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INFLUENCE OF VARIOUS PARAMETERS ON UNDERGROUND ACCIDENTS IN QUÉBEC MINES: A MULTIFACTORIAL APPROACH

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IMPACT OF VARIOUS PARAMETERS ON UNDERGROUND ACCIDENTS IN QUÉBEC MINES: A MULTIFACTORIAL APPROACH

by

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ABSTRACT

Following two inquiries in Canada that recommended banning individual or small crew incentives, one in Ontario and one in Québec, a study was undertaken at Laval University in 1982 to investigate potential links between bonus payments and underground mine accidents. The work was subsequently expanded to investigate the impact of other quantifiable variables like age and miner's experience on accidents.

The presentation will describe the methodology followed in gathering information at ten mines from three mining camps in the Province of Québec, and its transfer to data banks for subsequent treatment.

Two and three variable relationships are first presented. The study showed a significant correlation between production bonus and accidents for activities related to production. Service and development activities seem unaffected or negatively affected by small crew incentives. A possible explanation for the difference could lie in the continuous nature of the work carried out in production mining compared to the piecewise nature of work in the other activities. This hypothesis is supported by a high correlation between the number of accidents and the total hours worked. Another conclusion drawn from the study has been the need for introductory training and subsequent retraining at regular intervals of all personnel. This conclusion is supported by the histograms of mine accidents versus age, which have regularly spaced peaks. It is thus important to improve these procedures to substantially reduce mine accident levels.

Separate multifactorial analyses of nine variable files for the ten mines has shown: that age, underground experience and mine seniority are linked in the first factor; that

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total working hours over the period are tied with overtime in the second factor, and independent of lost time by accidents; that bonus is linked to the main activity of the miner in the third factor, and not to accidents; and that, in some mines, there is a link between the number of accidents and total working time. Two populations were investigated: accident and total worker populations. It was found that bonus was a main factor at only one mine and only when the total miner population was considered; this particular mine lacked the data base required to carry out a nine variable study.

IMPACT DE DIVERS PARAMÈTRES SUR LES ACCIDENTS EN SOUTERRAIN AU QUÉBEC: UNE APPROCHE MULTIFACTORIELLE

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RÉSUMÉ

Suite à deux enquêtes ayant eu cours au Canada, l'une en Ontario et l'autre au Québec, et qui recommendaient l'abolition des systèmes de boni individuel ou de groupe dans les mines souterraines, une recherche fut initiée à l'Université Laval en 1982, afin d'investiguer les liens potentiels entre les primes au rendement et les accidents miniers. Le travail fut ensuite étendu à d'autres variables quantifiables, notamment l'âge et l'expérience du mineur, et leur impact sur les accidents.

La présentation décrit la méthodologie suivie lors de l'acquisition des données à dix mines de trois régions minières de la province de Québec, ainsi que leur transfert informatique dans des banques de données pour traitement ultérieur.

Les relations entre deux et trois variables sont d'abord présentées. L'étude établit une corrélation significative entre boni et fréquence d'accidents pour les activités de production seulement, alors que, pour les activités de services et de mise en valeur, les accidents ne sont pas affectés par le boni ou le sont négativement. Une explication possible des différences pourrait résider dans le fait que les activités de production sont rémunérées en proportion de l'effort, alors que les autres activités sont bonifiées globalement. Cette hypothèse est appuyée par une forte corrélation entre le nombre d'accidents et les heures cumulatives travaillées. Un autre élément important que l'étude a fait ressortir, c'est le besoin de formation à l'accueil pour tout nouvel employé et le besoin de réentraînement à intervalles réguliers par la suite. Ce sont les histogrammes de fréquence d'accidents versus l'âge qui soutendent cette conclusion, à cause de pics récurrents à intervalles réguliers. Il importe donc d'améliorer la planification de ces procédures, si l'on veut significativement réduire les accidents.

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Mots clés: taux de boni, fréquence d'accident, âge, exploitation souterraine, production, développement, services, analyse multifactorielle.

Les analyses multifactorielles à neuf variables effectuées à partir des fichiers de chaque mine ont démontré que l'âge, l'expérience totale en souterrain et l'ancienneté à la mine constituent le premier facteur, que le nombre total d'heures travaillées est lié au temps supplémentaire et indépendant du nombre de jours perdus pour cause d'accident dans le second facteur, que le boni est dépendant de l'activité du mineur et indépendant du nombre d'accidents dans le troisième facteur, et enfin que, dans plusieurs mines, il existe un lien entre le nombre d'accidents et les heures totales travaillées. Les travaux ont investigué deux populations: celle des accidentés et celle de l'ensemble des mineurs. Le boni n'a été identifié comme responsable d'accidents qu'à une seule mine et uniquement pour la population globale des employés; cette mine ne possédait cependant pas l'ensemble des données requises pour une analyse à neuf variables.

INTRODUCTION

Four years ago, a study was undertaken at Laval University to identify quantifiable variables that could have an impact on the safety of underground Québec metal miners. The first variable identified for investigation was the individual or small crew incentives. This was prompted by recommendations from two public enquiry commissions that suggested banning bonus or small crew incentives on the assumption that this single variable was perceived as a major cause of mine accidents. Data on incentives from four mines were gathered for the initial study. The goal of the study was: find if bonus had an impact on underground accidents. Subsequently, millions of individual data involving 3381 miners at 10 mines from three mining camps: Matagami, Chibougamau and Val d'Or, were gathered and analyzed.

The presentation shows typical two- and three-variable results stemming from relationships between accident frequency at mines on one part and age, experience and bonus on the other. It then proceeds to multifactorial analysis, which shows that previous results can be highlighted by this approach. Recommendations and conclusions are then drawn from results.

METHODOLOGY

A considerable amount of preliminary research was required to gather basic background data for the study. Extensive clerical work was required to develop homogeneous computer files containing the following personnel information:

- a code to identify each worker;
- a reference number for each pay period;
- the number of hours worked at regular rate in each pay period;
- the number of overtime hours worked during each pay period;
- the basic salary earned for normal hours worked at standard rate;
- the bonus earned during each monthly period;
- the age of the worker at a given date;
- the total underground experience of each miner at a given date;
- the seniority of each miner at a given date; and
- the main activity of the miner for the survey period;

and the following accident information:

- the day of the accident;
- the number of days of compensation;

– the number of days of light duty;
– the attributed percentage of anatomo-physiological deficit;
– the number of hours worked the day the accident occurred;
– the number of days worked since the last holiday;
– the number of hours worked since the last holiday; and
– the duration of the last holiday.

Collected data had to be standardized before analysis could be undertaken for the following reasons:

– companies had paydays on different dates;
– basic salary was paid every two weeks; and
– bonus was calculated each month and paid in two unequal amounts (the first payment was based on anticipated future performance).

Because it was found easier to determine a miner's daily basic salary than the crew's earned incentives, an interval period of a month was selected for comparison purposes. It was relatively easy with work schedules to determine the basic monthly salary of individual miners. The study consisted of 30 monthly interval periods from July 1979 to December 1981, where there was no interruption in the mining activities of the mine under study.

The methodology used to analyze small crew incentives data was based on the use of relative bonus rates. Relative bonus rate is defined as the percentage over basic salary earned by the miner as a bonus in the individual monthly periods of the study. It is important to note that bonus rate in the study varied from 0% to over 100% of basic salary. Bonus is a significant part of most miners' income. Québec miners receive on an average 20-30% of their total income in the form of small crew incentives.

There are as many bonus systems used in the mining industry as there are management philosophies. As well, special incentive systems are normally used to better adapt to local geological and geographical conditions. The main types of workers' incentives are the following:

– bonus based on tonnage;
– bonus based on quality target –metal– criteria;
– bonus based on safety or accident record.

PROCEDURE

The basic salary of individual miners is quite stable from month to month. Deviations are mainly the result of changes in the number of days worked, excluding statutory holidays. The individual monthly bonus rate for miners was calculated by dividing earned small crew incentives by basic salary. This procedure was used to yield 30 different bonus rates per worker. These various rates were then divided into classes in order to provide a distribution for each mine. In this study, 5% intervals have been selected to record other events such as accident frequency and severity, and lost days per accident.

Another independent variable that was investigated was age. For this purpose, miners were divided among two year interval age groups, from 17 to 66 years. This variable changed for each individual over the period of the study. Consequently, the date selected to adjust each worker's age was the last day of December 1980. The same rule was applied with respect to experience. In this case, however, the following separations were used: 0-1 year, 1-2 years, 2-5 years, 5-10 years and over 10 years. The unequal division, in terms of years of experience, was made necessary by the available data base.

The job allocation of a miner often changes from day to day. In this study, a miner's assignment to development, production or services was made on the basis of the broad category of jobs most frequently carried out. Development activities are considered to be those related to the development of drifts, raises, subdrifts and drawholes in order to access the ore. Production activities are concerned with the drilling, blasting and mucking of ore. Service activities relate to the maintenance of the openings, the installation of piping for ventilation, compressed air and water, and all other activities required to support production operations. It must be recognized that the method used to assign miners to occupational categories (activities) has produced some distortion in compiled data, particularly with regard to service operations.

Accident frequency rates have been compiled on a 200 000 hours norm rather than on a 1 000 000 hours basis as prescribed in Québec, because it represents approximately 100 man-years and is more suitable to mining firm size in the Province. Lost days per accident include not only legally compensated days, but also light duty days on the basis of half a day loss per day at work. Medical visits are equivalent to a half day loss.

RESULTS OF DIRECT RELATIONSHIPS WITH ACCIDENT FREQUENCY

In the following presentation, Mines 1 to 4 are located in the Chibougamau area, Mines 5 to 8 in the Val d'Or area, and Mines 9 and 10 in the Matagami area. Results thus illustrate very different situations, because of geographical location, geological and geotechnical conditions, and mine organization.

Impact of miner's experience

In this study, the impact of miner's experience was investigated in terms of total accumulated underground experience and seniority in the mine where the survey was made. This latter investigation also provides some indication of labour force stability at individual mines. The inclusion of two kinds of experience on the same figure permits the impact of diversified experience on accidents to be studied. Large, unequal experience intervals were used because of the limited data available per mine. The small number of intervals prevented the generation of regression lines.

Figure 1 provides histograms of accident frequency as a function of experience for all miners at four mines studied, which are representative of various minesites in the Province of Québec. Mine 1 shows a normal learning curve in a working environment, where the introductory period is limited to the simplest terms. It is also possible to see that the mine has almost always trained its own personnel, at least in the last five years; total underground experience and mine seniority are almost superimposed.

Mine 3 histograms show that a good training of new miners without experience has a positive impact on mine safety. During the survey period, the mine was experimenting with school-stopes to introduce these new miners to the mining environment. The training has proven to be extremely effective. As a sub-group, miners who received this training established an accident frequency rate lower than the average rate for their seniority category.

Mines 4 and 9 exemplify even more progressive introductory training to work complexity, but without school-stopes. After about two years, workers are introduced to more demanding tasks. This explanation was put forward to explain the higher accident frequency rate in the two to five years interval, compared to the one to two year interval. Other mines included in the study are in a somewhat intermediate situation to the mines of figure 1.

In summary, the average training period for newcomers at Mine 1 is less than one year; at Mine 3, the training period extends over a year and involves the use of school stopes for newcomers without previous mining experience; at Mines 4 and 9, the training period extends over two years.

Influence of workers' age

Figure 2 provides histograms of accident frequency rate versus miners' age. All regression curves have negative slopes with very high correlation coefficients. They show that accidents frequency significantly decreases with age, which is already well documented in the industrial sector. The early introduction of young miners at Mine 1 to more demanding tasks probably accounts for the rather high accident frequency rate in the first few age intervals. The increase in responsibility would appear to be more gradual at the other mines, where the peak accident frequency is reached between 24 and 28 years of age rather than 19 to 22 years of age as in the case of Mine 1.

The most interesting feature of the individual histograms is the resurgence of accident peaks at regular intervals on the basis of miners' age: around 20-22 years, 26-28 years, 32-34 years, 40-42 years and 52-55 years. They would appear to correspond to periods when work reassignment is occurring with age and experience.

The mean periodicity of these cycles is 8 years. In terms of workers' age: 20-22 years is when miners with a few years experience transfer to stope work; 26-28 years is when workers are assigned to development activities; 32-34 years is when vertical development workers return to production duties; 40-42 years is when worker assignment to development activities stops because of the physical demands of such assignments; and 52-55 years is when stope miners transfer to service activities.

Study results suggest that miner retraining is required to prevent unnecessary accidents from occurring, when workers are assigned new responsibilities or duties. Cyclical accident peaks could also be partly due to workers challenging their work environment once they become comfortable with their assignments. This situation would militate for regular retraining even without job reallocation. The same would also be true if miners are being too attentive to the production aspects of their job and not sufficiently attentive to the safety aspects.

Direct impact of bonus

Assessing the influence of individual or small crew incentives on safety at work is an important issue. Many official enquiries into tragedies and accidents in mines[3,4] have perceived bonus as a major problem with respect to safety. Histograms of mine accident frequency rate in the text treat overall mine activity as well as component activities (development, production, services). Seniority is also taken into consideration.

Histograms of mine bonus rate versus accident frequency rate are often quite flat (horizontal) when considering total underground worker population, indicating a complete lack of relationship between the variables. Figure 3 shows the results for four typical mines, selected in three different camps. The increase in accident frequency is small at most mines, however, and does not permit conclusions to be drawn as to the influence of bonus on accident frequency rate. This indicates that bonus is not a major contributor to accidents at the four representative mines. In order to determine if other information could be drawn from the data, the data was afterwards grouped according to the main activity of the individual mine workers in the study.

Figure 4 shows the results for development miners at different mines. The results for Mine 1 show a certain affinity to those of figure 1, a typical on-site learning curve for newcomers receiving a limited apprenticeship. The histogram for Mine 2 would seem to reflect the benefits on accident frequency rate of the school-stope system in effect at that mine. A lack of follow-up training could explain the surge in accident frequency rate for the 30-50% bonus rate group. At Mine 7, the recruiting of miners, the lack of proper knowledge of specific geological conditions and a safety program still under development are factors which could explain the histogram for this new mining operation. Results at Mine 9 seem to imply that a very good safety system can reduce accident risks even for new miners undergoing training on more difficult jobs. A miner working on development normally has a certain number of well defined duties which must be completed to earn extra money. From the above comments, it seems that the more experienced miners at each mine use their advanced mining skills not only to earn larger bonuses but also to mine more safely.

Figure 5 shows typical results for production workers, except at Mine 6 where the histogram also includes development activities. Histograms for Mines 1 and 2 are representative of data compiled for stope mining in the study. Regression lines are always significantly different from the horizontal line, except for Mine 4 where the data was insufficient to produce a histogram, Mine 7 where stoping activities were very limited and Mine 9 where the impact of an excellent safety program is evident. Production miners receive their bonus according to the amount of work completed; there is no limit on work load. It is assumed here that both small crew incentives and accidents are related to work output for production miners.

Some mines have a policy of keeping service workers exclusively on service activities, while other organizations regularly transfer them to production activities as needed. Figure 6 illustrates the different mine attitudes to service worker reassignment: Mines 1 and 5 never reassign service workers; Mine 9 occasionnally reassigns them and Mine 2 regularly reassigns them. Québec mines do not normally allow more than 30-40% bonus rates for service activities.

Previous figures indicate that new introductory procedures for employees are required to reduce mine accident frequency. Moreover, retraining should become a regular safety procedure, whenever miners are shifted from regular to new assignments.

Safety auditing should be a standard procedure for miners in the 30-60% of basic salary bonus rate.

Combined influence of bonus and seniority

One question that arises from the previous section is the possible impact of the bonus system on the accident frequency of lower seniority miners. Figure 7 presents accident frequency rate versus bonus rate data on the basis of two worker populations. An arbitrary initial training period of two years was selected at each mine. Those with less than two years seniority by the end of December 1980 were assigned to the first group.

Knowledge of local safety procedures and of local geotechnical conditions seems quite important for personnel safety. One must remember that many miners with lengthy underground experience are included in the less than two years seniority group. Mines should consider an introductory training period for new miners with previous external experience. The study results seem to indicate that these miners are vulnerable to risks related to local environmental conditions and mine specific equipment utilization procedures. Figure 7 once again shows that Mine 9 has a very efficient safety program as evidenced by crisscrossing curves. The diverging curves of Mines 1 and 2 are more representative of most mines and show the influence of seniority on miner accident frequency rate.

Number of accidents vs time from start of shift

This tedious study was done with respect to only two mines, because of availability of data and time required for its compilation. Figure 8 shows quite clearly a link between accidents and a worker's physical state. Very few miners reach their working place within the first half hour of a shift. They must then check the environment to make sure the place is safe. Moreover, a reduction in activity takes place during lunchtime and at the end of the shift. Accidents are more frequent in the first than last hour, because muscles must be conditioned to carry out tasks. In this period of their workshift, miners are more liable to hurt themselves in falls or slides. Such curves strenghten the assumption that there is a link between a miner's activity and accident susceptibility, as stated earlier in discussing Figure 5.

FACTORIAL ANALYSIS

A brief discussion of multidimensional statistics is essential before treating the main subject of this section (tables 2 to 8). First of all, the objective of the method is to extract in a condensed manner most of the interrelationships and information contained in the data. In this case, the matrix contains pertinent information on mines and miners for the two year study period (1980-1981).

Each miner in the study has been characterized in seven to nine of the following variables: age, total underground experience, mine seniority, total number of hours worked during the period, overtime worked during the period, bonus rate, main duty (development, production, services), number of accidents and number of lost days due to accidents. Some of the non-accident variables, as shown on table 1, fluctuate from month to month for individual miners and differ from miner to miner. Variances are often not of the same order of magnitude, either in absolute or relative terms (when dividing by the average). Summing up variances for variables is not a straightforward process, since some variables are correlated. Actual variances for variables were established by subtracting cross-correlation contributions.

In the present study, an attempt is made to identify correlations between variables. The method used is based on defining new theoretical variables called 'factors', linear functions of the initial seven or nine variables. The factors, which number less than the variables, can be used to explain most variations observed in a population. Factorial analysis is a statistical method to analyze a correlation matrix for a set of variables. Factors represent basic phenomena underlying observed variations between initial variables. The presentation makes use of the principal factor method, where the first factor must explain as much of the total variance as possible. The second factor explains as much of the remaining variances, excluding the part explained by the first factor, and so on. Such factors must indicate links between at least two basic variables, either associative or opposite.

Although all of the initial variables are associated to each factor with a coefficient between -1 and +1, those with values furthest from zero are the major contributors to the factor. They indeed are the essential elements for interpreting factors. When more than two original variables are prominent in any one factor (coefficients diverging from zero), it becomes more difficult to understand the underlying phenomena. Figure 9 is a representation of the first two factors at Mine 1. The following part of the presentation will try to explain results from the study using the aforementioned methodology.

FACTORIAL ANALYSIS RESULTS IN QUÉBEC

Even though results were first compiled using only seven variables, excluding accidents, to permit comparison of accident and non-accident populations, the present study compares accident and total populations. No special relationships were found between the populations in terms of the seven variables. This presentation limits discussion to the first three factors which can be used to explain over 80% of all variances. Tables 2 and 3, Tables 4 and 5 and Tables 6 and 7 are first, second and third factor tables respectively for accident and total worker populations.

Factor 1

Examination of Tables 2 and 3 indicates that both populations show similar behaviour with the exception of mines 6 and 7. Also, that Mine 10 does not follow the general model for the seven other mines, representing three different mining camps. The first factor primarily concerns the diversity of age and experience level which are quite uniform in the mines in the study.

In most mines, total hours worked is a secondary contributor to this factor. This means experienced miners (mostly local) either have less serious accidents and come back faster to work or work more overtime. The first assumption does not seem reasonable, because it is more difficult with age to physically recover from an accident. Moreover, overtime seems to be related to age or experience, as indicated by the contribution of these variables to the first factor, notably at Mines 2, 4 and 9. This results from a well known policy in the industry to assign overtime on the basis of seniority.

Mine 6 is a special case; it was impossible to compile the total underground experience of miners, and as a result production and development activities were grouped together. Consequently, miner variable fluctuations compared to other miners in the population are reduced. All factors for this mine are more complex, because of the influence of several variables in each factor. Moreover, the two populations were not stable, increasing the complexity of interpretation. The first factor highlights the fact that workers are more liable to accident when less knowledgeable about mine specific conditions. It also indicates that accidents occur more frequently when production/development work is involved. The negative relation to bonus rate seems to correlate accident frequency rate to worker inexperience. This conclusion was reached earlier when examining histograms of accident frequency rate versus experience.

For the overall miner population at Mine 6, the first factor highlights the relationship between seniority and production/development activities. This means that miners with considerable seniority are well represented in the non-accident population; it is the reverse of the trend in the accident population. Also, accident influence is considerably reduced in the overall underground population when compared to the accident population, because of the high proportion of uninjured miners (60%).

At Mine 10, the annual turnover rate (122%) was too high to permit seniority to influence the first factor. In 1980-1981, the level of activity in the Canadian mining industry was such as to cause a shortage in manpower supply. Workers after a few months experience at remote mines offered their services as experienced miners to mines more closely located to population centers.

Mine 7 started operations in 1979 and was still recruiting personnel in 1980-1981. As in the case of Mine 10 for the accident population, the combined effects of workforce increase and rotation of some workers has considerably muted seniority fluctuations. For the total population, fluctuations in overtime and total hours worked were more important in terms of factors than fluctuations in age and total experience. The study does not provide a clear understanding of the causes of the low percentage of variance explained by the first mine factor.

Factor 2

For the accident population at seven of the ten mines and for the total population at four mines, Factor 2 relates bonus rate to main miner activity, as shown in Tables 4 and 5. Simply stated, development activities lead to more bonus than production activities which, in turn, command more bonus than service jobs. Development is a true contract activity. It is physically more demanding since high productivity is required. As previously stated, miners do not last long on development and companies pay more to maintain a pool of higher skilled labor for this activity. Production also pays more than services, because of its importance to the economic survival of a mine. Variations in bonus rate is, therefore, the second major cause of variance between miners in Québec underground mines, and is linked to worker's main activity.

The second factor for Mine 6 is a relationship between the number of accidents and overtime for the accident population. This may indicate that the mine either selects overtime workers on the basis of availability or has a policy of choosing those less prone to accidents for overtime work. Since Factor 1 at the mine showed that workers with more seniority were less often injured and more tied to services, it seems that overtime miners are senior service workers. This factor also includes the relation between bonus rate and department as a complement. Mine 7 shows the already explained relation between seniority and total hours worked. Mine 9 shows that a strong association between overtime and total hours worked is more important than a relation between activity and bonus rate.

For the total miner population, a link exists between overtime and total hours worked at Mines 9 and 10. This implies that injuries do not significantly influence total hours worked within the population. Overtime, though, is variable enough to have an influence. At Mine 7, as at most other mines, the first factor is a relation between age and experience. At Mine 6, the relation between age and seniority constitutes the second factor. One must remember that data for total underground experience was unavailable for Mine 6.

Factor 2 at Mines 5 and 8 indicates a link between total number of accidents and total hours worked. This supercedes other potential factors because their bonus rates are the lowest of the 10 mines studied and overtime was quite limited. This seems to reinforce a previous hypothesis suggesting that the link between bonus and accidents for production miners is influenced by the hours worked.

Factor 3

The third factor (Tables 6 and 7) is much less stable than the previous two, although bonus rate/department links are evident at Mines 7 and 9 and overtime/total hours worked links are evident for Mines 1, 4 and 6 for injured miners. As well for the overall miner population, a link between total hours worked and overtime is evident for Mines 1 and 4 while a link between bonus and activity is evident for Mines 5, 7, 8 and 9.

Mines 3 and 10 shows links between seniority and total hours worked within the injured worker population while Mine 5 links overtime to seniority. It has already been indicated that this results in part from the organizational structure of Québec underground mines. Mines 2 and 8, as is the case of other mines, show a link between total hours worked and the number of accidents.

For the overall population of Mines 2, 3, 6 and 10, the number of accidents is included in factor 3. Mines 2 and 3 show a relation between the number of accidents and total hours worked. At Mine 10, the correlation between the number of accidents and number of days is outstanding. it can be qualified as an 'accident' factor. At Mine 6, the number of accidents is linked to bonus rate and, to a lesser extent, to seniority and work classification. The proportion of the variance explained by the factor is rather low, however, a fact attributable in part to the limited data available. It could be a combination of different linkages: work classification/bonus rate; seniority/number of accidents; etc.

Pooling ten mines together

Table 8 is an attempt to summarize this part of the study by pooling results obtained, as a unit, for the ten mines. Local variations are evidently lost in such a grouping and it becomes possible to assess individual mine deviations from the performance of a population of ten mines and 3381 miners. The first factor groups age, underground experience and seniority, like in most individual mines. The factor explains 47.5% of the fluctuations in the accident population and 48.2% of the fluctuations in the general population. In both cases, total hours worked are a secondary contributor to the factor, implying that older and more experienced miners accumulated more working hours during the study period.

A link was established in the study between bonus rate and miner activity at nine mines for the accident population and at eight mines for the total population. It thus shows as second factor and explains 24.2% and 22.1% of the variations realized respectively for accident and total study populations. It must be considered a uniform and coherent characteristic of Québec underground mines.

The third factor for both populations is the link between overtime and total hours worked. It explains 16.5% of the variations within the accident population and 18.5% in the total underground population. It is a surprise to see the importance of this factor in the study results, realizing that it was a factor at only four of the ten mines.

A fourth factor highlights the link between total hours worked and number of accidents. Although the factor is not statistically significant, it reinforces the possibility of a link between increased accident risk and total work effort. Clearly, bonus does not show up as the major cause of underground accidents in Québec underground mines.

CONCLUSION

Although bonus does not appear as a major contributor to accidents in the multidimensional analysis, a problem is nonetheless apparent when examining production activities (figure 5). In most mines, a significant positive linear regression is present. One potential explanation is that both bonus and accidents are linked to a third variable, namely worker effort. Development activity effort is limited in scope, and bonus is earned more on skills than effort in many cases. On the other hand, stope production is an endless series of varied activities requiring considerable effort. Production bonus is thus based on the level of effort more than on skill. Higher production bonus earners would be miners working harder than others, taking less breaks, rushing to their working place and leaving it late.

Based on a limited number of variables, the study shows that the prime cause of mine accidents is the lack of worker training, either to familiarize them with equipment and work environment or to instill in them proper safety procedures. This clearly comes out of accident frequency histograms plotted against total underground experience and mine seniority. Job assignment policy is indeed very dependent on the ease with which qualified workers can be recruited and retained. The more successful mines can afford a training period for employees assuming new duties. Thus the miners are better trained to cope with the risks associated with their new duties. However, lack of follow-up training also seems to cause a significant number of accidents for workers with some experience, as perceived from age and experience figures as well as from bonus histograms.

A probable cause of many accidents occurring to younger workers could be their strong desire to prove themselves. In this process, they ignore standard safety precautions. In this regard, it is essential that an environment be established that does not unduly challenge young, inexperienced miners. Other studies in progress at Laval University are looking at the impact of organizational factors on mine accidents, and should identify factors with a negative impact on mine accident rate.

The study showed that older miners may be less able than younger miners, but effectively use their greater experience to achieve targeted goals. There was a constant reduction in accident frequency rate with age at the ten mines. Most regression lines show a significant reduction in accident frequency rate with age. The data related to experience has shown that there is a learning curve for each organization. The use of school stopes reduces accident frequency rates.

In a part of the study not shown here, no correlation between the severity of accidents and bonus rate was established. Other variables not investigated in this study probably must be taken into consideration to explain accident severity, and this is why it is not included.

The first recommendation derived from the present study was to standardize introductory training procedures in the Québec mining industry. Such a policy would insure proper training not only for newcomers to the workforce with no underground experience but also for those with prior training elsewhere in order to acquaint them with unfamiliar equipment and mine specific environmental problems. Such factors are variable from mine to mine and need to be addressed when bringing new workers on staff.

A second recommendation is to establish a system to identify and meet the retraining needs of workers in relation to individual careers. Different training procedures may be required in each case.

ACKNOWLEDGMENTS

This research study has been carried out with the support of the Québec Metal Mining Association (QMMA) who has fully endorsed the goals and procedures followed. The participating mines provided to Laval University Department of Mining Engineering access to the base data for the study without restrictions. The information has been compiled and stored on computer files at Laval University for further processing.

The QMMA, the Centre de Recherches minérales of the Québec Government and EMR Canada through both the Mineral Policy Sector and the Mining Research Laboratories of CANMET have financially supported the study. Staff of the latter organization has reviewed the manuscript, in particular G. E. Larocque.

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FIGURE 1: ACCIDENT FREQUENCY IN RELATION TO MINER'S EXPERIENCE

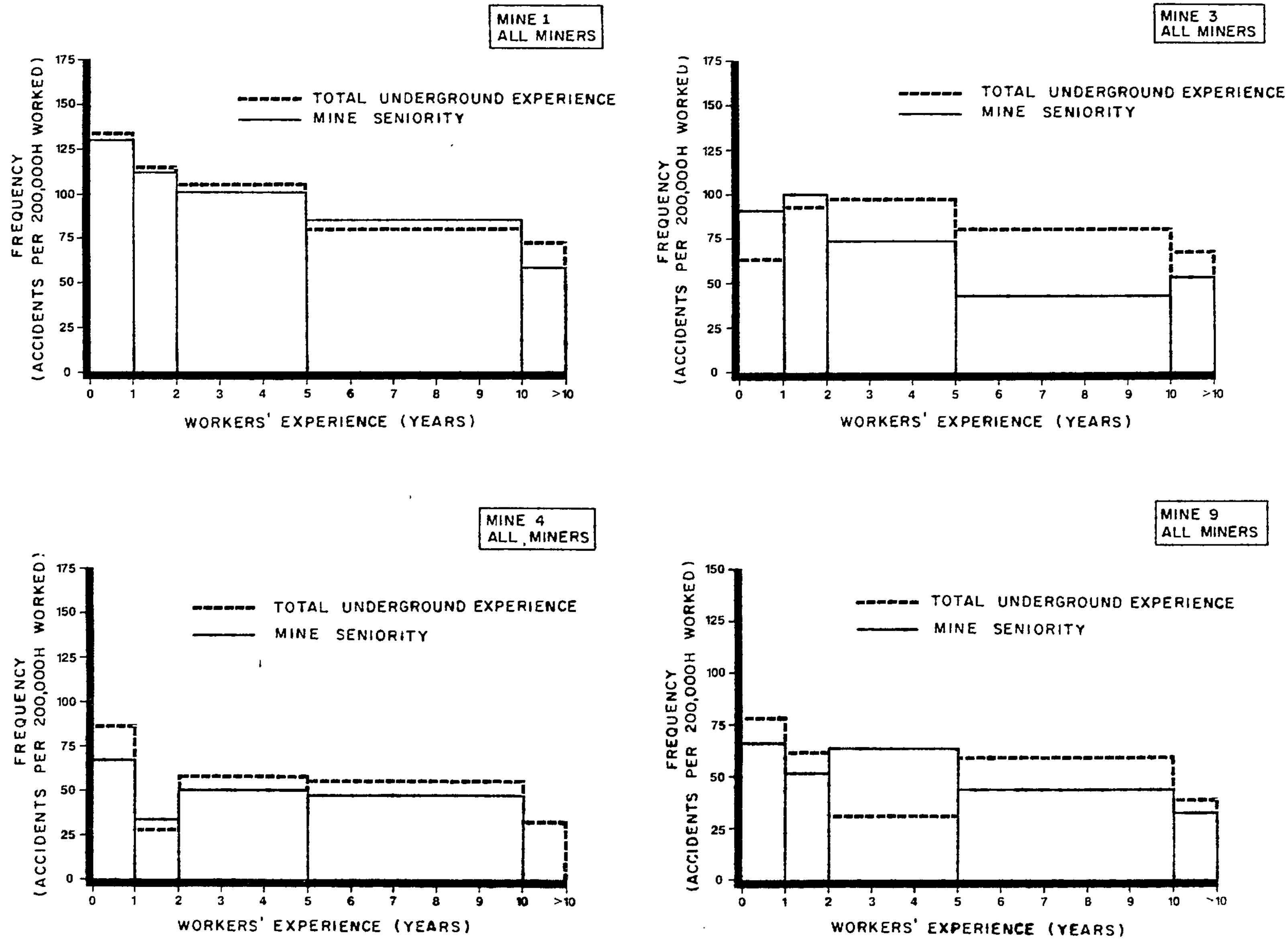


FIGURE 2: ACCIDENT FREQUENCY IN RELATION TO AGE

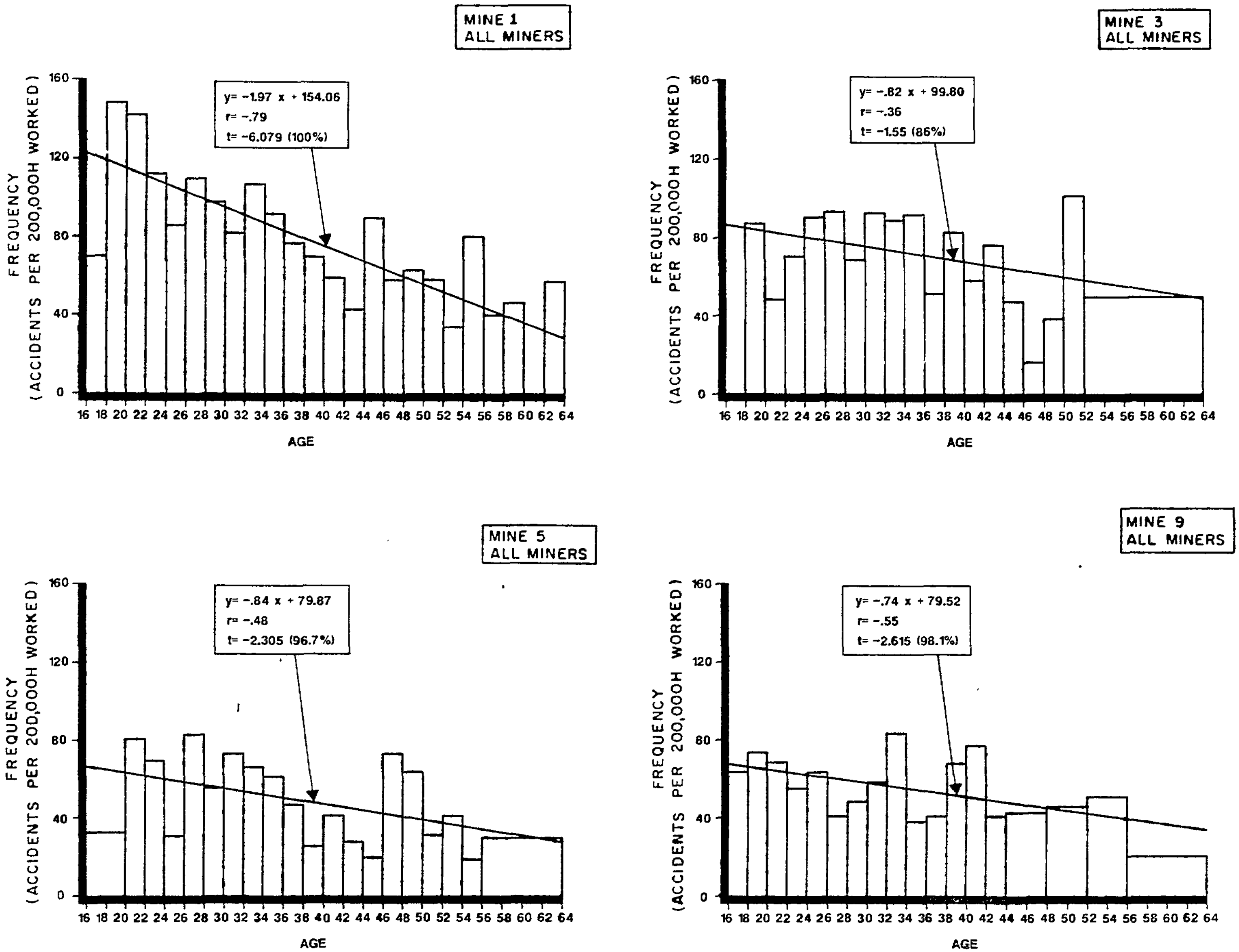


FIGURE 3: ACCIDENT FREQUENCY IN RELATION TO BONUS RATE

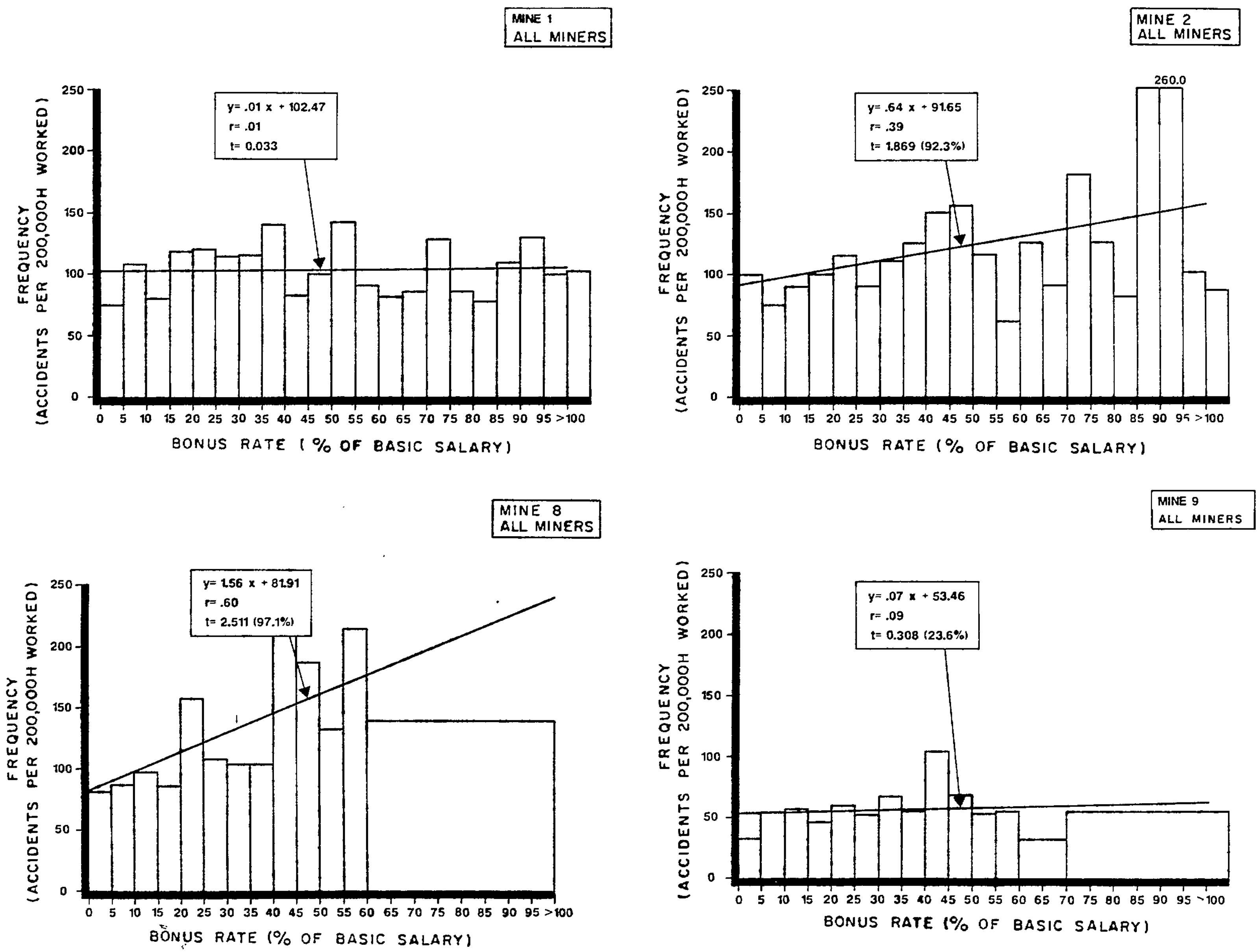


FIGURE 4: ACCIDENT FREQUENCY IN RELATION TO BONUS RATE

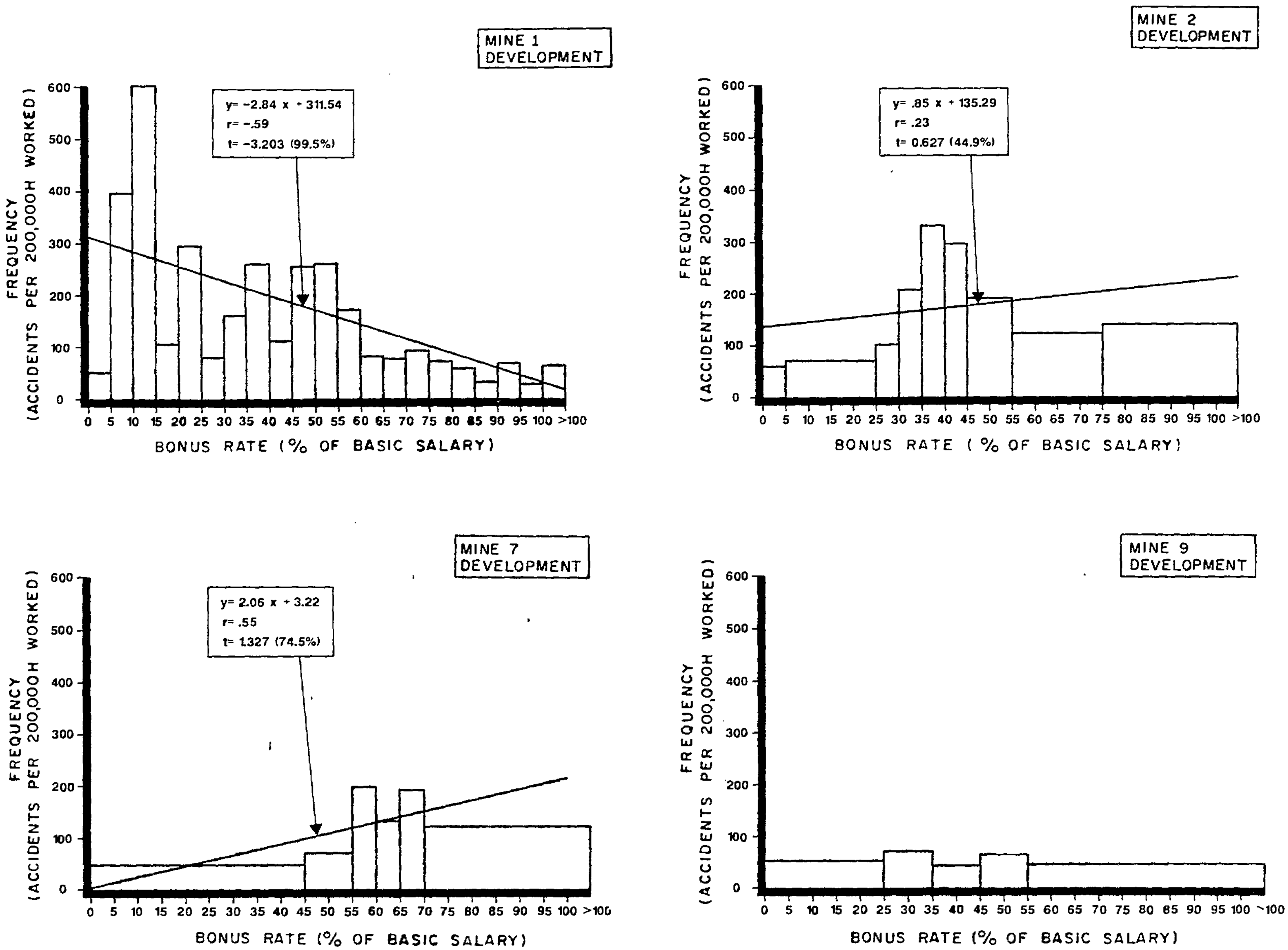


FIGURE 5: ACCIDENT FREQUENCY IN RELATION TO BONUS RATE

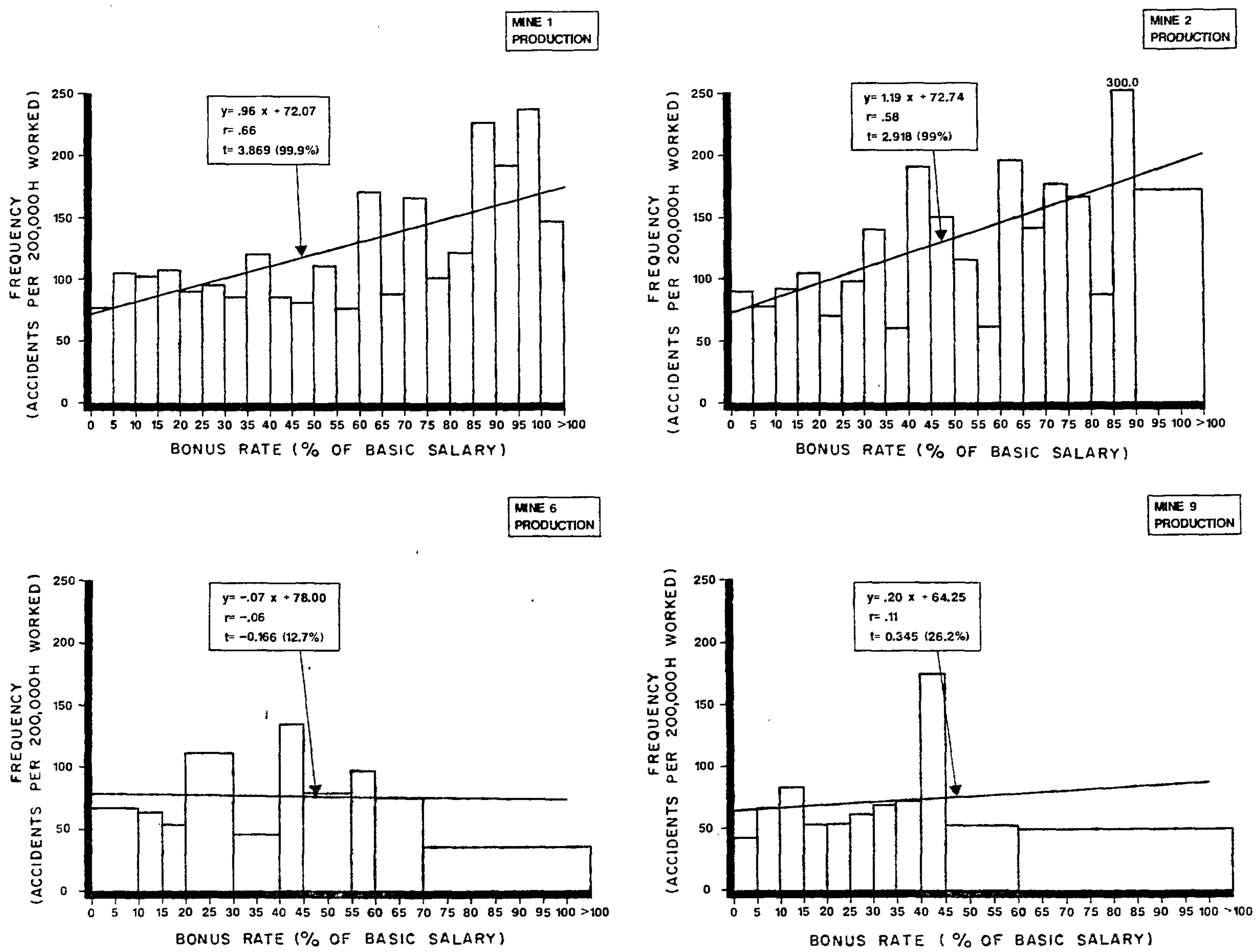


FIGURE 6 : ACCIDENT FREQUENCY IN RELATION TO BONUS RATE

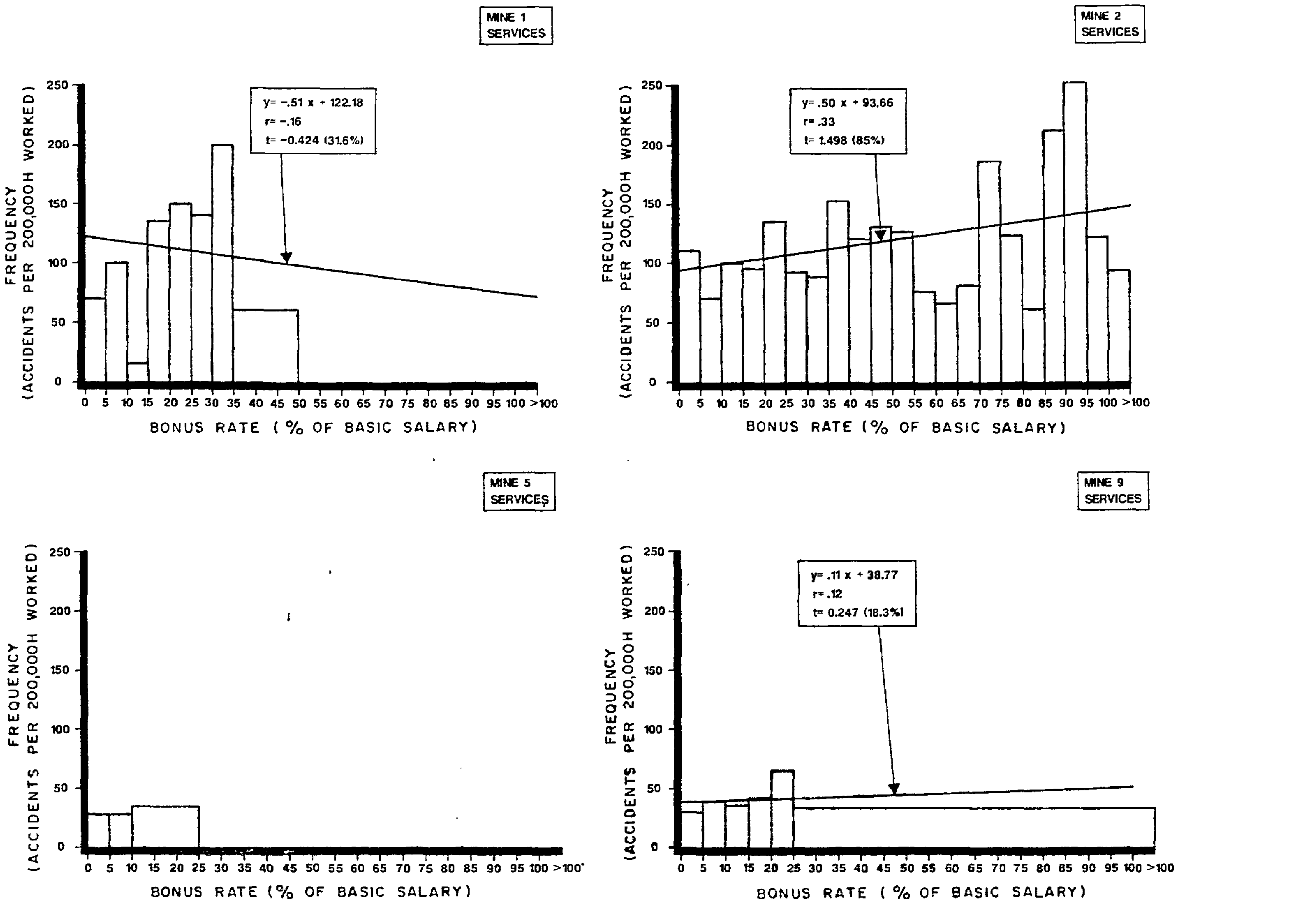
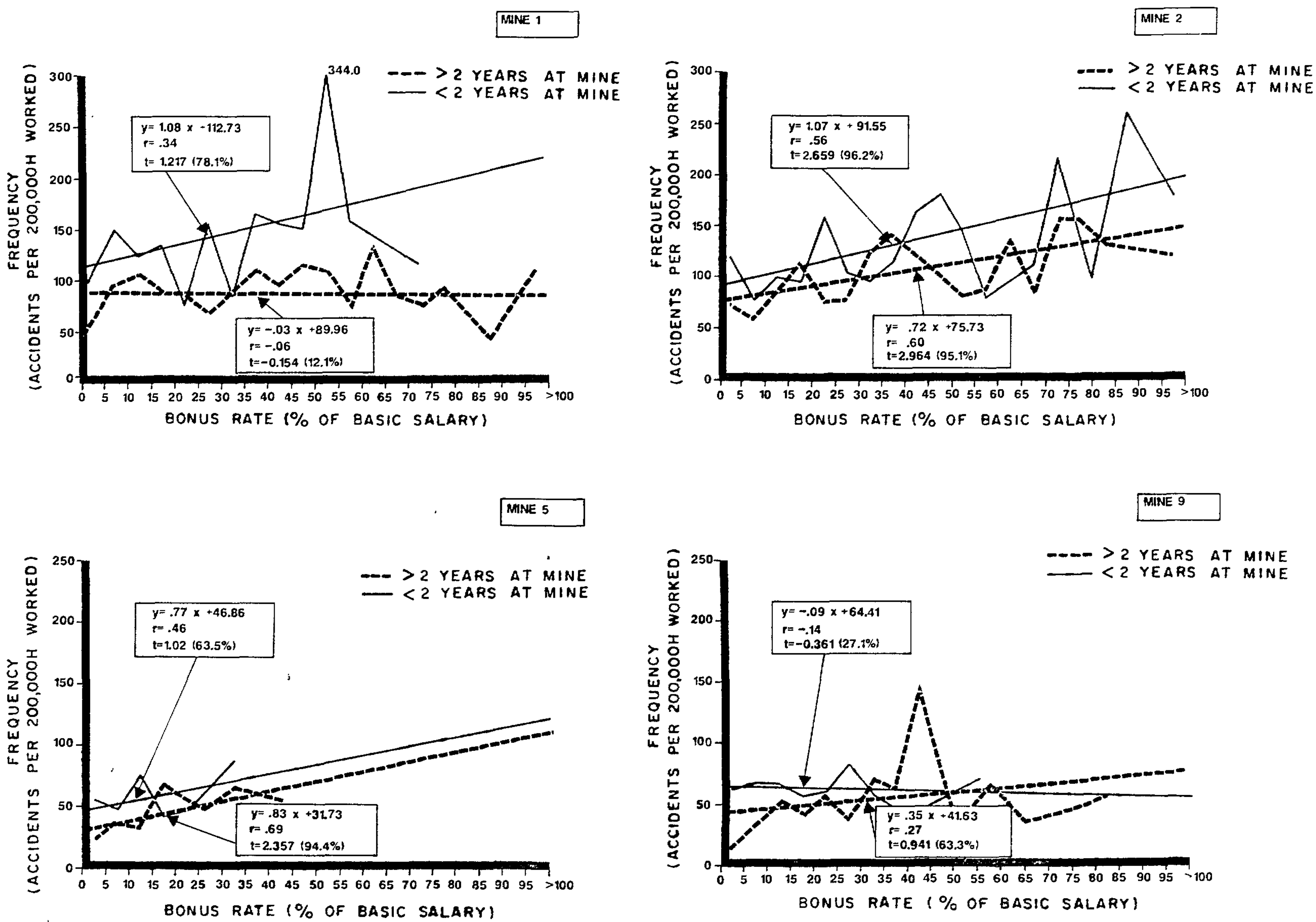
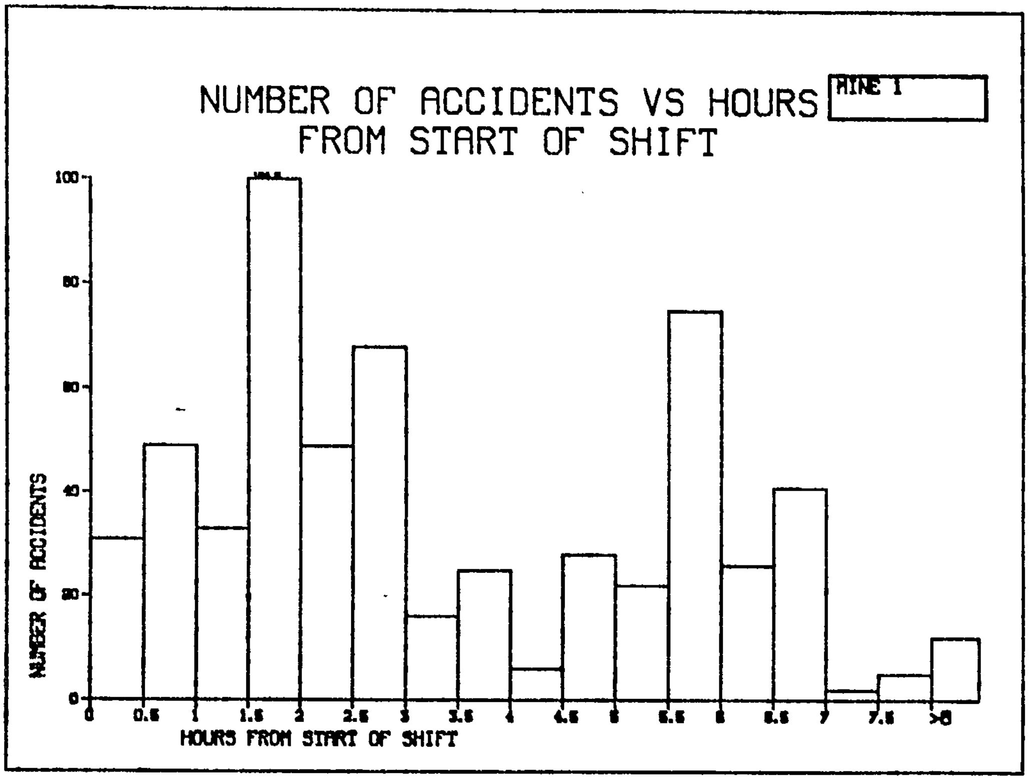


FIGURE 7 : ACCIDENT FREQUENCY IN RELATION TO BONUS RATE AND EXPERIENCE




NUMBER OF ACCIDENTS VS HOURS FROM START OF SHIFT
MINE 1
NUMBER OF ACCIDENTS
HOURS FROM START OF SHIFT

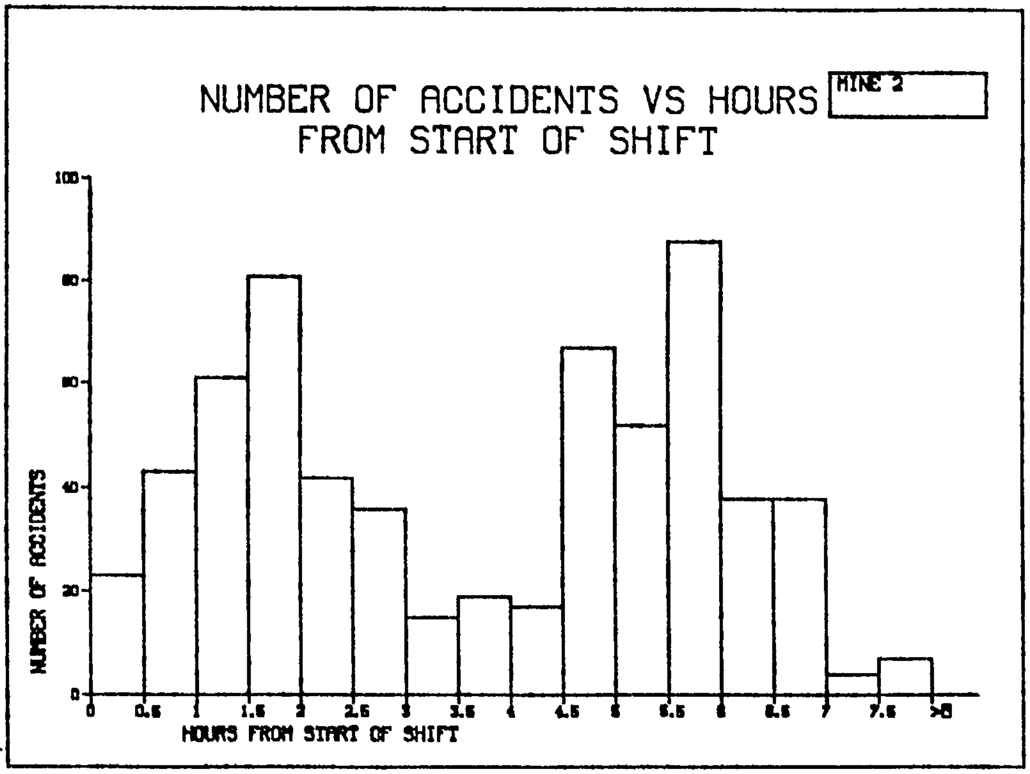

NUMBER OF ACCIDENTS VS HOURS FROM START OF SHIFT
MINE 2
NUMBER OF ACCIDENTS
HOURS FROM START OF SHIFT

FIGURE 8

TABLE 1: COMPREHENSIVE DATA READY FOR MULTIFACTORIAL ANALYSIS

CODE	PERIOD	WORKED HOURS	OVERTIME	BASIC SALARY	BONUS	AGE	MINE SENIORITY	TOTAL EXPERIENCE	MAIN ACTIVITY
598.1	1	136	0	1092	152	32	8.2	12.1	2
	2	168	0	1349	373				
	3	168	8	1349	229				
	4	171	4	1511	310				
	5	160	0	1410	175				
	6	144	0	1269	26				
	7	128	16	1128	78				
	8	128	8	1128	130				
	9	168	8	1480	173				
	10	160	0	1410	215				
	11	156	4	1374	127				
	12	184	32	1621	420				
	13	156	0	1374	64				
	14	135	8	1194	288				
	15	168	0	1480	383				
	16	176	8	1683	267				
	17	128	0	1224	160				
	18	136	0	1300	214				
	19	181	8	1730	116				
	20	152	8	1453	186				
	21	136	8	1300	204				
	22	160	0	1530	293				
	23	168	8	1606	279				
	24	120	0	1147	284				

TABLE 2: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, ACCIDENTEES POPULATION, FIRST FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	**0,85**	**0,78**	**0,87**	**0,81**	**0,83**	0,04	**0,93**	**0.89**	**0,86**	**0,82**
SENIORITY	**0,80**	**0,82**	**0,61**	**0,64**	**0,55**	**-0,61**	0,21	**0,72**	**0,69**	0,16
TOTAL EXPERIENCE	**0,94**	**0,91**	**0,93**	**0,86**	**0,90**	*	**0,93**	**0,94**	**0,97**	**0,83**
WORKED HOURS	0,24	0,43	0,26	0,30	0,20	0,10	0,12	0,31	0,30	0,02
OVERTIME	0,03	0,24	0,11	0,00	0,15	0,08	0,13	0,16	0,07	0,14
BONUS RATE	0,13	0,09	-0,03	0,45	0,17	-0,28	0,00	0,20	0,22	-0,02
ACTIVITY (S,P,D)	0,07	0,08	0,02	0,15	-0,20	**0,54**	-0,09	-0,10	-0,04	0,05
NUMBER OF ACCIDENTS	-0,03	-0,06	0,06	-0,01	-0,11	**0,84**	-0,06	-0,12	-0,05	0,02
LOST DAYS/ACCIDENT	0,01	-0,03	0,05	0,08	0,03	0,39	0,06	0,09	0,03	-0,07
VARIATION EXPLAINED (%)	42,8	51,3	46,1	52,1	46,7	47,8	37,9	48,8	47,0	37,0

* information not available at mine

TABLE 3: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, GENERAL MINER POPULATION, FIRST FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	**0,84**	**0,75**	**0,88**	**0,69**	**0,85**	-0,07	0,05	**0,89**	**0,89**	**0,83**
SENIORITY	**0,85**	**0,77**	**0,58**	**0,73**	**0,62**	**0,72**	**0,87**	**0,81**	**0,63**	0,17
TOTAL EXPERIENCE	**0,95**	**0,91**	**0,89**	**0,76**	**0,91**	*	0,23	**0,97**	**0,95**	**0,85**
HOURS WORKED	0,31	0,24	0,24	0,46	0,27	-0,01	**0,90**	0,36	0,27	0,12
OVERTIME	0,08	0,23	0,12	0,21	0,19	0,02	**0,51**	0,18	0,22	0,09
BONUS RATE	0,04	0,04	0,01	0,41	0,06	0,07	0,12	0,11	0,05	0,00
ACTIVITY (S,P,D)	0,12	0,08	0,15	0,10	-0,23	**0,67**	-0,14	-0,12	0,06	0,13
NUMBER OF ACCIDENTS	-0,05	-0,01	0,03	-0,06	-0,06	0,27	0,22	-0,18	-0,04	0,00
LOST DAYS/ACCIDENT	0,00	-0,02	0,03	0,05	0,02	-0,06	-0,03	0,05	0,04	-0,03
VARIATION EXPLAINED (%)	44,9	47,6	47,7	53,3	50,2	54,9	41,9	50,8	49,6	41,0

* information not available at mine

TABLE 4: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, ACCIDENTEES POPULATION, SECOND FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	0,07	-0,01	0,04	0,20	-0,13	0,20	0,08	-0,02	0,08	-0,11
SENIORITY	0,05	0,11	-0,09	0,36	0,04	0,40	**0,86**	0,04	0,21	0,07
TOTAL EXPERIENCE	0,15	0,11	0,01	0,13	0,08	*	0,24	0,10	0,06	0,16
HOURS WORKED	0,11	0,10	-0,11	0,26	0,02	0,02	**0,82**	-0,10	**0,77**	-0,02
OVERTIME	-0,19	-0,33	0,15	-0,07	-0,27	**-0,42**	0,31	-0,09	**0,79**	-0,03
BONUS RATE	**0,85**	**0,78**	**0,80**	**0,78**	**0,69**	0,41	0,21	**0,71**	0,05	**0,79**
ACTIVITY (S,P,D)	**0,81**	**0,71**	**0,79**	**0,85**	**0,71**	0,41	0,04	**0,67**	-0,04	**0,77**
NUMBER OF ACCIDENTS	0,11	0,06	0,03	0,03	0,07	**0,73**	0,10	0,13	0,04	0,27
LOST DAYS/ACCIDENT	-0,06	-0,07	-0,11	-0,04	0,02	0,24	-0,10	0,06	-0,11	-0,04
VARIATION EXPLAINED (%)	25,2	25,9	26,5	16,3	21,1	21,8	28,6	19,8	21,0	24,3

* information not available at mine

TABLE 5: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, GENERAL MINER POPULATION, SECOND FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	0,06	0,06	0,10	0,10	0,10	**0,84**	**0,94**	-0,02	0,15	0,12
SENIORITY	0,03	0,01	-0,03	0,25	0,25	**0,70**	0,15	0,03	0,34	0,32
TOTAL EXPERIENCE	0,13	0,08	0,14	0,21	0,09	*	**0,93**	0,00	0,19	0,07
HOURS WORKED	0,14	0,15	0,08	0,21	**0,79**	0,26	0,10	**0,64**	**0,85**	**0,81**
OVERTIME	-0,14	-0,18	0,13	-0,12	0,15	0,17	0,18	0,06	**0,77**	**0,71**
BONUS RATE	**0,82**	**0,81**	**0,71**	**0,83**	-0,03	0,05	-0,09	0,16	0,02	0,12
ACTIVITY (S,P,D)	**0,78**	**0,79**	**0,72**	**0,85**	0,06	-0,29	-0,08	0,01	0,01	-0,14
NUMBER OF ACCIDENTS	0,12	0,14	0,21	0,04	**0,48**	-0,04	-0,01	**0,74**	0,18	0,27
LOST DAYS/ACCIDENT	-0,04	-0,03	-0,03	-0,03	-0,02	0,12	0,04	0,03	-0,07	0,00
VARIATION EXPLAINED (%)	21,9	25,8	20,9	21,0	18,0	20,6	26,8	21,8	21,9	24,4

* information not available at mine

TABLE 6: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, ACCIDENTEES POPULATION, THIRD FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	0,08	-0,08	0,21	-0,13	0,19	0,20	-0,13	-0,08	0,00	0,14
SENIORITY	0,10	0,09	**0,47**	0,29	**0,66**	**0,30**	0,11	0,05	0,11	**0,82**
TOTAL EXPERIENCE	0,02	-0,01	0,06	0,18	0,16	*	0,02	0,01	0,09	0,05
HOURS WORKED	**0,72**	**0,53**	**0,68**	**0,58**	0,29	**0,77**	0,13	**0,53**	0,24	**0,71**
OVERTIME	**0,77**	0,01	0,10	**0,59**	**0,61**	**0,59**	-0,05	-0,01	-0,11	0,16
BONUS RATE	-0,09	0,12	-0,24	0,05	-0,10	-0,11	**0,82**	0,23	**0,74**	0,20
ACTIVITY (S,P,D)	-0,07	0,03	0,05	-0,06	-0,10	**-0,30**	**0,83**	-0,05	**0,68**	-0,10
NUMBER OF ACCIDENTS	0,05	**0,57**	0,05	0,06	-0,07	-0,02	0,21	**0,75**	0,07	0,14
LOST DAYS/ACCIDENT	-0,06	-0,01	-0,05	-0,11	0,00	-0,11	0,07	-0,02	0,07	-0,07
VARIATION EXPLAINED (%)	18,5	14,0	9,0	14,2	13,5	16,9	18,6	16,9	19,0	19,8

* information not available at mine

TABLE 7: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN QUÉBEC UNDERGROUND MINES, GENERAL MINER POPULATION THIRD FACTOR

VARIABLES	MINE									
	1	2	3	4	5	6	7	8	9	10
AGE	0,12	-0,09	0,05	0,13	-0,10	-0,01	-0,13	-0,01	0,03	0,01
SENIORITY	0,09	0,21	0,17	0,22	-0,08	0,27	0,04	-0,02	0,11	-0,04
TOTAL EXPERIENCE	0,10	0,08	0,15	0,25	0,00	*	-0,04	0,06	0,08	-0,05
HOURS WORKED	**0,73**	**0,67**	**0,74**	0,52	-0,04	-0,02	-0,06	-0,02	0,24	0,20
OVERTIME	**0,76**	0,11	0,06	**0,60**	-0,24	0,04	-0,17	-0,09	-0,13	0,08
BONUS RATE	-0,07	0,18	0,26	-0,11	**0,62**	**0,46**	**0,80**	**0,70**	**0,78**	0,10
ACTIVITY (S,P,D)	-0,02	0,07	0,00	-0,03	**0,63**	0,31	**0,81**	**0,59**	**0,72**	0,02
NUMBER OF ACCIDENTS	0,15	**0,66**	**0,61**	0,03	0,08	**0,88**	0,11	0,22	0,17	**0,70**
LOST DAYS/ACCIDENT	-0,01	0,04	0,07	-0,08	0,02	0,20	0,05	0,07	0,06	**0,64**
VARIATION EXPLAINED (%)	19,8	17,7	13,1	11,0	14,5	12,6	19,0	15,1	15,0	18,8

* information not available at mine

TABLE 8: RESULTS OF NINE VARIABLE MULTIDIMENSIONAL ANALYSIS IN TEN QUÉBEC UNDERGROUND MINES POOLED TOGETHER, FOUR FACTORS

VARIABLES	ACCIDENTEES POPULATION FACTOR				GENERAL MINER POPULATION FACTOR			
	1	2	3	4	1	2	3	4
AGE	**0.84**	0,02	0,12	-0,14	**0,83**	0,03	0,15	-0,08
SENIORITY	**0,67**	-0.03	0,16	0,03	**0.70**	-0,06	0,15	0,10
TOTAL EXPERIENCE	**0,86**	0,13	0,03	-0,01	**0,88**	0,10	0,08	0,03
HOURS WORKED	0,33	0,09	**0,58**	**0,36**	0,33	0,08	**0,60**	**0,53**
OVERTIME	0,07	-0,12	**0,60**	-0,03	0,12	-0,11	**0,62**	0,06
BONUS RATE	0,07	**0,73**	0,02	0,07	0,01	**0,71**	0,01	0,09
ACTIVITY (S,P,D)	0,02	**0,71**	-0,16	0,09	0,06	**0,70**	-0,13	0,07
NUMBER OF ACCIDENTS	-0,06	0,08	0,01	**0,49**	-0,04	0,12	0,09	**0,59**
LOST DAYS/ACCIDENT	0,02	-0,02	-0,04	0,00	0,01	0,00	-0,01	0,06
VARIATION EXPLAINED (%)	47,5	24,2	16,5	5,3	48,2	22,1	18,5	5,6
CUMULATIVE (%)	47,5	71,7	88,2	93,6	48,2	70,3	88,8	94,4