EFFECTS OF HEAT ON SAFE WORK BEHAVIOR

FINAL REPORT

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ABSTRACT

General agreement exists and considerable research effort has been expended in the validation of relationships between hot environmental conditions and fatigue or physiological strain. There is also good evidence suggesting an optimal range of environmental conditions above which and below which performance of sedentary or mental tasks is less than optimum. However, the effects of the thermal environment on safety behavior, which is a correlate of accidents, have not previously been thoroughly investigated, due in part to the difficulty of evaluating safety behavior. This report describes a study which established that the thermal conditions of the workplace have an effect on the safety related behavior of workers.

The study was conducted in two industrial plants, a metal products manufacturing plant and a foundry. A wide variety of industrial work tasks and work stations were observed. The data were collected over a 14-month period starting from the first of July through the end of August of the following year. Measurements were taken daily for a total of over 17,000 observations. A typical data collection visit consisted of first measuring the thermal environment of a work area, using Wet Bulb Globe Temperature as the unit of measurement. Then, randomly observing the specific workers in the work area, using a taxonomy of unsafe behaviors as an indicator of work activity.

Statistical analysis indicated that temperatures below and above the preferred level have a significantly detrimental effect ($p<0.01$) on worker safety related behavior. The relationship between the rate of unsafe behavior and the ambient temperature was found to form a U-shaped curve. The minimum unsafe behavior rate occurred within the zone of preferred temperature (approximately 17°C to 23°C, WBGT). Other factors such as metabolic workload and period of the shift were also found to have significant effects ($p<0.01$) on worker safety related behavior.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is responsible for conducting research to determine the effects of various work place conditions on employee health and safety. One factor of concern is the effect of thermal extremes present at the work place on work-related accidents. There is evidence which suggests that an optimum range of environmental conditions exist within which people demonstrate the best performance (Poulton, 1972). Outside of this range, an individual's performance deteriorates. Unfortunately, the paucity of evidence to support this concept is not predicted on safety-related performance. The need to establish these relationships prompted the initiation of this study.

Most studies of the effects of environmental temperature conditions on human performance use measures such as error rate, production values, and learning time. Parameters typically employed in safety-related studies include such measures as injury rates, worker compensation payments, or clinic visits. These direct measures are not sensitive indicators of safety performance because numerous factors can affect the reporting of their occurrence, they are rare events in a statistical sense, and not all reported occurrences are documented. In addition, a particular breakdown in the operating system can lead to a wide range of consequences, e.g., no damage, lost production, property damage, injury or death. A more sensitive measure of safety related performance is preferred for research.

One method of evaluating safety related worker performance is to study the behaviors which are correlated with injury risk. This technique involves defining those behaviors which are unsafe for specified operations, and subsequently making random observations of workers performing those operations. The observational aspects of this approach are based on well-established work sampling techniques used extensively by industrial engineers. Tarrants (1980) describes the basics of behavioral (work) sampling for measuring safety performance. This methodology is well suited for this study to determine if worker safety is affected by the thermal conditions of the worksite.

The purpose of this study was to establish the relationships between worker safety related behavior and thermal conditions through the use of sampling procedures on actual industrial work activities.

BACKGROUND

The phenomenon of accidents constitutes one of the major human, social and economic problems of modern civilization. The losses occur not only in terms of fatalities and injuries but also through the countless days of productive labor which are lost through disablement. Although statistics serve to demonstrate the gravity of the problem of accidents in pure economic terms, they hide the real cost of accidents which is measured in terms of human suffering of the victims as well as of their families and friends.

Very little research has been conducted to assess behavioral factors which may contribute to the risk of occupational accidents, however, a few attempts have been made to establish correlations between certain factors and the occurrence of injuries based on information contained in accident reports. One problem with this approach to research is that the data which lend themselves to such retrospective epidemiological comparisons tend to be factual data about the victim such as age, gender, and occupation. Accident reporting systems in the United States and most other countries lack factual information about environmental conditions, task factors, behavioral factors, employee training, etc.

Another problem with the use of data from accident reports is that the reports only include activities which were directly involved in the accident. Thus, it is common to find that occupational injury reports attribute the injury to an improper or unsafe act by the victim or a co-worker. The shortcoming of this line of thinking is typified by Heinrich's (1959) observation that nine incidents out of 10 could be attributed to unsafe acts as primary causative factors. This failure to look further to understand the factors which caused the unsafe behaviors limits the suitability of accident reports for behavioral research. Dunn (1971) said:

> There have been a large number of correlational studies that have established relationships between personal characteristics and the environmental characteristics, and accident frequency. The psychoanalysts on the other hand have suggested, and sometimes demonstrated a connection between personal trauma and accident frequency. There is a major drawback with both these approaches to the problem of accident causation, and that is the ommission of any attempt to analyse the whole sequence of events that lead from some personal or environmental characteristics to the occurrence of an accident. The missing link is the behavioral manifestation of the personal trauma, or the 'Unsafe behavior' that is the result of environmental conditions or personal factors.

Another reason for not using injury rates or other direct measures of safety based on reported injuries is that for every fatality or serious accident there are a large number of minor accidents and correspondingly, a much larger number of unsafe acts and hazardous opportunities (Ramsey, 1973). Accident reporting schemes and investigation procedures which localize on serious, major, or even reportable accidents represent a much smaller population than that associated with unsafe behaviors, and/or the hazardous conditions which result from unsafe behaviors.

The nature of this phenomenon lends itself very well to a sampling procedure. The use of work sampling, ratio delay, or safety sampling has ample precedence for a wide variety of industrial applications (Tarrants, 1980; Johnston and Rogers, 1975; Barnes, 1972; and Peterson, 1971). A statistically valid representation of any reoccurring activity can be made through random event sampling. If random observations of a continuous activity are made, and if the number of these random observations are sufficiently large, then the ratio between two mutually exclusive conditions (eg., safe or unsafe) will not be statistically different from that obtained by continuous monitoring of the activity. Although some have expressed concern about workers changing their behavior when they are being observed, it is well documented that this is a transient change which disappears after repeated observations (Barnes, 1972).

There are many factors which influence unsafe behavior. Margolis and Kroes (1975) classified them into two major categories: environmental factors and psychological factors. The stress level of the work environment, characterized by heat, noise, light, information overload, etc., should be within tolerable limits so that human behavior can remain near optimum, error-free and productive. If workers are exposed to a lower or higher level of environmental stress, they are very likely to develop neurological or physiological strain, or behavioral disruption or disorganization.

In the case of thermal environments the classifications by Margolis and Kroes are based more on other relationships than on known influences on unsafe behavior (e.g., temperatures beyond extreme limits affect both personal feelings of comfort and physiological responses; and, studies conducted in a wide variety of work tasks and conditions, indicate that extreme environmental temperatures correlate with decreased productivity and increased error rates). Limited attempts have been made to directly relate accident experience with worksite thermal conditions.

The comprehensive report from the National Institute of Industrial Psychology by Powell, et al. (1971), described a shop-floor study which included forty-two continuous months of observation and 2,367 accidents in four different types of industrial workshops. A thermograph was used to continuously record dry bulb temperature and the humidity so that it was possible to categorize accidents as a function of the ambient temperature conditions. Dry bulb temperature showed a significant effect on accidents in two of the observed plants. The temperatures observed were in the 15°C to 24°C range, with the higher accident rates occurring at the low temperatures and with the lower rates occurring as the temperatures increased. A third plant showed no temperature effects on accidents, and a fourth plant was analyzed differently due to fewer accidents and a greater range of temperature and humidity (i.e., wet bulb temperatures ranged from -5°C to +30°C). In this shop, a direct relationship between the workload and the number of accidents was discovered, so workload factors were isolated before the effect of climatic conditions on accidents was studied.

The relationship between climate and accidents did not show statistical significance, but it was suggested that this was due to the small number of observations which precluded adequate analysis. The investigators, however, in discussing the effect of clothing mentioned that in hot weather the men were able to take off their shorts to keep comfortable. Therefore, in the higher temperature range they expected an increase in accidents because the men wore less protective clothing (Powell, et al., 1971).

NIOSH in its criteria document recommended a set of upper limits of thermal exposure for unimpaired mental performance (NIOSH, 1972). The premise of this recommendation was that thermal environments which would impair mental performance would also have potential negative safety implications. This document also reports a study by Moses which suggests that increasing the workers' body temperature and discomfort, increases the levels of irritation, anger, and emotion, which may in turn induce workers to act rashly or to have their attention diverted from hazardous tasks. Results of a four-year study of accidents in a steel mill shows the peak accident rates to occur at the period of the year that corresponds to the peak dry bulb and dew point temperatures (Belding, et al., 1960). Although there are other seasonal factors which peak during the summer (e.g., vacation schedules, long daylight hours), which may have a confounding influence on accident rates, this relationship does suggest a definite parallel between weather and accident frequency.

Surry (1968) makes the comment that "It will be seen that the conditions for thermal comfort are essentially the same for peak work efficiency and for minimum accident rates." The increase in accidents with temperature can result from a large number of possible factors; e.g., increase in metabolic cost and fatigue, faster heartbeat and respiration changes, creation of slippery tool handling due to sweating, and reduction of peripheral vision and perceptual motor abilities. In hot work places, such as handling molten metals, glass, or other disagreeable tasks, special hazards are created in addition to the heat, due to general annoyance and discomfort (Surry, 1968).

Osborne, et al., (1922), demonstrated that industrial accidents in manufacturing increased above and below an optimum air temperature of approximately 18.3°C (65°F) dry bulb. A study by Farmer, et al., (1933), suggested an increase of 25% in accident rates with a ± 2.8°C (5°F) change in air temperature. Both of these early studies depict a similar U-shaped curve that has been confirmed frequently over the years.

Performance and accidents in cold environments have received less attention and study than those in hot climates. Physiological and performance effects are very noticeable when exposure to a cold temperature is prolonged and at a substantial decrease in temperature level. Exposure to cool or moderately cold environments, such as found in most indoor work places, does not result in such noticeable effects. This is especially so when the exposed workers have the freedom and ability to modify their clothing in concert with the environment. The sense of touch and the manipulative ability of the fingers and hands are among the first functions affected by the cold environment. Potential causes of accidents in the cold might be sluggish movement, reduced sensitivity in fingers and toes, slowed visual response, interference from bulky clothing, annoyance, and discomfort in the cold (Surry, 1968).

The loss of manipulative ability is initially encountered in a cold environment and this is amplified by loss of flexibility in the muscles of the forearm, fingers, and in the joints due probably to increases in synovial fluid viscosity. The general concensus is that the loss of perceptual-motor performance in the cold is primarily a result of deterioration of motor capabilities rather than of mental deterioration resulting from the cold.

The human body usually maintains body temperature at an approximately constant level in spite of wide variations in the surrounding thermal environment. To maintain a constant body temperature, an organism must balance its rate of heat loss against that of heat gain. The balance of heat exchange between the worker and the environment can be represented by the equation:

$$Q = M \pm R \pm Cv \pm Cd - E$$

where

Q = heat storage and equals zero as a body is in heat balance,
M = metabolic heat,
R = radiant heat,
Cv = convective heat,
Cd = conductive heat,
E = evaporative heat.

The metabolic heat (M) must be positive as a gain of heat, while the evaporative heat (E) must be negative as a heat loss in this equation.

ASHRAE has defined thermal comfort as "that condition of mind which expressed satisfaction with the thermal environment," (ASHRAE Standard 55-74). Some investigators employed the phrase "thermally neutral" as synonymous to thermal comfort. As comfort is judged by a person exposed to a particular thermal environment, and as it is based on personal feelings of comfort, the estimate of thermal comfort is subjective in nature. The most common scale of thermal comfort is the thermal sensation scale. The seven levels in this scale are: 1. cold, 2. cool, 3. slightly cool, 4. neutral, 5. slightly warm, 6. warm, and 7. hot.

Two of the major factors that affect the level of comfort are the rate of metabolic activity and the amount of clothing worn. In general, the higher the metabolic workload, the lower the temperature necessary for comfort (McNall, et al., 1967).

From the studies that have relied on subjective estimates of thermal sensation, it can be seen that there is a general agreement about the preferred temperature. Fanger has suggested preferred air temperatures for seated persons dressed in cotton twill shirts and trousers of 25.7°C and 24.5°C (Fanger, 1972 and Fanger, et al., 1973, respectively). ASHRAE (1977) recommended a comfort zone of 73°-77°F (22.75°-24.95°C respectively) for office work.

An investigation of thermal stress and comfort is reported by Hindmarsh and Macpherson (1962) for a group of seated adults wearing normal indoor clothing. The comfort curve as voted upon by these respondents centered with a mean, mode, and median all near an air temperature of 22.9°C. It was noted, however, that at the mean point only eighty percent of the population voted to be "comfortable"; ten percent considered conditions too warm, and another ten percent considered them too cool.

Humphreys (1981) summarized results from over thirty independent studies of thermal comfort which have been reported in the literature. He found that the preferred air temperature reported in the majority of these studies ranged between 17°C and 26°C. Studies used in this summary included data for both males and females and included data from offices, schools, laboratories, and light industry. Humphreys further noted that as the monthly mean outdoor temperatures increase into a hot range, the preferred temperature for comfort tended to increase. Persons working at higher levels of metabolic workload will tend to select a comfort temperature lower than they would for sedentary activity; however, if such work is performed in the summer with its hot seasonal temperatures, there would be a tendency, according to Humphreys, for the preferred temperature to occur at an increased level.

Investigations concerning heat and performance demonstrate a wide variety of results; however, there is general agreement that thermal conditions beyond certain limits affects performance. A summary of relationships between hot environment and the performance of sedentary tasks as reported in the literature shows that certain tasks are affected by thermal environment, some are partly affected, and some tasks are not affected at all (Ramsey and Morrissey, 1978). A commonly reported relationship between performance of perceptual-motor tasks and thermal conditions is the inverted-U, where highest performance is associated with optimal midrange temperatures, and decreases with positive or negative changes in the temperature (Poulton, 1972).

Salvendy (1982) in his article on stress related factors says,

> "Currently no documented relationship exists between stress and accidents. However, it can be hypothesized that such a

relationship may indeed exist....... Research is needed to determine the optimal level of stress needed for minimizing the occurrence of accidents."

His curve of the hypothesized relationship between the level of stress at the work place and the rate of accidents depicts the rate of accidents to be a U-shaped curve as a function of increasing stress levels.

It is also hypothesized by Surry (1968) that accidents as well as errors are more likely to occur to a person when experiencing a very high arousal level because he is unable to coordinate all the necessary information and act directly upon it. Also if the arousal level is low, accidents could occur because the person is not observing the environmental clues to be able to act upon them. Optimal alertness is thus vital for efficiency of output and safety, and this relationship can readily be described with the U-shaped curve (Surry, 1968).

The characteristics of thermal environment are temperature, radiation, humidity, and air velocity. The effects of these factors on people have been studied under a wide variety of conditions, yet comparisons between the studies have been complicated by a lack of consistency in the indices used to report the environmental conditions. Cold exposure studies generally use one index, thermal comfort studies use others, and heat stress studies use several indices. No single thermal index has been established as a valid measure of danger due to cold, thermal comfort, and danger due to hot conditions.

The thermal index recommended by NIOSH (1972) for use in hot environments is the Wet Bulb Globe Temperature (WBGT). Yaglou and Minard (1957) developed the WBGT to serve as a relatively simple substitute for the Corrected Effective Temperature index which requires the measurement of air velocity. Experience has shown that indices which require air velocity measurements are difficult to use in industries where the workers are mobile. Consequently, the WBGT index has found greater use in industry than other thermal indices. For outdoor use when solar radiation is present, the WBGT requires measurement of air temperature (DB), globe temperature (GT) and natural wet-bulb temperature (NWB). Indoors or when solar radiation is absent, only the globe and natural wet-bulb temperatures need to be measured.

For outdoor use:

$$WBGT = 0.7NWB + 0.2GT + 0.1DB,$$

For indoor use:

$$WBGT = 0.7NWB + 0.3GT$$

By virture of its simplicity and broad acceptance, the WBGT index was selected to describe the thermal conditions found in this study.

RESEARCH PROCEDURES

Experimental Protocol

This study was conducted using indoor work tasks at two industrial plants: a metal products manufacturing plant and a foundry. The layouts of the two plants are shown in Appendix A. A wide variety of industrial work tasks and work stations were observed, including welding, crating, painting, machine tool operations (e.g., turning, tapping, milling, boring, grinding, drilling), shipping and receiving operations, pattern making, thermal and chemical core making, mold shaking, pin machining, milling, shot tumbling, and casting.

The data were collected over a fourteen month period at the rate of approximately 60 observations per day from the first of July through the end of August of the following year. Prior to the data collection period, a taxonomy of unsafe worker behaviors and data sheets for the two plants were developed.

Each data sheet lists the observer, day of the week, time of observation, date, and the outside ambient temperature conditions, (See Appendix B). Data were obtained for each machine/work station according to a numerical identifier. Also included on the data sheet was a listing of safe/unsafe behavior observations, an estimate of workload at the time of the observation, and a set of thermal measures which will be explained in the independent variables section. Observers made daily trips to the plants so that both plants received approximately the same number of visits throughout the study. Observers carried the temperature measurement equipment to each work station during each trip to the plant. The time of each visit was chosen at random. Each trip to a plant included two separate data collection walks through the plant. Temperature data was collected at all points shown on the layouts.

At the first data collection point, the wet-bulb wick was wetted, and the monitor was allowed to stabilize for 5-15 minutes depending on the temperature. An unsafe behavior taxonomy, which will be discussed later, was used to identify the type of behavior. Subjects were observed for approximately 30 seconds to determine their work behavior. The tripod with the mounted equipment was placed close enough to the subject to assure that it evaluated the thermal environment of the subject, but not so close that it interferred with the work or activities of the worker. After data were collected at the first station, the next station was chosen at random to avoid any bias. At the end of the first walk, the observer waited for about 10 minutes before commencing his second walk. After completion of a 30 day pilot study, workers displayed little concern or behavioral change due to the presence of an observer.

Statistical Design

The major groups of variables which will be discussed in this section are: the independent variables; the dependent variables; and other variables.

Independent Variables

The independent variables were: ambient temperature, metabolic workload, job risk group, period of the day, day of the week, and observer.

Ambient Temperature

Since the primary purpose of this study was to correlate unsafe behavior with hot working environments, comprehensive monitoring of the industrial environment was required. The Wet Bulb Globe Temperature (WBGT) was used to evaluate the environmental heat stress. A heat stress monitor was mounted upon a tripod and carried by the observer to the measurement locations through the plants. The monitor provided a direct reading in degrees Celsius of the WBGT indoor, WBGT outdoor, dry-bulb temperature (DB), wet-bulb temperature (WB), and globe temperature (GT). The WB reading was actually natural wet-bulb (NWB). The WBGT indoor scale was used in this study as all of the selected jobs were indoors. Three Reuter-Stokes instruments were used in this study, one was model RSS-211A and two were model RSS-211D. It was necessary to use three sets of instruments because of repeated electronic circuit failures. However, all instruments used in the study were initially calibrated after any repair, and then periodically recalibrated in an environmental chamber.

A Taylor hygrometer which measures dry-bulb (TDB) and natural wet-bulb (TWB) temperatures was mounted on the back of the Reuter-Stokes instrument. This hygrometer was used to check the DB and WB readings of the Reuter-Stokes instrument whenever the observer suspected its accuracy.

All thermal instruments were periodically calibrated in an environmental chamber over a range 10-35°C WBGT by comparison with a standard WBGT tree as suggested by NIOSH (1972). A comprehensive calibration was conducted monthly and a simple calibration check was conducted weekly. The difference between the standard WBGT tree and the field collection instruments did not exceed 1°C for the different heat measures.

Metabolic Workload

In addition to the heat of the environment, the thermal equilibrium of a worker is also directly affected by the metabolic heat generated as a result of the work task. It is difficult to accurately measure the metabolic heat generated by a worker in a non-laboratory situation. It is feasible, however, to use data such as that in Table 1 which provides a means of estimating general metabolic workload (Ramsey, 1978).

Table 1 was used in this study to provide a general estimate of metabolic workload; a procedure which avoids many of the problems encountered when trying to precisely determine metabolic heat in a field location. Typical problems include: job intereference, increased metabolic workload, safety hazards, reliability of laboratory equipment in field use, access to power for equipment, and distraction of worker. Three levels of metabolic workload (M) were used in this study: light workload ((M) range is $\leq$ 200 Kcal/h); moderate workload (201 $\leq$ M $\leq$ 300 Kcal/h); and heavy workload (M $\geq$ 301 Kcal/h).

Job Risk Group

Every job in industry involves some degree of associated safety risk although some jobs involve more risk than others. For instance, a person operating a numerically controlled machine would be exposed to less risk than a person working as a member of a pouring crew in a foundry. The numerically controlled machine operator, by the very nature of the job is exposed to less risk than is the foundry worker. Hence, a study of safety behavior for these two jobs should take into account the inherent risk in the job in order to prevent the risk factor from masking the effects of temperature on safety behavior.

After a short period of data collection, this risk phenomenon was recognized by the high variability in unsafe work behavior among the different jobs included in the study. Consequently, the jobs were categorized based on the preliminary data and on a judgemental assessment of the general level of risk. Three job risk categories were established: low-risk ($p<.05$), moderate-risk ($.05\leq p<.1$), and high-risk ($p\geq.1$) as follows:

1. Low-risk jobs: NCTAP (numerical control machine operators), THERM (thermal-set core makers), CHEMS (chemical-set core makers), ISO (iso-set core makers), COREM (core operators), MULLR (mulling machine operator), PIN (molding machine operators), and SHAKE (shake-out operators).

2. Moderate-risk jobs: DRILL (drilling machine operators), LATHE (lathe operators), S/R (shipping and receiving), ASSY (assembly personnel), SHAKR (shakers), SHOT (shot blasters), and PATRN (pattern makers).

3. High-risk jobs: GRIND (grinders), BORML (bore-mill operators), CRATE (craters), WELD (welders), BENGR (bench grinders), FLOGR (floor grinders), and CREW (pouring crew).

Work Level	Energy Expenditure Range
Level 1—*Resting*	100 kcal/hr or less
Level 2—Light *Sitting at ease; light hand work (writing, typing, drafting, sewing, bookkeeping); hand and arm work (small bench tools, inspecting, assembly, or sorting of light materials); arm and leg work (driving car under average conditions, operating foot switch or pedal). Standing: drill press (small parts); milling machine (small parts); coil taping; small armature winding; machining with light power tools; casual walking (up to two mph).*	101 to 200 kcal/hr
Level 3—Moderate *Hand and arm work (nailing, filing); arm and leg work (off-road operation of trucks, tractors, or construction equipment); arm and truck work (air hammer operation, tractor assembly, plastering, intermittent handling of moderately heavy materials, weeding, hoeing, picking fruits or vegetables); pushing or pulling lightweight carts or wheel barrows; walking two to three mph.*	201 to 300 kcal/hr
Level 4—Heavy *Heavy arm and truck work; transferring heavy materials; shoveling; sledge hammer work; sawing, planing, or chiseling hardwood; hand mowing, digging, ax work; climbing stairs or ramps; jogging, running, walking faster than four mph; pushing or pulling heavily loaded hand carts or wheel barrows; chipping castings; concrete block laying.*	Above 301 kcal/hr

TABLE 1: METABOLIC WORKLOAD CLASSIFICATIONS

(Ramsey, 1978)

At the end of the study, the proportion of unsafe behavior rate (p) for each job was determined in order to verify the grouping of risk-levels made at the beginning of the study. No major difference was found.

Period of the Day

Another independent factor in the present study is the period of the day or shift. This factor potentially reflects the effect of fatigue and time-at-work on the safe work behavior. Four periods were used to classify observations, i.e., early morning, late morning, early afternoon, and late afternoon. The lunch break was used to distinguish between morning and afternoon observations. The midmorning and midafternoon breaks, which were taken at slightly different times at the two plants, were used to distinguish between the early and late sessions of the morning and afternoon respectively.

Day of the Week

The day of the week (Monday, Tuesday, Wednesday, Thursday, and Friday) was considered as an independent variable in this study in order to evaluate its influence on unsafe behavior.

Observer

The data of this study were collected by three observers. In order to maintain the emphasis on consistency of definitions of unsafe behavior among observers, a file of definitions and examples was prepared for each individual unsafe behavior category as shown in Appendix C. This file served as a basis for re-orienting the observers to common definitions of when a worker's behavior should be identified as unsafe. Prior to actual data collection, each observer completed a training period to insure understanding the definition of each unsafe behavior category and for evaluating the metabolic workload rate. As a means of assuring consistency in observation techniques and definitions of unsafe behavior during the study, each observer conducted a joint visit with another observer at least once a month. During joint visits, independent observations of safety behavior and the environmental conditions were made by each observer. The data were then compared at the end of each walk in order to provide corrective feedback and to assure consistency in defining unsafe behaviors, reading the instruments, and estimating metabolic workload.

Dependent Variable

Unsafe Behavior Rate

Unsafe work behavior rate is the dependent variable of this study. It is well known that the number of occurrences per unit (e.g., defects per piece or unsafe behavior per work station) often follows a

Poisson distribution, and such response variables are not only nonnormal, but where the variances and means are equal. When proportions or percentages are used as the response variable, the data are binomial, variances are related to means and the basic assumptions of analysis of variance do not hold. In order to make them amenable to regression and analysis of variance, the proportional data of this study were transformed as the arc sin square root of p ($\sin^{-1} \sqrt{p}$) (Davies, 1954).

The proportion of unsafe behavior (p) is defined as the ratio of unsafe observations to total number of observations as follows:

$$p = \# \text{ Unsafe Observations } / \# \text{ Total Observations}$$

Unsafe behavior rate (USBR) then is defined as the transformed proportion for use in subsequent statistical analysis:

$$USBR = \sin^{-1} \sqrt{p}$$

It should be noted that unsafe behavior rate (USBR) is an increasing function of the proportion of unsafe behavior (p). Therefore, any statistical conclusion drawn concerning USBR will apply to the proportion (p).

Accident occurrence was originally considered as a potential dependent variable of interest in this study. However, the actual number of accidents was very small, and the ability to determine the thermal conditions at the time of the accidents proved to be limited. These deficiencies were not found in the unsafe behavior data which were selected for analysis.

<u>Other Variable</u>

Taxonomy of Unsafe Worker Behaviors

A taxonomy of unsafe worker behaviors was developed to provide a means of systematically categorizing the behavioral activities which could potentially precede an accident. This taxonomy is shown in Table 2. The two basic references utilized in developing this taxonomy were the American National Standards Institute (ANSI) Z16.2 (1963) and the Department of the Interior's Accident/Incident Code (Pope, 1972).

The taxonomy of unsafe worker behaviors was divided into three major types: related to the worker; related to tools, equipment or materials; and, related to materials handling equipment. Unsafe worker behaviors related to the worker included: improper use of body, unsafe position or posture, unsafe body movements, failure to use protective clothing, and failure to dress properly. Unsafe worker behaviors related to tools, equipment, or materials included: tool,

TABLE 2

TAXONOMY OF UNSAFE WORKER BEHAVIORS

100. RELATED TO WORKER

110. Improper Use of Body

111. Used hands, not tool (to feed, clean, adjust, grip, hammer).
112. Insecure grip (oily, pinch, grasp, too many objects).
113. Inappropriate lifting (with back, not legs, extended, torsional).
114. Should use mechanical lift or get help (crane, hoist, two person load).
119. Not elsewhere classified.

120. Unsafe Position or Posture

121. Cramped, awkward or unsafe position (bend, stoop, work in small quarters).
122. Working too close together (gang too close to each other, tripods in assembly, materials handling).
123. Exposed under suspended load (under hoist or fork).
124. Unnecessary exposure (to heat, cold, fumes, paint, electricity, sand, dust).
125. Riding in unsafe position (on forks of lift, on hook of crane).
126. Unnecessary exposure to moving material or equipment (work in aisle or travelway).
129. Not elsewhere classified.

130. Unsafe Body Movements

131. Operating too fast (movement of body members, material handling).
132. Moving whole body too fast (walking, running).
133. Feeding two fast (supplying, pushing, drilling, sawing, grinding too fast, motor bogs down).
134. Throwing not handling (warehouse, handling parts/pumps).
135. Descending, ascending unsafely (jumping off, down, two steps at a time, truck/storage platforms).
136. Inattention to footing, seat, or surroundings (tripping over curb, platform edges).
137. Distracted from task (woman walking by, watching horseplay, radio too load).
138. Failure to follow regulations/policy (horseplay, smoking in non-smoking area).
139. Not elsewhere classified.

140. Failure to Use Protective Clothing

141. Goggles, glasses (protective eyewear, side shields).
142. Foot/toe protection (shoe and toe devices).
143. Gloves (special to fit job done, hand protection).
144. Face/respiratory protection (dust mask, shield, ear plugs, welding masks, respiratory protection).
145. Trunk/leg protection (chain saw, firefighting, foundry).
146. Hard hat/bump cap.
149. Not elsewhere classified.

150. Failure to Dress Properly

151. Loose or inappropriate clothing (sleeves improper length, long trousers, belts).

152. Unrestrained long hair (should use band, net, hat).

153. Adornments (rings, watches, necklace, neckties, pocket chains).

159. Not elsehere classified.

200. RELATED TO TOOLS, EQUIPMENT, OR MATERIALS

210. Tools, Equipment, or Materials Errors

211. Wrong tool, equipment, or material for job done (wrench as hammer or cheater, screw driver to clean).

212. Unsafe use of tools, equipment or materials (correct equipment used unsafely, spray paint outside booth, welding outside area or in aisle).

213. Cleaning, oiling, adjusting, moving equipment (changing bits while drill is moving, under power not coasting to a stop, clean lathe).

219. Not elsewhere classified.

220. Unsafe Placing of Tools, Equipment, or Materials

221. Unsafe placing of material moving/handling equipment (parking, stopping, or leaving carts, elevators, conveying apparatus).

222. Unsafe placement of tools, materials, scrap (tripping, bumping, slipping hazards, poor housekeeping).

223. Inattention to tool, material placement (placement on table, unstable, precarious).

229. Not elsewhere classified.

230. Failure to Shut Down Potential Energy

231. Power circuit or flame not secured (maintenance on electric motors, high voltage lines, unguarded open flame).

232. Machine device not shut off, unattended (motors and engines, auto feed, welding gases, saws).

233. Failure to lock, block, or secure against unexpected motion (gas bottles, shafts unblocked, tubing on end).

239. Not elsewhere classified.

240. Making Safety Device or Equipment Inoperative

241. Making device inoperative or failure to use (welding shields, barriers, rails, switches, guards, remove, disconnect, or misadjust safety devices).

249. Not elsewhere classified.

300. RELATED TO MATERIALS HANDLING EQUIPMENT

310. Relating to Crane, Hoist, or Fork Truck

311. Failure to warn (starting, stopping, backing, turning, signals, releasing loads, move load above people).

312. Driving or moving too fast.

313. Misjudged clearance, lane, or position (cross over line, between boxes, aisles, pass on wrong side).

314. Overloaded, load insecure (beyond capacity, load too high).
315. Dropping, not placing carefully.
316. Suspended load unattended.
319. Not elsewhere classified.

<u>320. Relating Only to Crane and Hoist</u>

321. Hook in passageway or in motion.
329. Not elsewhere classified.

<u>330. Relating Only to Fork Truck</u>

331. Improperly parked or positioned (no parking zone including aisle, unauthorized parking space).
332. Passenger without seats (operator allows standing or sitting on vehicle).
333. Fork truck unattended, engine running.
339. Not elsewhere classified.

material or equipment error, unsafe placing, failure to shut down potential energy, and making safety device or equipment inoperative. Unsafe worker behaviors related to material handling equipment included: those relating to crane, hoist and fork truck; relating only to crane and hoist; and relating only to fork truck. Appendix C gives a description of each individual category within the taxonomy.

The taxonomy of unsafe worker behaviors served as an independent variable in the analysis of variance for unsafe behavior rate. The analysis in Appendix D, however, considers taxonomy basically as a dependent variable. Thus taxonomy serves both variable roles, depending on the specific analysis.

Statistical Methods

Data obtained during observation periods and recorded onto the data sheets, as previously described, were keypunched into a machine retrievable format for Statistical Analysis System (SAS) output. Data recorded for each observation included date, day of the week, observer, time of observation, machine or activity, metabolic work load, values of thermal variables, and code identification of any unsafe worker behaviors, up to a total of three, which were noticed for each work site observation. The statistical design of the present study consisted of two general models: the analysis of variance (ANOVA) model and the regression model.

Analysis of Variance Models

Two assumptions used in the application of the analysis of variance technique are that the response variable is normally distributed, and that the variances of the experimental errors are equal throughout the experiment. In this study it is necessary to deal with attribute data where the response variable is either 0 or 1, thus the data were the numbers of occurrences of a particular phenomenon (unsafe behavior) or the proportion (p) of such occurrences. As previously mentioned, a transformation (i.e., $USBR = \sin^{-1} \sqrt{p}$) was performed on the data to make it amenable to statistical analysis.

The analysis of variance models were developed to determine the effects of the independent variables and their interactions on the dependent variable. The levels of significant differences between the main effects and their interactions were tested at alpha equal to 0.01. Differences between means using the Duncan Multiple Range test (Hicks, 1973) were tested at alpha equals .05 significance levels.

Regression Models

It was also possible to develop regression models (equations and coefficients of correlation) for the dependent variable and each of the independent variables. For example, each unsafe worker behavior was accompanied by a corresponding WBGT which was observed at the same time. It was not only possible to relate, in an overall sense, unsafe behavior and WBGT, but it was also possible to group the observation data by metabolic load. Thus, correlations between unsafe worker behavior and temperature under light work conditions were compared with those under moderate metabolic work conditions. Similarly, unsafe worker behavior data was grouped by job risk, period of the day, day of the week, and observer. The total unsafe behavior data was grouped into the appropriate categories so that comparative assessment of regression and correlation could be performed.

RESULTS AND DISCUSSION

Developing the relationship between temperature as an independent variable and unsafe work behavior as a dependent variable was the main objective of this study. However, the interactive influences of the other independent variables; metabolic workload level; job risk level, and period of the day are also important.

The statistical technique of analysis of variance (ANOVA) was first used to test the hypothesis that these variables and levels affect the safe work behavior:

1. Temperature. (Five levels: 1 cold ($T < 15°C$ WBGT), 2 cool ($15° \leq T < 20°C$ WBGT), 3 comfort ($20° \leq T < 25°C$ WBGT), 4 warm ($25° \leq T < 30°C$ WBGT), and 5 hot ($T \geq 30°C$ WBGT)),

2. Workload. (Three levels: 1 light workload, 2 moderate workload, and 3 heavy workload),

3. Job risk level. (Three levels: 1 low risk jobs, 2 moderate risk jobs, and 3 high risk jobs),

4. Period of the day. (Four levels: 1 early morning, 2 late morning, 3 early afternoon, and 4 late afternoon),

5. Variable interactions

The results obtained from this ANOVA are shown in Table 3. The table shows that all the independent variables and their interactions have significant effects ($p < .01$) on worker safety behavior with the exception of the temperature*job risk, and temperature*period interactions. The significant effects will be discussed in the same order of their appearance in Table 3.

Since temperature, workload, and temperature*workload interaction all appear to be significant (as shown in Table 3), regression analysis of these variables was also conducted. The linear regression model did not correlate as well as did the second order quadratic model:

TABLE 3

Analysis of Variance (ANOVA) for Unsafe Behavior Rate (USBR)

Source of Variation	DF	Sum of Squares	F-Value	PR>F
Temperature, TL	4	5.5541	8.00	0.01
Workload, WL	2	62.5540	180.18	0.01
Job Risk	2	86.0051	247.72	0.01
Period	3	6.4299	12.35	0.01
TL*WL	8	17.2991	12.46	0.01
TL*Job Risk	8	1.1563	0.83	0.57
TL*Period	12	1.3574	0.65	0.80
WL*Job Risk	4	11.3721	16.38	0.01
WL*Period	6	4.2196	4.05	0.01
Job Risk*Period	6	9.4126	9.04	0.01

See Appendix E for definitions of statistical abbreviations.

$$USBR = A + B(Temp) + C(Temp^2)$$

where,

USBR	is the unsafe behavior rate after applying the arc sin $\sqrt{p}$ transformation.
Temp	is temperature in degrees Celsius WBGT units
A,B,C	are constants
p	is the proportion of unsafe behavior and is defined as the ratio of unsafe observations to total number of observations.

The regression models for the relationship between the unsafe behavior rate (USBR) and ambient temperature at the three different levels of workload are shown in Figure 1 and Table 4.

At temperature levels throughout the range, as shown in Figure 1, the heavy workload tasks have the highest unsafe behavior rates, followed by the moderate workload tasks, and then the light workload tasks. The significance of ambient temperature*workload interaction shown in Table 3 ($p < .01$) demonstrates that differences between the three workload curves shown in Figure 1 are statistically significant.

Figure 1 also shows that the unsafe behavior rate increases, as the metabolic workload requirement of a job/task increases. The work tasks with low levels of metabolic cost appear to have less risk exposure and opportunity for unsafe worker behaviors. The figure also shows that the minimum level of the unsafe behavior rate occurs in the 18° to 23°C WBGT range for light, moderate, or heavy workload. This range coincides with or is slightly below the range specified as thermal comfort for light or sedentary work activities. Beshir and Ramsey (1981) found the comfort temperature for light workload to be 22°C WBGT, and Humphreys (1981) reported numerous studies with preferred air temperatures between 17° and 26°C.

The data for this study were collected over a 14 month period such that a wide array of seasonal weather conditions and indoor temperatures were observed. The clothing selected for use by the workers ranged from short sleeved shirts and cotton trousers to overalls and jackets, but was directly related to the need of the workers to adjust their personal microclimate as a function of temperature and metabolic work load. The U-shaped character and the tendency for all three curves of Figure 1 to reach minimum USBR in the same general range suggest that this ability to regulate the clothing allows a similar

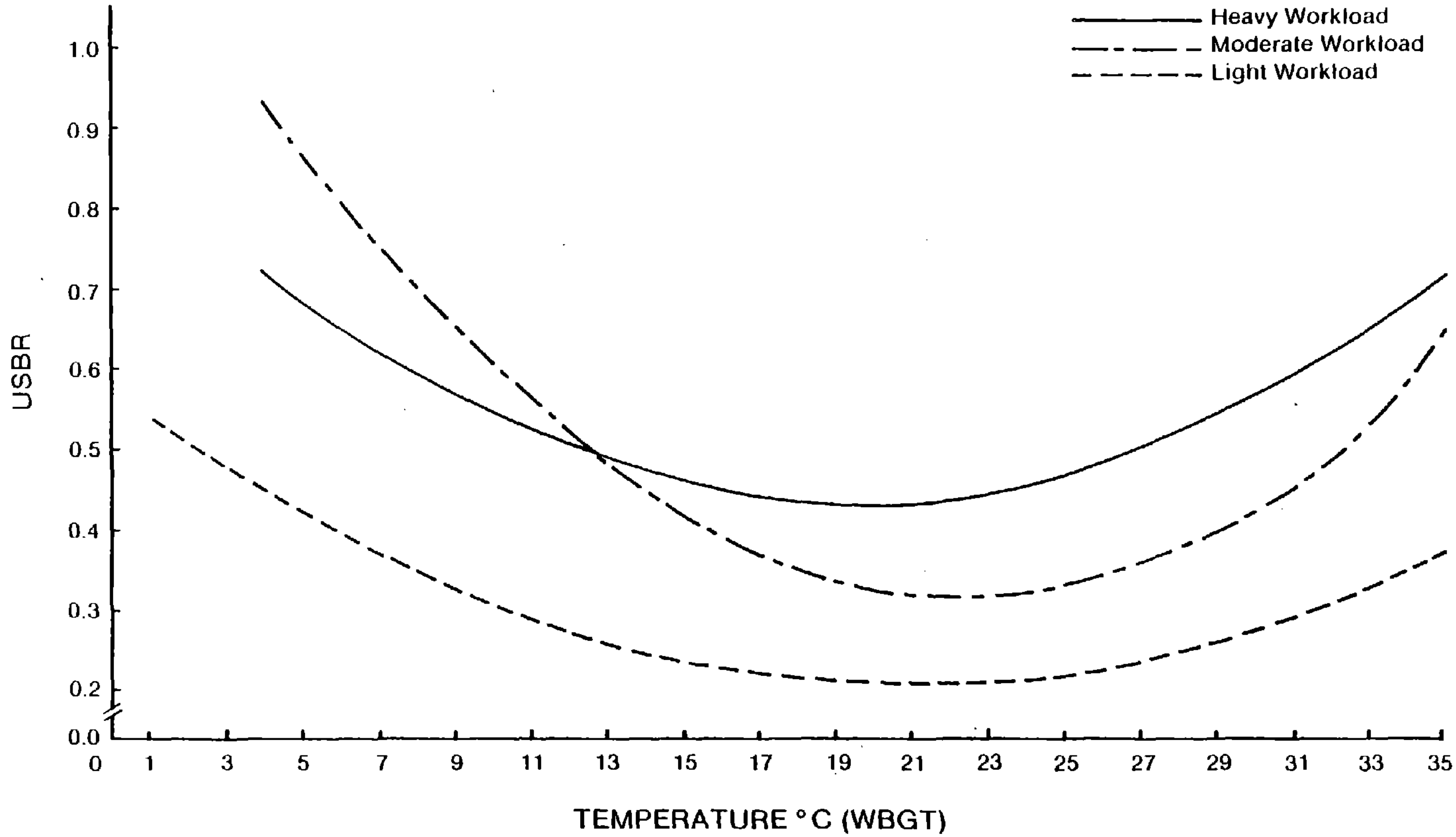

Figure 1: Unsafe Behavior Rate (USBR) as a Function of Temperature: Predicted Second Order Regression for Three Different Workloads

TABLE 4

Relationship Between Unsafe Behavior Rate (USBR) and Ambient Temperature For Different Workload Groups

Workload	No. of Observations	USBR=A+B(Temp)+C(Temp^2)			F-Value	PR>F	R	PR>R	C.V.	S.D.	Mean
		A	B	C							
Light	12379	0.5829	-0.0341	0.0008	13.64	0.01	0.7155	.01	27.35	0.0792	0.2894
Moderate	4595	1.2526	-0.0839	0.0019	9.53	0.01	0.6731	.01	40.79	0.1890	0.4633
Heavy	818	0.8889	-0.0456	0.0012	4.94	0.01	0.5567	.01	26.15	0.1380	0.5276

See Appendix E for definitions of statistical abbreviations and for additional statistics for predictive USBR equations.

comfort zone for light, moderate, and heavy work. A possible explanation for the cross over of heavy and moderate work curves of Figure 1 is that heavy work generates enough heat in the body to counteract the negative effect of the colder environment, thus reducing the resulting USBR.

Table 4 shows the coefficient of correlation for the relationship between unsafe behavior rate and temperature for each workload level (R ranging from 0.5567 to 0.7155). These values of R are highly significant at the one percent level based on the number of observations (Edwards, 1967). Appendix E contains the detailed statistics resulting from this analysis.

As previously mentioned, the job risk level of each job was estimated at the beginning of the study and verified at the end of data collection. Different jobs included in each job risk group are listed in the independent variables section. The low risk group was defined as including those jobs having a proportion of unsafe behaviors (p) less than .05. The moderate risk group was defined as jobs having a proportion of unsafe behaviors between .05 and .10. The high risk group was defined as including those jobs having a proportion of unsafe behaviors greater than .10.

Table 3 shows that job risk level has significant effects on unsafe behavior rate (USBR). The second order regression models for the relationship between USBR and ambient temperature according to the three different job risk groups are shown in Figure 2 and Table 5.

Figure 2 shows that for each of the three job risk groups, the unsafe behavior rate (USBR) increases as the ambient temperature either increases or decreases from the midrange values. The figure also shows that the high risk group has the highest USBR followed by the moderate risk group, and then the low risk. This hierarchy was expected since the work stations were originally assigned to the different job risk groups according to their preliminary proportions of unsafe behaviors, but it is interesting to note that the minimum unsafe behavior rate occurs in the same general preferred temperature range of 17° to 22°C WBGT for each of the job risk groups. Table 5 reveals high coefficients of correlation between USBR and temperature for the different risk groups (R ranging from 0.6298 to 0.7979). These correlation coefficients are also significant at the one percent level in view of the number of observations of each group (Edwards, 1967). Appendix E contains the detailed statistics resulting from this analysis.

Figures 1 and 2 demonstrate clearly that the relationship between USBR and ambient temperature takes a U-shape. The minimum unsafe behavior rate value consistently occurs within this preferred temperature zone, i.e., ranging from 17° to 23°C WBGT (from 18° to 23°C WBGT in Figure 1 and from 17° to 22°C WBGT in Figure 2) for each of the metabolic workload and job risk group levels. If the ambient temperature increases above or decreases below this zone, an increase in

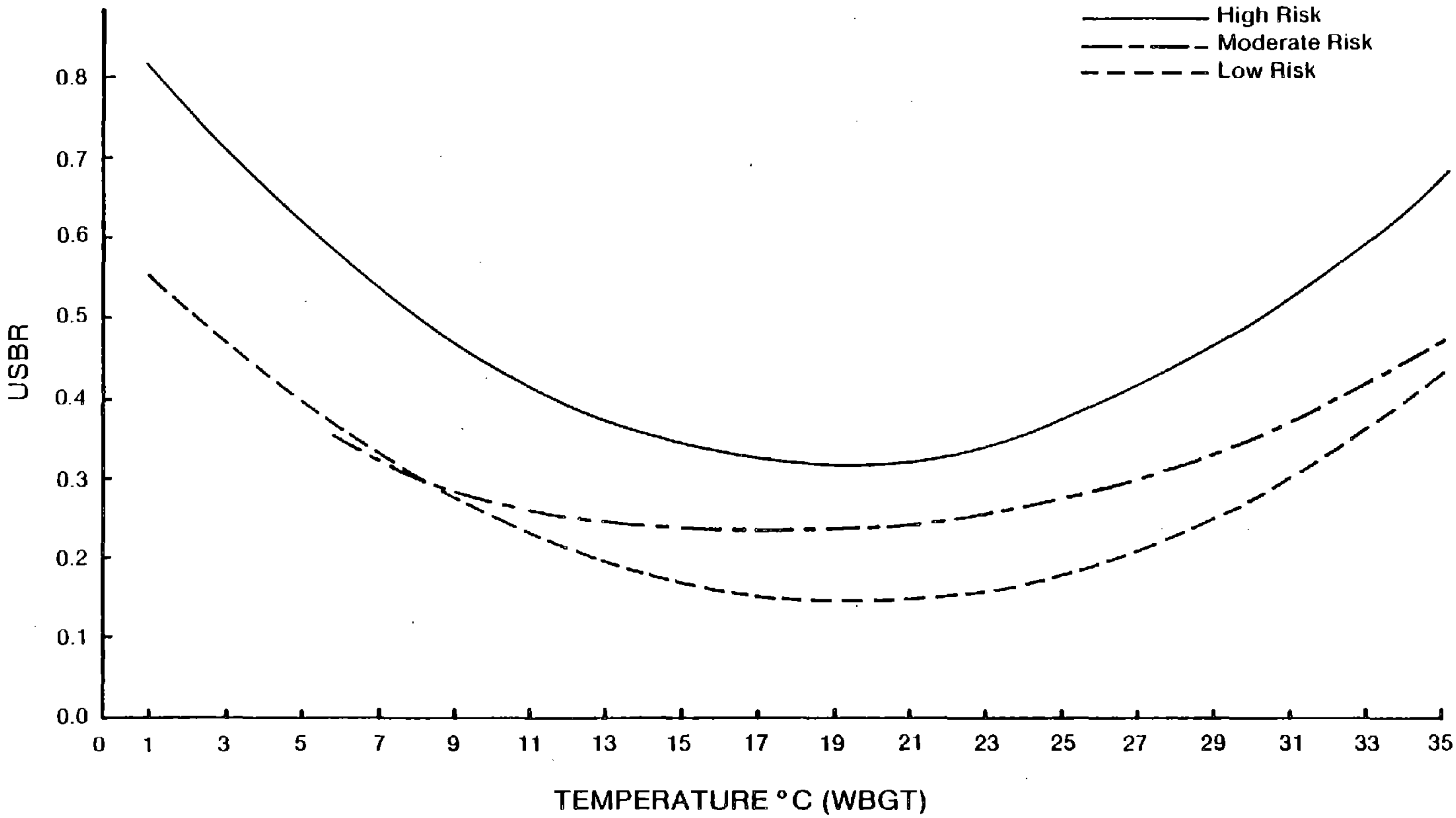

Figure 2: Unsafe Behavior Rate (USBR) as a Function of Temperature: Predicted Second Order Regression for Three Different Risk Levels

TABLE 5

Relationship Between Unsafe Behavior Rate (USBR) and Ambient Temperature for Different Risk Groups

Risk Groups	No. of Observations	USBR=A+B(Temp)+C($Temp^2$)			F-Value	PR>F	R	PR>R	C.V.	S.D.	Mean
		A	B	C							
Low	5354	0.5973	-0.0462	0.0012	10.68	0.01	0.7100	.01	45.71	0.1141	0.2495
Moderate	5844	0.5093	-0.0293	0.0008	5.59	0.01	0.6298	.01	20.76	0.0600	0.2890
High	4694	0.8850	-0.0592	0.0016	18.39	0.01	0.7979	.01	22.21	0.0930	0.4188

See Appendix E for definitions of statistical abbreviations and for additional statistics for predictive USBR equations.

the USBR appears to result. The fit for each of the curves in Figures 1 and 2 is statistically significant at the one percent level.

The U-shaped curve for unsafe behavior translates to an inverted-U curve for safety behavior. The inverted-U phenomenon has also been used to describe increasing performance efficiency as a function of both increasing levels of environmental conditions and increasing levels of arousal (Poulton, 1972). This curve is also consistent with that hypothesized by Salvendy (1982) and Surry (1968). The persistance of a preferred thermal zone in which unsafe behavior appears to be minimum, perceptual-motor performance appears to be maximum, and comfort appears to be optimal is likely a function of several factors. This thermal zone represents conditions which the human normally encounters, and for which, human heat balance is relatively stable, most indoor climates are designed, and clothing is normally selected and worn. These factors tend to reinforce one another as a person selects a preferred temperature.

Table 3 shows that the period of the day (i.e., four levels: 1-early morning, 2-late morning, 3-early afternoon, and 4-late afternoon) has a highly significant effect at the one percent level upon USBR. The relationship between the period of the day and both USBR and temperature is shown in Figure 3, which depicts an increase in unsafe behavior rate throughout the four periods of the day. During the periods of the day time on task also increases as does a potential for fatigue build-up. The WBGT temperature also increases, as shown in Figure 3 and Table 6, in the same direction, so both fatigue and temperature have the potential for affecting the observed increase in USBR.

A Duncan Multiple Range test for period of the day was made for each treatment separately, i.e., for each period level, and it was found that a significant effect on USBR (at the five percent level) occurs only between periods 1 & 2 and periods 3 & 4, i.e., between morning and afternoon. The results of the Duncan Multiple Range test are given in Table 6.

Figure 4 shows the workload*risk interaction effect on USBR. For each job risk group, the increase in the metabolic workload level results in an increase in USBR. It should be noted, however, that the high risk-heavy workload combination yields an unsafe behavior rate that is disproportionately higher than the other combinations.

The relationship between USBR and workload*period interaction is shown in Figure 5. Unsafe behavior rate does not show a period effect for light workload, but does indicate increase under moderate workload. Unsafe behavior rate is higher under heavy workload conditions, except during period one. A possible explanation for this observation is that many of the heavy workload jobs in the foundry and plant have cooler temperature during period one and thus lower USBR. This inconsistency more likely resulted, however, from the small data set available in the period one-heavy workload combination. As shown

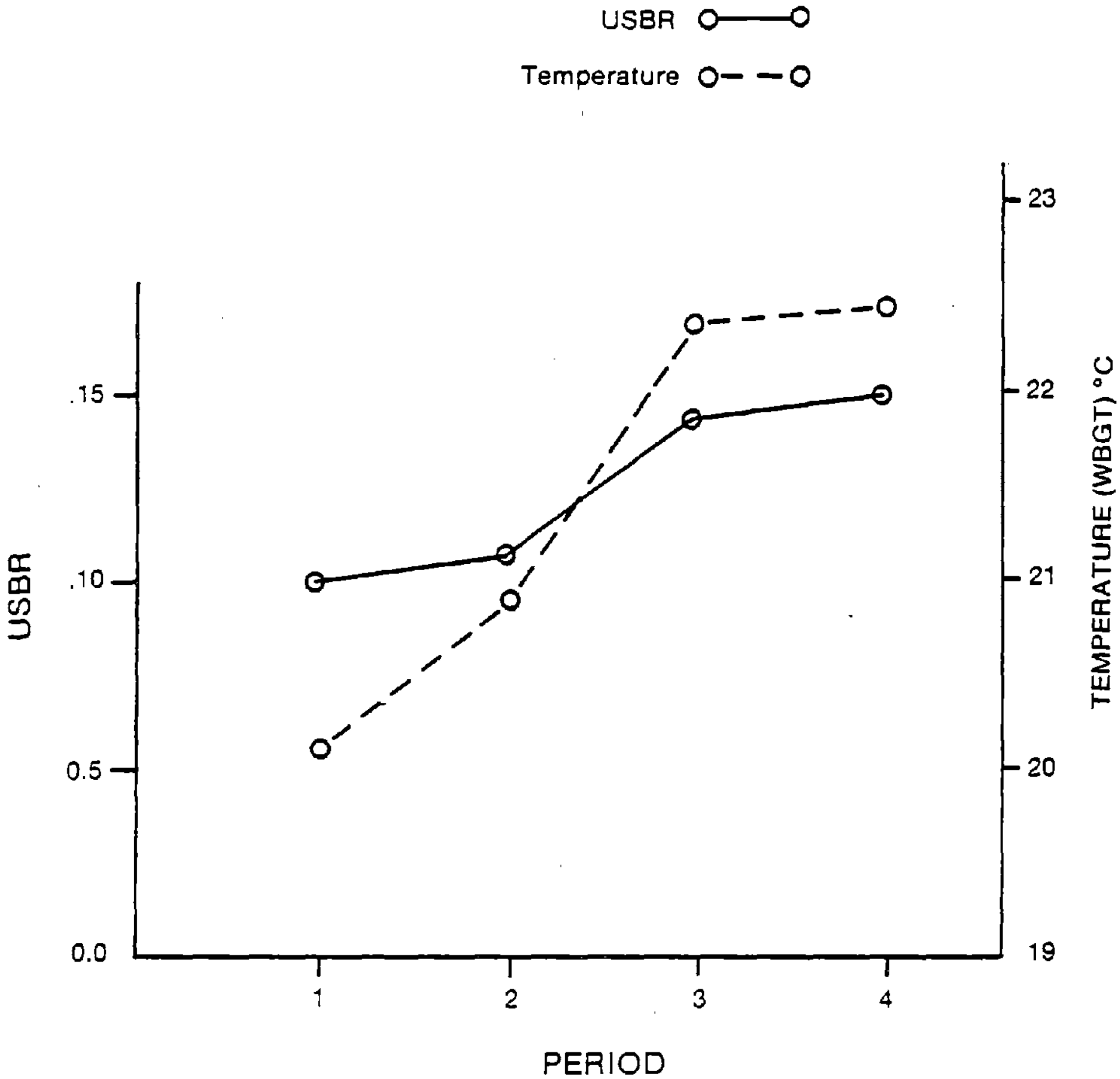

Figure 3: Relationship between Period of the Day and Both Unsafe Behavior Rate (USBR) and Temperature

TABLE 6

Duncan Multiple Range Test for Unsafe Behavior Rate (USBR) and Associated Average Temperature Means with Period of the Day (.05 Level)

Period	No. of Observations	USBR		Associate Average Temperature (WBGT,°C)	
		Mean	Grouping*	Mean	Grouping
1	1313	0.1017	A	20.13	C
2	5853	0.1082	A	20.96	D
3	4765	0.1447	B	22.25	E
4	3916	0.1500	B	22.28	E

*Periods with the same letter are not significantly different.

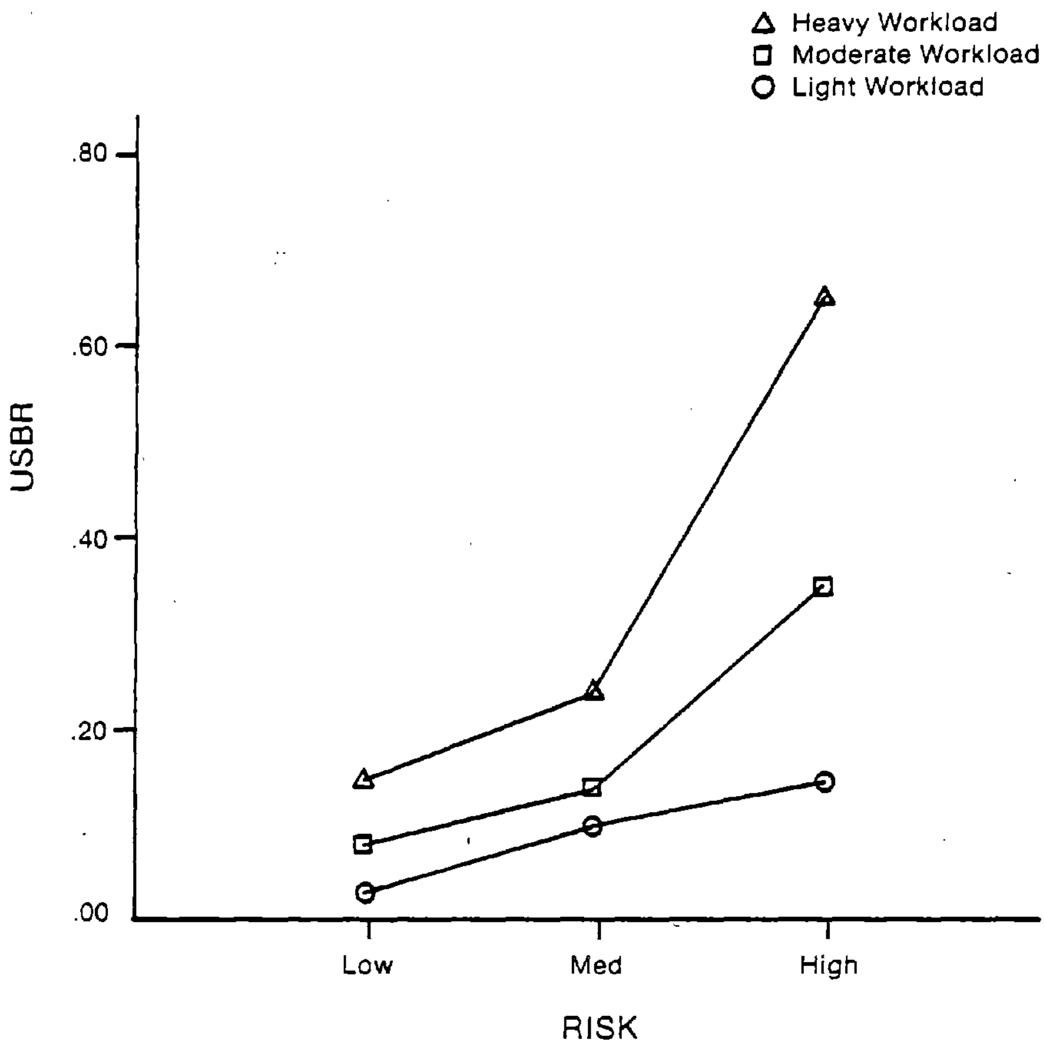

Figure 4: Relationship between Unsafe Behavior Rate (USBR) and Workload*Risk Interaction

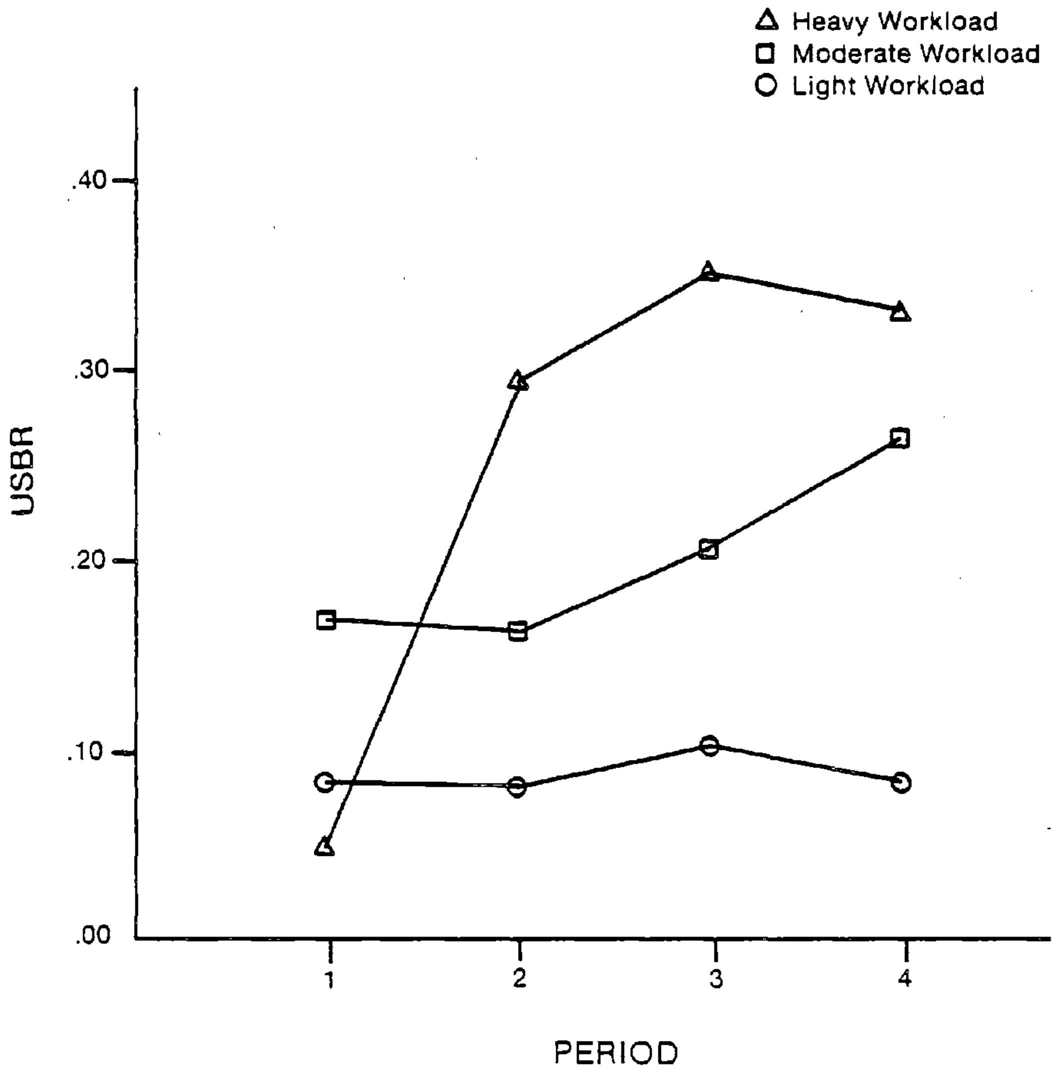

Figure 5: Relationship between Unsafe Behavior Rate (USBR) and Workload*Period Interaction

in Appendix F, this data set of 30 observations was much smaller than the other combinations.

Table 3 shows a significant effect at the one percent level of job risk*period interaction upon USBR. This relationship is demonstrated graphically in Figure 6; with unsafe behavior rate increasing very little over the four periods for the low job risk group, but increasing substantially over the four periods for the high job risk group. Safety behavior on the low risk jobs was apparently influenced very little, or not at all, by the time of day. This is the same relationship that was observed for the light workload pictured in Figure 5. In both instances the nature of the jobs and work is such that the build-up of fatigue is less likely than for the other combinations of risk or workload. This supports the premise that USBR is adversely affected by the time on task or fatigue. On the other hand the temperature which is increasing during the day does not have a noticeable affect on USBR for these light workload or low job risk conditions.

An analysis of variance was performed on the variable, day of the week (i.e., five levels: 1-Monday, 2-Tuesday, 3-Wednesday, 4-Thursday, 5-Friday), with the results showing no significant difference between the different days.

The second order regression models for the relationship between USBR and ambient temperature for the data sets obtained by each observer were also determined. The model obtained for each data set (i.e., for each observer) showed the same patterns shown in Figures 1 and 2 for the relationship between USBR and ambient temperature. Each model showed a U-shaped relationship with the minimum USBR occurring in the range of 17° to 23°C WBGT. This supports the consistency of observations obtained by the different data collectors; as well as the persistence of the U-shaped phenomenon.

The total number of observations in this study was 17,841, with some 16,107 being reported as safe and 1,734 as unsafe. This indicates that according to the definitions of this study, 90% of the worker behavior was safe and about 10% was unsafe. A more detailed analysis and discussion of the unsafe worker behavior classifications can be found in Appendix D.

It should be mentioned that the results obtained from the present study are relevant for industrial environments similar to those utilized in this study (i.e., metal products manufacturing plants, and foundries). However, the large variety of tasks observed in this study are representative of those found in many other industrial situations, and this makes the results more generalizable and broadly applicable.

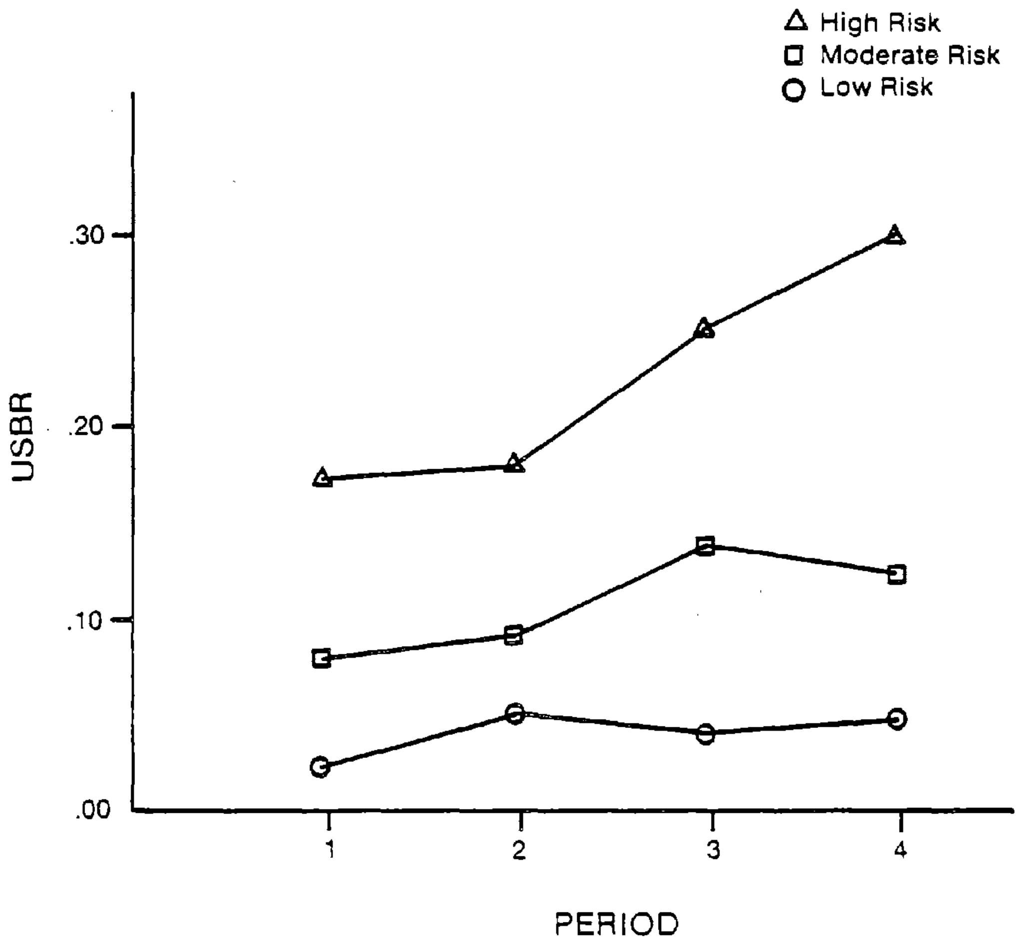

Figure 6: Relationship between Unsafe Behavior Rate (USBR) and Risk*Period Interaction

SUMMARY AND CONCLUSIONS

The study was conducted in two industrial plants, a metal products manufacturing plant and a foundry. A wide variety of industrial work tasks and work stations were observed. The data were collected over a 14-month period starting from the first of July through the end of August of the following year. Measurements were taken daily for a total of over 17,000 observations. A typical data collection visit consisted of first measuring the thermal environment of a work area, using Wet Bulb Globe Temperature as the unit of measurement. Then, randomly observing the specific workers in the work area, using a taxonomy of unsafe behaviors as an indicator of work activity.

The significant observations and conclusions drawn from the results of this investigation are:

1). Ambient temperature has a statistically significant effect on unsafe work behavior rate (USBR) at the one percent level. The relationship between the unsafe work behavior rate and ambient temperature takes a U-shaped curve. The minimum unsafe behavior rate values occur in the preferred temperature zone of, 17° to 23°C WBGT. An increase in the unsafe behavior rate occurs when ambient temperature increases above or decreases below this range.

2). The metabolic workload has a statistically significant effect on unsafe work behavior rate at the one percent level. The increase in the metabolic workload is associated with an increase in the unsafe work behavior rate. The average unsafe behavior rate for any metabolic workload level (i.e., light, moderate, or heavy) is significantly different from the average unsafe behavior rate for any other metabolic workload level. The U-shaped relationship between ambient temperature and unsafe behavior rate occurs for each workload level.

3). Grouping machines and work tasks into different job risk groups (i.e., low, moderate, and high) allows the assessment of differential effects associated with each group. The U-shaped pattern of unsafe behavior rate was consistent for each of the job risk groups. However, the unsafe behavior associated with the combination of heavy workload and high risk level was significantly higher than for other workload-risk combinations.

4). The unsafe behavior rates occurring during the morning were significantly lower than those observed in the afternoon.

5). The effect of the day of the week on the unsafe work behavior rate was not observed to be significant.

6). The U-shaped relationship between ambient temperature and unsafe behavior rate was very persistent for each workload level, risk level, and for the data sets obtained by different observers. A generalized curve demonstrating the observed relationship between unsafe behavior rate and temperature is given in Figure 7.

7). Since the inverse of unsafe work behavior is safe work behavior, the inverted-U can be used to describe the relationship between safe work behavior and temperature. The inverted-U is also commonly used to describe human perceptual-motor performance as a function of increasing environmental conditions and increasing levels of arousal. The findings of this study suggest that the thermal environment has influences on safety behavior similar to those found for perceptual-motor performance, such that the highest levels of both safety and performance occur at the mid-range and the level decreases beyond both sides of this range.

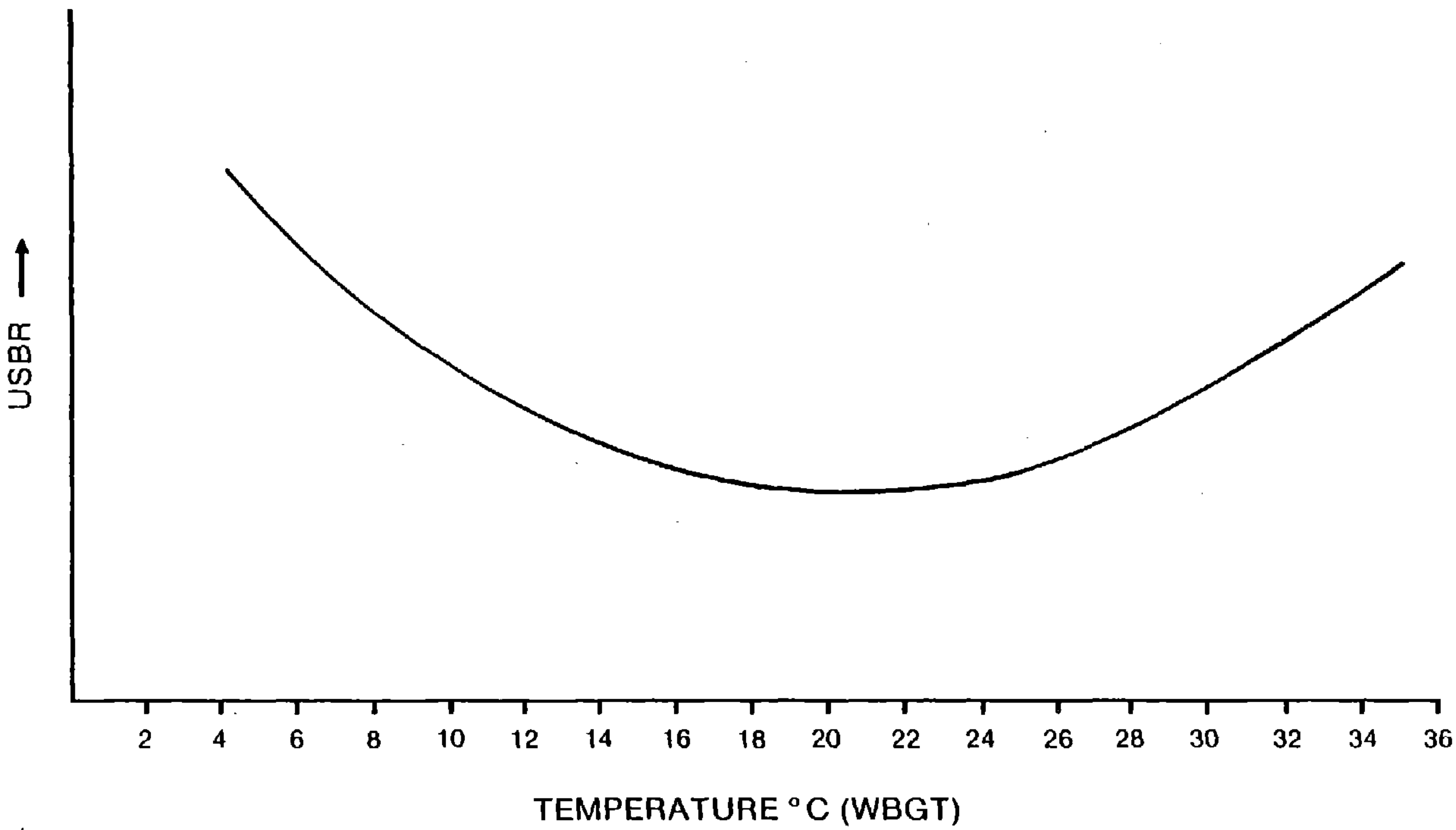

Figure 7: Observed General Relationship between Unsafe Behavior Rate (USBR) and Temperature

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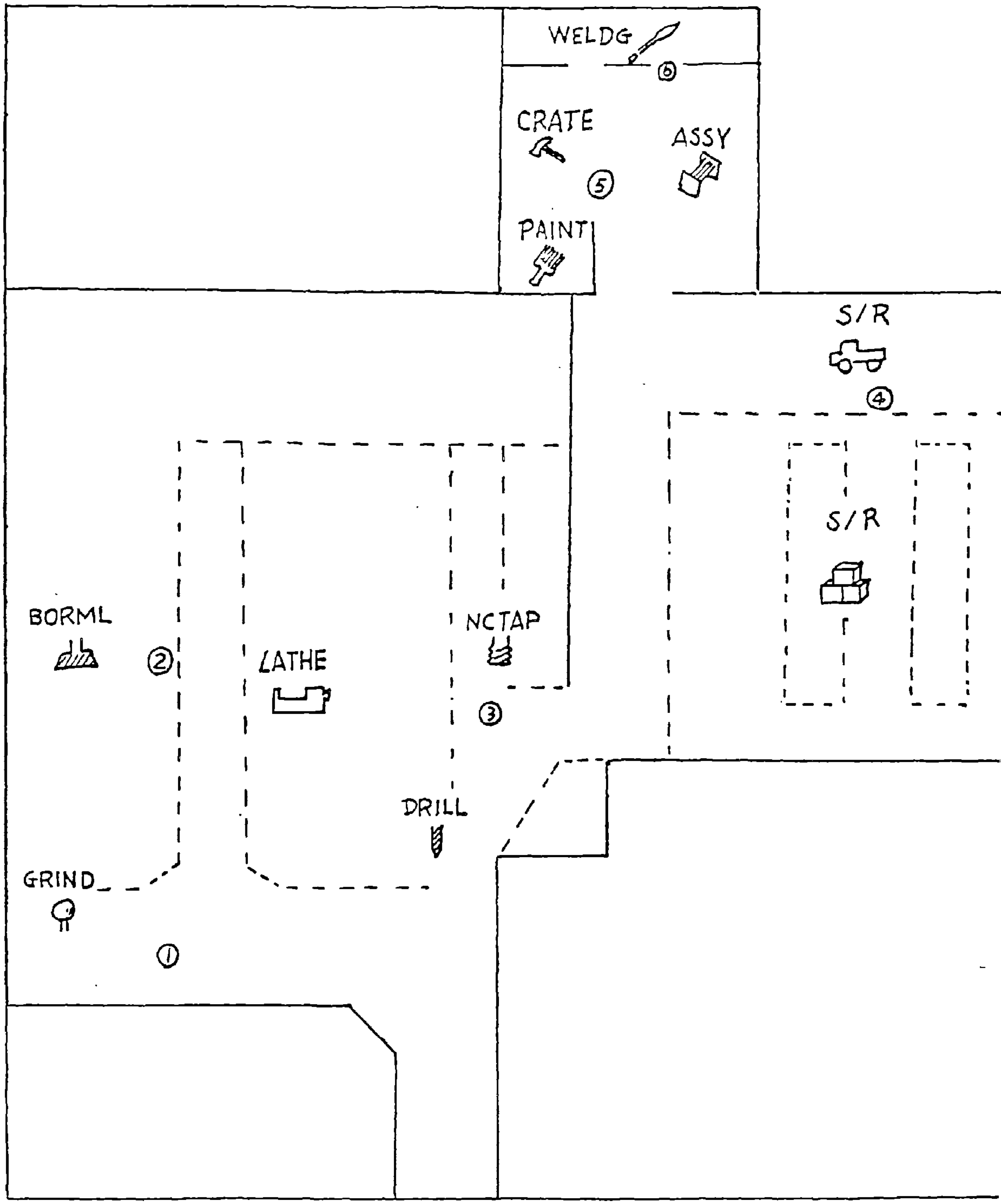
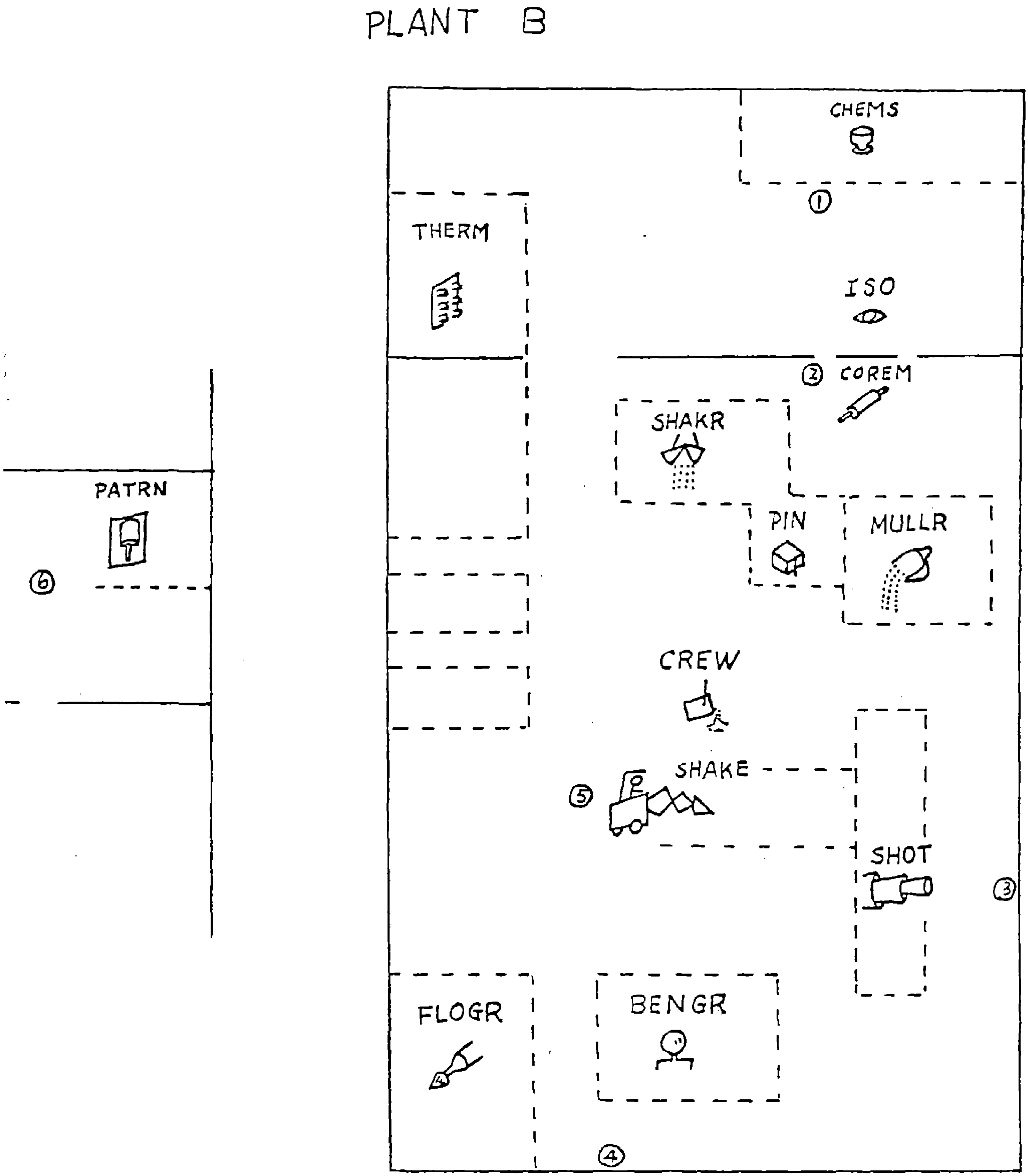
APPENDIX A

Plant Layouts

PLANT A



PLANT A LAYOUT



PLANT B LAYOUT

APPENDIX B

DATA SHEETS

HEAT STRESS DATA SHEET - PLANT A

								A			COMMENTS		
			YEAR	MONTH	DATE	SET	DAY	PLANT	OBSER-VER	TIME			
M/C	ID	WL	BB	WBGT IN	WBGT OUT	DB	WB	GT	WIND	TDB	TWB	OBSERVATION	NOTE
OUTDR													
DRILL	1												
	2												
GRIND	3												
	4												
	6												
	7												
LATHE	11												
	13												
	17												
BORML	20												
	21												
NCTAP	31												
	33												
	36												
S/R	1												
	2												
	3												
	4												
	5												
ASSY	1												
	2												
	3												
	4												
	5												
PAINT	1												
CRATE	1												
	2												
WELDG	1												
	2												

HEAT STRESS DATA - PLANT B

			YEAR	MONTH	DATE	SET	DAY	PLANT B	OBSER-VER	TIME	COMMENTS		
M/C	ID	WL	BB	WBGT IN	WBGT OUT	DB	WB	GT	WIND	TDB	TWB	OBSERVATION	NOTE
OUTDR													
THERM	1												
CHEMS	2												
	3												
	4												
ISO	5												
	6												
	7												
	8												
	9												
	10												
SHAKR	1												
	2												
	3												
	4												
COREM	1												
MULLR	1												
PIN	1												
	2												
SHOT	1												
BENGR	1												
	2												
	3												
FLOGR	1												
	2												
	3												
	4												
SHAKE	1												
	2												
CREW	1												
	2												
	3												
	4												
PATRN	1												
	2												
	3												

Appendix C

Descriptive Taxonomy

Descriptive Taxonomy of Unsafe Worker Behaviors

100. RELATED TO WORKER

110. Improper Use of Body

111. Used hands, not tool (to feed, clean, adjust, grip, hammer)

Record when the hands are used for hammering or when the hand is within 6" of the blade on a jointer or woodworking table saw due to the failure to use a push stick; or anytime there is a danger to the hands which can be avoided through the use of a tool rather than the hands.

112. Insecure grip (oily, pinch, grasp, too many objects)

Record in the carpentry shop if long lengths of lumber slip around because they are only held in the middle; when a worker is holding an object in a pinch grasp and the object begins to fall causing the worker to stoop over; or if one man is carrying a load and must change his grasp to facilitate carrying it or to prevent it from falling. When oily pumps are handled, 113 may also be recorded.

113. Inappropriate lifting (with back, not legs, extended, torsional)

Record if torsional or twisting lifting movements are used; if working while bent at the waist, or if materials are thrown (see also 221).

114. Should use mechanical lift or get help (crane, hoist, two person load)

Record if one person or one fork truck is carrying an object that is too bulky or cumbersome. This may be determined by the size of the load, its value, whether or not it is fragile or has an awkward shape, or whether it weighs more than 50 pounds. In making this subjective judgement about distinguishing a one-man from a two-man load, the judgement must also include considerations of route.

119. Not elsewhere classified.

120. Unsafe Position or Posture

121. Cramped, awkward, or unsafe position (bend, stoop, work in small quarters)

Record at Plant A if one person is working on the floor, or stooping to weld or crate a large project; at Plant B if a person is grinding on the floor area. This recording will only be made if the person is working in a cramped position.

122. Working too close together (gang too close to each other, tripods in assembly, materials handling)

This unsafe behavior involves more than one person. If an accident occurred, could the person jump, fall or be propelled into another person; or if people touch one another while working.

123. Exposed under suspended load (under hoist or fork)

Record anytime any part of the body (head and toes included) is exposed to a possible hazard from above.

124. Unnecessary exposure (to heat, cold, fumes, paint, electricity, sand, dust)

In general this recording will be made when a worker is in a hazardous area unnecessarily. If a worker must be in the area (or fails to remove himself), protective clothing must be worn. However, discretion is important; if work must be done in a certain area, then exposure is not the worker's fault.

Record at both plants, when observing pouring without eye protection, or being exposed to a hazard (blowing down or paint) and failing to remove oneself from exposure.

Record at Plant A when a worker is around a paint booth, painting is being done outside the booth, and the worker fails to remove himself.

Record at Plant B, when a worker is shoveling under the conveyor that carries sand back to be conditioned (include particulates).

125. Riding in unsafe position (on forks of lift, on hook of crane)

Record in the event there is only seating for one and more than one person is on the equipment, or if the driver is in an unsafe position.

126. Unnecessary exposure to moving material or equipment (work in aisle or travelway)

Record if there is unnecessary exposure to moving material and equipment. If the work is required to be done in the aisle, it is not unsafe (if not discretionary). One man was seen to bump his thumb leveling sand with his hands while shaking at Plant B, i.e., too close to moving machinery or equipment. Record in crating area when a fork truck goes by a stack of materials at the same time the crater is squeezing between the materials and fork instead of waiting.

129. Not elsewhere classified.

130. <u>Unsafe Body Movements</u>

131. Operating too fast (movement of body members, material handling)

Record if loss of control is reasonably possible, in the judgement of the observer.

132. Moving whole body too fast (walking, running)

Record if loss of control is reasonably possible due to undue haste.

133. Feeding too fast (supplying, pushing, drilling, sawing, grinding too fast, motor bogs down)

Record if a tool drill bit or a saw blade breaks or flexes or is damaging to the equipment, as in pumping (hogging) a drill handle. It is appropriate whenever loss of control is reasonably possible.

134. Throwing not handling (warehouse, handling parts/pumps)

Record when materials are thrown or released (dropped); when there is a 1" movement of a work piece or material after release. The important consideration is that of imparting of uncontrolled kinetic energy; throwing is not unsafe by itself, just if the edges are sharp.

135. Descending, ascending unsafely (jumping off, down, two steps at a time, truck/storage platforms)

Record if jumping from a furnace platform at Plant B.

136. Inattention to footing, seating, or surroundings (tripping over curb, platform edges)

Record when inattention occurs around fixed objects in the work environment, e.g., the crating box at Plant A.

137. Distracted from task (woman walking by, watching horseplay, radio too loud)

This is a natural companion to 138 (for those nearby). Record when a worker has an undue emotional reaction to something, i.e., a temper tantrum or a lesser degree of action.

138. Failure to follow regulations/policy (horseplay, smoking in non-smoking area)

Record for smoking in the crating or pattern area, and for horseplay anywhere (throwing things, pushing people). The horseplay must be invasive and have potential for creating a hazard; almost always accompanied by 137.

139. Not elsewhere classified.

140. <u>Failure to Use Protective Clothing</u>

141. Goggles, glasses (protective eyewear, side shields)

Record anytime there is one or more substances in the air or the probability thereof, especially from air hoses. There is an additional problem during sanding, grinding, or blowdown at Plant B which requires goggles. Also one individual requires glasses with side shields during blowdown.

142. Foot/toe protection (shoe and toe devices)

This is difficult to determine since there are so many styles of safety shoes. Record when obvious, as with sandals, mocs, thongs. Also laceup shoes should not be worn near molten metal by the pouring or ladle crew.

143. Gloves (special to fit job done, hand protection)

Record if gloves are not used at banding, crating, or other tasks that could cut the hands; in the handling of sharp materials, wood splinters, or hot objects.

144. Face/respiratory protection (dust mask, shield, ear plugs, welding masks, respiratory protection)

This applies when masks or respiratory protection is not used; it will only be recorded in areas where there is a visible air quality problem, especially at Plant B in the painting and pattern shops, in the large room, and during a shakeout.

145. Trunk/leg protection (chain saw, firefighting, foundry)

Record if a metal weave apron providing reflective protection is not worn to protect from radiant heat. Calls on respiratory protection should be deferred until available or required.

146. Hard hat/bump cap

Record if such protective gear is not worn during shakeout or while shoveling under the conveyor.

149. Not elsewhere classified.

150. <u>Failure to Dress Properly</u>

151. Loose or inappropriate clothing (sleeves improper length, long trousers, belts)

This applies if sleeve length is too short or too long, especially in pouring and welding tasks; if coat tails are long or loose, and if clothing comes too close to moving equipment. It is especially applicable in molten metal or welding operations if an apron has a pocket, or there are cuffs on pants, or if there is cloth around welding.

152. Unrestrained long hair (should use band, net, hat)
Record if long hair is not restrained around rotary movement of equipment.
153. Adornments (rings, watches, necklace, neckties, pocket chains)
Record only if inappropriate, excessive or hazardous adornments.
159. Not elsewhere classified.

200. RELATED TO TOOLS, EQUIPMENT, OR MATERIALS

210. Tools, Equipment, or Materials Errors
211. Wrong tool, equipment, or material for job done (wrench as hammer or cheater, screw driver to clean)
Record if using a hammer handle as a hammer (or a wrench handle as a hammer); standing on a barrel or chair rather than on a ladder or step stool.
212. Unsafe use of tools, equipment, or materials (correct equipment used unsafely, spray paint outside booth, welding outside area or in aisle)
Record if the correct tool is handled improperly, or if an unsafe blowdown occurs, e.g., blowing chips towards others.
213. Cleaning, oiling, adjusting, moving equipment (changing bits while drill is moving, under power--not coasting to a stop, clean lathe)
Record if the operator is using a rag to clean a lathe while it is moving, or is oiling (lubricating) gears when moving. This does not include using cutting fluid during processing of material.
219. Not elsewhere classified.

220. Unsafe Placing of Tools, Equipment, or Materials
221. Unsafe placing of material moving/handling equipment (parking, stopping, or leaving carts, elevators, conveying apparatus)
Record if a hand operated vehicle or fork lift is left unattended in the aisle.
222. Unsafe placement of tools, materials, scrap (tripping, bumping, slipping hazards, poor housekeeping)
Record anytime a person stands or walks on something in his work area other than the floor or working platform; specifically when transferring material, litter or scrap, or tools are placed so as to prevent safe footing and pallet placement. Sand on the floor area should be excluded since not within workers control.
223. Inattention to tool, material placement (placement on table, unstable, precarious)
This applies only to the bench table. (See 222)
229. Not elsewhere classified.

230. Failure to Shut Down Potential Energy
231. Power circuit or flame not secured (maintenance on electric motors, high voltage lines, unguarded open flame)
This is difficult to determine. If a worker is inside a crucible performing a function, it is not recorded, but if the area is unattended, it should be recorded.

232. Machine device not shut off, unattended (motors and engines, auto feed, welding gases, saws)

This applies to machine cutting tools with large or assymetrical work pieces being spun or unbalanced if the worker is out of the immediate area so that visual or auditory contact is lost. Record also if the key way cutter is left unattended and smoking between the cutting mill and the workpiece. There should be some evidence that the operator should not have left the equipment unattended.

233. Failure to lock, block, or secure against unexpected motion (gas bottles, shafts unblocked, tubing on end)

Record if the worker is present and using unsecured tubing, shafts, or gas bottles at the work site. They should be secured by placement against a wall and one another. When stored on end, record if tube is longer than 3'.

239. Not elsewhere classified.

240. <u>Making Safety Device or Equipment Inoperative</u>

241. Making device inoperative or failure to use (welding shields, barriers, rails, switches, guards, remove, disconnect, or misadjust safety devices)

Record if the operator is not behind the splash shield; when the exhaust fan on the paint booth is not turned on, or when the door is left open in the welding area. This must be recorded if the operator decided not to use or to circumvent an existing safety device.

249. Not elsewhere classified.

300. RELATED TO MATERIALS HANDLING EQUIPMENT

310. <u>Relating to Crane, Hoist, or Fork Truck</u>

311. Failure to warn (starting, stopping, backing, turning, signals, releasing loads, move load above people)

Record independent of the skill of the operator, but especially involving the front end loader or during a shakeout at Plant B.

312. Driving or moving too fast

Record when conditions cause a lack of control. Examples are high rpm, wobbly handling (erratic), moving too fast, steering overcompensation or quick erratic movements of fork trucks.

313. Misjudged clearance, lane, or position (cross over line, between boxes, aisles, pass on wrong side)

Record when the equipment bumps into something, when the fork truck places a load and then bumps it while going after another load, or when boxes are hit or the line is crossed over.

314. Overloaded, load insecure (beyond capacity, load too high)

Record when long pipes are not tied together or to the fork truck, or when gas bottles or anything that is likely to roll is not secured during transport by fork truck. This is not recorded if speed is reduced and greater care is taken.

315. Dropping, not placing carefully

Judgement should be used when recording possible hazard or apparent loss of control. This can be determined by high truck noise or movement after placement. It involves the hoist, fork, and crane being used to descend material too rapidly, or dropping bags of chemicals from the front end loader.

316. Suspended load unattended

This recording covers several areas including an unattended raised fork with or without additional load, or anything at Plant A left suspended and unattended. At Plant B this would include leaving the cope and drag suspended and unattended following a shakeout, but would exclude the pouring ladle.

319. Not elsewhere classified.

320. <u>Relating Only to Crane and Hoist</u>

321. <u>Hook in passageway or in motion</u>

Record when a hoist chain is swinging. At Plant A after the hoist was used and emptied it was left swinging in the passageway. At Plant B, it is done on purpose during a shakeout.

329. Not elsewhere classified.

330. <u>Relating Only to Fork Truck</u>

331. Improperly parked or positioned (no parking zone including aisle, unauthorized parking space)

Record if the vehicle is left unattended or is left in a position not demanded by the work situation.

332. Passengers without seats (operator allows standing or sitting on vehicle)

333. Fork truck unattended, engine running

Record if an engine is left running and the operator leaves the fork or shovel.

339. Not elsewhere classified.

APPENDIX D

Analysis of Unsafe Behavior Data

Figure D-1 classifies the data collected in this study according to the two main categories: safe or unsafe behavior. It is shown from the Figure that out of 17,841 observations, some 16,107 observations were safe and 1,734 were unsafe. Approximately 90% of the worker observations were safe and only about 10% were classified as unsafe behavior (Figure D-1). This appendix provides a more detailed look at the unsafe behavior data according to the different categories and subcategories of the taxonomy. Figure D-2 classifies the 1734 unsafe behavior observations according to the three major types of the taxonomy. The figure demonstrates that 1263 unsafe behavior observations were related to the worker, 383 were related to the tools, equipment, and materials, and 88 unsafe behavior observations were related to materials handling equipment. Hence, about 73% of the unsafe work behavior was related to the worker, 22% related to tools, equipment, or materials, and about 5% related to materials handling equipment.

Figure D-3 classifies the unsafe behavior observations according to the different categories within each major type. The most dominant subcategories for the unsafe behavior are: unsafe position or posture, unsafe body movement, failure to use protective clothing, and unsafe placing of tools, equipment, or materials, which yielded 352, 401, 339, and 254 unsafe behavior observations, respectively. Figures D-4, D-5, and D-6 give a detailed breakdown of the number of specific unsafe behaviors and their percentage within each of the three types of unsafe behavior, e.g. related to worker, to tools, equipment, or materials, and to materials handling equipment, respectively.

Figure D-1: Safe/Unsafe Behaviors

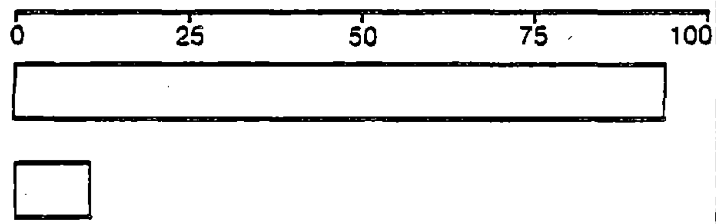
Code	Description	No. of Obser.	Percentage
001	Safe Behaviors	16107	
XXX*	Unsafe Behaviors *Code from Taxonomy of Unsafe Behaviors	1734	
	Total Observations	17841	

Figure D-2: TYPES OF UNSAFE BEHAVIORS

Code	DESCRIPTION	No. of Obser.
100	Related to Worker	1263
200	Related to Tools, Equipment, or Materials	383
300	Related to Materials Handling Equipment	88
	Total Observations	1734

PERCENTAGE OF UNSAFE BEHAVIORS

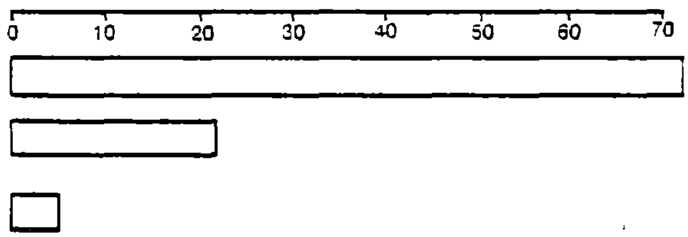


Figure D-3: CATEGORIES OF UNSAFE BEHAVIORS

Code	DESCRIPTION	No. of Obser.
110	Improper use of body	111
120	Unsafe position or posture	352
130	Unsafe body movements	402
140	Failure to use protective clothing	339
150	Failed to dress properly	59
	TOTAL (Worker)	1263
210	Tool equipment materials errors	87
220	Unsafe placing of tools, equipment	254
230	Failure to shut down...	28
240	Making safety device...	14
	TOTAL (Tools, Equipment ...)	383
310	Relating to crane, hoist and fork	55
320	Relating only to crane and hoist	6
330	Relating only to fork truck	27
	TOTAL (Materials ...)	88

PERCENTAGE WITHIN TYPE OF UNSAFE BEHAVIORS

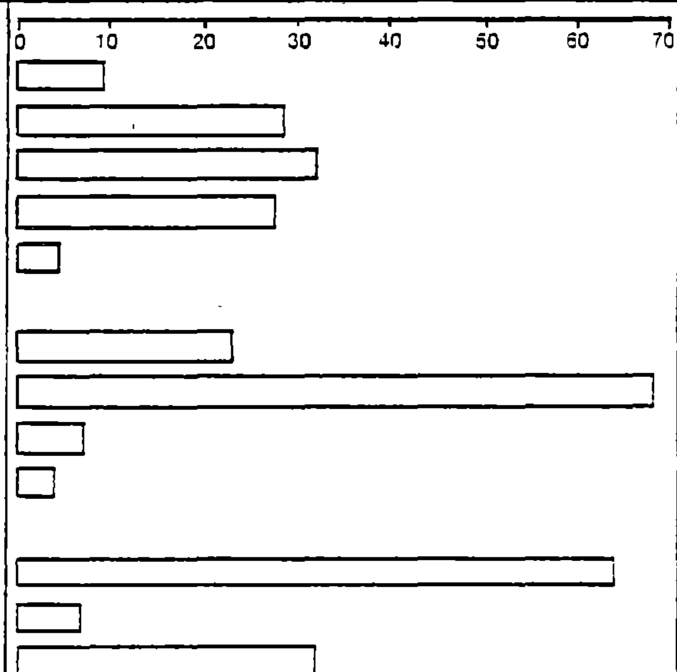


Figure D-4: SPECIFIC UNSAFE BEHAVIOR WHICH ARE RELATED TO WORKER

Code	DESCRIPTION	No. of Obser.
111	Used hands, not tool (to feed, ...)	11
112	Insecure grip (oily, pinch grasp, ...)	25
113	Inappropriate lifting (with back, ...)	30
114	Should use mech. lift or get help, ...	43
119	NEC. (not elsewhere classified)	2
121	Cramped, awkward, or unsafe position...	206
122	Working too close together (gang, ...)	31
123	Exposed under suspended load, ...	19
124	Unnecessary exposure (to heat, cold...)	52
125	Riding in unsafe position (on forks, ...)	2
126	Unnecessary exposure to material...	18
129	NEC. (not elsewhere classified)	24
131	Operating too fast (movement of body...)	49
132	Moving body too fast (walking,...)	4
133	Feeding too fast (supplying, ...)	36
134	Throwing not handling (warehouse, ...)	64
135	Descending, ascending unsafely...	2
136	Inattention to footing, seat...	12
137	Distracted from task ...	94
138	Failure to follow reg./policy...	118
139	NEC. (not elsewhere classified)	23
141	Goggles, glasses. (protective eyewear ...)	40
142	Foot/toe protection (shoe/toe ...)	23
143	Gloves (special to fit job ...)	126
144	Face/respiratory protection (dust mask...)	139
145	Truck/leg protection (chain saw....)	1
146	Hard hat/bump cap.	2
149	NEC. (not elsewhere classified)	8
151	Loose or inappropriate clothing...	54
153	Adornments (rings, watches, ...)	4
159	NEC. (not elsewhere classified)	1

PERCENTAGE WITHIN TYPE OF UNSAFE BEHAVIORS

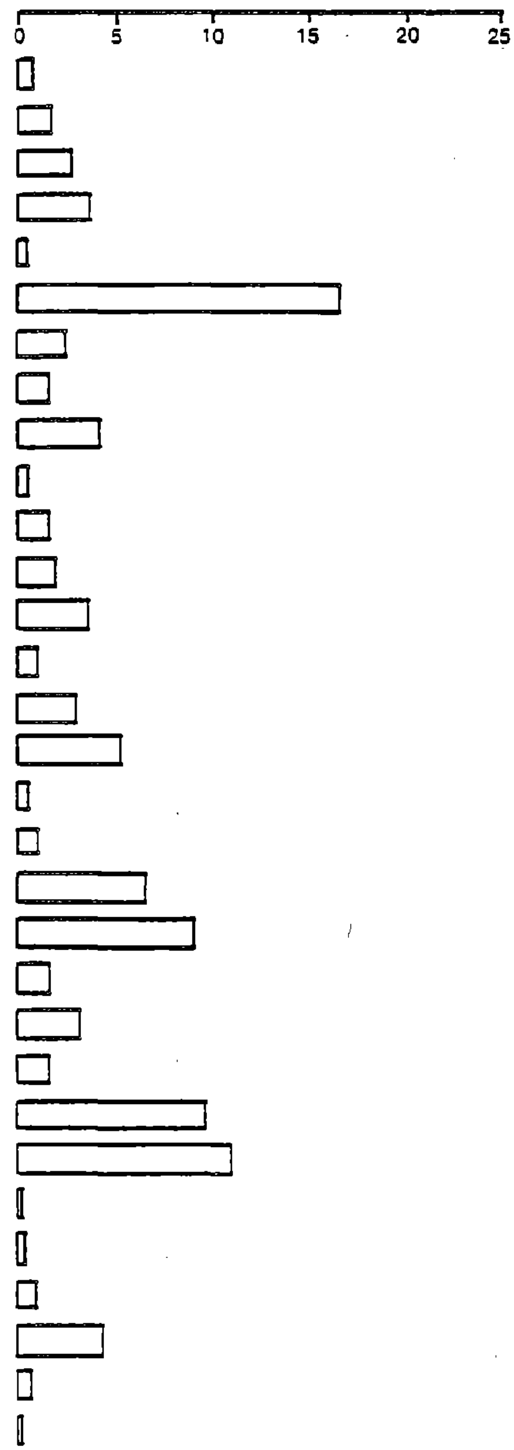


Figure D-5: SPECIFIC UNSAFE BEHAVIOR WHICH ARE RELATED TO TOOLS, EQUIPMENT, OR MATERIALS

Code	DESCRIPTION	No. of Obser.
211	Wrong tool, equipment or matl. ...	19
212	Unsafe use of tools, equip., matl. ...	50
213	Cleaning, oiling, adjusting, moving...	3
219	NEC.	15
221	Unsafe placing of matl. mov/handl...	69
222	Unsafe placement of tools matl. ...	101
223	Inattention to tool, matl. placement	51
229	NEC.	33
231	Power circuit or flame not sec. ...	7
232	Machine device not shut off...	14
233	Fail to lock, block, or sec. against ...	5
239	NEC.	2
241	Making device inoperative or fail. ...	14

PERCENTAGE WITHIN TYPE OF UNSAFE BEHAVIORS

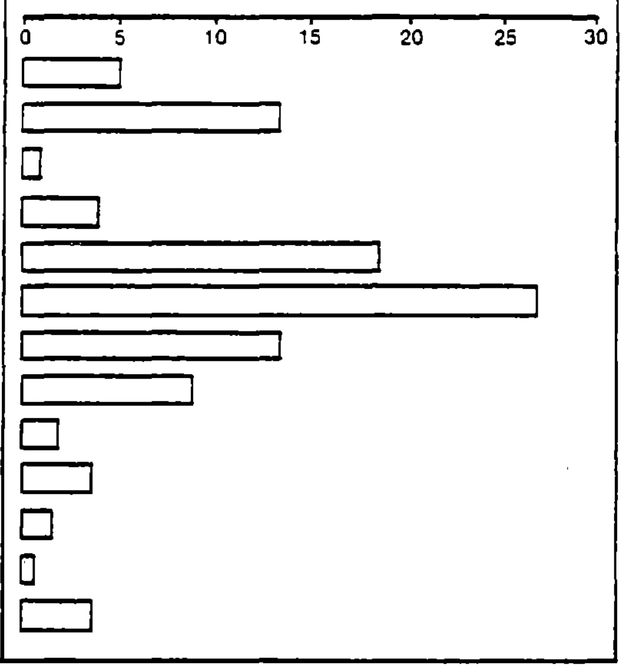
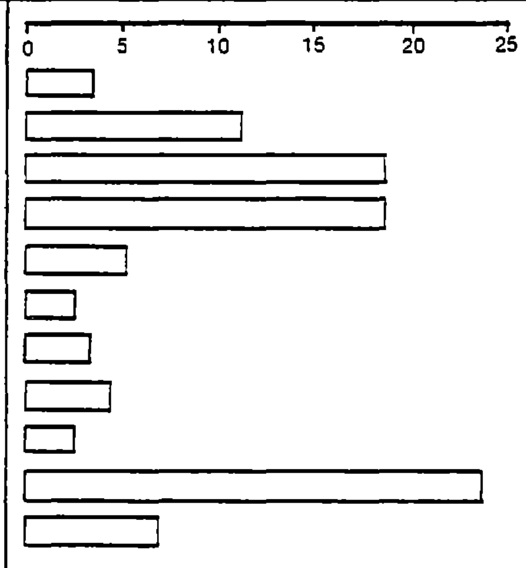


Figure D-6: SPECIFIC UNSAFE BEHAVIOR WHICH ARE RELATED TO MATERIALS HANDLING EQUIPMENT

Code	DESCRIPTION	No. of Obser.
311	Failure to warn (start, stop ...)	3
312	Driving or moving too fast.	10
313	Misjudged clearance, lane or position	16
314	Overloaded, load insecure (beyond...)	16
315	Dropping, not placing carefully.	5
316	Suspended load unattended...	2
319	NEC.	3
321	Hook in passageway or in motion.	4
329	NEC.	2
331	Improperly parked or positioned...	21
339	NEC.	6

PERCENTAGE WITHIN TYPE OF UNSAFE BEHAVIORS



Appendix E

Definitions of Statistical Abbreviations and
Additional Statistics for Predictive
Unsafe Behavior Rate (USBR) Equations

Definitions of Statistical Abbreviations
(SAS, 1979)

F VALUE This value is the ratio produced by dividing MS(MODEL) by MS(ERROR). It tests how well the model as a whole (after adjusting for the mean) accounts for the dependent variable's behavior. If the significance probability, labeled PR>F, is small, it indicates significance.

R measures how much variation in the dependent variable can be accounted for by the model. R^2, which can range from 0 to 1, is the ratio of the sum of squares for the model divided by the sum of squares for the corrected total. In general, the larger the value of R, the better the model's fit.

C.V. This measure is the coefficient of variation, and is often used to describe the amount of variation in the population. It is equal to the standard deviation of the dependent variable, divided by the mean, times 100. The coefficient of variation is often a preferred measure because it is unitless.

S.D. This is the standard deviation of the dependent variable. It is equal to the square root of MS(ERROR).

MEAN This is the mean of the dependent variable.

PR>F values for TYPE IV tests in this section of the output are equivalent to the results of a t-test for testing the hypothesis that the regression parameter equals zero.

REPORT ON THE PARAMETER ESTIMATES This section of the output gives the estimates for the model parameters--the intercept and the coefficients.

"T FOR H_0: PARAMETER = 0"

means "the Student's t value for testing the null hypothesis that the parameter equals zero."

The value given in the table for PR>|T| answers the question, "If the parameter is really equal to zero, what is the probability of getting a larger value of t?" Thus, a very small value for this probability indicates that the parameter is not likely to equal zero, and therefore that the independent variable contributes significantly to the model.

TABLE E-1. Additional Statistics for Predictive Unsafe Behavior Rate (USBR) Equations for Workload (Re: Table 4)

Workload	Estimate	T for H_0: Parameter=0	PR>|T|	Standard Error of Estimate
Light				
Intercept	0.5829	9.85	0.01	0.0592
Temp	-0.0341	-5.15	0.01	0.0066
$Temp^2$	0.0008	4.79	0.01	0.0002
Moderate				
Intercept	1.2526	6.71	0.01	0.1866
Temp	-0.0839	-4.30	0.01	0.0195
$Temp^2$	0.0019	4.03	0.01	0.0005
Heavy				
Intercept	0.8889	6.38	0.01	0.1393
Temp	-0.0456	-3.05	0.01	0.0150
$Temp^2$	0.0012	3.14	0.01	0.0004

TABLE E-2. Additional Statistics for Predictive Unsafe Behavior Rate (USBR) Equations for Job Risk Group (Re: Table 5)

Job Risk Group	Estimate	T for H_0: Parameter=0	PR > |T|	Standard Error of Estimate
Low				
Intercept	0.5973	6.37	0.01	0.0937
Temp	-0.0462	-4.55	0.01	0.0102
$Temp^2$	0.0012	4.60	0.01	0.0003
Moderate				
Intercept	0.5093	4.73	0.01	0.1077
Temp	-0.0293	-2.63	0.01	0.0111
$Temp^2$	0.0008	2.97	0.01	0.0003
High				
Intercept	0.8850	10.85	0.01	0.0816
Temp	-0.0592	-6.02	0.01	0.0098
$Temp^2$	0.0016	5.67	0.01	0.0003

Appendix F

Supplementary Data

TABLE F-1. Frequency of Temperature Occurrences

Temperature (WBGT)	Frequency	Cumulative Frequency	Percent	Cumulative Percent
0	2	2	0.011	0.011
1	8	10	0.045	0.056
4	6	16	0.034	0.090
5	10	26	0.056	0.146
6	28	54	0.157	0.303
7	19	73	0.106	0.409
8	3	76	0.017	0.426
10	18	94	0.101	0.527
11	34	128	0.191	0.717
12	107	235	0.600	1.317
13	140	375	0.785	2.102
14	374	749	2.096	4.198
15	719	1468	4.030	8.228
16	1296	2764	7.264	15.492
17	1467	4231	8.223	23.715
18	1267	5498	7.102	30.817
19	1304	6802	7.309	38.126
20	841	7643	4.714	42.840
21	674	8317	3.778	46.617
22	838	9155	4.697	51.314
23	1171	10326	6.564	57.878
24	1383	11709	7.752	65.630
25	1527	13236	8.559	74.189
26	1569	14805	8.794	82.983
27	1158	15963	6.491	89.474
28	830	16793	4.652	94.126
29	454	17247	2.547	96.671
30	268	17515	1.502	98.173
31	93	17608	0.521	98.694
32	84	17692	0.471	99.165
33	33	17725	0.185	99.350
34	41	17766	0.230	99.580
35	53	17819	0.297	99.877
36	3	17822	0.017	99.894
37	3	17825	0.017	99.911
38	9	17834	0.050	99.961
39	7	17841	0.039	100.000

TABLE F-2. Supplemental Data for Relationship Between Workload*Job Risk Interaction and Both Unsafe Behavior Rate (USBR) and Temperature (Re: Figure 4)

Workload	Job Risk	No. of Observations	USBR Mean	USBR S.D.	Associated Temperature (WBGT,°C) Mean	Associated Temperature (WBGT,°C) S.D.
Light	Low	4089	.0376	.2402	21.5440	4.9786
Light	Moderate	4341	.1031	.3890	21.2352	4.1333
Light	High	2823	.1475	.4586	21.2625	4.2596
Moderate	Low	1070	.0807	.3464	22.7844	5.3502
Moderate	Moderate	1217	.1381	.4448	21.9211	4.7130
Moderate	High	1730	.3423	.6490	22.0606	4.8222
Heavy	Low	167	.1411	.4505	24.0958	5.1217
Heavy	Moderate	275	.2456	.5699	21.9386	5.4180
Heavy	High	135	.6516	.7779	20.6765	4.9425

TABLE F-3. Supplemental Data for Relationship Between Workload*Period Interaction and Both Unsafe Behavior Rate (USBR) and Temperature (Re: Figure 5)

Workload	Job Risk	No. of Observations	USBR		Associated Temperature (WBGT, °C)	
			Mean	S.D.	Mean	S.D.
Light	1	1037	.0864	.3888	20.0559	4.0302
Light	2	4287	.0824	.3737	20.6647	4.2254
Light	3	3332	.1056	.4196	22.1570	4.6300
Light	4	2597	.0859	.3953	21.9823	4.6629
Moderate	1	246	.1724	.5302	20.4756	5.1315
Moderate	2	1379	.1629	.5111	21.8977	4.5594
Moderate	3	1272	.2210	.5777	22.3478	5.0557
Moderate	4	1120	.2665	.6177	22.8286	5.6155
Heavy	1	30	.0524	.4293	19.8667	5.4353
Heavy	2	187	.2940	.6422	20.7947	4.9687
Heavy	3	161	.3512	.7175	23.4658	5.5101
Heavy	4	199	.3315	.6925	23.0553	6.4131

TABLE F-4. Supplemental Data for Relationship Between Job Risk*Period Interaction and Both Unsafe Behavior Rate (USBR) and Temperature (Re: Figure 6)

Job Risk	Period	No. of Observations	USBR		Associated Temperature (WBGT,°C)	
			Mean	S.D.	Mean	S.D.
Low	1	325	.0338	.2284	19.9385	5.2106
Low	2	1930	.0545	.2871	21.1699	4.7440
Low	3	1592	.0434	.2577	22.5810	4.9550
Low	4	1479	.0531	.2840	22.4611	5.4379
Moderate	1	563	.0837	.3531	20.2629	3.9887
Moderate	2	2178	.0959	.3756	20.7922	4.0010
Moderate	3	1766	.1459	.4560	22.0397	4.4528
Moderate	4	1326	.1279	.4303	22.0837	4.6005
High	1	425	.1774	.4978	20.1012	3.8853
High	2	1745	.1827	.5055	20.9388	4.2096
High	3	1407	.2579	.5830	22.1464	4.6585
High	4	1111	.3054	.6219	22.2691	4.7691