-values
UG	153.32	0.000	75.212	0.000
OC	46.535	0.000	454.15	0.000
SU	68.426	0.000	28.473	0.000

So, in both of the cases, the company effect is statistically significant.

5 Are all the shifts equally risky ?

5.1 Summary statistics

The Indian coal miners work in three shifts: 8 a.m. to 4 p.m. (shift 1), 4 p.m. to midnight (shift 2) and midnight to 8 a.m. (shift 3). The following table gives the shiftwise breakup of the accidents occurring in each company.

Table 7. Shiftwise breakup of Indian coal mine accidents

Company	Undergound			Open Cast			Surface		
	Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3	Shift 1	Shift 2	Shift 3
ECL	67	33	59	9	3	9	21	6	10
BCCL	82	53	64	21	8	11	22	10	16
CCL	17	18	13	19	17	19	22	10	16
NCL	NA	NA	NA	13	4	8	4	0	4
WCL	43	24	19	12	4	8	6	4	4
SECL	52	23	25	15	10	8	13	8	9
MCL	2	5	3	6	0	6	9	1	3
NEC	4	3	3	2	0	1	0	0	0
Total	267	159	186	97	46	70	97	39	62

It appears that the first shift is the most accident-prone, followed by shift 3. The second shift is relatively the safest one. This pattern is remarkably consistent across the companies. A follow-up study revealed that in addition to mining, most of the repair and routine maintenance work take place during the first shift. Consequently, the number of manshifts is also believed to be larger for this shift, although a shiftwise breakup of the manshifts is not readily available. The reason for shift 3 being more accident-prone is somewhat different, and more important from a managerial perspective. It is believed that the alertness of workers as well as supervisors reduces during the early morning hours. This is certainly an important safety issue.

5.2 A formal test

There are $r+1=3$ shifts and $k=8\times 9=72$ observation times (i.e. 8 companies each for 9 years). With production and manshift taken as the "volume", the table given below show the values of Dewanji's (1999) test statistic and the corresponding p-values:

Table 8. Values of Dewanji's test statistics with their corresponding p-values

	production		manshift	
	$d^TV^{-1}d$	p-values	$d^TV^{-1}d$	p-values
UG	35.42	0.000	39.08	0.00
OC	17.61	0.000	17.61	0.00
SU	17.61	0.000	17.61	0.00

In a similar manner, pairwise comparison was done. All pairs of shifts showed significant difference. The only exception was shifts one and three in underground mines.

6 Is there any seasonal effect ?

We used the following formulation for checking the effect of the month of the year on the accident count. We compiled all the accidents occurring in the ith month of the jth year, ($i = 1, 2, \ldots 12,\ j = 1, 2, \ldots, 10$). [Note that the accident count for the year April'98–March'99 could not be used earlier because the manshift figures for this year was not available.] We conducted one-way analysis of variance for each type of accident (underground, open cast and surface), with 10 observations per cell, to test for the month effect. The p-values of the usual F-statistic, under the assumption of normality, turned out to be 0.674, 0.483 and 0.758 for underground, open cast and surface, respectively. Thus, month effect can be safely ruled out.

It may be noted that there was no perceptible month effect in the case of the disaster data for British coal mines, reported by Jarrett (1979).

7 Regression models for accident count

The results of the foregoing sections suggest that the company, type of mines (underground, open cast, surface) and shift (shift 1, shift 2, shift 3) have considerable effect on the accident count, when scaled by production or manshift. On the other hand, the effect of the month may be ignored. In this section, we try and build a model which incorporates the first three factors, along with production and manshift. Since the manshift data was available only till March 1998, the data on other variables for the period April 1998 to March 1999 have been ignored in this section.

7.1 Linear Regression

The number of events over a fixed period of time is often modeled by the Poisson distribution. Our findings in Section 2 indicate that this assumption is satisfied in the case of fatal accident data in Indian mines. The square-root transformation on the count is used in order to stabilize the variance before a least squares analysis is carried out (see Sen and Srivastava, 1990). In addition to the three discrete variables, we also use log(production) and log(manshift) as additional regressors. Thus, the model is

$$\begin{aligned}&\sqrt{number\ of\ accidents} = b_0 + b_1 * (surface) + b_2 * (opencast) + b_3 * (shift1)\\&+ b_4 * (shift3) + b_5 * \log(production) + b_6 * \log(manshift) + b_7 * (ECL) + b_8 * (BCCL)\\&+ b_9 * (CCL) + b_{10} * (NCL) + b_{11} * (WCL) + b_{12} * (SECL) + b_{13} * (NEC)\end{aligned}$$

where the variables in italics are indicators of a specific type, shift or company. The results of the least squares regression analysis on the square root transformed data are given below:

```
Coefficients:
               Value Std. Error  t value Pr(>|t|)
(Intercept)  -0.363   0.201    -1.805   0.072
    surface  -1.929   0.179   -10.807   0.000
   opencast  -1.190   0.103   -11.566   0.000
     shift1   0.448   0.063     7.130   0.000
     shift3   0.198   0.063     3.158   0.002
 production   0.566   0.090     6.279   0.000
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```
 manshift  -0.024  0.045  -0.524  0.601
      ecl   0.845  0.114   7.436  0.000
     bccl   1.114  0.112   9.944  0.000
      ccl   0.779  0.111   6.990  0.000
      ncl   0.088  0.136   0.646  0.519
      wcl   0.514  0.120   4.272  0.000
     secl   0.371  0.120   3.079  0.002
      nec   1.373  0.271   5.057  0.000

Residual standard error: 0.625 on 580 degrees of freedom
Multiple R-Squared: 0.519
F-statistic: 48.08 on 13 and 580 degrees of freedom, the p-value is 0
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It is observed from the above results that all the regression coefficients except for those of the intercept term, log(*manshift*) and NCL, are statistically significant at any reasonable level. Thus, all the companies except for NCL have a significantly higher accident count compared to MCL, after taking into account the linear effect of the other variables. A histogram of the residuals of the above regression showed an expected bell-shaped pattern. This plot is not given here. The plot confirmed the effectiveness of the variance stabilizing transformation. [A similar plot for the untransformed count data was found to be skewed heavily to the right.]

The above analysis indicates that accidents are more common inside underground mines, when the effect of production and manshift are taken into account in the manner described above. A similar analysis reveals that accidents in open cast mines are also significantly more frequent than surface accidents.

The preliminary analysis of Section 5 had suggested that shift 1 is the most unsafe, while shift 2 is the safest. The above analysis confirms that shifts 1 and 3 are significantly more unsafe than shift 2. A follow-up analysis reveals that shift 1 is significantly more unsafe than shift 3.

The company effects as found from the above analysis generally follow the trend of the preliminary analyses of Section 4. NEC and BCCL stand out as the companies which are by far the most unsafe.

7.2 Generalized Linear Model (Poisson family)

The variance stabilizing transformation on the accident count data made it amenable to least squares regression. However, since there is sufficient evidence that the accident count has Poisson distribution, an appropriate regression model would be the generalized linear model for Poisson family. The model is

$$E(\log(\textit{number of accidents})) = b_0 + b_1 * (surface) + b_2 * (\textit{opencast}) + b_3 * (shift1)$$
$$+ b_4 * (shift3) + b_5 * \log(\textit{production}) + b_6 * \log(manshift) + b_7 * (ECL) + b_8 * (BCCL)$$
$$+ b_9 * (CCL) + b_{10} * (NCL) + b_{11} * (WCL) + b_{12} * (SECL) + b_{13} * (NEC)$$

Note that, while analyzing explosion-related accidents in the coal mines of USA, Lawrence and Marsh (1984) had used a *linear* regression model very similar to the above one (with a different set of discrete predictors). The results of the analysis of the GLM are given below.

```
Coefficients:
             Value Std. Error t value
(Intercept) -1.659   0.376    -4.42
    surface -1.689   0.283    -5.98
   opencast -1.033   0.168    -6.15
     shift1  0.468   0.105     4.47
     shift3  0.234   0.110     2.14
 production  0.493   0.150     3.29
   manshift  0.019   0.080     0.24
        ecl  0.882   0.220     4.01
       bccl  1.118   0.213     5.24
        ccl  0.984   0.219     4.50
        ncl  0.157   0.294     0.53
        wcl  0.643   0.232     2.77
       secl  0.586   0.229     2.55
        nec  0.459   0.540     0.85
    Null Deviance: 613 on 593 degrees of freedom
Residual Deviance: 346 on 580 degrees of freedom
```

If the regression model is inappropriate, the difference between null deviance and residual variance is expected to have a chi-square distribution with $593-580 = 13$ degrees of freedom. The observed difference (267) is much higher than any reasonably large quantile of this distribution. Hence, it can be said that the regressors have significant explanatory power.

The t-values greater than 1.96 or less than -1.96 indicate significance of the coefficients at the 95% level. It is seen that all the coefficients, except those of log(manshift) and *NCL* are significant. This is similar to the findings of Section 7.1. Likewise, the shift and type effects confirmed the orders found significant in that section. There is some discrepancy between the order of the company effects in this analysis and that in the previous one. However, BCCL continues to be seen as more unsafe than most other companies.

7.3 Analysis of Variance (ANOVA)

We now turn to the number of accidents per million ton production and that per million manshifts. Analyses have been made for these two ratios separately. Once the scaling with respect to production or manshift is done, there is no need to keep these as explanatory variables. The remaining explanatory variables are all categorical. Therefore an analysis of variance can be carried out. In particular, we can examine the possible interaction between the three major factors, namely the type (underground, open cast, surface), shift(1, 2 and 3) and company. We continue with the linear regression model with $\sqrt{\frac{number of accidents}{production}}$ as the response. In the absence of any interaction, the model suggests that the mean response changes by a constant amount when the value of one factor is changed while keeping the other two factors same. Presence of interaction implies that the mean response depends on the factors in a more complicated way. We symbolically write the Analysis of Variance model as:

$$\begin{aligned}\sqrt{\frac{number\ of\ accidents}{production}} &= (type) + (shift) + (company) \\ &\quad +(type * shift) + (shift * company) + (company * type) \\ &\quad +(type * shift * company)\end{aligned}$$

$$\text{where } (type) = \begin{cases} 1 & \text{for underground mine accidents,} \\ 2 & \text{for opencast mine accidents,} \\ 3 & \text{for surface accidents,} \end{cases}$$

similarly for ($shift$), ($company$) and other parameters.

The data on NCL is discarded from the present analysis because it has no underground mines which makes testing of interaction impossible in this case. The result of the analysis of variance is given below :

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
type	2	22.39	11.194	159.866	0.000
shift	2	1.18	0.589	8.408	0.000
company	6	3.11	0.518	7.398	0.000
type:shift	4	0.29	0.071	1.024	0.394
type:company	12	2.79	0.232	3.314	0.000
shift:company	12	0.32	0.026	0.378	0.971
type:shift:company	24	0.48	0.019	0.282	1.000
Residuals	477	33.40	0.070		

All the first order terms, namely, ($type$), ($shift$) and ($company$) effects are significant. Among the interaction terms, only the ($type * company$) interaction is significant. So a model has been fitted with these effects only:

$$\sqrt{\frac{\text{number of accidents}}{\text{production}}} = (type) + (shift) + (company) + (type * company)$$

The results of the analysis are given below :

Coefficients:

	Value	Std.Error	t value	Pr(>|t|)
(Intercept)	0.104	0.060	1.72	0.086
underground	0.039	0.083	0.47	0.637
surface	-0.038	0.083	-0.46	0.647
shift1	0.068	0.025	2.72	0.007
shift2	-0.043	0.025	-1.73	0.085
ecl	0.477	0.075	6.33	0.000
bccl	0.634	0.075	8.41	0.000
ccl	0.436	0.075	5.78	0.000
ncl	-0.037	0.075	-0.49	0.628
wcl	0.414	0.075	5.50	0.000
secl	0.299	0.075	3.97	0.000
nec	0.494	0.075	6.56	0.000
ecl:opencast	-0.404	0.107	-3.79	0.000
bccl:opencast	-0.498	0.107	-4.67	0.000
ccl:opencast	-0.293	0.107	-2.75	0.006
ncl:opencast	0.052	0.107	0.48	0.629
wcl:opencast	-0.366	0.107	-3.43	0.001
secl:opencast	-0.249	0.107	-2.34	0.020
nec:opencast	-0.457	0.107	-4.29	0.000
ecl:surface	-0.422	0.107	-3.96	0.000
bccl:surface	-0.551	0.107	-5.17	0.000
ccl:surface	-0.370	0.107	-3.47	0.001

wcl:surface	-0.421	0.107	-3.95	0.000
secl:surface	-0.291	0.107	-2.73	0.007
nec:surface	-0.568	0.107	-5.33	0.000

```
Residual standard error: 0.248 on 569 degrees of freedom
Multiple R-Squared: 0.475
F-statistic: 21.43 on 24 and 569 degrees of freedom, the p-value is 0
```

	Df	Sum of Sq	MeanSq	F Value	Pr(F)
type	2	22.39	11.194	167.84	0.000
shift	2	1.18	0.589	8.83	0.000
company	6	3.11	0.518	7.77	0.000
type:company	12	2.79	0.232	3.48	0.000
Residuals	517	34.48	0.066		

Note that the major part of the variance of the response is explained by the factor (*type*) alone. Specifically, the sign of the coefficients of the variables *underground* and $surface$ in the fitted model for accident per million ton production, as well as the findings of Section 3, indicate that underground mines have higher accident rates. Is this because the underground mines are more unsafe or because these are less productive? Indeed, the *Annual Performance Report* of CIL indicates that the output per manshift ratio (tons of production per manshift) for underground mines is consistently five to ten times less than that for open cast mines. It appears that this is the main reason why *type* is a significant factor in the above analysis.

Now consider the second ratio: number of accidents per million manshifts. Here also in order to invoke all the second and third order interaction terms, we fit the ANOVA discarding the company NCL, which has no underground mines. The model is

$$\begin{aligned}\sqrt{\frac{\textit{number of accidents}}{manshift}} &= (\textit{type}) + (shift) + (\textit{company}) \\ &+ (\textit{type} * shift) + (shift * \textit{company}) + (\textit{company} * \textit{type}) \\ &+ (\textit{type} * shift * \textit{company})\end{aligned}$$

The result of the analysis is given below.

	Df	Sum of Sq	MeanSq	F Value	Pr(F)
type	2	6.13	3.066	42.11	0.000
shift	2	1.84	0.917	12.60	0.000
company	6	2.71	0.451	6.20	0.000
type:shift	4	0.36	0.089	1.23	0.297
type:company	12	2.92	0.244	3.34	0.000
shift:company	12	0.58	0.048	0.66	0.792
type:shift:company	24	1.09	0.045	0.62	0.918
Residuals	477	34.74	0.073		

In this case also only the first order terms and $(\textit{type} * \textit{company})$ interactions are significant. Therefore, the following simplified model is used.

$$\sqrt{\frac{\textit{number of accidents}}{manshift}} = (\textit{type}) + (shift) + (\textit{company}) + (\textit{type} * \textit{company})$$

The results of the analysis are given below.

```
Coefficients:
               Value Std.Error t value Pr(>|t|)
  (Intercept)  0.211  0.065     3.24   0.001
  underground -0.094  0.089    -1.05   0.293
      surface -0.088  0.089    -0.99   0.324
       shift1  0.089  0.027     3.31   0.001
       shift2 -0.065  0.027    -2.39   0.017
          ecl  0.287  0.082     3.52   0.001
         bccl  0.413  0.082     5.06   0.000
          ccl  0.265  0.082     3.25   0.001
          ncl  0.019  0.082     0.23   0.816
          wcl  0.342  0.082     4.19   0.000
         secl  0.287  0.082     3.52   0.001
          nec  0.282  0.082     3.46   0.001
 ecl:opencast -0.253  0.115    -2.20   0.029
bccl:opencast -0.261  0.115    -2.27   0.024
 ccl:opencast -0.096  0.115    -0.83   0.406
 ncl:opencast  0.125  0.115     1.08   0.281
 wcl:opencast -0.494  0.115    -4.28   0.000
secl:opencast -0.051  0.115    -0.44   0.661
 nec:opencast -0.219  0.115    -1.90   0.058
  ecl:surface -0.269  0.115    -2.33   0.020
 bccl:surface -0.336  0.115    -2.92   0.004
  ccl:surface -0.154  0.115    -1.34   0.183
  wcl:surface -0.362  0.115    -3.14   0.002
 secl:surface -0.239  0.115    -2.08   0.038
  nec:surface -0.413  0.115    -3.58   0.000

Residual standard error: 0.268 on 569 degrees of freedom
Multiple R-Squared: 0.265
F-statistic: 8.56 on 24 and 569 degrees of freedom, the p-value is 0

              Df Sum of Sq MeanSq  F Value   Pr(F)
        type   2   6.13   3.07     43.12     0.00
       shift   2   1.84   0.92     12.90     0.00
     company   6   2.71   0.45      6.35     0.00
type:company  12   2.92   0.24      3.43     0.00
   Residuals 517  36.76   0.07
```

Although the three main effects and the *type∗company* interaction effect are statistically significant, the residual sum of squares is much higher than the sum of squares explained by these factors. This indicates that the accident count per million manshifts is somewhat evenly spread across various combinations of factors.

Although the coefficients of *underground* and *surface* are not statistically significant, these are much smaller than the coefficient of *opencast* in the analysis of number of accidents per million manshifts. (Note that the implied coefficient of *opencast* is 0.) This is a remarkable outcome of the analysis. It means that, when the number of accidents is viewed in relation to the number of manshifts involved, open cast mines are equally unsafe, if not more unsafe, than underground mines. This confirms the findings of Section 3. The message is that Indian open cast mines are more productive (as expected), but these are not safer, although common knowledge (see Melinkov and Chesnokov, 1969, pp. 21–22 and *Work Time Quarterly Reports*) suggest that these should be safer.

For both the analyses, the shift effect is significant. The preliminary analysis of Section 3 had suggested that shift 1 is the most unsafe, while shift 2 is the safest. The above two sets of analyses confirm this order.

The company effects as found from the above two sets of analysis generally follow the trend of the preliminary analyses of Section 4. BCCL stands out as the company which is by far the most unsafe one.

Since the *type*company* interaction is found to be statistically significant, a follow-up analysis was undertaken in order to examine the significance of one particular combination of type and company at a time, in the presence of the main effects only. It was found from this analysis that the combinations *underground:BCCL*, *underground:WCL*, *opencast:SECL* and *surface:MCL* are worse than the general trend.

8 Exponential regression model for inter-accident time

Let T be the time between successive accidents for a particular combination of shift, company and type. On the basis of our findings in Section 2, we assume that T has the exponential distribution with density $\lambda e^{-\lambda t}$, where $\log \lambda$ is a linear combination of the variables *shift1, shift2, underground, opencast, ECL, BCCL, CCL, NCL, WCL, SECL, MCL*, $\log(production)$ and $\log(manshift)$. The maximum likelihood estimates of the coefficients of the above linear combination, their p-values and some related quantities are reported below.

```
Coefficients:
                   Value Std.Error z value    p
(Intercept)    b0 14.111   0.292    48.31   0.000
(underground)  b1 -2.076   0.149   -13.98   0.000
(opencast)     b2 -0.412   0.112    -3.69   0.000
(shift1)       b3  0.007   0.073     0.10   0.924
(shift2)       b4 -0.052   0.086    -0.60   0.547
(production)   b5 -0.866   0.123    -7.04   0.000
(manshift)     b6 -0.027   0.067    -0.41   0.684
(ECL)          b7  0.659   0.497     1.33   0.185
(BCCL)         b8  0.296   0.484     0.61   0.540
(CCL)          b9  0.591   0.461     1.28   0.200
(NCL)         b10  1.637   0.535     3.06   0.002
(WCL)         b11  0.994   0.479     2.08   0.038
(SECL)        b12  1.279   0.525     2.44   0.015
(MCL)         b13  1.912   0.495     3.86   0.000

Degrees of Freedom: 1028 Total; 1014 Residual
-2*Log-Likelihood: 3414
```

The chi-square test statistic for lack-of-fit is highly significant.

The coefficient of *underground* is significantly negative, indicating shorter time in between accidents in the case of underground accidents as compared to surface accidents. This confirms earlier findings. The coefficient of *opencast* is also significantly negative, although smaller than that of *underground*. This result is similar to the findings of Sections 7.1 and 7.2.

Both the shift indicators turn out to be insignificant in this case, unlike in the case of linear regression of accident count. It has to be remembered that the present analysis is based on much larger number of cases as compared to the earlier analysis. Specifically, there are 1028 cases in this analysis as opposed to the 594 cases for the analysis of yearly accident count data.

The coefficients of the indicators of various companies are generally in line with the findings of Sections 3 and 7.

9 What are the important causes of accidents ?

The records on the causes of accidents are available in the form of thirteen broad categories. These are:

Table 9. Terminology of causes of Indian coal mine accidents

Roof/side fall	accidental fall of roof or side at the time of excavation
Winding	accident in the course of raising or lowering coal or man in shaft
Haulage	accident in the course of raising or lowering coal by tubs
Dumper	accidents associated with dumper – wheeled vehicles for carrying coal with tipper mechanism
Conveyer	accident in the use of belt or chain conveyers
Other transport machinery	accident associated with trucks and wagons
Other machinery	accident associated with nontransport machinery like loading machinery, crusher etc.
Explosives	accident in the course of using explosives
Electricity	accidents resulting out of the use of electricity
Dust/gas	accidents due to explosions of noxious gases, due to absence of oxygen, due to explosion of coal dust etc.
Fall of object/person	accidents occurring due to sudden fall of an object or a person
Inundation	accidents due to sudden rushing in of water
Miscellaneous	other causes of accidents

Table 10 gives the causewise breakup of accidents for the period April '89 to March '99 for different companies in underground and open cast mines and at surface respectively.

Table 10. Causewise breakup of Indian coal mine accidents

Causes	Number of accidents			percentage		
	ug	oc	su	ug	oc	su
Roof/side fall	372	10	0	56.79	4.59	0.00
Winding	16	0	3	2.44	0.00	1.43
Haulage	117	2	8	17.86	0.92	3.81
Dumper	0	75	25	0.00	34.40	11.90
Conveyer	6	4	14	0.92	1.83	6.67
Other transport mach	5	25	43	0.76	11.47	20.48
Other machinery	17	36	31	2.60	16.51	14.76
Explosives	22	8	2	3.36	3.67	0.95
Electricity	4	11	23	0.61	5.05	10.95
Dust/gas	9	4	2	1.31	1.83	0.95
Fall of person/object	52	18	37	7.94	8.26	17.62
Inundation	7	0	0	1.67	0.00	0.00
Miscellaneous	17	20	17	2.60	9.17	8.10
Cause unknown	11	5	5	1.68	2.29	2.38
Total	655	218	210	100.00	100.00	100.00

Among the thirteen causes, ‘roof/side fall’ is the most important one for accidents in underground mines, followed by ‘haulage’. In NEC, other causes are also significantly important which indicate possible scope for improvement in management practices.

In open cast mines, ‘dumper’ is the most important cause of accidents. ‘other transport machinery’, ‘other machinery’ and ‘miscellaneous’ are also significant causes.

In surface, except ‘roof/side fall’, more or less all other causes are important. ‘other transport machinery’, ‘other machinery’ and ‘fall of objects’ appear to be consistent sources of fatal accidents across all the companies.

A comparison of the causewise breakup of the accident rates with those in other countries was not possible. The *Analysis of Annual Accident Statistics* of the Chamber of mines of South Africa (http://www.bullion. org.za/bulza/panl/genrl/accianal.htm) gives a causewise breakup of the *fatality* rates (number of deaths per year) during the period 1989 to 1997. All the fatalities presumably correspond to underground mines, since this is known to be the only type of mines in South Africa. The approximate manshift figures corresponding to these yearly fatalities were calculated by multiplying the *Average Labour at Work* per annum by 365×3. The causes given there are classified in a somewhat different manner. In order to make the causes comparable, some causes for each country were grouped together, as indicated in the following table.

Table 11. Causes of coal mine accidents in Indian and South African nomenclature

Cause list	Causes of Indian coal mines	Causes of South African coal mines
Cause 1	Roof/Side fall	Fall of ground
Cause 2	Winding	Other shaft accidents
Cause 3	Fall of person/object	Falling in shafts, excavations etc. Falling material
Cause 4	Haulage Dumper Other transport machinery	Trucks and tramways
Cause 5	Conveyer Other machinery	Machinery
Cause 6	Explosives	Explosives
Cause 7	Electricity	Electricity
Cause 8	Dust/gas	Explosion of gas Burning and scalding
Cause 9	Inundation Other misc. causes	Other causes

The comparison of the fatality rates per million manshifts due to nine groups of causes for the period 1989–1997 is given in Table 12. In the case of the Indian fatalities, the 'year' refers to the period starting from April of the reported year till the March of the following year. The fatalities from two major Indian disasters (deaths of 55 people due to fire on 25 Jan 1994 and another 64 deaths due to inundation on 26 November 1995) were excluded from the calculation of these figures.

Table 12. Fatalities per million manshifts in Indian and South African coal mines

Causes	SA	India
Cause1	0.184	0.463
Cause2	0.004	0.015
Cause3	0.035	0.063
Cause4	0.163	0.132
Cause5	0.013	0.022
Cause6	0.006	0.023
Cause7	0.023	0.006
Cause8	0.006	0.025
Cause9	0.063	0.043
Total	0.497	0.790

Cause 1 (reported as 'Roof/side fall' in Indian mines and as 'Fall of ground' in South African mines) appear to be the single most important cause of fatalities in each country. However, this cause accounts for a much higher fatality rate in India.

10 Summary and conclusions

Indian mines have much higher accident rates than the mines of USA and much higher fatality rates than the South African mines. The accident rate, when scaled with respect to production, compares even less favorably with the rates in USA. However, productivity of the Indian mines is not the focus of the present paper. There is enough cause for alarm if we restrict our attention to the safety issues.

The cumulative number of accidents in Indian coal mines have shown a linear increase with time over the period from April 1989 to March 1998, with no significant sign of diminishing of the rate as yet.

The inter-accident time is generally found to have an exponential distribution. This implies that the number of accidents in a fixed period has a Poisson distribution.

It is easy to understand the finding that the number of accidents per million ton production is less in the case of open cast mines. Thus, these mines may be preferable from the management's point of view. However, the safety implications for the workforce are clearer when one considers the number of accidents per million manshifts.

As far as the rate of accident per million manshifts is concerned, several factors seems to be significant. Among the companies, BCCL and NEC have higher rate of accidents than the other companies. Open cast mines appear to have marginally worse record than the underground mines, which goes against conventional wisdom. It may be recalled from Section 9 that the main causes of accidents in open cast mines are Dumper, Transport and Other machinery. While the reasons for more accidents in Shift 1 are understandable (involvement of more workers), there is no similar explanation for the higher accident rate in Shift 3. Alertness levels of workers and supervisors in the early morning hours may have to be reviewed. Some combinations of type and company have worse accident rates than most other combinations. These include underground mines of BCCL and WCL and open cast mines of SECL. Surface accidents of MCL also demand special attention. (See the last paragraph of Section 7.3.) The most important cause for underground accidents in BCCL is Roof/side fall, Haulage, and Fall of objects/persons. The first of these two causes is most important in the case of underground mines of WCL. The open cast mines of SECL have accidents due to a wide variety of reasons. Perhaps a review of the overall safety practices in the open cast mines of that company is in order. In the case of surface accidents of MCL, the most important causes are Transport and Other machinery and Dumper. These causes must be investigated further.

It may be noted that the 'causes' of accidents as decribed in Section 9 are in fact secondary events, which are caused in turn by other events. Therefore, every cause identified above opens the door for further investigation. Studies such as the work of Ghatak (1996) on Roof falls assume great significance in this context. It may be noted that Roof/side fall accounts for considerably higher fatality rate, compared to the South African rate, in all the underground mines in general.

Using the analysis of Section 7.3, one can predict the number of accidents in each shift for any combination of type and company, with some accuracy. For example, using the ANOVA model for the number of accidents per million ton production in a year, the predicted number of accidents in shift 3 of underground mines of ECL in the year 1998-99 should be between 0 and 16 (with a confidence level of 0.95). The expected count is 5. In this calculation, the actual production figure of ECL from underground mines for the year 1998-99 (12.937 million tons) has been used. The corresponding prediction interval obtained from the model for accident count per million manshift happens to be from 0 to 24, using the manshift figures of the year 1997-98. The expected count is 5.

The actual number of accidents in shift 3 of underground mines of ECL in that year was also 5.

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