Journal of Safety Research, Vol. 19, pp. 71-8

0022-4375/88 $3.00 + .00
Printed in the USA

Risks of Hand Tool Injury in U.S. Underground Mining from 1978 through 1983 Part I: Coal Mining

William S. Marras, Thomas G. Bobick, Steven A. Lavender, Thomas H. Rockwell, and Robert L. Lundquist

The underground coal mining work place represents a dangerous environment where workers are constantly exposed to hazards involved in using hand tools. In order to describe the injury components associated with hand tools, a review of all underground coal mining injuries was conducted for the years 1978 through 1983. This was performed by evaluating injuries recorded in the Mine Safety and Health Administration's Safety and Health Technology Center database. This review identified the injury-component sequences that were most frequent and those sequences that were most severe as measured by days lost from work. The analysis showed that injuries associated with the scaling bar and jack were responsible for over half of all lost days resulting from hand tool-related injuries. Almost 90% of all lost days due to hand tool-related injuries are accounted for if the bar, hammer/axe, and pneumatic drill are also included. This study discusses the sequence of injury-component events that results in an increased risk of injury from these tools and also discusses ergonomic changes that may reduce these risks.

Hand tools have been in use by humans since prehistoric times. Today, hand tools are used regularly in most occupations and are commonly found in most households. However, along with their many benefits, hand tools also present risks of injury. Ayoub, Purswell, and Hicks (1977) reviewed injury data and found that injuries resulting from hand tool use were responsible for 5% to 10% of all compensable injuries. Furthermore, the vast majority (70% to 80%) of

William S. Marras, PhD, is an associate professor, Steven A. Lavender is a research associate, and Thomas H. Rockwell, PhD, is a professor in the Industrial and Systems Engineering Department, Ohio State University, 1971 Neil Avenue, Columbus, OH 43210-1271. Thomas G. Bobick is a mining engineer at the U.S. Bureau of Mines Pittsburgh Research Center. Robert L. Lundquist is an associate professor in the Department of Mining Engineering, Ohio State University.

and tool-related injuries were due to the use of nonpower tools.

Certain occupations require workers to use hand tools more often than others, and many times the nature of the task or tool puts the workers at a greater risk of injury. For example, Rockwell (1982) has reported that hand tools caused a total of 10% of all on-the-job injuries in the rail industry. These accidents represented a loss of 3 to 4 million worker-hours per year. Hand tool-related injuries in the rail industry account for more lost time than injuries from manually handling materials and are exceeded in severity only by injuries from slips and falls.

UNDERGROUND COAL MINING

Underground coal mining is another industry in which the nature of the jobs and of the tools utilized can cause the work force to be at greater probability of injury than the typical industrial population. Statistics from the Mine Safety and Health Administration (MSHA), Department of Labor, indicate that from 1980 to 1984 hand tools were involved in a total of 8% of all lost-time nonfatal injuries. Quisenberry (1985) has reported that hand tools were involved in a total of 21% of all hand and finger injuries during the same 5-year period.

Environment

The underground coal mining environment leaves little room for error and presents very hazardous working conditions. Since mining is the brute force extraction of raw materials from the surrounding rock, the extraction equipment is very large and quite powerful. Handheld power tools, such as pneumatic drills, which are used to drill holes for the insertion of rock-securing bolts, are heavy and made for rough handling. Even nonpower maintenance tools (wrenches, screw drivers, hammers, etc.) are usually larger, heavier, and more durable than the same types of tools found in home workshops. Because the tools are heavy and bulky, they may cause a more severe accident if they slip or are dropped. Additionally, the mass of the tool may also place the worker at greater risk of an overexertion injury due to greater moment loading on the body.

Personal illumination for underground miners is provided by small battery-powered lights worn on the individual's hard hat. Area illumination exists only in the vicinity of the large, mobile mining equipment. This limited illumination diminishes the perception of the surrounding environment and can severely compromise the tasks that have to be accomplished. This can lead to tool slippage and misstrikes. Often, the underground environment is wet and can cause slipping accidents when heavy items, such as drills, are carried from one work place to another. Dampness also contribute to a tool's slipping from the worker's grasp.

Additionally, low-seam coal mines (seam thickness ≤ 48 in. [121.9 cm]) cause the workers to do their jobs in awkward, restricted postures. Typically, the workers kneel on both knees, on one knee (the other leg used as a brace or support), or while in a stooped-over posture (Bobick & Unger 1985; Gallagher, 1985). Using or moving heavy tools while in an awkward posture can contribute to tool mishandling or struck-by-tool accidents. Restricted postures can also contribute to musculoskeletal injuries when handling heavy items, especially when the worker is fatigued (Chaffin & Andersson, 1984). If a heavy tool slips, thus causing the worker to react suddenly to either prevent the tool from falling or to move out of its way, the sudden movement can cause a lower back or upper torso injury (Marras, Rangarajulu, & Lavender, 1987).

Another important point is that the workers who use hand tools generally use them a lot. Thus, a mechanic, an electrician, or a drill operator, who uses hand tools more often, has an increased probability of injury. Quisenberry (1985) has reported that from 1980 to 1984, the second and third most common activities that contributed to lost-time hand and finger injuries were maintenance-repair tasks (17%) and using hand tools in jobs other than maintenance and repair (16%). Thus, one out of every three lost-time hand and finger injuries involved the use of hand tools.

Other problems associated with the constant use of hand tools involve the cumulative trauma disorders, such as carpal tunnel syndrome, tenosynovitis, tendonitis, or vibration white finger disease (Raynaud's syndrome). Cumulative trauma results from repetitive insult to a portion of the body. Unlike acute trauma (where damage is produced instantaneously), the effects of cumulative trauma may take months, or even years, to appear. In effect, cumulative trauma represents the gradual "wear and tear" on the body from repetitive action. Although these types of repetitive motion disorders are traditionally associated with smaller, lighter-weight tools, they also can occur in mining where heavier, more massive hand tools, such as pneumatic rock drills (75 to 140 lb [33.9 to 63.4 kg]), are used.

Tools Used

As in most industrial work places, the usual variety of maintenance tools are used in mining. Wrenches, screw drivers, pliers, hammers, knives, axes, pry bars, and so on, are used for routine work. As mentioned, the tools used in mining are considerably larger than the normal versions. Also, the hand tools used in mining have to be more durable than those used in most other industries due to the harshness of the mining environment.

In addition to the routine tools, certain specialty tools have been developed for specific mining activities. One very important tool found in all underground mining operations is the scaling bar. This tool is similar to a pry bar, but is generally longer. The scaling bar, which can be equipped with different tips for different tasks, permits a worker to remove any loose rock from the roof. To do this job safely, the worker has to be positioned sufficiently far away from the unstable roof. Thus, a rather lengthy bar (4 to 8 ft [1.2 to 2.4 m]) is used so that the miner can remain under more secure roof conditions.

Additionally, hand-carried pneumatically powered percussion drills are used to some extent in underground coal mines. Those operations that have fairly hard rock above the coal seam will primarily use pneumatic drills instead of the usual hydraulically powered rotary drills. Mines with weaker rock overhead will typically use self-propelled hydraulic drills for drilling the roof bolt holes; even these mines, however, will have one or two pneumatic rock drills for the specific task of cleaning up after an extensive rock fall.

Objectives of the Injury Data Analysis

The objectives in analyzing hand tool injury data were three-fold: (a) to define the circumstances (accident type, part of body injured, activity at the time of injury, etc.) of the lost-time hand tool injuries; (b) to define the probability of occurrence for each circumstance; and (c) to define the sequence of injury-component events and identify the most probable and most severe component links.

METHOD

Data Base Selection

To achieve the objective of this study, data regarding hand tool injuries and usage were required. Several potential sources of information were investigated. These included insurance company files, individual mining companies, mine unions, hand tool manufacturers, and government agencies as well as other potential sources. For a potential information source to be practical for research purposes, it had to meet several criteria. These include:

1. A computerized database,
2. The ability to sort the data base in several ways according to the components of hand tool injuries, and
3. Up-to-date statistics that were coded according to standard procedures in all environments.

The only database that satisfied all of these criteria was that maintained by the MSHA Safety and Health Technology Center in Denver, Colorado. The MSHA database provided an excellent source of hand tool information for the years of interest, 1978 through 1983. This database was the most complete and well documented source available for a quantitative evaluation of hand tool injuries.

One restriction of the MSHA database, however, is that the reported injuries were primarily acute disorders. Cumulative trauma reporting depends upon the recognition of the problem by the medical profession.

Often, these individuals are unaware that the problem may be of a cumulative nature. Such diagnosis problems lead to inaccurate estimates of true incidence rates. Hence, some injuries, which are cumulative in nature, may be classified as acute or may not be reported at all if the injury can not be linked with a specific incident.

Injury Components

Several components of hand tool-related injuries were evaluated. These injury components served as independent variables in this analysis. The components consisted of: (a) the type of tool used during the accident, (b) the type of accident, (c) the part of the body injured, and (d) the nature of the injury.

Several types of hand tools used in the mining industry were evaluated in this study. These tools were: the pneumatic drill, scaling bar, pry bar, axe and hammer, jack, knife, and wrench. All of these tools are widely used in coal mining, and they account for the vast majority of hand tool-related injuries reported in underground coal mining.

The MSHA classification defines the type-of-accident component as the event that directly resulted in the reported injury. The type of accident directly relates to the source of injury. Typical accident types include struck against, struck by, fall, caught, or overexertion.

The part-of-body component identifies the portion of the worker that was injured while using the hand tool. Usually, there is only one part of the body reported. If more than one part is reported, this component is coded as multiple injuries. In this particular analysis, the parts of the body were considered in general terms: head, neck, arm, leg, trunk. Thus, when a limb was involved in an injury, any part of the limb was included in the data for that limb. For example, a finger injury was recorded as an arm injury. Also, when a trunk injury was reported, it was not known whether the injury was to the upper back, lower back, or the abdomen. Such differences have different biomechanical implications. However, discrepancies could often be resolved by examining the narrative report associated with the injury.

In the MSHA database classification, the nature-of-injury component identifies the principal physical characteristics of the injury. Generally, the basic injury, not something that occurred later, is described. If more than one injury occurs and one injury is more severe than the other, the more severe injury is reported. On the other hand, if several injuries of similar severity occur, the nature of injury is reported as multiple. Descriptions of nature of injury include breaks, muscle tears, dust in the eyes, cuts, inflammation of joints, tendons, or muscles, dislocations, and strains and sprains. In the case of breaks, a limb recorded as broken included a broken bone in any part of the limb. For example, a break to the arm may indicate a break to the upper arm, lower arm, or fingers.

As mentioned earlier, brief narrative descriptions were acquired from the database for specific accidents. In some instances, narratives provided additional information regarding the components of a particular accident.

Two dependent measures were evaluated in this study: (a) the frequency of occurrence and (b) the number of days lost associated with an accident. These dependent measures permitted the data associated with a sequence of accident components to be evaluated as a percentage of all injuries or lost days attributable to a particular tool. The frequency data were used to compute the relative probabilities of each accident sequence, and the number of lost days formed an index of severity for each sequence. Because the database did not report total hours worked with each tool analyzed, it was not possible to derive an exposure rate of injury for each specific tool.

Injury Component Analysis

The method used to interpret the database consisted of several steps. First, conditional relationships were established among the injury components as a function of each hand tool for each year of data reported. These conditional relationships described the components of each injury sequence based on accident frequency and days lost from work. In this manner, the analysis was able to establish, for an injury occurring with a specific tool, the probabilities that a particular type of accident had occurred, that a particular part of the body was involved, and that a particular nature of injury had resulted. Thus, the expected number of lost days could be identified for each injury sequence. The analysis methodology enabled the identification of sequences of injury components that were associated with greater probability and severity of injury.

Once the conditional relationships were derived for individual years, the data were statistically evaluated to determine if there was justification to combine the data for all 6 years. In every case, the pooling of data was statistically justified. For the combined years of data (1978 through 1983), the conditional relationships among the injury components were established and were then represented by probabilistic tree diagrams.

The conditional probabilities of injury components were used to rank the injury-component sequences according to the number of lost days due to the injury sequence. In this manner, it was possible to identify the sequences that represented the greatest risk, in terms of frequency and severity, of hand tool injuries in coal mining over the 6 years that were analyzed. These sequences were used to gain insight into the ergonomic problems associated with hand tool design, the method of tool usage, and the environmental factors contributing to the injury.

More in-depth analyses of the data consisted of task analyses, narrative reports of accidents, worker interviews, and ergonomic assessments of tool use. Task analyses were produced from videotapes made at underground work sites. These analyses broke each task into elements and quantitatively described the work postures observed. For example, orienting the scaling bar with a 2.7-m (8.9-ft) roof height, the miner has 10 degrees of sagittal bend and the left shoulder is abducted 45 degrees and is in 30 degrees of flexion. Each joint and limb position was described in this manner, leading to a detailed description of each task element. These descriptions were used to identify possible mechanisms of injury for each element.

Accident narratives were available for most injuries reported in the database. Some of the narratives were incomplete and, when possible, worker interviews were used to supplement this analysis. Interviews concentrated on having miners describe accidents they had been involved in or had seen while on the job.

Based on the information from the above analyses, ergonomic assessments for each tool were developed using a seven-link biomechanical model. The model estimated the compressive forces at the L5/S1 juncture and compared the strength requirements of the task elements with a database containing anthropometric strength data.

RESULTS

The severity (lost days) of injuries due to hand tool use in coal mining is shown in Table 1. This table indicates that the most severe hand tool-related injuries are caused by scaling bar use, followed closely by jack use. In fact, these two tools account for over half the lost days due to hand tool accidents. The pry bar, hammer and axe, pneumatic drill, wrench, and knife follow in order of severity. In the present analysis, only tools that represent a value of greater than 10% of all lost days in hand tool accidents will be discussed. Thus, the five tools shown in Table 1 will be evaluated.

The scaling bar represents the largest lost-time category due to hand tool use. Over 23,000 days were lost due to scaling bar use over the 6 years. This number represents over 26% of all lost days due to hand tool injuries. This tool is particularly dangerous, because it also represents the greatest average lost days per accident (31 days). Although no exposure metric data can be produced, actual time spent scaling tends to be relatively small. With the exception of when loose material is detected during another activity, scaling is typically performed at the start of a shift, upon entering a new work site, or after blasting.

The conditional relationships between the injury components of scaling bar use are

TABLE 1
LOST DAYS ASSOCIATED WITH VARIOUS TOOLS
USED IN COAL MINING, 1978–1983

Tool	Number of Accidents	Total Days Lost	Average Days Lost Per Accident	% of Total Days Lost, All Hand To[ol] Accidents
Scaling bar	760	23,601	31.05	26.63
Jack	1,139	22,205	19.50	25.05
Pry bar	677	14,065	20.75	15.87
Hammer and axe	1,104	11,105	10.05	12.53
Pneumatic drill	555	9,717	17.51	10.96
Wrench	430	5,688	13.20	6.42
Knife	840	2,258	2.69	2.54
Total	5,505	88,639		100:00

shown in tree diagram form in Figure 1 (for all years). This figure indicates that the prevailing mechanism of injury is due to struck-by (STBY) type accidents. Nearly 80% of injuries are due to this type of injury. Of the struck-by injuries, almost 40% occur to the leg, and the most costly nature of injury involves breaks. This sequence of injury components represents over 55 average lost days per accident. Other costly nature-of-injury components are shown in this figure and involve tears, multiple injuries, and cuts. Other parts of the body often affected by struck-by type injuries include the trunk and multiple body parts. Breaks to the trunk represent a high severity rate, an average of over 80 days lost. Figure 1 also shows that exertion injuries to the trunk from using the scaling bar are fairly prevalent.

The jack is also associated with a high number of lost days—over 25% of all lost days due to hand tool injuries. Figure 2 shows the sequence of injury-component events associated with jack use in coal mining for the 6-year period of interest. This figure indicates that the two main types of injuries associated with jack use are struck-by and exertion injuries. About 52% of the injuries involve struck-by accidents. Of these, the arm, head, and leg are most often affected. The greatest average lost days are associated with breaks to those body parts. Two events typically occur that cause the struck-by accidents. First, the latching mechanism does not lock properly, thus permitting the bar to fly up and strike the miner. Second, often the jack is not securely positioned and kicks out, striking the miner. Exertion injuries occur in over 28% of the injuries due to jack use. Of these, over 90% occur to the trunk, and most of these are of a tearing nature.

The pry bar is associated with almost 16% of all lost days due to hand tool injuries. The sequences of injury-component events associated with the use of this tool are shown in Figure 3. This figure indicates that the types of injuries most often experienced with pry bar use are exertion and struck-by events. Approximately 51% of the injuries are caused by a struck-by accident. This type of injury was responsible for 17 mean lost days per accident. Further examination of Figure 3 shows that about 41% of the

FIGURE 1
SCALING BAR USE RISK SEQUENCES

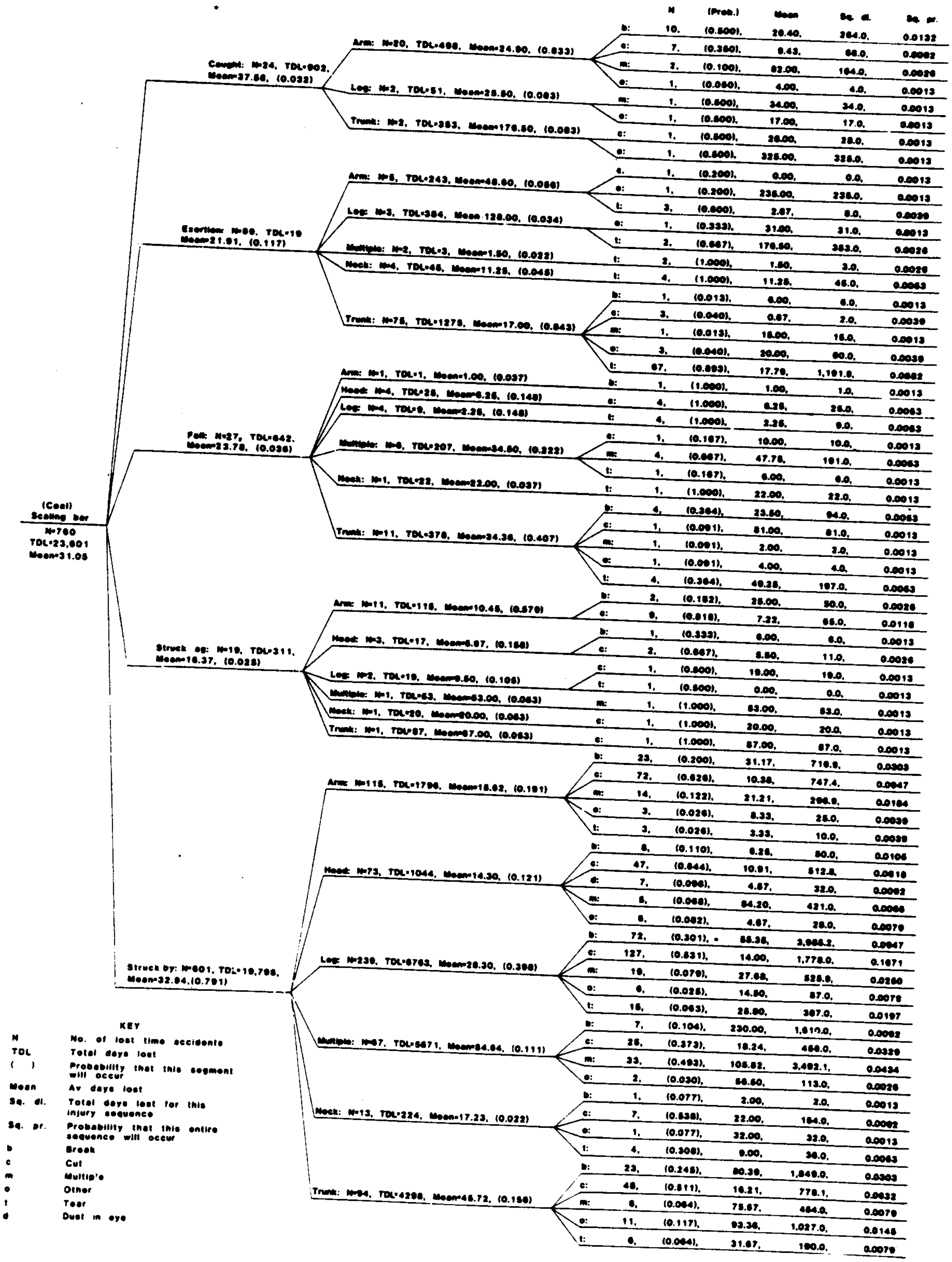


FIGURE 2
JACK USE RISK SEQUENCES

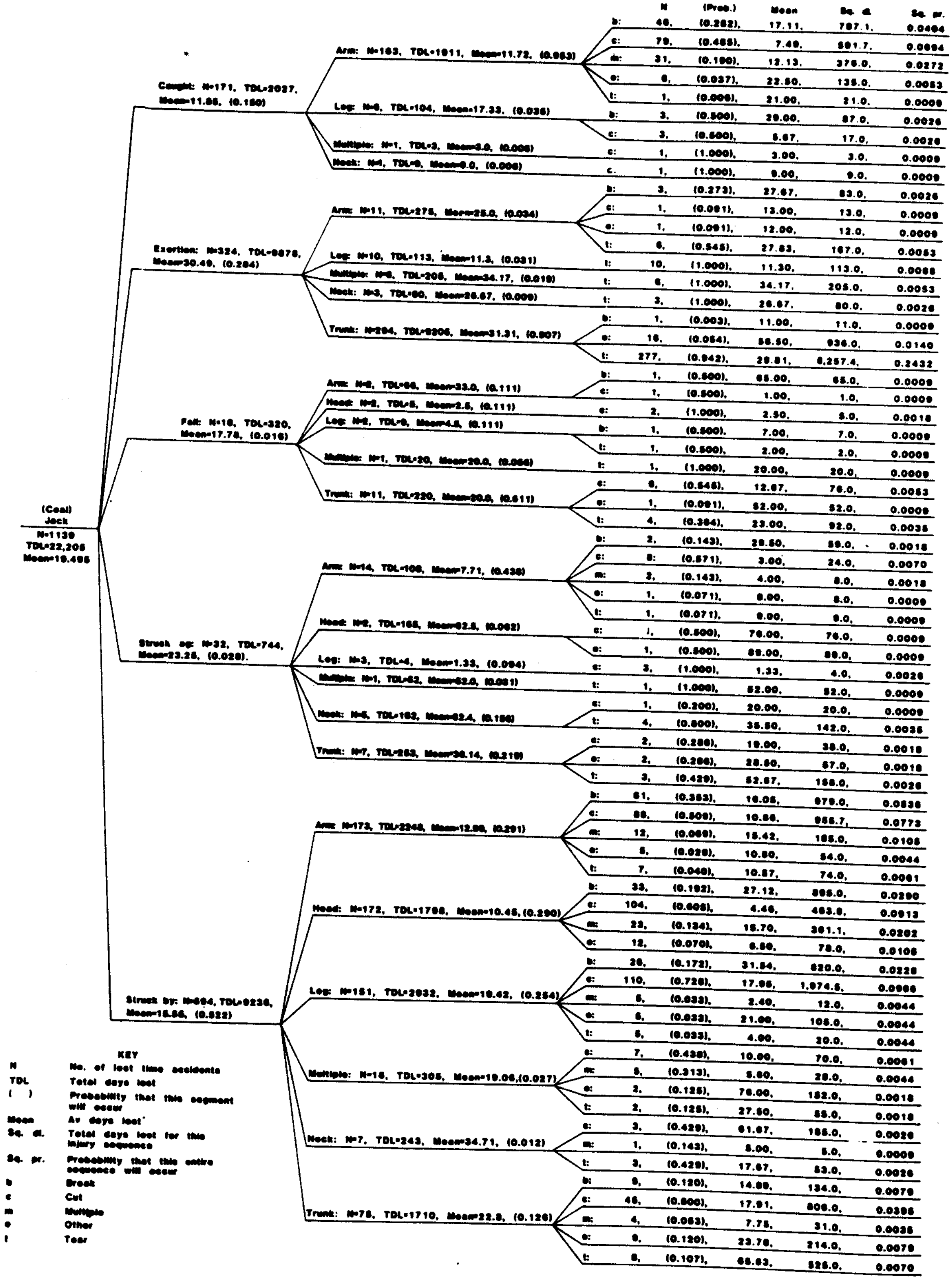
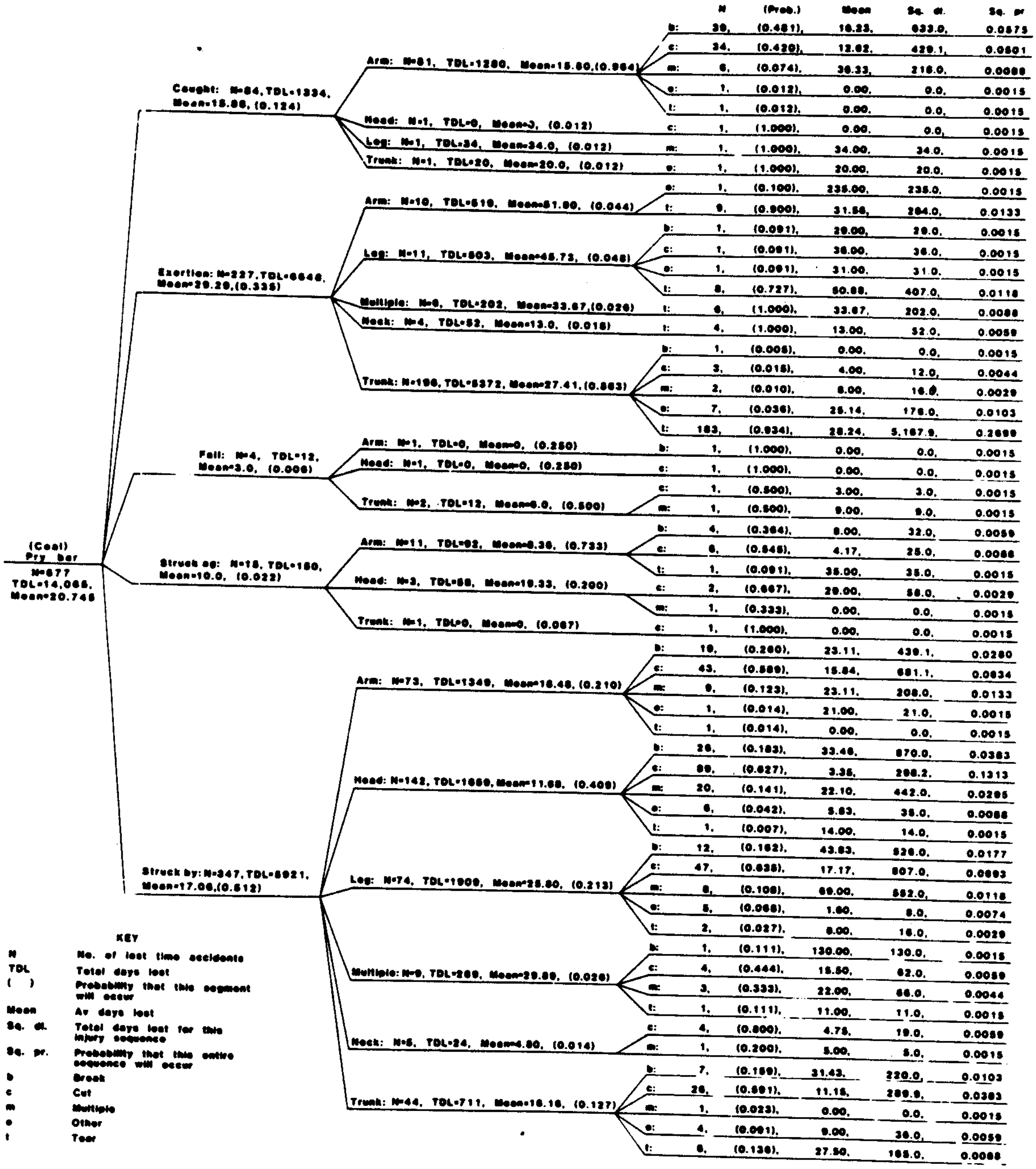


FIGURE 3
PRY BAR USE RISK SEQUENCES



struck-by accidents involve the head. The greatest probability in this sequence involves a cut to the head and results in few lost days. Breaks and multiple injuries to the head region involve a lower probability but greater lost days. Other high-risk sequences involving a struck-by injury are cuts to the arm, leg, and trunk. Generally, in those instances where a sequence involves a large number of lost days, the probability of the event's occurring is low. For example, breaks to multiple body parts result in 130 average lost days. However, there was only one accident of this sort over the 6-year period.

Exertion injuries occur about one third of the time in pry bar accidents. However, this event results in the greatest number of average lost days (29.29). The vast majority of the injuries occurred to the trunk and involved tearing injuries. This sequence resulted in an average of 28.24 lost days. In fact, this sequence involved the greatest probability event during pry bar use. If an accident occurred with the pry bar, there was about a 27% probability that this sequence would occur. This is significant, considering that the next greatest probability event involved a struck-by accident to the head with a 13% probability.

Hammer and axe (hammer/axe) accidents were responsible for about 12.5% of all lost-day hand tool injuries. Figure 4 shows the sequence of injury-component events that occur with these tools. This figure also shows that most injuries were due to exertion and struck-by accidents. Struck-by accidents have the greatest probability of occurrence (83.5%), with an average of 8.51 lost days. Of the struck-by accidents, most injuries occur to the arm (78%) and involve primarily breaks and cuts. Of these high-probability events, breaks result in a greater number of lost days. Many of these accidents involve injuries to the hand and fingers.

Exertion injuries involving the hammer/axe occur in only about 11% of the cases, but have a much higher number of lost days associated with them (22.65) compared to struck-by injuries (8.51). As with other types of exertion injuries observed, most involve the trunk (73.4% probability) and result in tears. This sequence occurs almost 8% of the time and results in an average of 24.13 lost days.

The final tool that will be discussed in this study is the pneumatic drill. This device is responsible for almost 11% of the lost days attributable to hand tool accidents. The tree diagram describing the sequence of injury-component events with the pneumatic drill is shown in Figure 5. The major risks associated with this tool involve caught, struck-by, and exertion injuries. Caught injuries occur 16.6% of the time and predominantly involve the arm. Of these injuries, breaks and cuts occur most often and result in an average of 50.36 and 11.88 lost days, respectively.

Struck-by accidents account for over 60% of pneumatic drill injuries and involve the arm, head, or leg equally as often (22% to 27% of the time). For these three body parts, breaks and cuts are most predominant and involve a majority of the lost days.

Exertion injuries are implicated in about 14% of all accidents with this tool. Over 70% of these accidents involve the trunk, and most of these trunk exertions (88.9%) result in tear injuries. This sequence resulted in the greatest number of average lost days (27.31) among the frequently occurring sequences.

DISCUSSION

The severity of the injuries due to hand tool use can be summarized by observing the injury components that are responsible for most of the lost time over all 6 years. This information is presented in two ways. First, Table 2 ranks the days lost associated with the various tools and the type of injury reported. This table indicates that struck-by and exertion are the predominant forms of injury in coal mining. In fact, the 10 tool-and-injury combinations listed in the table account for over 82% of all lost days due to hand tool use. This table also indicates that over 40% of the lost days are due to the use of the jack and scaling bar alone.

Second, Figure 6 indicates the major components of injuries stemming from the use of coal mining hand tools. This figure also supports the hypothesis that the predominant types of injuries for all tools are struck-by and exertion injuries. When this figure is considered in conjunction with Figures 1 through 5, the sequences of injury components associated with the greatest risks of injury become apparent. It appears that the greatest number of lost days occurs in exertion injuries that are associated with the trunk. The other major category of lost days is related to struck-by injuries. Struck-by accidents usually involve the arm, leg, head, or trunk.

These major-risk sequences of injury components were further examined through the

FIGURE 4
HAMMER AND AXE USE RISK SEQUENCES

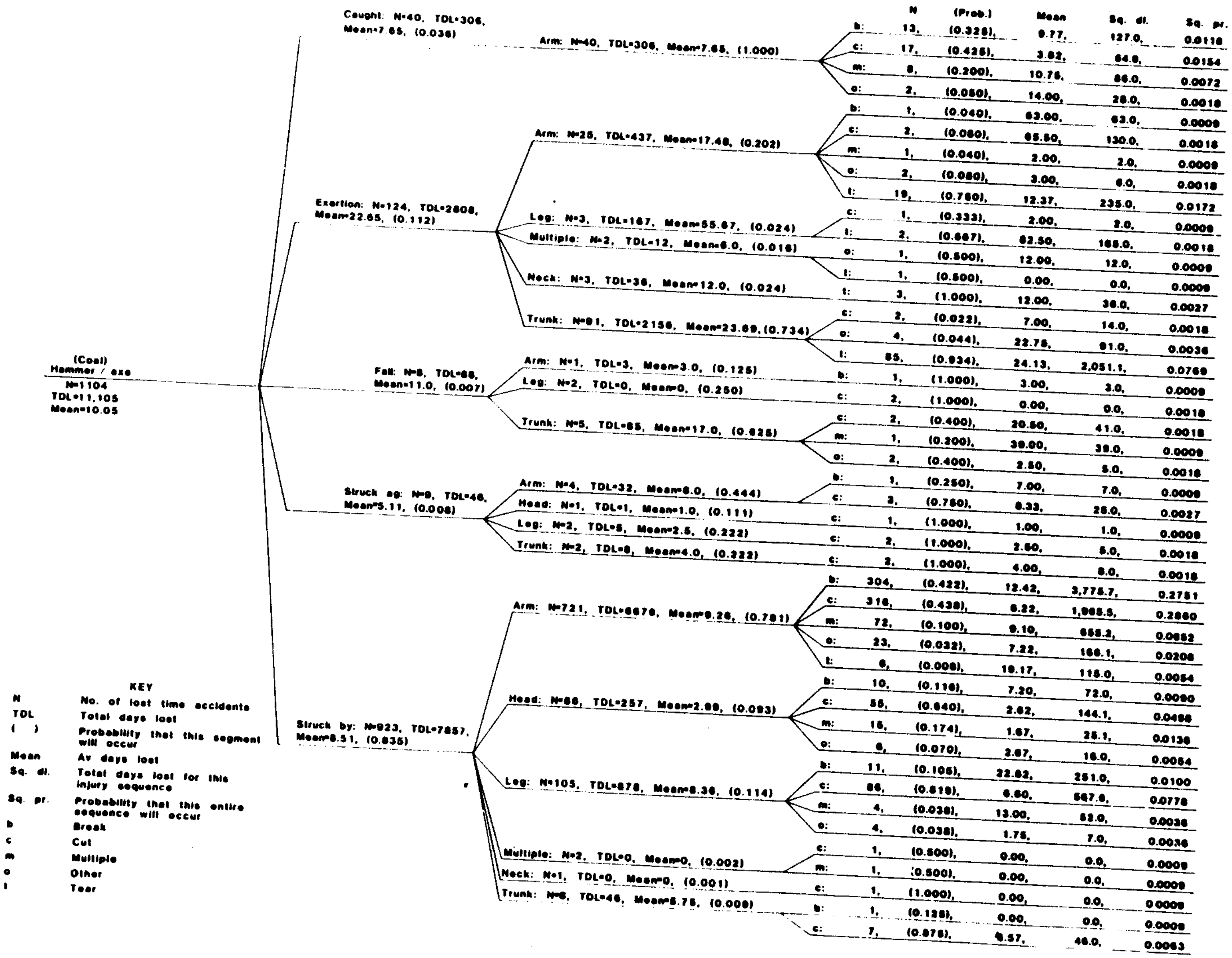


FIGURE 5
PNEUMATIC DRILL USE RISK SEQUENCES

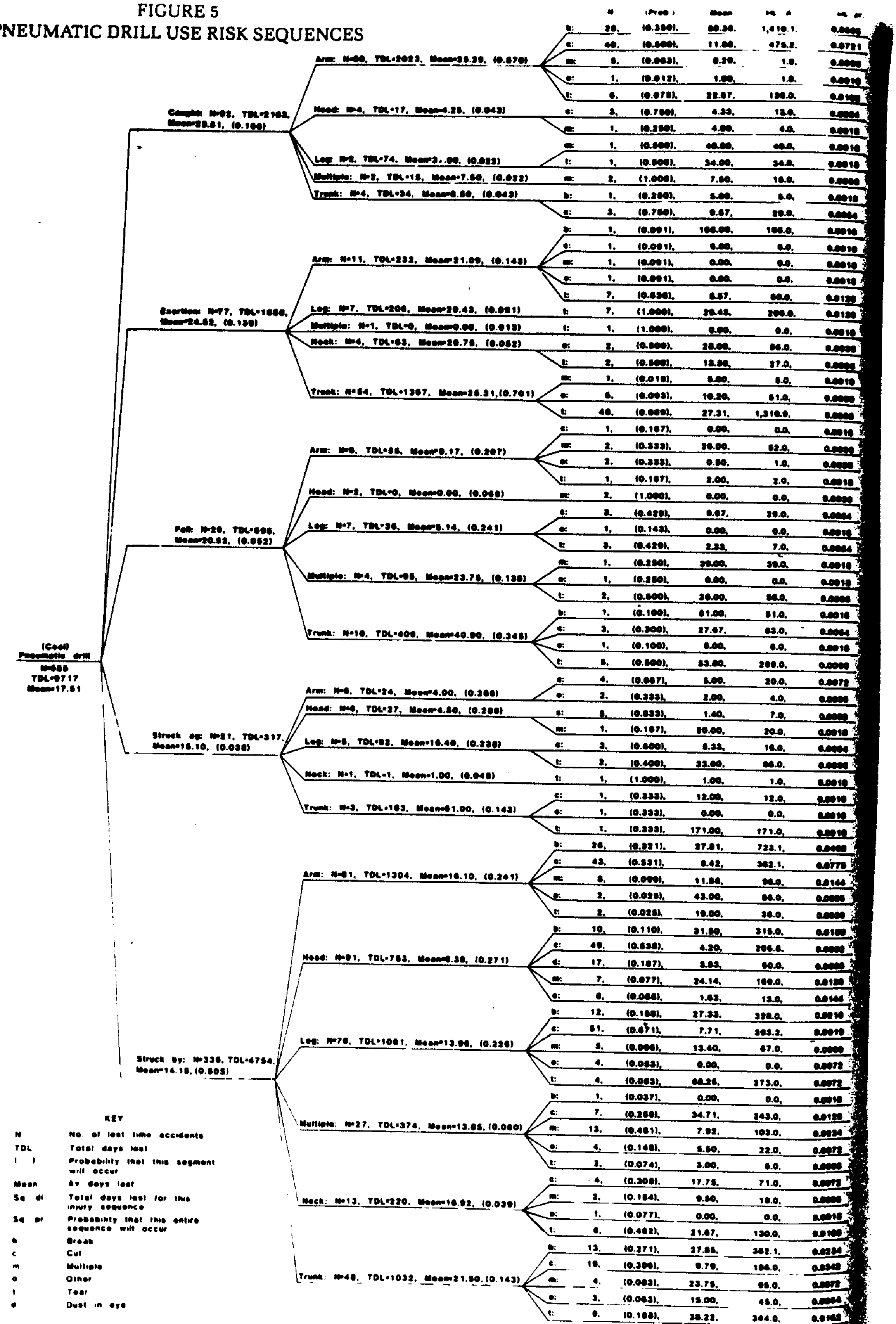
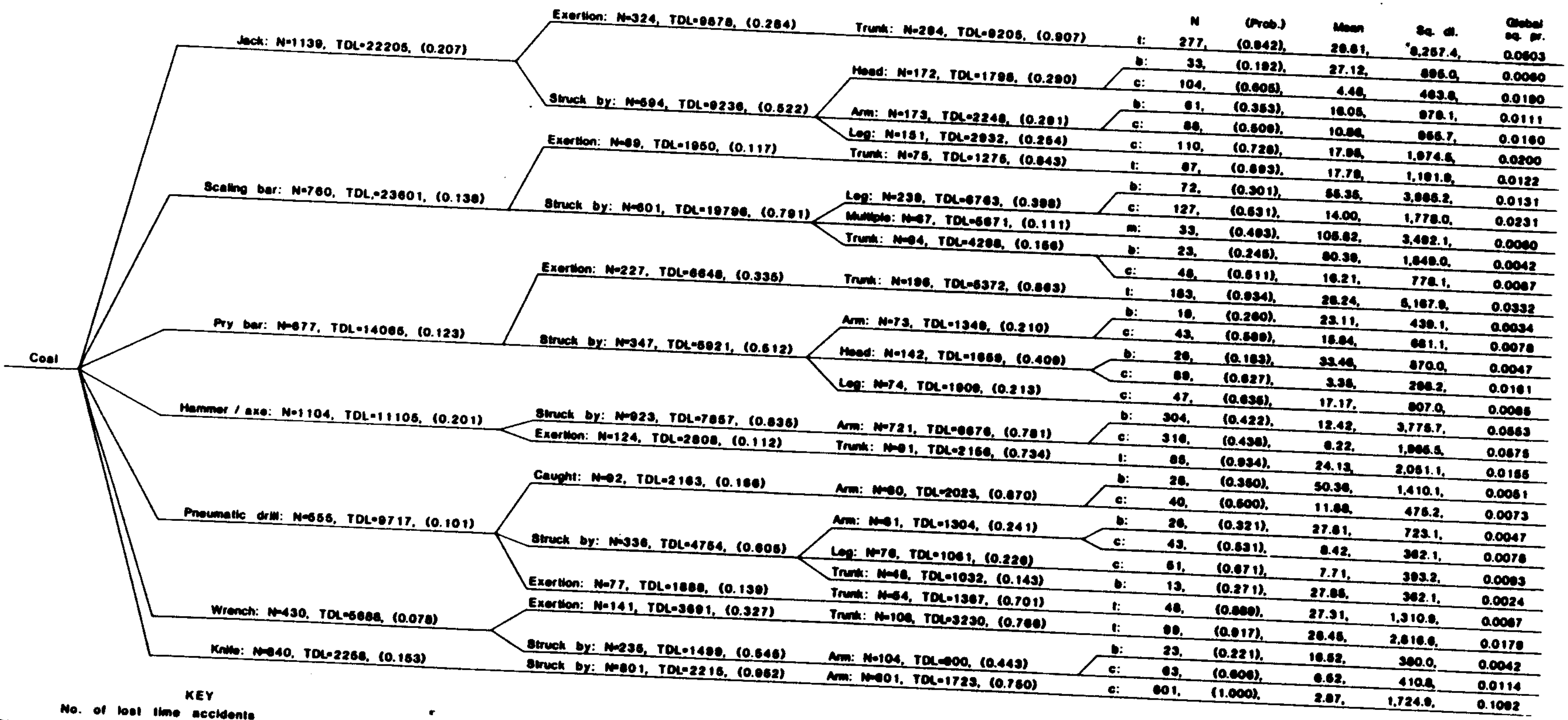


FIGURE 6
MAJOR RISK SEQUENCES ASSOCIATED WITH
HAND TOOL USE IN UNDERGROUND COAL MINING



KEY

N	No. of lost time accidents
TDL	Total days lost
( )	Probability that this segment will occur
Mean	Av days lost
Sq. di.	Total days lost for this injury sequence
Global sq. pr.	Probability that this sequence occurs relative to all the tools used in underground coal mining
b	Break
c	Cut
m	Multiple
t	Tear

uncontrollable forces are not permitted. Force governors can be incorporated into tools for this purpose.

On-site observations and task analyses have suggested the hypothesis that when a worker is struck by a rock while using a scaling bar he usually is working with the tool at such an angle that his body is underneath the work area or the falling rock is out of his perceptual range. Proper design of the tool and proper use can minimize the risk associated with this injury sequence. Further research has been conducted at The Ohio State University to experimentally evaluate these factors.

Hypotheses based upon task analyses have also shown that most struck-by injuries involving the hammer/axe are due to the tool's striking a person who is working in a confined or awkward posture. The establishment of a proper method for tool use could potentially reduce the risk of this injury.

This data analysis has identified the elements of hand tool injuries in underground coal mining. Similar research in other industries (Marras & Rockwell, 1986; Rockwell & Marras, 1986) has shown that an ergonomics approach to hand tool redesign can reduce the risks of injury. This paper has defined the problem, which is the first step in ergonomic intervention. Future research will empirically evaluate several of the suggestions made here in an attempt to develop more concrete means of intervention thereby bringing the hand tool injury problems under control.

In Part II, to be published in the next issue of the *Journal of Safety Research*, the authors describe the components of injury in the underground metal-nonmetal mining industry where the tools and environment are quite different.

REFERENCES

Ayoub, M., Purswell, J., & Hicks, J. (1977). Data collection for handtool injury: An approach. In V. Pezoldt (Ed.), *Rare event/accident research methodology* (pp. 71-103). Washington, D.C.: National Bureau of Standards.

Bobick, T. G., & Unger, R. L. (1985). Preventing accidents in the handling of materials. In *Proceedings of the Fourth Annual Meeting, Collegiate Association for Mining Education* (pp. 106-130). Rolla, MO.

Chaffin, D. B., & Andersson, G. B. J. (1984). *Occupational biomechanics*. New York: Wiley.

Gallagher, S. (1985). Back injury research at the U.S. Bureau of Mines Ergonomics Laboratory. In *Proceedings of the Fourth Annual Meeting, Collegiate Association for Mining Education* (pp. 170-191). Rolla, MO.

Kroemer, K. H. E. (1987). Matching individuals to the job can reduce manual labor injuries. *Occupational Health and Safety News Digest*, 3(6), 4-7.

Marras, W. S., & Rockwell, T. H. (1986). An experimental evaluation of method and tool effects in spike maul use. *Human Factors*, *28*, 267-281.

Marras, W. S., Rangarajulu, S. L., & Lavender, S. A. (1987). Trunk loading and expectation, *Ergonomics*, *30*, 549-560.

Rockwell, T. H. (1982). *An evaluation of hazards in the use of railroad portable handtools: Phase I report*. Columbus, OH: R & R Research, Inc.

Rockwell, T. H., & Marras, W. S. (1986). An evaluation of tool design and method of use of railroad leverage tools on back stress and tool performance. *Human Factors*, *28*, 303-315.

Snook, S. H. (1978). The design of manual handling tasks. *Ergonomics*, *21*, 963-985.

Quisenberry, S. (1985). *Hand and finger injuries in the coal mining industry: 1980-1984* (Mine Safety and Health Administration Technical report PC 7004). Denver, CO: MSHA.