# AGRICULTURAL SAFETY AND HEALTH FOR ENGINEERS

An ASAE Instructional Module

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# PREFACE

Organized efforts to reduce the number of injuries occurring in the agricultural work environment began about 50 years ago. The philosophical approach to this effort is evolving slowly. The conceptual models of the three Es of safety, engineering, education, and enforcement, and man-machine-environment are giving way to human factors and epidemiological models. In chapter 5 of the text *Safety and Health for Production Agriculture*, Dr. Dennis J. Murphy lists principles that should be considered in creating a new model:

- Injuries have identifiable causes that are either preventable or controllable.
- An injury incident normally derives from multiple causes rather than a single cause. This results in multiple approaches to hazard and injury prevention and control being more effective than any single approach.
- Risk is inherent and omnipresent in life.
- To be human is to err.
- Human perceptions of risk are not very accurate.
- Human behavior can be changed.
- Occupational safety and health is a function of management.

A discussion of these principles is contained in chapter 5 of the text. This evolution of a safety philosophy is illustrative of the changes taking place through the effort to reduce injuries in the agricultural workplace. It is the challenge of keeping pace with this evolution that will require the instructor of this course to read and use this module.

This module is addressed to college-level faculty teaching power and machinery/systems courses in the agricultural engineering curriculum. It is anticipated that this module will be covered in five or six hours of class time.

# ABSTRACT

To be effective, the designer of a product or structure to be used in production agriculture must be aware of hazards found in agriculture. The designer must then evaluate and modify the design to eliminate or reduce the risks associated with those hazards. A review of the injury statistics is a first step, but the limitations of those statistics must also be known. This is the subject of unit I.

A review of the accident statistics reveals the most common hazards in production agriculture. These hazards are presented in unit II.

The discipline for analyzing the person in a man-machine system is called human factors. The person in this system serves as a controller with physical, physiological, and psychological limitations. These issues are the subject of unit III.

Techniques for conducting a hazard analysis are presented in unit IV.

Most products are designed using a well-defined product development sequence. During that development cycle, the issues of managing risk are addressed. The safety hierarchy is a model that is commonly used to manage risk. These issues are the subject of unit V.

# ACKNOWLEDGMENTS

# ILLUSTRATIONS

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# Unit I
# AGRICULTURAL ACCIDENT STATISTICS, LIMITATIONS, AND WEAKNESSES

**PURPOSE**

To introduce students to the sources of agricultural accident statistics that are available and the limitations in using those statistics.

**OBJECTIVE**

After completing this unit, the student will be able to:

1.  Explain the difference between agriculture as an industry and farming as an occupation
2.  List the factors which complicate the understanding and interpretation of statistics that are published in a variety of sources
3.  List a variety of sources of injury statistics
4.  List a few of the statistics of farm and agricultural injury

**SPECIAL TERMS**

1.  SIC Codes
2.  Agriculture
3.  Farming
4.  Industry
5.  Occupation
6.  Production agriculture
7.  National Traumatic Occupational Fatality (NTOF)
8.  National Electronic Injury Surveillance System (NEISS)
9.  Census of Fatal Occupational Injuries (CFOI)
10. Fatal Accidents Reporting System (FARS)

**INSTRUCTOR MATERIALS**

1.  Lesson plan
2.  Chalkboard

**TRAINEE MATERIALS**

1.  Participant outlines made by instructor
2.  Supplementary materials

**INTRODUCTION**

One tool for assessing the safety of a new product design is data concerning the incidence of personal injury among persons using products of similar design. This accident history is the basis of understanding the hazards of any new product. A risk analysis of the design options for a new product is based on understanding the hazard exposure. The need for quality farm injury data is clear, but the data that are desired are difficult to obtain.

**LANGUAGE AMBIGUITIES**

Several ordinary words used to describe important characteristics of production agriculture contribute to a lack of understanding of production agriculture by many people. The casual use of two pairs of words, agriculture and farming, and industry and occupation, cause particular problems from a safety and health perspective.

**Agriculture and farming**

*Agriculture* and *farming* are often used interchangeably. Webster's Ninth New Collegiate Dictionary defines agriculture as "...the science or art of cultivating the soil, producing crops, and raising livestock...". Farming is listed as a synonymous cross-reference, and defined as "... the practice of agriculture". Therefore, using these terms synonymously seems appropriate. However, when these terms are used interchangeably within the context of safety and health, confusion and distortion often result because of the way injury statistics are grouped by official bodies of the U.S. government.

**SIC Code**

The Standard Industrial Classification (SIC) Code is the official U.S. document for defining and describing industrial establishments (U.S. Department of Commerce, 1989). Establishments are defined as "...economic units (places) where business is conducted or services performed". The SIC Code has several divisions, one of which is division A — Agriculture, Forestry, and Fishing. Division A is divided into major groups, often called sectors. The sectors of division A are as follows:

01.   Agricultural Production — Crops
02.   Agricultural Production — Livestock and Animal Specialties
07.   Agricultural Services
08.   Forestry
09.   Fishing, Hunting, and Trapping

Each of these major groups is further subdivided. For example, sector 01. Agricultural Production — Crops, has six subgroups that identify types of crop production, such as cash grains, vegetables and melons, etc.

**Production Agriculture**

Only sectors 01 and 02 are synonymous with the work and activities commonly associated with the term *farming*. Other terms used to describe major groups 01 and 02 are *agricultural production, farm production,* and *production agriculture.* Agricultural production may include establishments that perform services such as operating fish hatcheries or raising forestry seedlings. These services, or activities, fall outside the range of activities most commonly associated with farming. Farm production may imply that all farming activity happens on a farm, which is not true. Therefore, *production agriculture* is the preferred terminology.

The assignment of establishments into the sectors within division A is not always intuitive or consistent with popular perception. It is easy to incorrectly guess where some types of establishments have been assigned, and there is little practical difference among some establishments, though they may be assigned to different sectors. Fish farming, such as raising catfish for human consumption, is a part of sector 02, while fish hatcheries are a part of sector 09. Tree farms are a part of sector 08 and not categorized as production agriculture. Yet, most tree farmers consider themselves to be farmers in the popular sense of that word.

Those establishments providing custom farm services, such as custom combining, are a part of sector 07, not 01, even though there is no practical difference in harvesting machinery or technique between custom farm services and production agriculture farmers engaged in combining. Adding to the confusion is the fact that a single establishment owner, say a farm crop producer, could also be an agricultural services provider. Combining his own crop of wheat is an activity within section 01; the same activity is within sector 07 if it is done regularly for neighbors on a contract basis.

Therefore, the agricultural industry is much broader than just farming or production agriculture. Most issues normally identified as agricultural safety and health issues really center on production agriculture sectors 01 and 02. Similarly, books and journal articles that use the words *agricultural safety* and *health* in their titles are usually referring to production agriculture safety and health. The primary problem in using such terms indiscriminately is that statistics identifying farming as a hazardous industry (occupation) incorrectly lump statistics from all sectors in division A of the SIC Code together. Consequently, there are more deaths and injuries than should be attributed to production agriculture activities (farming).

**Industry – Occupation**

Another source of confusion is the mixing of the terms *industry* and *occupation*. Industries are defined by establishments, which are economic units where business is conducted or services are performed. Farms are the establishment units used for industrial classification in production agriculture. The term *industry*, therefore, infers a place of business or service.

*Occupation*, on the other hand, refers to the type of activity performed. (U.S. Department of Commerce, 1980). Remember that farming is defined as the "practice of agriculture". Thus, farming is an occupation. The activity, or occupation, can happen irrespective of place, although many occupations are associated with identifiable places, such as farms. The occupation of farming normally happens on a farm, the farm being an establishment within the industry of agriculture. It is accurate to say "farming is a hazardous occupation", but it is incorrect to say "agriculture is a hazardous occupation" because agriculture is an industry. Here again, the result of mixing these two terms is that more deaths and injuries than should be are attributed to production agriculture activities.

This lecture is about production agriculture safety and health. At the same time, there is recognition that production agriculture, as defined by the SIC Code, is only a part of the industry of agriculture. The distinctions among words such as agriculture, farming, industry, and occupation are most important when used with injury statistics. The literature on production agriculture safety and health is most commonly found under the headings of "Agriculture" and "Farm". Throughout this lecture *agriculture* will denote the industry of agriculture, and *farm* or *farming* will be used synonymously with production agriculture.

**PRODUCTION AGRICULTURE WORK**

Production agriculture work encompasses many things, places, and people. The nature of production agriculture work precludes simple descriptions of what it is and where it occurs. As with the terms discussed in the previous section, accurately describing production agriculture work is most important in discussing injury statistics. In this section, three categories are examined that help characterize production agriculture work.

**Workplaces**

Most production agriculture work takes place on farms, ranches, feedlots, dairies, and in orchards, greenhouses, and nurseries, to name just a few common production agriculture units. These same units are most commonly referred to simply as "farms". A

farm is officially defined as any place from which $1,000 or more of agricultural products were produced or sold, or normally would have been sold, during a census year.

The total number of farms listed by the 1987 Census of Agriculture is 2,087,759. The dispersion of farms across the country is uneven. For instance, Texas has by far the most farms, 188,788; second is Missouri with 106,105. The state with the least number of farms is Alaska with 574. Next is Rhode Island with 701. The size of farm units across the United States also varies greatly. The average size for all farms is 462 acres, but the range is large: a Rhode Island farm averages 84 acres, while a Wyoming farm averages 3,650 acres. Some states have a few types of farms that dominate farming in that state; other states are very diversified. For example, dairy operations dominate Wisconsin farming, while California is noted for its diversity.

Production agriculture work occurs on and at locations other than farms. For instance, homes, public roads, rural community business establishments, forested lands, and roadside markets are all possible sites where farm work may be accomplished. Maintaining farm records, transporting harvested crops to a rural elevator, or selling homegrown produce at a roadside market are all work activities associated with production agriculture. That these activities may occur off a specific farm premise is immaterial in terms of occupational workplaces.

Not all work done on farms is related to production agriculture. Two broad categories of work on farms are often inaccurately considered production agriculture work. One category is work or services provided by hired or contracted agricultural services. For example, the custom combine work referred to earlier is officially considered agricultural service work, not production agriculture work. Contract builders of barns, sheds, silos, etc., and veterinarians, farm equipment dealer mechanics, and volunteer fire fighters are all groups that may engage in work on the farm but whose work should not be counted as production agriculture work. The confusion often stems from the fact that if the same work was done by the farmer, or a family member, or hired farm employee, that same work would count as production agriculture work.

The other broad category of work on farms often mistakenly identified as production agriculture work is miscellaneous work around the farm home, farmstead (buildings, fields, pastures, etc.), and in rural areas. Examples include farm home and yard maintenance, gardening for home use, gathering or cutting firewood for personal use, and restoring antique machinery. For work to count as occupational, it must be directly related to the occupation of farming. It is not enough for work to just be done by a farm resident or on farm land.

Production agriculture work incorporates a wide variety of machinery, tools, equipment, structures, animals, etc. Some of these, such as tractors, field machinery, and farm animals, are strongly identified with the occupation of farming. However, many of these things are used for nonfarming purposes. Tractors are used in the construction industry, barns are used as meeting sites and are converted into restaurants and other businesses, and some animals are used for recreational purposes. Adding to the confusion is the use of equipment and structures by farmers for nonfarming purposes. For instance, tractors pull stranded motorists out of ditches, and farm ponds are used for recreational fishing and swimming.

**Workplace variables vs. injury prevention and control**

The variability among workplace locations, sizes, and activities hinders our understanding and ability to focus on important production agriculture safety and health issues. The nature and extent of hazards and problems can be vastly different, even among similar types of farming. This means generalized safety and health educational

programs are not relevant to most farmers. Sweeping engineering or administrative solutions to common hazards may not be feasible for all situations. This reduces the advantages that single locations, uniform job sites, and narrowly defined work procedures and tasks offer in terms of hazard and injury prevention and control.

**Farm Operators and Family Workers**

The total number of farmworkers has declined by almost 70% from 1950 to 1985 (Whitener and Munir, 1990). The farm labor force includes farm operators and unpaid workers and hired laborers. Unpaid workers are usually family members of farm operators and includes older workers and children. The hired labor force includes domestic hired labor, foreign nationals, and undocumented foreign workers (illegal aliens). Each of these groups is examined to better understand its role in production agriculture and in issues relating to safety and health.

Family farms still dominate American agriculture. The 1987 Census of Agriculture reports that 87% of all farms are operated by individuals or families. Another 10% are partnerships, many with family ties. Yet, fewer and fewer farm operators devote full time to farming; only 55% of farm operators list their principal occupation (50% or more of work time) as farming. Thirty-five percent of all farm operators work at least 200 days a year off the farm. Other farm labor statistics also show multiple job holding by farm workers. Oliveira and Cox (1989) report that in 1987 there were 4.4 million farm operators and unpaid farmworkers 14 years of age and over. Over 60% of these workers also worked in nonfarm jobs.

**Older Workers**

As shown in figure I-1, the average age of farm operators was 52 in 1987, up from 50.5 years in 1982. Similarly, the percent of farm operators 65 years of age and over was 21.4% in 1987, compared to 17.8% in 1982. An additional 4.8% and 2.7% of unpaid and paid farmworkers, respectively, were 65 years old or older in 1987 for a total working group of 28.9%. Farm operators age 65 and over are more likely to be full-time farmers than are other age groups of farmers, but they operate smaller farm units with fewer and older pieces of machinery than farm operators aged 45 to 64. This implies a greater overall exposure to farm hazards with fewer financial resources to apply toward replacement or maintenance of older machines. Older equipment is less likely to have guards and warnings in place, safety devices in working order, and the safety features of newer equipment.

The 65-and-over age group is a working group not normally found in other hazardous occupations. Forced retirement, pensions, retirement incentive programs, and failure to meet or maintain minimum job skills or proficiency requirements normally eliminate this age group as workers in other occupations, particularly those identified as hazardous. Such inducements or requirements simply do not exist in most production agriculture operations. Failing eyesight, loss of hearing, slower reaction time, and arthritis are just a few of the age-related problems affecting the safety and health of
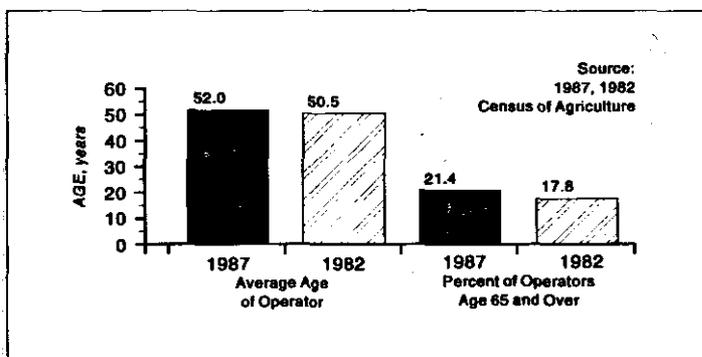


Figure I-1. Average age of operators and percent aged 65 and over.

older farm workers. Older workers are a significant part of the total farm injury and illness picture.

The specific effects of age-related characteristics on injuries and illness to older farm workers appear to be the neglected area of farm safety and health research. This issue has not generated much discussion within the popular press or professional associations. One reason for the lack of attention to this issue may be that focusing on it calls for examination of cultural concepts and practices deeply woven into the fabric of American culture. Society simply may not know how to come to grips with the underlying issues.

## Children on Family Farms

There is no set age group (or age) that corresponds to the word *children (child)* when this group is discussed in the context of production agriculture safety and health. Other terms such as *youth, teens,* and *adolescents* describe the same general populations, particularly those at the upper end of the age scale. In this book, age groups are identified by including the specific age or age parameters as appropriate. If an age is not given, children will be persons under the age of 14. This is arbitrary but consistent with traditional U.S. Department of Agriculture (USDA) age group delineations.

Child safety on the farm and in farm work is another one of production agriculture's stickier issues. Because the work site and the home site are often one and the same, children are injured while at work and at play on farms. Some of the difficult issues to be faced include: children working because of economic necessity, parents wanting to instill a sense of responsibility and work ethic, a lack of childcare options while parents work, and a cultural tradition of the entire farmstead as a giant playground for children. Practical solutions to these kinds of dilemmas are often beyond the means of a single farm family.

The actual number of hours per day or days per year farm family children work in production agriculture is not well documented. A profile of agricultural workers in 1987 reported 3,129,000 households headed by farm operators with children less than 14 years of age. However, the USDA does not record production agriculture work data for those workers under the age of 14. The U.S. Department of Labor, which compiles occupational work data for industries, does not collect labor data on those under the age of 16. Indirect measures of production agriculture child labor are occasionally found in farm injury studies. For example, a tractor and machinery use study by Doss and Pfister (1972) reported that children ages 5 through 14 operated tractors during 1971 in Michigan a total of 2,650,000 hours, and in Ohio 2,708,000 hours. Regardless of specific documentation, unpaid child and teenage labor in production agriculture is a common and accepted practice. In some instances, children and teens make a substantial contribution to a farm's total annual hours of labor.

## The Hired Workforce

The hired workforce consists of contract laborers, domestic hired workers, foreign nationals, and undocumented foreign workers. This hired workforce is often characterized by the nature of length of their employment. For instance, there are full- and part-time workers, and seasonal and migrant workers. Seasonal workers are those who work particular seasons of the year but have permanent residences near where they work. Migrant workers may also only work particular seasons, but they move from one job site to another, far from their permanent residences.

The total number of hired workers is not precisely known. The USDA suggests the number has remained relatively constant throughout the 1970s and 1980s, between 2.5 and 2.8 million. Advocates for seasonal and migrant workers suggest that the total number is much higher, perhaps twice the USDA estimate. The uncertainty is attributed to widely varying estimates of migrant and seasonal workers. The reasons estimates

vary include: differing survey (estimating) methods; workers working in more than one farm labor category; the number of illegal workers; and the contribution of seasonal migrant children to farm labor. Though the estimates vary, there is agreement that the contribution of the hired work force to total farm labor is increasing. The USDA suggests that the hired labor contribution to the percent of total farm work has increased from about 24% in 1940 to about 35% in the 1980s.

The number of days worked by the hired workforce varies greatly because of the seasonal nature of farm work. About two-thirds of hired farm workers are casual (less than 25 days per year) or seasonal (25 to 150 days per year) laborers. These two groups, though comprising a majority of the workforce, are responsible for only about 25% of the total days of hired workforce labor.

Little is actually known about the relationship between production agricultural income and safety and health. Conventional wisdom has it that the lower economic status generally associated with production agriculture, particularly farm operators who work off the farm and seasonal and migrant workers, affects safety and health in a negative way. Some evidence has been found that suggests part-time farmers have less safe machinery than full-time farmers (Napier et al., 1985). There is also evidence that higher farm prices are associated with higher agricultural fatality rates (Kelsey, 1992). The relationship between production agriculture safety and health and the farm economy is an area that needs more exploration.

**ACCIDENT REPORTING SYSTEMS**

It is collectively these characteristics that have created accident reporting systems that are not easily compared. During 1984, agriculture was credited with three different totals of accidental work deaths by three different statistical sources. These totals were 110 by the U.S. Bureau of Labor Statistics (BLS), 710 by the National Institute for Occupational Safety and Health (NIOSH), and 1,600 by the National Safety Council (NSC), respectively. Underlying issues, such as inconsistent terminology, different numerator and denominator sources, source surveillance biases, etc., have a significant effect on enumerating farm and agricultural injury and illness cases and on injury and illness rates. No current surveillance system is completely adequate.

**Numerator Sources and Data**

There are two types of numerator data. The first type is referred to as numerator values and is the designation of the number of cases of interest. For instance, the number of work injuries, how many falls occurred to a group of persons, or how many times a person was exposed to a hazard are all examples of numerator values. The second type of numerator data is known as descriptive data. This type of data includes descriptive information about the injuries, the victim, and the circumstances surrounding the injuries. Examples are age of the victim, agent of injury, time of injury, location of the incident, and body part injured. There are many others. Appropriate descriptive data may provide an in-depth understanding of the events of interest.

Numerator data (numerator values and descriptive data) can enumerate how often an event occurs. These data may describe the event in detail but cannot accurately tell the rate at which one event occurs in comparison to another event. To accurately compare events, exposure to the hazard must be considered; exposure is not a part of numerator data. Thus, numerator data are limited in providing a basis for ranking or prioritizing risks. To do this, denominator data are required.

**Newspaper Clippings**

Fatalities related to farms or farm machinery typically appear in newspapers. Other serious injuries or unusual incidents may appear as well. If a dependable newspaper clipping service is used, and daily and weekly newspaper articles are clipped from across a state, a good picture of that state's situation can be obtained. The accuracy and

completeness of the description of individual events depends on the knowledge of the writer and the editorial priorities of the day. For instance, an injury incident may not be considered "newsworthy" enough on a particular day to be included by the newspaper.

**Death Certificates**

Death certificates are an important source of fatality information and one of the most commonly used. A death certificate provides an official cause of death as well as geographic and demographic information such as age and occupation. The description of the injury incident depends upon the coroner or medical examiner filling out the certificate and can vary in detail and accuracy. Usefulness of death certificates depends upon the criteria used to select them from the large numbers of other fatalities. For example, if occupation of farmer is used, then part-time farmers with other primary occupations will be missed. If location of farm is used, then farm-related incidents occurring off the farm, such as on roadways, are often missed.

Death certificates are particularly useful because they are universally required; every state has a computerized registry of death certificates. Cause of death is classified by a nosologist (a person who classifies cause of death) using an internationally agreed-upon system called ICD9 (U.S. Department of Health and Human Services, 1980). This system of ICD9 codes includes classifications for external causes of death, known as E-codes. The ICD9 coding system is extensive, but E919.0 (injuries from agricultural machines) is the only code specifically involving agriculture; there is no specific E-code for falls on farms, for example. Also, because numerous codes exist for motor vehicle accidents, a fatality involving a tractor on a public highway will be classified under a motor vehicle E-code. Not every data field on a death certificate may be computer searchable. Because of variations in detail recorded, and the need to examine the narrative description of cause of death for any mention of farm involvement, manual searching/selection may be necessary (Stallones, 1990; Field and Tormoehlen, 1982).

**Surveys**

The advantage of using a survey is that non-fatal injuries and illness can be included. Also, by using a representative random sample of farms, statistically sound conclusions can be drawn about rates of injury per farm in that state. Three types of surveys have been used: on-site interviews, mail surveys, and telephone surveys. The on-site interview survey was very popular in the 1970s and 1980s but is no longer used because it is a labor-intensive approach. In the 1970s and early 1980s, thirty-one statewide surveys were conducted by state Cooperative Extension Services under the auspices of the National Safety Council (Hanford et al., 1982). These surveys involved mobilizing a large group of volunteers (e.g., 100 or more) who would visit selected farms on a quarterly basis for one year. The volunteers would ask about and record information on injuries and illness occurring to farm family members and hired workers. The skill and devotion of the interviewer determines the accuracy of the survey. More recently, a rigorous telephone interview methodology has been successfully used to collect farm injury data (Gunderson et al., 1990).

The mail survey has gained recent popularity because it does not require a large labor force. Although it does have the disadvantage of less than 100% response, and requires follow-up to achieve an acceptable response rate, it has been used successfully (Murphy and Huizinga, 1989). The mail survey also normally utilizes a one-year recall period, which may introduce recall bias by participants.

**Workers' Compensation Records**

The workers' compensation system was developed to provide compensation to workers injured on the job on a no-fault basis, i.e., regardless of whether fault lay with the worker, the employer, or with neither. To receive compensation, the injured party must file a claim. The database of claims can serve as an occupational injury database. However, in many states participation by farmers is optional and typically farmers have

opted not to join. Often, this is because joining requires payment of workers' compensation insurance premiums. Additionally, farmers without any employees may not be required to participate even in states where all farm employees are included in the system. In states where most farms participate in the system, the workers' compensation system is a readily available and relatively complete source of farm injury information.

**Hospitals**

Two sources of potential farm injury data exist in hospitals. These are hospital emergency departments and discharge records. Hospital emergency departments treat people injured in farm-related accidents when the injuries are severe enough to require such treatment. Thus, the emergency department can be used to monitor farm injuries on a prospective (starting at the present and going into the future) basis (Stueland and Lee, 1989). If the normal emergency department records are detailed enough to include the fact that the injury was farm-related and other desired details, the emergency department records can be used retrospectively (starting at a point of time and looking into the past). Unfortunately, the records are not often that detailed or available.

Discharge data are data collected and stored about every patient who has been admitted to a hospital. These data include the injury or illness responsible for patient admission, but may not provide the cause or source of the illness or injury. This means the data may not necessarily be searchable to locate farm-related injuries or illness. A supplemental questionnaire may be required from the patient (Fuortes et al., 1990). Also, discharge data are by definition limited to patients actually admitted to the hospital. Given the increasing emphasis on out-patient treatment and the high level of care available in the emergency department, many agricultural injuries may be treated without admission (Gunderson et al., 1990). Some states have statewide discharge databases.

**Physicians' Records**

Theoretically, every farm injury or illness severe enough to require physician care has a physician's medical record. However, these are confidential and not generally available as a data source. Public health laws in many states require reporting certain injuries or illness, such as sexually transmitted diseases. In some states, occupational injuries must be reported; however, uniform reporting is not assured, in spite of the law. If laws required reporting of farm injuries, physicians' reports could be a source of data if they were prepared consistently. Reporting an injury based on cause rather than on a medical diagnosis is a more complicated process, however. Physicians can be a source of data for well-defined incidents, such as certain insect bites, via survey and/or patient questionnaire (Schuman and Caldwell, 1991; Owens et al., 1990).

**Emergency Medical Service (EMS) Records**

When an EMS ambulance transports a person to a hospital for any reason, a record of that "run" is made. Depending upon the state, these run records or logs are filed with a state agency. If the location of the victim (such as a farm) and/or the reason for the run (such as an injury) are listed, it is possible to use these EMS run records for data. However, many farm injury victims are self-transported, thus not showing up in the EMS records; one farm injury study (Schnieder and Morgan, 1988) reported 68% of emergency department cases arrived by private vehicle. A study of 48 hospital-treated cases of agricultural chemical exposure found only one record of ambulance or rescue squad use (Rettig et al., 1987).

**Insurance Companies**

Insurance companies that process medical claims resulting from farm-related injuries or illness maintain records of such claims. However, to be of benefit to production agriculture safety and health researchers and educators, insurance companies need to collect information on cause, record it in a searchable manner, and then be willing to make the files available. Insurance records are generally considered private. Additionally, there are many health insurance companies that may provide coverage to

farmers. The typical farm property and casualty insurer may not be the health insurer, and some farm families may not be insured at all. The result of this variability is that there is no central source of insurance records. A rural health maintenance organization (HMO) that can generate data for farmers would be an exception.

## Coroner and Medical Examiner Reports

Sudden or unexplained deaths require investigation by the local coroner or medical examiner to determine cause of death. The results of the investigation are used to establish the cause of death for the death certificate, and in the case of death due to injury, a brief description of how the injury occurred. In addition to the death certificate, a report may be filed with county or state agencies. Depending upon the state, the report may require certain information, the report may be filed in a central state office, and much of the information on the report may be computer searchable. Searches may be conducted by occupation (such as farmer) or location (such as a farm).

Medical examiner reporting systems have been used in at least one farm fatality study (Bernhardt and Langley, 1991). If there is no central reporting requirement, and the filing and reporting depend upon individual counties, the contents and availability of the reports will vary. There may be no way of searching for farm-related fatalities, other than manually or by requesting specific reports. In some cases the report may not contain details of interest, such as the circumstances surrounding the incident. Even if it does, the accuracy would depend on the knowledge of the coroner.

## Law Enforcement Agency Reports

Law enforcement officers may also investigate fatalities or serious injuries. They may be called by the coroner to assist or be called to the scene by another party. They may also be normally responsible for some investigations, such as when accidents occur on public roads. The level of detail in such a report will vary by the officer's understanding and knowledge of the farm environment, plus the level of detail required to fulfill reporting requirements. These reports are not likely to be available to the public, although it may be possible to request specific reports for research purposes. It is unlikely that report files would be computer searchable; reports would be dispersed throughout the state by county except for investigations by state police.

## State Motor Vehicle Accident Reports

Every state has a central database of motor vehicle traffic accident reports. For those accidents involving farm equipment, the data may be available if "farm equipment" or something similar is a distinct item on the report form. These data would provide information only on those accidents involving farm equipment on public roads. Such reports would include incidents where property damage, but no personal injury, occurred. Information would also be available on other, non-farm-related parties involved in the accident.

## Manufacturers' Records

Manufacturers of farm equipment often receive reports of injuries involving their machines. These reports may be followed up by investigations. Such records are proprietary and generally not available to the public. There may be a considerable time lapse before manufacturers learn of incidents involving their products. Also, incidents do occur that are never reported.

## Court Records

Because farm accidents sometimes result in litigation, some farm injury information exists in court records. These records are distributed by jurisdiction, although some may be published. They will include only cases litigated: many other cases are settled out of court.

## Denominator Sources and Data

The sources of denominator data are fewer than for numerator data, and the data are more difficult to obtain. Use of such data requires surveillance of the entire population to which the numerator belongs. The most realistic denominator value to use in rate calculations of farm injury is hours of exposure. This is because the working hours of

farmers, hired farm workers, and farm family members are so irregular and varied from one person to another. One person on a farm may work 100 hours a week and another person only five or six. During planting and harvest, operations may continue around the clock. A given piece of equipment may be used heavily for a month and not used at all the rest of the year. As can be seen in the following discussion, no denominator data source currently captures hours of exposure. Thus, population values are the most frequently used denominator values.

**Census of Agriculture**

The U.S. Department of Commerce, Bureau of the Census, conducts a Census of Agriculture every five years; the most recent was in 1987 (Bureau of the Census, 1989). The results are typically published two to three years later. The Census of Agriculture provides data on farms and farm operators by county, by state, and for the nation. An interesting statistic provided is the number of farm operators whose primary occupation (the occupation in which they spend more than 50% of their time) is not farming. Prior to the 1987 Census of Agriculture, data were provided on the number of hired farm workers, including the number working more than or fewer than 150 days per year. The number of farms employing workers, categorized by the number per farm, was also provided. These data were not collected in the 1987 census.

The U.S. Bureau of the Census considers a farm operator to be the person doing the day-to-day management of a farm. It also considers the number of farm operators to be the same as the number of farms. The Census of Agriculture provides data on the number of farms by county, by state, and for the nation as a whole (Bureau of the Census, 1989).

The farm population consists of all those who live on farms, including children. The farm population does not represent the number of people who work on farms, as not everyone who lives on a farm works on a farm. And, some people who operate or work on a farm may not live on a farm. (See Bureau of the Census, 1988.)

**USDA Farm Labor Report**

These quarterly reports from the U.S. Department of Agriculture Agricultural Statistics Board provide an estimate of farm labor based on surveys taken by USDA during one week in January, April, July, and October (Agricultural Statistics Board, 1991). The number of workers reported includes people self-employed, unpaid family members, and hired workers. Totals for each of these classes are provided by category for those expecting to work 150 or more days that year and those expecting to work less than 150 days. Self-employed workers must work at least one hour on their farm during the survey week to be counted, and unpaid workers must work 15 or more hours during that week to be counted. The number of agricultural service workers (custom crews and crew leaders working on farms during the survey week) is provided separately; they are not included with the farm workers (self-employed, unpaid or hired) discussed above.

**Census of the Population**

The well-known Census of the Population (Bureau of the Census, 1984), taken every 10 years by the Bureau of the Census, provides a "snapshot" of employment during the week prior to Census Day (1 April). Persons age 16 and older are asked to list the occupation and industry in which they worked that week; if they had more than one job, they are to respond based upon the job in which they spend the most hours. An unpaid family member who worked at least 15 hours that week is included as if he/she was employed. Persons not employed that week are asked to give their most recent occupation and industry from the previous five years, if any. This total is added to the total of employed persons to come up with the total for the "experienced civilian labor force".

Occupations and industries do not necessarily correspond. For example, a person working on a farm would not necessarily have the occupation of farm worker or farm

manager; other possibilities could include mechanic, bookkeeper, truck driver, etc. Landscape contractors and nurserymen are included within the occupational category "farm operators and managers". The broad occupational category, "farming, forestry, and fishing" is not the same as the broad industrial category "agriculture, forestry, fishing". The occupational category includes logging jobs, which the industry category does not. Care must be taken to fully understand what is included in each category.

**Employment and Earnings**

Employment and Earnings is a report of the U.S. Department of Labor, Bureau of Labor Statistics (Bureau of Labor Statistics, 1988). The data come from the monthly Current Population Survey of the Bureau of the Census. The data are reported as household data, which are collected from a sample of households, and establishment data, which are collected from business establishments. Agricultural data are found only in the household data. Numerous tables present data on workers age 16 and over employed in the industry of agriculture or in farm-related occupations. Unpaid family labor is included only for persons working at least 15 hours during the survey week.

**Rural and Rural Farm Population Report**

This report provides annual averages on monthly Current Population Survey data collected by the Bureau of the Census (Bureau of the Census, 1988). Tables are provided on residency, occupation, and industry of employed persons. The occupations and industries reported are those in which the respondent worked during the survey week. The classifications are the same as for the Census of the Population. The data are collected one week each month and are based on a sample rather than a census. Data are only published as aggregate U.S. data: state totals are not provided.

**SURVEILLANCE SYSTEMS**

Many organizations and agencies use systems to provide numerator and denominator data and information on farm and agricultural injury. The data from surveillance systems often result in national estimates of work injury, deaths, illness, etc., for several industries, occupations, and products. The primary surveillance systems are discussed below.

**National Safety Council**

Estimates of the number of accidental work deaths in agriculture and other industries are compiled in the National Safety Council's annual publication, *Accident Facts* (National Safety Council, 1991). These estimates are used by NSC to compute deaths per 100,000 workers by industry, and industries are ranked by this death rate. The NSC develops these estimates by using published national mortality totals from the National Center for Health Statistics (NCHS). They perform three basic operations on the data: 1) the deaths are allocated among the four fatal accident reporting classes used by NSC (motor vehicles, home, public, and work accidents); 2) the totals are projected ahead from the most recent published NCHS figures to the current year, based upon state reports received by NSC; and 3) the work deaths are allocated to major industry groups. A portion of motor vehicle deaths are also considered work-related and are added to the industry allocations.

The National Safety Council estimate for agriculture is from the sectors listed in the Standard Industrial Classification (SIC) Code for agriculture, forestry, and fishing. The majority of fatality cases apparently come from sectors 01 and 02, since logging is not included in agricultural and commercial fishing, a part of sector 09 (Fishing, Hunting, and Trapping), contributes an estimated 109 deaths per year (Marine Safety Evaluation Branch, 1989) to agriculture's total. It should be noted that the agricultural fatality total includes deaths to workers under age 14, although these deaths are not included in the rate calculation. According to instructions (National Safety Council, 1978) given to state vital statistics agencies which report to NSC, a child fatality is only to be included as a work fatality if the child is performing "gainful work" when the accident occurs. This excludes deaths occurring while performing household chores or while being a bystander in a working environment (such as riding on a tractor with a parent).

**NIOSH – NTOF**

The National Institute for Occupational Safety and Health (NIOSH) operates the National Traumatic Occupational Fatality (NTOF) surveillance system (Myers, 1990). This system purchases all death certificates in the nation that meet all three of the following criteria:

1. The person died of an external cause of death (injury), and thus the death certificate has ICD9 E-codes of E800-E999.
2. The age of the deceased is 16 years or older.
3. There is a positive response to the question "Injury at Work" on the death certificate.

The NTOF system provides a census of all traumatic occupational fatalities in the United States, including those due to intentional injuries like homicide and suicide. The deaths are allocated to industry categories based upon the usual occupation and kind of business or industry recorded on the death certificate. The selection criteria of the NTOF system are important to farm injury statistics. The age limitation excludes children, even those performing production agriculture work at the time of their deaths. The "injury at work" question relates directly to the usual occupation and industry recorded on the death certificate. For a part-time farmer, a farm accident would not be considered an injury at work if the occupation listed was nonfarm. Since approximately 45% of U.S. farmers have a nonfarm primary occupation (Bureau of the Census, 1989), this could be a significant factor.

**CPSC – NEISS**

The Consumer Product Safety Commission (CPSC) operates the National Electronic Injury Surveillance System (NEISS). This system collects information on consumer-product-related injuries treated in hospital emergency departments (Consumer Product Safety Commission, 1986). A relatively small sample (64) of the nation's 6,000+ hospital emergency departments is selected to be representative of the nation; they report any injuries in which one or more of a large list of consumer products is involved. Injuries involving certain select products under special study may be selected for telephone follow-up or even on-site investigation.

Agricultural machines are included on the consumer product list, and 32 different agricultural machinery codes are used. No projections are given for many agricultural machines because of small (less than 20) sample counts of injuries involving those machines. In 1987, only 8 of 32 agricultural machine categories were given a national estimate. Tractors are consistently given a national estimate, but two estimates are given: one for "farm tractors", and the other for "tractors, other or not specified", which could be a farm tractor or garden tractor. If a product is not specified on the emergency department record, the injury will not be included in the system. This approach does have the advantage of reporting nonfatal injuries on a timely basis. Whether or not the sample statistically represents farming areas has not been studied.

**CFOI**

The Census of Fatal Occupational Injuries (CFOI) is a new system devised by the Bureau of Labor Statistics. As the name implies, it is a census of all work-related occupational injuries from participating states. A unique feature of this system is that each case requires a secondary source for verification of the work-relatedness to an occupation. The system was expected to be operational in all states by 1993.

**NHTSA – FARS**

The National Highway Traffic Safety Administration (NHTSA) operates the Fatal Accident Reporting System (FARS) to collect data on all fatal traffic accidents in the United States and Puerto Rico (National Highway Traffic Safety Administration, 1988). Accidents in which a person dies within 30 days of the incident are reported by state analysts. Some 90 different data elements characterize the accident, the vehicles and the people involved. Included in the vehicle description is a code for vehicles classified as

"farm equipment except trucks", so data on fatal traffic accidents involving farm equipment can be extracted.

**NCHS**

The National Center for Health Statistics (NCHS) compiles and publishes national statistics on live births, deaths, fetal deaths, abortions, marriages, and divorces (National Center for Health Statistics, 1988). These statistics are derived from state registration of such events; every state has laws providing for continuous and permanent registration. States can thus provide to NCHS individual records or computer data files of deaths. Within the published mortality data are tables of "nontransport accidents", in which location is provided. "Farm" is one defined location, exclusive of the "farm home and home premises". Accidents within a given location are classified by ICD9 E-code. Data for E919 "accidents caused by machinery" are provided. It is presumed that most accidents coded E919 occurring on farms involved farm machinery. Other types of accidents occurring on farms are reported to include falls, firearms, fires, suffocation or drowning, animals, poisoning, electrocutions and other types and agents. There is no differentiation between work-related injuries and non-work-related injuries.

**BLS Annual Survey**

The Bureau of Labor Statistics (BLS) of the U.S. Department of Labor conducts an annual survey of work establishments, such as factories, offices, and stores (Bureau of Labor Statistics, 1988). A stratified random sample of employers is drawn from each state, and employers in the sample must summarize and report injury and illness data from their OSHA Log 200. (The OSHA Log 200 is a record required by the Occupational Safety and Health Administration of any workplace injury or illness resulting in death, loss of consciousness, restriction of work or motion, transfer to another job, and/or medical treatment, excluding simple first aid). The BLS survey excludes farms with fewer than 11 employees. With fewer than 11% of U.S. farms reporting 11 or more employees (Myers, 1990), it is unlikely that the injury and illness experience of those farms is representative of all farms across the nation.

**DATA LIMITATIONS AND WEAKNESSES**

The limitations and weaknesses associated with numerator and denominator sources, and the data they provide, result in industry-wide problems with farm and agricultural injury and illness data. These problems hamper communicating the nature and extent of production agriculture risks. As will be shown in later units, an ability to accurately describe an injury problem is the first step in mobilizing the necessary resources to remedy the identified problems.

**Sensitivity**

The sensitivity, or ability of a given data source to detect individual cases, often involves a tradeoff between practicality and the severity of the injury. The less severe the injury, the more difficult it is to detect because the injured person may not come into contact with professional medical care or attract the attention of a newspaper or other public information source. Conversely, the more severe the injury, the more likely it will require medical attention at a hospital emergency department or, in the case of fatalities, a coroner's or medical examiner's investigation and newspaper coverage. Consequently, with limited resources, it is often more practical to attempt to detect the more severe injuries. This practice, of course, results in a picture of farm injury that is less than comprehensive and representative. This fact sometimes gets overlooked in discussions of farm injury statistics.

Sensitivity is particularly important when a survey is being used. While properly planned and conducted surveys can yield representative data, surveys are often not sensitive enough to locate infrequent events. For example, the National Safety Council's 31-state survey compilation only includes a small number of fatalities (Hanford et al., 1982). This is because fatalities are relatively infrequent events when

compared to nonfatal injury events. The number of fatalities nationally, as projected from the survey data, is much less than the estimate given in *Accident Facts* (National Safety Council, 1991).

## Inconsistent Use of Terminology

The term *farm accident* is used to describe several different types of events. In its broadest interpretation, it means any unintentional event that causes personal injury or property damage on a farm. Even if farm accident is more narrowly defined, and limited to those events involving injuries, there are two distinctly different interpretations. One interpretation includes any injury event that occurs on a farm, regardless of whether it was related to farm work, to recreation, or to any other activity occurring on farm property. The second interpretation includes only those injuries involving the farm operation in some way, such as farm work or the farm work site. It excludes injuries involving recreation or other miscellaneous activities. The second interpretation could also include farm work-related injuries occurring off the farm, such as on a public road.

## Work-related Injury

What is a work-related injury? When the term *farm accident* is used to refer to events resulting in farm work-related injuries, the interpretation is still not clear. For example, one interpretation of a farm work-related injury may include only those injuries suffered while the victim was actually working. This excludes victims who are bystanders to a work activity and are injured at that time, such as a person riding along on a tractor to keep the operator company, a child being watched by the parent doing farm work, or a child in the barnyard who is run over by someone backing a farm implement. A different interpretation of work-related injury may include anyone injured during a farm work activity. This includes the bystanders who were excluded in the previous definition, as long as a farm work activity was occurring when the victim was injured. However, it excludes victims injured by a machine, structure, tool, etc., related to or used in farm work when no actual work was in progress. Therefore, a third interpretation of work-related injury may include these victims of the farm work site. One example could be a child playing on a tractor tire leaning against a wall; the tire tips over and crushes the child.

A fourth interpretation or definition exists for work-related injury. This interpretation includes only those injuries suffered in the course of working at the victim's usual occupation. NIOSH uses this definition when compiling fatality data with its NTOF system. An injury is considered work-related if it occurred while the victim was working at his or her occupation; in the case of NTOF, this is the occupation stated on the death certificate. A victim injured while performing a farm work activity would not be included if his or her usual occupation did not involve farm work, e.g., a factory worker, a physician, a truck driver, a teacher, etc.

In addition to the interpretations of work-related injury as it applies to farm accident given above, there are two other issues involving farm injury data and the inclusion or exclusion of certain cases. These are intentional injuries, and work-related injuries only incidentally occurring on the farm.

NIOSH considers intentional injuries and fatalities, such as homicides and suicides, to be work-related if they occur in the course of occupational work. For example, a gas station attendant murdered during a robbery would be included in the census of work-related injuries and fatalities. Most counts of farm injuries include only unintentional injuries and exclude intentional injuries such as suicides. Under the NIOSH system, they could be included if the coroner or medical examiner filling out the death certificate concludes the death occurred "at work".

Some work-related injuries occur on a farm but involve a victim engaged in his or her nonfarm occupation. For example, a farm equipment mechanic may be injured while repairing a machine on a farm. A carpenter or electrician may come to a farm for a construction job and be injured while working. These are injuries occurring on farms that are indeed work-related, but are related to the work of that non-farm occupation. Whether or not these injuries are included in counts of farm injuries depends on the inclusion criteria used. In general, these injuries are not normally counted as farm work-related injuries because they would be included in statistics of other industries.

To help overcome these inconsistencies, the Farm and Agricultural Injury Classification (FAIC) Code has been developed to provide classification guidelines based upon place of occurrence, victim, and activity at time of injury. The code separates the injuries into distinct categories which allow numerator data from various sources to be accumulated in rational categories. The code allows for uniform collection and categorization of not only production agriculture work-related injuries, but for injuries occurring on a farm that are not related to the agricultural operation (such as a recreational injury); for injuries related to farm work that occur off the farm (such as tractor roadway accident); and for a number of other distinct combinations of occurrence, victim, and activity. This code is published in appendix B of *Safety and Health for Production Agriculture*, by Dennis J. Murphy.

**Noncomparable Rates**

Farm injury rates are important because they put the number of injuries into perspective relative to the hours of exposure, the size of the population, or other denominator values. Comparing numbers of injuries by themselves, without corresponding information on the size of the exposed population or some other measure of exposure, can be misleading. Farm injury rates are often difficult to compare because different denominator populations are used in the rate calculations. Rates based upon total farm population are different from rates based upon number of farm operators; the total farm population is much greater than the number of farm operators. Including hired farm labor in the rates, by adding the number of hired workers to the number of farm operators, increases the denominator value. However, the size of the increase depends upon whether only full-time hired workers are included, or whether all hired workers are included. Because many seasonal workers are employed, some for just a few days at harvest time, the total number of hired workers is much greater than the number of full-time hired workers.

Many migrant and seasonal farm workers are not hired directly by the farmer but by a labor contractor who in turn provides labor services to the farmer. These workers are considered to be employed in the agricultural services area and, depending upon how the number of hired farm workers is calculated, may or may not be included in the total. Another issue with respect to farm workers is the inclusion of unpaid family labor and the different criteria used for such classification. For example, the USDA Farm Labor Report (Agricultural Statistics Board, 1991) includes unpaid family labor regardless of age if the person worked at least 15 hours on the farm during the survey week; self-employed workers are included if they did at least one hour of work on the farm during the survey week.

Another complicating factor involving rates and different denominator populations is the effect denominator changes have upon the numerator. Strictly speaking, cases should be included in the numerator only if the victims are included in the denominator population. Thus, it would be necessary to eliminate from the numerator all those farm injuries that involved someone not in the denominator population. Based on imprecise information, this task may be difficult or impossible. Conversely, if all farm injuries were included in the numerator, it may not be possible to find an inclusive denominator population. This is because some injuries may have involved visitors to the farm, such

as retired parents or other relatives, who are not included in the populations previously discussed.

Because injury rates based on population values (e.g., 100,000 workers) do not take into account the actual exposure of these populations to farm hazards, such as hours worked, population based rates are not as meaningful as they may seem. Rates based on number of hours worked can be compared over time to determine whether injury rates have truly decreased, whereas changes in rates based on population values may, for example, be due to changes in hours worked by the subject population. Even for full-time farm operators and hired workers, the number of hours worked per year varies greatly.

**Lack of Reporting Requirements**

It is estimated that 89% of all U.S. farms use only unpaid family labor or have fewer than 11 hired workers (Myers, 1990). These farms are exempt from OSHA requirements to keep OSHA 200 logs, listing occupational injuries. Therefore, there is no record of injuries on the vast majority of U.S. farms. Further, these farms are also exempt from OSHA requirements to report all fatalities and catastrophic accidents resulting in the hospitalization of at least five workers (OSHA, 1989). The lack of reporting requirements means that most farms are excluded from BLS statewide and national surveys of occupational illness and injuries. Only farms with 11 or more employees are included in these surveys, and it is not expected that their injury experience is representative of smaller farms or of all farms. Consequently, a farmer, hired worker, or family member may suffer a serious injury, and only family, friends, and health care providers may learn of it.

Numerous descriptive characteristics are used in the presentation and publication of farm injury data. These include age of victim; agent of injury; time, day, and dates of injury; how the injury occurred; type of injury; severity; type of farming operation; and others. However, comparison of these data between one publication or presentation and the next is often limited by the variation in categories used to describe these characteristics. A prime example is the age of the victim. A variety of age categories is used, some in 5-year increments, some in 10-year increments, and some with varying increments. For instance, the National Safety Council's summary of 31 state surveys (Hanford et al., 1982) uses age increments of 5-14 years, 15-24, 25-44; 45-64; and 65+. No data are provided for children less than age 5. Murphy (1991) and Stueland and Lee (1989) each use 5-year increments, but for different ages. Fritsch and Zimmer (1980) use totally different age increments. Some reports define children as age 0-15; others may use an upper age limit of 14 or 18. Comparisons of data are difficult given these different categories.

**Agent of Injury**

Agent of injury is another characteristic for which differing categories and subcategories can make comparisons difficult. Even if consistent definitions of farm injury or work-related injury are used, as discussed earlier, agent of injury can vary widely because there are so many potential agents of injury on a farm. In addition to commonly used agent categories, such as tractors, or other farm machinery, there can be categories for electrocution; tree-felling or being hit by trees and limbs; drowning; suffocation in flowing grain; animals; tools; other vehicles; chemicals; gases/vapors; trucks; fires; structures; falls; etc.

Within a category for agent of injury, such as tractors, or other farm machinery, there can be varying descriptive subcategories. For example, some tractor-related injuries involve falls from tractors and subsequent runovers by the tractors. Some authors may categorize these as falls, while others categorize them as runovers. Another example is the power take-off entanglement; some authors may include them under tractor-related

injuries, while others may include them under other machinery-related injuries. Murphy (1990) provides an excellent discussion of concerns with tractor accident data.

**Resource Costs**

Collecting and analyzing farm injury data is relatively expensive compared with other industries because of the number of farms, their geographic distribution, and the lack of reporting or record keeping. Use of data from existing sources may be incomplete or inconsistent from one source to another. Most farms have fewer than 11 employees, so it is generally not possible to simply contact a few large establishments and collect injury data for hundreds or thousands of employees as it is in many industries. If a mail survey is desired, a sample size of over 1,000 farms will generally be needed. If phone interviews are desired, the cost will be greater, and still more costly if on-site interviews are desired, as considerable travel costs will be involved in visiting a sample of farms.

Collection of data through medical sources, such as hospital emergency departments, incurs costs for the time and paperwork necessary to collect the data. Intensive data collection efforts could require personnel dedicated to data collection alone. Such is the case with the Consumer Product Safety Commission NEISS system, where participating emergency departments have a clerk assigned to the task. Existing sources of information may also carry a cost. State agencies which collect workers' compensation data or death certificates may provide computer searches or summaries of data at no cost, or they may charge. Individual certificates may or may not be available free. Newspaper clipping services generally charge a monthly reading fee plus a charge per clipping.

Unless analyzed farm injury data are provided, time and effort will be required to record and analyze data on individual injuries. Whether these data are collected via survey, death certificates, newspaper clippings, medical records, or otherwise, they must be assimilated in some orderly fashion. Inclusion criteria must be applied, missing data located, inconsistent data verified, duplicates removed, and other quality control methods used prior to analysis.

**THE FARM AND AGRICULTURAL INJURY PICTURE**

Fatal injury data represent some of the most long-term, scientifically collected data available on farm and agricultural injury. This is important because over time, and on a broad scale, fatality data become an evaluation criterion of safety and health efforts within large segments of society, and for society as a whole.

As discussed earlier in this chapter, the NSC publishes estimates of accidental work death totals and rates by industry. Construction and mining have historically joined agriculture as the three most hazardous industries, based on fatality rates. Table I-1 provides a historical comparison of the total number of fatalities in these three industries, plus the "all industry" total; table I-2 provides the death rates. As the tables show, the number of agricultural work deaths has declined by more than 60% over the last 30 years (2,000 fewer deaths), while the agricultural death rate has declined less than 28%. This contrasts with the other industries, where the decrease in total deaths has not been as dramatic. However, the death rates have declined 65% for mining, 55% for construction, and 59% for all industries.

The National Institute for Occupational Safety and Health (NIOSH) has reported agricultural data from its National Traumatic Occupational Fatalities (NTOF) database. As discussed earlier, these deaths include only those victims age 16 and older whose death certificates indicate "injury at work" and whose usual industry is recorded as an agricultural industry. The five sectors from the SIC Code for agriculture (01, 02, 07, 08, 09) are used. For the years 1980-1985, the annual average number of fatalities was

**Table I-1. National Safety Council estimates
for accidental work deaths, 1960-1990**

| Year | Agriculture | Mining* | Construction | All Industries |
|------|-------------|---------|--------------|----------------|
| 1960 | 3300 | 800 | 2400 | 13,800 |
| 1965 | 3000 | 700 | 2700 | 14,100 |
| 1970 | 2400 | 600 | 2800 | 14,200 |
| 1975 | 2100 | 500 | 2200 | 12,600 |
| 1980 | 2000 | 500 | 2500 | 13,000 |
| 1985 | 1600 | 500 | 2200 | 11,600 |
| 1990 | 1300 | 300 | 2100 | 10,500 |

\* Includes quarrying, oil, and gas extraction.
From: National Safety Council Accident Facts, 1961-1991.

**Table I-2. National Safety Council estimates for accidental
work death rates (deaths per 100,000 workers), 1960-1990**

| Year | Agriculture | Mining* | Construction | All Industries |
|------|-------------|---------|--------------|----------------|
| 1960 | 58 | 123 | 73 | 22 |
| 1965 | 65 | 108 | 73 | 20 |
| 1970 | 67 | 100 | 72 | 18 |
| 1975 | 58 | 63 | 61 | 15 |
| 1980 | 61 | 50 | 45 | 13 |
| 1985 | 49 | 50 | 37 | 11 |
| 1990 | 42 | 43 | 33 | 9 |

\* Includes quarrying, oil, and gas extraction.
From: National Safety Council Accident Facts, 1961-1991.

742; the death rate (per 100,000 workers) was 20.7 (National Institute for Occupational Safety and Health, 1989). The corresponding total and rate for all industries were 6,757 and 7.9, respectively.

Fatality rates (per 100,000 workers) for individual sectors were given by Myers (1989):

| | |
|---|---|
| Agricultural Production (SIC sector 01, 02) | 21.2 |
| Agricultural Services (SIC sector 07) | 8.6 |
| Forestry (SIC sector 08) | 17.1 |
| Fishing (SIC sector 09) | 80.0 |

It was noted, however, that agricultural production accounted for the great majority of deaths, and fishing accounted for very few, despite its high rate. Of the 742 annual average deaths, 583 were in agricultural production, and 57 were in agricultural services, which was said to have the second highest total. Therefore, although totals for forestry and fishing were not given, they must have been less than 57.

The type of fatal accident that is occurring on farms can be estimated from the analysis of 10 years of data as reported in the chart in figure I-2. These percentages do not include "transport" deaths and, thus, do not exactly match figures from the National Safety Council.

The National Safety Council estimates that about 430 fatalities a year occur from tractor accidents. Figure I-3 shows the most common types of tractor accidents.

These estimates of the number and type of farm accident are based on nationwide data and 10-year averages. The number of fatalities varies from year to year. Also, the
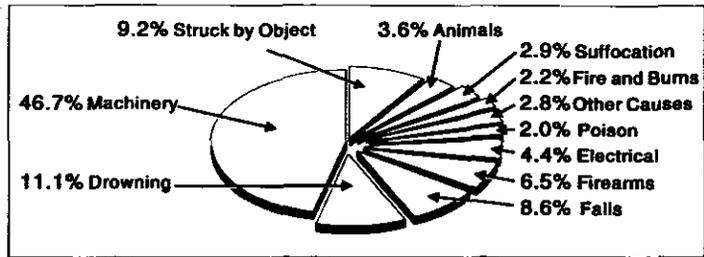
Figure I-2. Nontransport deaths on farms: 10 years, 1979-1988 (Deere & Co., unpublished).

proportion of accidents will vary in different regions of the nation because of the differences in farming operations.

**SUMMARY**

Farm and agricultural injury statistics are neither simple to obtain nor do they compare with other data. A variety of sources exists, each with its own strengths and limitations. Because of variations in definitions, inclusion criteria, methodologies, and denominator values, data must be interpreted with care. In spite of this caveat, it is clear from existing data that:

a) Production agriculture is a relatively hazardous occupation.
b) All age groups are at risk, including children and older workers.
c) There are many agents of injury on farms.
d) Tractors and machinery are involved in a high proportion of fatal and permanent injuries.
e) Various occupational illnesses affect farm workers.
f) Lack of exposure data makes developing comparable rates difficult.
g) More consistent use of terminology and inclusion criteria will improve data collection and analysis efforts.
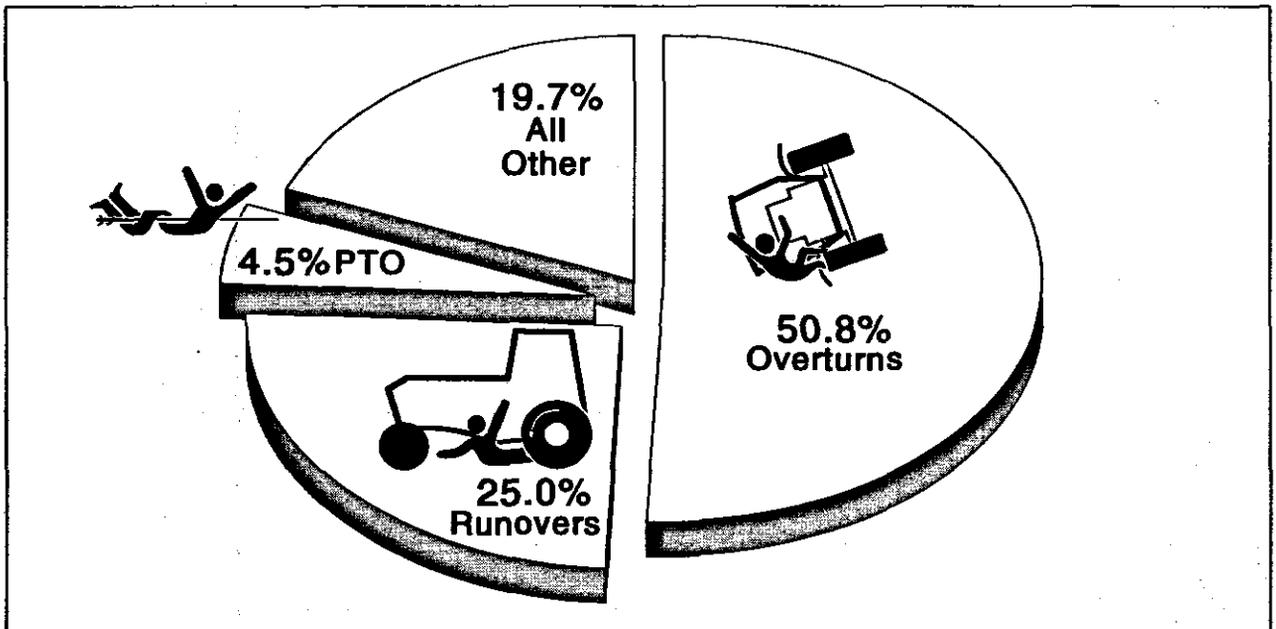


Figure I-3. Tractor accidents are the single most common farm fatal accident and tractor overturns are the leading cause of tractor accidents (Deere & Co., unpublished).

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**SAMPLE QUIZ QUESTIONS**

1. Obtain farm/agricultural statistics reports from several different sources.
   (a) Determine if consistent and clear, unambiguous definitions of farm or agriculture are used. Why is this distinction important?
   (b) Who is included in reports concerning age groups, hired workers vs. family workers, etc.?
   (c) Does the report contain all of the events in a time period or are there gaps because of the data collection method, i.e., newspaper clippings vs. death certificate reports vs. sampling methods?
   (d) Can these reports be compared to reports from other industries?
   (e) Are these reports presenting qualitative information or quantitative data?

# Unit II
# AGRICULTURAL HAZARDS

**PURPOSE**

To introduce students to the hazards that most commonly cause personal injury on farms.

**OBJECTIVE**

After completing this unit, the student will be able to identify and define:

1. Hazard
2. Power take-off (PTO)
3. Angle of pull
4. Implement input driveline (IID)
5. Implement input connection (IIC)
6. Slow moving vehicle (SMV)
7. Farmer's lung disease (FLD)

**INSTRUCTOR MATERIALS**

1. Lesson plan
2. Chalkboard

**TRAINEE MATERIALS**

1. Participant outlines made by instructor
2. Supplementary materials

**INTRODUCTION**

This lecture discusses the nature of the most common hazards identified with modern production agriculture. Specific remedies for these hazards are not discussed; to do so would call for a book in and of itself. Nevertheless, it is important to keep in mind that for each hazard identified, methods are available to eliminate, reduce, or otherwise control the named hazard.

**Hazard**

The word *hazard* is used here, consistent with the definition used by the American Society of Safety Engineers. This definition is, "a condition or changing set of circumstances that presents a potential for injury, illness, or property damage. The potential or inherent characteristics of an activity, condition, or circumstance which can produce adverse and harmful consequence".

**Agent of Injury**

An injury to a person usually involves the interaction between an agent of injury and a person. An agent of injury is that thing (item) that is involved in the injury incident. The major agents of injury in production agriculture are machinery, structures, animals, ground surfaces, etc. The interaction between the agent of injury and the person takes place within some existing environment, such as a field, road, livestock confinement building, farm shop, etc. The environment itself may have contributed to the injury event. The following sections will incorporate all three factors (person, agent, environment) in the discussions without regard for which factor may contribute the most to a hazardous condition or situation, or what role a factor may play in eliminating or reducing a hazard.

It also should be understood that most production agriculture hazards overlap into different hazard categories. For instance, a chemical substance could be discussed in a chemical hazards section or in an animal hazards section, depending upon how the chemical is used. There is no set method for grouping agricultural injury and illness hazards. The arrangement chosen here is consistent with traditional groupings of hazards often found in the farm safety and health literature. Hazards that may overlap into different hazard sections are discussed in the section where the interaction between a person and the hazard most commonly occurs.

**TRACTOR HAZARDS**

No other farm machine is so strongly identified with the hazards of production agriculture as the tractor. The rubber-wheeled, row-crop tricycle tractor of the 1930s revolutionized production agriculture. This tractor had the speed, power, flexibility, adaptability, and handling ease that completed the move of farming from the horse power era into the machine power era. The addition of hydraulic controls, the three-point hitch, direct engine-driven power take-off (PTO), and, in later years, variable shift transmissions have firmly established the tractor as the primary machine in modern farming. Hazards associated with tractors may be grouped in the following way: stability/instability, runovers, PTO stub, and miscellaneous. Aged tractors warrant special attention.

**Overturns**

Tractor overturns are the single leading cause of fatalities on the farm. Overturns occur wherever the tractors are used, on roads, in the fields, and in the farm yard. The most common conditions for an overturn occur when traveling on local roads. The tractor can edge off the road for many reasons, and by the time the operator recognizes the problem, one side of the tractor is well off the pavement. The operator now tries to turn the tractor back onto the road and may use the individual wheel brake to assist in making the turn. The combination of the tractor being on a slope and the centrifugal force of the turn back onto the road causes the tractor to overturn. While this is the most common overturn description, side overturns can also occur from sharp turns on flat ground, especially at higher speeds, and from hitting bumps

or holes when operating on a side slope. More than 80% of all tractor overturns are side overturns.

Rear overturns occur when the tractor engine powers the tractor to rotate about the rear axle. Any condition that will stop the rear wheel from turning when the tractor is under power to move forward will provide a lifting torque to raise the front end of the tractor.

As shown in figure II-1, once the front end of the tractor begins to lift, and if adequate power is available, a tractor may overturn to the rear. The "point of no return", the point at which an overturn becomes irreversible, may be reached in three quarters of a second, and many operators will not be able to recognize the danger and react in this short of a response time.

The most common cause for rear overturns is attaching the load to some point above the drawbar, such as attaching a chain around the rear axle or to a raised three-point hitch. The high hitch increases the load on the tires, increasing traction such that the rear tires may stop rotating. A high hitch also reduces the resistive torque to an overturn that is normally produced as the product of the vertical distance between the drawbar and rear axle times the load being pulled. If the hitch point is the rear axle, the resistive torque is reduced to zero. If a hitch point above the rear axle is used, such as the attachment point for the upper link, the torque produced by the load will work to overturn the tractor, rather than resist the overturn. Driving up a steep slope will also cause a rear overturn.

Occasionally, a tractor will overturn more or less forward when the operator drives off of a bridge or down a steep slope when the front wheels get stuck at the bottom of the slope (ditch).

**Runovers**

There are three basic types of tractor runover incidents. One is when a passenger (extra rider) on the tractor falls off the tractor when it is in motion. A second is when the tractor operator falls off the tractor. The third type occurs when a person already on the ground is runover by the tractor. The person already on the ground may be a bystander (nonworking person, a small child, etc.), a coworker, or the tractor operator. The tractor runover event often involves trailing machinery hitched to the tractor: it may be the trailing machinery that inflicts the injury. An event of this type may or may not be counted by statistical data as a "tractor runover" event.

Extra rider injuries occur because there is no safe location for an extra person on a tractor, yet the practice is common. Reasons for extra riders on tractors are, among other things, saving time, convenience, work assistance, and babysitting. Whether an extra rider can be justified is strictly in the eye of the beholder. Safety experts and
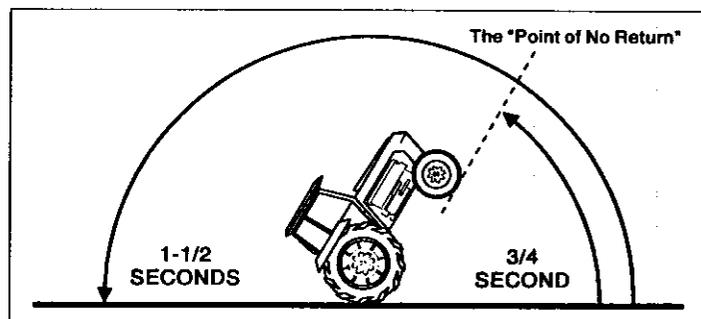


**Figure II-1. The "point of no return" during a rear turnover may be reached in three-quarters of a second (Source: Deere & Company, 1983).**

tractor manufacturers strongly recommend against an operator carrying an extra rider for any reason. This advice, however, conflicts with several factors farmers must face on a daily basis. For instance, it is human nature to want to complete work tasks as easily and quickly as possible; different transportation may call for added expenditure of a meager money supply; other babysitting options simply may not exist; and new tractor drivers must be taught how to operate tractors.

Common extra rider locations on tractors include persons standing on drawbars, side links of three-point hitches, rear axle housing, rear wheel fenders, and the area immediately around the operator's seat. This latter situation usually happens when small children ride. A larger person often will have his or her feet, body, and hands spread out on different parts of the tractor. Extra riders may intend to hang on tightly to the tractor, but it is difficult to maintain the concentration and the finger/hand strength needed for more than a few minutes at a time. Older riders tend to lose their grip and concentration as they engage in conversation with the operator, or focus their attention on field equipment operation. Younger riders may simply have wandering minds, or their hands/fingers may tire quickly. Neither group can foresee all the stops, starts, bumps, and jerks that may occur during tractor operation, nor can they always handle the shocks and jarring from rough terrain, even when expected.

Tractors are designed to provide a reasonably safe place for the operator, and that is the operator's seat. For a second person to ride safely, tractor operator stations would have to be significantly redesigned. This would require a substantial investment in engineering by manufacturers, changes in some international engineering standards that govern tractor manufacturing, and a change in the federal safety law that rules farm tractor operation by employees, among other changes. In other words, it would be an enormous undertaking. The provision of a second seat introduces other risks that are less problematic when only the operator is in the operator's station. For example, adequate protection for the passenger during a rollover event may not be provided, and interference with tractor controls may occur. A major impediment for mounting such an effort is the real possibility that even with the second seat, the extra rider hazard on tractors would still exist.

Other runover incidents involve the tractor driver either falling off the tractor as it is operating, or being knocked out of the seat, usually by a low hanging tree branch. Many of these incidents happen with older model tractors that have less shock absorption capacity in their seat assembly, no back or side arm supports on seats, and no rollover protection. The operator may also be reaching back to adjust hitched equipment, or standing on the operator's platform to stretch his or her legs. Abrupt movement of the tractor, such as from hitting a hole, may throw an operator off, especially when the operator is standing or isn't wearing a seat belt.

Tractors are often operated close to trees. A limb may have dropped lower from the previous year as it extended out from the tree trunk, a tractor that is slightly higher off the ground is being used, or the operator's attention is diverted. In any case, the operator is knocked out of the seat. Lastly, another type of runover incident occurs when operators attempt to hurriedly remount a tractor because it has unexpectedly started to drift or roll. This is particularly risky if the person tries to enter the operator's station from in front of the rear wheel, or when there is trailing equipment attached to the tractor.

Persons already on the ground are occasionally runover by tractors and their attached equipment. Two groups form most of these types of incidents: tractor operators and small children. Tractor operators sometimes try to start their tractor from the ground, instead of from the operator's seat. Most of these incidents occur with older tractors

that will start with the tractor in gear, or on newer tractors where the starting interlocks built into the tractor have been bypassed. Small children, usually under the age of 5, are sometimes run over by tractors and machinery as they are moved around the farmstead. Often, the tractor operator is unaware that the child is even near the equipment. A loud noise, such as the start-up of a tractor, is often attractive to young children and may draw them near and the practice of allowing extra riders may bring them running to the tractor.

**Power Take-Off (PTO) Stub**

The tractor's PTO stub shaft, often simply called the PTO, transfers power from the tractor to PTO-powered machinery. Power transfer is accomplished by connecting a drive shaft from the machinery to the tractor's PTO. The PTO-driven implement's drive shaft slips over the tractor's PTO. The PTO and drive shaft rotate at 540 rpm (9 rev/s) or 1,000 rpm (16.6 rev/s) when operating at standard PTO speed. At all speeds, they rotate in proportion to the speed of the tractor engine.

Most tractor PTO stub shafts operate independent of tractor ground speed, though there are some exceptions. This means that the PTO can be engaged and operated while the tractor is stationary. PTO operation independent of ground speed is one of the fundamental reasons a tractor is the primary farm work machine. This feature allows considerable flexibility for: basic types of work (field and stationary); functioning of machinery (servicing, adjusting, harvesting, etc); and crop conditions (slightly wet, course vegetation, weedy, etc.). Most incidents involving PTO stubs stem from clothing caught by an engaged but unguarded PTO stub. The reasons a PTO stub may be left engaged include: the operator forgets or otherwise is not aware the PTO clutch is engaged; the operator sees the PTO stub spinning but does not consider it dangerous enough to disengage it; or the operator is involved in a work activity requiring PTO operation. Pant legs, overalls and coveralls, sweatshirts, and windbreakers are among clothing items that may become caught and wrapped around a spinning PTO stub shaft.

The PTO master shield is attached to the tractor and extends over and around the PTO stub on three sides. This shield is designed to offer protection from the PTO stub and the front joint of the drive shaft of the connected machine. Many tractors, particularly older tractors, may no longer have PTO master shields. Master shields are removed or are missing from tractors for several reasons, including: damaged shields that are never replaced; shields removed for convenience of attaching machine drive shafts; shields removed out of necessity for attaching machine drive shafts; and shields missing when used tractors are sold or traded. There are many more injuries associated with the drive shaft than with the PTO stub. Implement drive shaft hazards and incidents are discussed in the Machinery Hazards section.

**Miscellaneous**

Other hazards associated with tractor operation are common to many types of self-propelled equipment. For instance, there are slips and falls during mounting and dismounting of tractors. Wet and muddy feet, inclement weather, steps high off the ground for clearance purposes, difficult-to-reach handholds, and hurrying operators are some reasons operators slip while getting on tractors. These reasons, plus difficult-to-see steps, crowded tractor platforms, and improper exiting (facing away from steps instead of toward them), are why operators sometimes trip or fall while getting off tractors. A person may be crushed between a tractor tire and a building from inadvertent tractor rolling, or a tree limb may break off and crush an operator in his seat during the pulling down of an old tree. Pressurized hydraulic systems, hitching and unhitching implements, refueling, changing or adjusting heavy tires, operating tractors on roads with faster vehicular traffic, towing heavy loads, and engine maintenance are just some other activities and operations that may present hazards to an operator. The point in identifying these types of miscellaneous hazards is to

underscore the range of ways in which an operator, a helper, or a bystander may become injured working with or around a tractor.

## Aged Tractors

Tractors, for functional reasons, are ruggedly built. Recent surveys in several states suggest that the average age of tractors across the United States is between 15 and 20 years of age. There are a substantial number of working tractors approaching 30 years of age, and many are over 30 years old. The design of tractors is an evolutionary process and so is improving safety. New standards, technology, and materials are continually incorporated into new tractor designs and manufacturing processes, resulting in safer tractors over time. Several safety-related improvements to tractors have been incorporated in their design. These include rollover protection, better visibility, safer seats, easier-to-operate controls, improved lighting systems, and more. Older, less safe machines are replaced by newer, improved machines through mechanisms of the marketplace. This same process has replaced older, less safe automobiles and trucks as well. What makes the tractor situation different from automobiles and trucks is the rate at which the replacements are made. There are few 20- or 30-year-old automobiles or trucks on the road today. There are as many as a million of these tractors that have been in use for over 20 years. Aged tractors are more likely to be used for: hauling supplies and materials among fields, the farmstead, and markets; mowing pastures and farmstead grounds; chores involving routing livestock care, gathering and hauling of firewood, miscellaneous transportation, and the like. When the untrained, inexperienced, or slowly reacting operator is placed on an older tractor that lacks rollover protection, has a seat without back or arm supports, a gear shift stick that is difficult to maneuver, and brakes that do not hold or cannot be locked together properly, the risk of an injury incident increases.

## MACHINERY HAZARDS

There are a multitude of machines used in production agriculture, and they are powered in many different ways including a PTO drive shaft, hydraulic fluid power, electrical power, internal combustion engine power, and ground traction. Components of the same machine may be powered by two or more methods. Horse and mule power is still the choice for certain religious sects. Regardless of how a machine is powered, injuries do happen. This section of the chapter identifies the most common types of farm machine hazards, and typical interactions between persons and machines that lead to injury. It is generally accurate to state that the interaction or exposure of workers to the hazards discussed below often occur during maintenance, servicing, adjusting, and cleaning/clearing activities, both in the field and at the farmstead.

Several farm machine hazards can be grouped by describing the actual machine component's action or motion that results in injury to a person. Many machines have several types of hazards. Pinch point hazards exist where two machine parts move together and at least one of them moves in a circle. Pinch points are, for example, where drive belts contact pulley wheels, drive chains contact gear sprockets, and feed rolls mesh together. Wrap point hazards are from exposed rotating machine components. The most commonly known example of a wrap point hazard is from the machine's primary PTO drive line, but, there are several other lesser-known examples, such as secondary drive shafts, beater bars on self-unloading ensilage wagons, and blades of some manure spreaders. The PTO wrap point hazard will be discussed more extensively later in this section.

Shear/cutting point hazards exist where the edges of two moving parts move across one another or a single edge moves against a stationary edge or soft material. There are many farm machines that contain shear/cutting hazards because the shearing/cutting action is the purpose for which the machines exist. Examples include

all types of mowers, forage harvesters, small-grain combine heads, bedding choppers, and grain augers. Grain augers are common on many crop and livestock farms and have been identified as the most hazardous farm machine per hour of machine use (Doss and Pfister, 1972). Crush point hazards are from two objects moving toward each other, or from one object moving toward a stationary object. This type of hazard also arises from handling animals. Machinery-related examples of crush point hazards include standing between the front and rear tires of articulating tractors, hitching machinery, and hydraulically controlled equipment under which a hand can be caught.

Freewheeling parts hazards arise from machine parts that continue to move after power to the part has stopped. Usually the movement is from continuing rotation of knife or fan blades. Many injuries result from a worker stopping power to the machine, and then opening an access door or panel to a part that has continued to rotate. Because many freewheeling parts hazards also involve knife blades, injuries resulting from freewheeling parts are often associated with shear/cut point hazards. Examples of machines with freewheeling parts are forage harvesters, feed grinders, rotary mowers, and ensilage blowers. Thrown objects hazards result from the chopping, grinding, cutting, and flinging motions of a variety of machines. Small objects such as rocks, metal, glass, sticks, and vegetation may be picked up by the machine and thrown with great force. Machines that may do this include rotary mowers, feed grinders, combines with straw choppers, and manure spreaders.

Stored energy hazards arise from energy that is confined and released unintentionally or unexpectedly. Stored energy involves pressurized systems or components and serves many purposes. For example, it may be used to maintain alignment between machine parts, lift heavy machines, force machine parts into the ground's surface, or speed the movement of fluids necessary for machine operation, among other tasks. Major types of stored energy on farm machinery include springs, hydraulic systems, compressed air, and electricity. Stored energy, in an uncontrolled or unexpected release, may cause the initiation of hazards identified in the paragraphs above. For instance, a crushing hazard might result from a leaking hydraulic system that allows a front-end loader bucket to suddenly fall to the ground. Or a shear/cutting hazard results from the movement of a knife blade when a broken bolt unexpectedly releases the tension on a spring. Nearly all powered farm machines have several stored energy hazards.

There are several burn point hazards associated with farm machines. Hot mufflers, engine blocks, pipes, and fluids (fuel, oils, chemicals) are all examples of possible burn hazards on tractors, self-propelled machinery, and pulled machinery. Machine inspection, servicing, and maintenance are the most common types of activities that may result in exposure to a burn hazard.

Pull-in point hazards are identified primarily with field harvesting machines. The pull-in hazard occurs at the point where the machine takes the crop material in for further processing. When the machine is running at full recommended PTO speed, crop material moves into the machine at split-second speeds. Examples of machines with a pull-in hazard includes corn pickers and combines, forage choppers, and hay balers. If a person is holding onto crop material as it begins to enter the machine, he or she is usually unable to react quickly enough to release the material before being pulled into the machine. This situation most often happens when crop material plugs the intake point of the machine. Many operators choose to unplug the machine with the power engaged because it is easier and quicker, instead of following the recommended safety practice of disengaging the power to the machine and shutting the tractor off. Other practices expose workers to pull-in hazards include hand feeding or kicking crop material into a machine.

**Power Take-Off (PTO) Drivelines**

The PTO driveline hazard is essentially a wrap point hazard. It is one of the oldest and most common farm machinery hazards and refers specifically to the part of the implement (machine) drive shaft that connects to the tractor. Many farm machines have additional drive shafts, so it is helpful to clarify what is meant by the phrase "PTO driveline hazard". The ASAE Standard S318.10, Section 2.4 (1990), defines what is popularly known as a machine's "PTO driveline":

> Implement Input Driveline (IID). Two universal joints and their connecting member(s) and fastening means for transmitting rotational power from the tractor PTO to the implement input connection. A double Cardan, constant velocity joint is considered a single joint. The IID also includes integral shielding (guarding) where provided.

Figure II-2 is a diagram of the important parts of a PTO driveline. By inference, *PTO driveline hazard* means the hazard associated with the IID shaft. Less often, the phrase is used in reference to the entanglement hazard of tractor PTO or input connection to the implement.

The entire IID shaft is the wrapping point hazard if the IID is completely unshielded. If the IID shaft is partly guarded, the shielding is usually over the straight part of the shaft, leaving the universal joints, the PTO connection (the front connector), and the implement input connection (IIC, the rear connector) as the wrapping point hazard. Protruding pins and bolts used as connection locking devices are particularly adept at catching clothing. If clothing doesn't tear or rip away, as it sometimes does for the fortunate individual, a person's limb or body may begin to wrap with the clothing. Even when wrapping doesn't occur, the affected part may become compressed so tightly by the clothing and the shaft that the person is trapped against the shaft.

The machine's IID shaft is coupled to the tractor's PTO stub. Therefore, it too rotates at either 540 rpm (9 rev/s) or 1,000 rpm (16.6 rev/s) when at full recommended speed. At these speeds, clothing is pulled around the IID shaft much more quickly than a person is able to pull back or to take other evasive action. Many IID shaft entanglements happen while the shaft is turning at one-half or one-quarter of recommended operating speed. This may be the situation on occasions when the tractor has been stopped but not turned off and the PTO is left engaged. Why an operator might do this is discussed in the paragraph below. The point to be made here is that even at slower speeds, once caught by a IID shaft, a person does not have time for evasive action. A 540 rpm shaft makes over two complete revolutions per second when operating at one-quarter speed. Even with a quick reaction time of one second, the wrapping action has begun. Once wrapping begins, the person's instinctive move
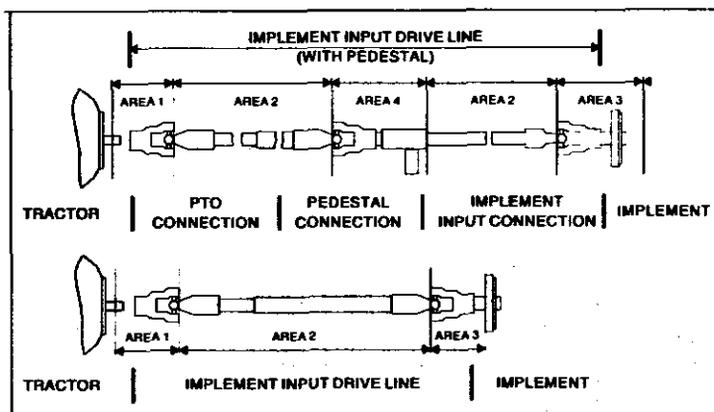


Figure II-2. Drawing of a PTO driveline (Source: Campbell, 1987).

is to try to pull away; this action simply results in a tighter, more binding wrap. The 1,000 rpm shaft decreases the opportunity for evasive action by approximately 50%.

There are many reasons why PTO-powered machinery may be engaged while no one is on the powering tractor. Some PTO-powered farmstead equipment is operated in a stationary position; it needs no operator except to start and stop the equipment. Examples are grain augers and silage blowers. At other times, adjustments or malfunctions of machine components can only be made or found while the machine is operating. Additionally, many work practices by machinery operators lead to exposure to operating PTO shafts. Clearing crop plugs has been mentioned. Other practices include mounting, dismounting, and reaching for control levers from the rear of the tractor, and stepping across shafts instead of walking around the machinery. Having an extra rider while PTO-powered machinery is operating is another exposure situation.

The wrapping hazard is not the only hazard associated with IID shafts. Serious injury has occurred when shafts have become separated while the tractor's PTO was engaged. The machine's IID shaft is a telescoping shaft. That is, one part of the shaft will slide into a second part. This feature of shafts provides a sliding sleeve that greatly eases the hitching of PTO-powered machines to tractors. If an IID shaft is coupled to the tractor's PTO stub but no other hitch is made between the tractor and the machine, then the tractor may pull the IID shaft apart. If the PTO is engaged, the shaft on the tractor end will swing wildly and may strike anyone in range. The swinging force may break a locking pin, allowing the shaft to become a flying missile, or it may strike and break something that is attached or mounted on the rear of the tractor. Separation of the driveline shaft does not commonly occur. It is most likely to happen when three-point mounted equipment is improperly mounted or aligned, or when the hitch between the tractor and attached machine breaks or accidentally uncouples.

**Slow Moving Vehicles (SMV)**

This topic could have been addressed in the tractor hazards section, but the greater hazard exists while machines and other equipment, such as wagons, are being towed by tractors. Tractors and machinery on public roads are called "slow moving vehicles" because they move slowly in comparison with automobiles, trucks, buses, and motorcycles normally found traveling public roads. The ASAE Standard S276.3 identifies slow moving vehicles as vehicles designed for and traveling at speeds less than 25 mph (40 km/h). This definition is supported by most state and federal bodies that govern or regulate the movement of agricultural machinery on public roads.

There are several hazards associated with the interaction of agricultural machinery and other vehicles on public roads. Regular vehicular traffic generally moves at a greater speed than agricultural traffic and is less accustomed to overtaking agricultural machines than other vehicles. These two factors contribute to closure-time errors by drivers of other vehicles. Closure time is the time it takes for one moving vehicle to overtake another moving vehicle. When a closure-time error is made, it usually results in the vehicle crashing into the slow moving vehicle, or leaving the road to avoid a crash. The following example helps to clarify the closure time concept and errors.

If one automobile is traveling at 45 mph (72 km/h) and an overtaking vehicle is 400 ft (122 m) behind it traveling at 55 mph (89 km/h), it will take the second vehicle 27 seconds to reach the first vehicle. This is closure time. Now substitute a tractor pulling a wagon traveling at 5 mph (8 km/h) for the first vehicle. In this case, the second vehicle, still traveling at 55 mph (89 km/h), will close the 400 ft (122 m) and reach the tractor and wagon in only 5 seconds. Time for the overtaking vehicle to react is actually less than 5 seconds because it takes a couple of seconds to recognize

the object ahead as slow moving, and then perhaps another second to brake. This situation is often compounded by hills and curves that obstruct viewing distance, narrow roads and berms, rural bridges, wide machinery that occupies more than one lane, and on-coming traffic that may not be visible to the overtaking vehicle. By the time the overtaking vehicle driver recognizes that he or she cannot pass safely, it is often too late.

A special emblem, appropriately named the slow moving vehicle (SMV) emblem, was designed in the mid-1960s to uniquely identify agricultural machinery as slow moving vehicles on public roads (see fig. II-3). The triangular orange fluorescent emblem, with a red reflective border, was designed to be mounted on the rear of tractors and trailing machinery. A widespread educational campaign was initiated to inform farmers and the motoring public on the benefits of the emblem, and many states adopted use and recognition of the emblem as a part of their state transportation laws. Research done in the early years of the emblem's use suggested the emblem was effective in identifying agricultural machinery as slow moving traffic and helped to reduce collisions between regular vehicular traffic and agricultural machinery.

Important reasons for the emblem's effectiveness in the early years were: the emblem was new and different, which itself drew attention; the color combination was highly visible; and use was restricted to the purpose for which the emblem was intended. Over the years all three of these reasons have dissipated to an extensive degree. Farmers allow faded emblems to stay on their equipment, there are many similar shapes of emblems and reflectors on the market today, and SMV emblems are misused as driveway, mailbox, guy wire, telephone pole, and building markers. Consequently, the value of the SMV emblem has been seriously eroded. This erosion contributes to the hazards of agricultural machinery operating on public roads.

Another serious hazard from agricultural machinery operated on public roads is turning maneuvers. This hazard may also involve the closure-time hazard but can exist even when an approaching vehicle has sufficiently reduced its speed. The turning hazard stems primarily from: the lighting and marking of agricultural machinery, obstructed views of both the machinery operator and the vehicle operator, machinery operators not checking behind them before making a left turn, or swinging to the left before making a right turn.

The lighting and marking of agricultural machinery refers to head lamps, tail lamps, amber warning lights, red reflectors, and turning signals. Problem areas include old machinery with no or nonworking lights and reflectors, an operator that doesn't use available lights, and trailing equipment that obscures tractor lights from the rear. Other situations that are potentially problematic include an absence of brake lights on agricultural machinery and a turning signal format that conflicts with the format of
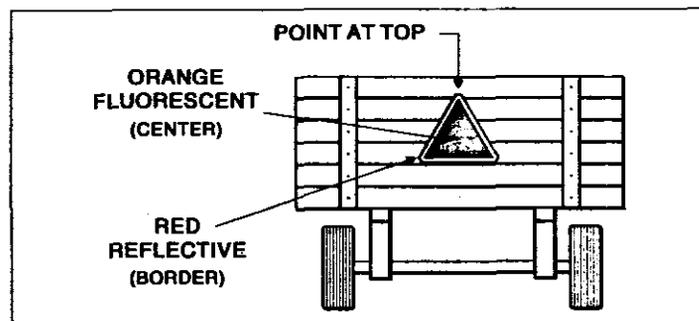


**Figure II-3. A slow moving vehicle emblem (SMV) on the back of a wagon (Source: Deere & Company, 1983).**

regular vehicular traffic. Some newer tractors use the amber warning lights as the signal lamps, and the amber lights may not catch the attention of the motorist.

Several of the conditions named above may compound the view obstruction hazard. This problem exists when regular vehicular traffic nears agricultural machinery from the rear; the machinery operator starts a lefthand turn, and neither the tractor nor vehicle operator can see the other because of large equipment. Ensilage wagons, produce wagons, wagons loaded with hay, and large round balers are all examples of towed loads that obstruct the view of tractor and motor vehicle drivers. Mirrors on tractors would minimize this problem for the tractor driver, but many tractors do not have mirrors. The view between the two drivers may also be obstructed when the tractor is towing large field equipment that may be folded up for road travel. When the two drivers cannot clearly see each other, there is no way for either of them to signal his or her intention to the other.

## Noise

Noise is unwanted sound. High levels of noise can cause permanent hearing loss, plus a host of other problems. Farmers, as an occupational group, suffer from noise-induced hearing loss to a greater extent than other occupational groups (May et al., 1990).

Hearing loss depends on duration of exposure and sound intensity. High frequencies are more damaging than low frequencies; continual noise is more damaging than intermittent noise. Identical exposures may not lead to the same loss in two people (Brauer, 1990). In addition to causing hearing loss, high levels of noise can interfere with speech communication, audible warning signals, the normal sounds of machinery, concentration on tasks, and sleep.

Potential noise sources on farms include tractors, field machinery, animals, grain augers and dryers, silo blowers, bedding choppers, feed grinders, and more. Older machines generally produce louder sounds than newer machines, and it may take two or more potential sources to produce enough noise to be considered hazardous. Unfortunately, most noise-induced hearing loss occurs gradually, with little awareness by the affected person until permanent hearing loss has occurred.

## RESPIRATORY HAZARDS

Many structures on farms contain toxic and irritant gases, an inadequate supply of breathable oxygen, and nuisance and toxic particulate matter (dust). Some of these hazards regularly are present in the structure, others are only intermittently present. Likewise, a person may be routinely exposed to these hazards, or the exposure may be very limited. A pesticide may or may not be involved. This section will identify and discuss the most prevalent types of respiratory hazards associated with production agriculture structures, and the work processes that take place within or around the structures.

## Manure Storages

Manure storage structures are designed to collect animal manure for later disposal. Storages usually handle a several-month supply. Storages may be belowground pits or tanks, aboveground holding ponds, aboveground holding tanks, or a combination of these. Belowground storage pits and tanks, on occasion, contain several dangerous gases and an insufficient supply of oxygen. Two types of belowground storages exist. One is the storage that is entirely or partly belowground, and the other is a pit or tank from which a pump transfers manure to an aboveground storage tank. The pump-out pit is usually found just outside the livestock building and near the storage tank.

During manure collection there is very little hazard to exposed workers or animals. The situation changes dramatically during pumping and emptying processes. To be pumped, whether for transferring to a storage tank or to a liquid manure disposal unit,

solid manure is converted to a slurry. This is done by mixing water with the manure and stirring with the help of a powered machine. The mixing and pumping processes may cause high levels of certain gases to be released. These gases are hydrogen sulfide ($H_2S$), carbon dioxide ($CO_2$), ammonia ($NH_3$), and methane ($CH_4$). Hydrogen sulfide is highly toxic, $CO_2$ and $CH_4$ are asphyxiant gases, and $NH_3$ is a severe irritant to the throat and lungs. Methane is also extremely flammable. Warm weather and poor ventilation increase the risks of dangerous accumulations of these gases. Below ground pits and tanks may hold toxic levels of gases, or lack oxygen, for months or years after the pit or tank has been emptied. This may occur if a solid lid covers the empty storage.

Belowground manure pits and tanks have been associated with multiple-victim fatality events. The usual scenario is similar to the following. One person enters the storage to inspect or service a pump, or to retrieve a dropped tool or other object. This person is overcome by gases or a lack of oxygen and collapses. A second person then tries a rescue and is also overcome. Tragically, as many as four or five people may enter the storage as would-be rescuers and end up as victims. These are usually family members and neighbors of the first victim, acting out of panic. Some would-be rescuers mistakenly think they can hold their breath during the entire rescue attempt while others feel there won't be any harm in taking one or two breaths. Experience strongly suggests otherwise.

## Silos and Gases

Three types of silo structures exist on farms: oxygen-limiting silos, conventional silos, and trench (bunker) silos. Trench silos use earthen or concrete retaining walls as sides, with no structural component over the top. Respiratory hazards are not normally identified with this type of silo. Each of the other two silos, also called upright or tower silos, do contain respiratory hazards, and a person may become exposed. Hazardous gases, such as $CO_2$ and various nitrogen gases ($NO_x$), are by-products of the fermentation process. Fermentation involves chemical and bacterial changes to forages that allow them to be preserved for a long time, and it makes the forage a more valuable feed product. The actual fermenting of the forage takes place in the absence of oxygen, in the sense that oxygen contained within the mass of the forage material is used up during the fermenting process. The specific respiratory hazard to humans depends on the type of silo in use.

Oxygen-limiting silos are built of glass-lined, steel-plated structures or concrete. These silos have openings at the top and also at the bottom, where silage is unloaded from the structure by a powered unloader. The majority of these silos are on dairy farms, but other livestock operations make use of these structures as well, particularly smaller-sized silos. Most oxygen-limiting silos are for forages, but some are used to store high moisture grains. Regardless of its use, the hazards are the same. Although it is a misnomer, an oxygen-limiting silo is sometimes identified as a sealed silo.

As mentioned above, $CO_2$ is a by-product of fermenting forages. The oxygen-limiting silo is designed to hold the $CO_2$ inside the structure and prevent oxygen from entering. Oxygen levels in this type of structure are often near 0%; below 6% is immediately hazardous to life. Toxic levels of $NO_x$ gases may also be produced but, because of the extreme oxygen deficiency, are not the primary concern. Nitrogen gases will be discussed in the conventional silo section.

Sometimes called a stave silo, the conventional silo is the most common type of silo found on farms. Conventional silos are used extensively in dairying operations, and to a lesser extent in beef operations. Concrete is the most common construction material, but there are still some wood and porcelain brick silos in use. Conventional silos have a series of hatch doors up the entire height of the silo. These small doors provide

openings through which silage is unloaded. The unloading is mostly by a powered unloader that rests on top of the silage, though some small and older conventional silos are unloaded manually. The hatch doors are surrounded by a metal or concrete covering called the silo chute. The silo chute contains the silage as it is hurled out the unloading door, allowing the silage to fall to the base of the silo.

Conventional silos do not limit oxygen inside the structure, and they do not capture $CO_2$ as does the oxygen-limiting silo. Therefore, the oxygen depletion hazard is not the primary respiratory concern, although this hazard may still exist. The primary respiratory hazard with conventional silos is nitrogen dioxide ($NO_2$) poisoning, a gas that may be produced during fermentation of the forage. Factors that influence the development of $NO_2$ include weather conditions, the type of crop ensiled, weeds mixed in with the forage, nitrogen levels in the ground, and harvesting practices. It is a heavier-than-air gas and may travel down the silo chute, enter livestock holding areas, and poison animals.

Nitrogen dioxide poisoning is also known as *silo gas poisoning* and *silo filler's disease*. The production of the gas may begin within a few hours after the crop is placed in the silo. It generally reaches its highest concentration during the first 48 to 60 hours but may be present in dangerous concentrations for up to two weeks. When inhaled, $NO_2$ combines with moisture in the respiratory tract and converts to nitric acid ($HNO_3$). This results in a variety of ill effects, depending on the concentration, amount breathed, and the quickness and appropriateness of first aid and medical treatment. These effects include a burning of respiratory tract tissue, fluid leakage in the lungs, and death. The most serious reactions to $NO_2$ poisoning are immediate. Delayed reactions do occur and may take up to six weeks.

Hay, small grains, and silage are common livestock feeds. All three may spoil while in storage and present respiratory hazards when later handled. The mold that develops from spoilage can become dried, break into microscopic particles, and become airborne when the hay, grain, or silage is handled. The mold spores, some of which are toxic, attach themselves to like-sized particles of dust already in the air, hence the name *toxic dust*. The dust is often called *organic dust* because it originates from organic material. Dust particles less than 10 µm, called *respirable dust*, may be inhaled into the respiratory tract, resulting in a variety of ill effects.

**Farmer's Lung Disease**

One of the ill effects of inhaling respirable dust is farmer's lung disease. Farmer's lung disease is one example of a respiratory disorder known as *extrinsic allergic alveolitis*, or as *hypersensitivity pneumonitis*. These are generic terms describing abnormal or extreme reactions of lung tissue to organic dusts. Farmer's lung disease can result in both acute (short-term) and chronic (long-term) ill effects, with reactions generally becoming more severe with each exposure. Typical responses to farmer's lung disease include fever, shortness of breath, fatigue, muscle ache, lung inflammation, and death. Victims who acquire farmer's lung disease are sometimes forced to change their type of farming operation, or quit farming altogether. Fortunately, only a small percentage of the population seems susceptible to farmers lung disease (Wright, 1989).

**Organic Dust Toxicity Syndrome**

Similar to farmers lung disease, organic dust toxicity syndrome is also caused by moldy feed dust, among other things. Acute responses by affected individuals are the same as from farmer's lung disease. A major difference between the two diseases is that organic dust toxicity syndrome is thought to cause neither permanent damage to the lungs nor death. Another difference is that all exposed persons are susceptible to this disease. Organic dust toxicity syndrome has been identified by many other names in the literature including *atypical farmer's lung, pulmonary mycotoxicosis, toxic*

*organic dust syndrome,* and *silo unloader's syndrome.* The silo unloader's syndrome reference is from the disease being closely associated with workers uncapping or opening a conventional silo, an activity that often involves handling moldy silage. Nevertheless, in recent years, scientists from several countries have agreed to call this disorder organic dust toxicity syndrome (Donham and Rylander, 1986).

## Animal Housing

The structural environment hazards discussed above occur within the structures themselves and within animal housing buildings. Many animal housing buildings are found directly over or under other structures such as manure storages and hay mows, or next to such structures as silos and grain bins, where gases and dusts may travel easily between them. Human exposure to animal feeds and bedding containing mold spores often occurs while they are being dispersed to or among animals within buildings. The types of animal housing most commonly identified with respiratory hazards includes confinement housing of swine, poultry, and veal, and dairy barns.

Confinement housing and dairy barns, particularly, are associated with organic dust toxicity syndrome, acute and chronic bronchitis, occupational asthma, chronic obstructive pulmonary disease, and other similar respiratory disorders. The dense stocking of animals within buildings results in large quantities of respirable dusts. These dusts generate not only from feeding and bedding activities, but from the animals themselves as dried urine and fecal matter, and hair and feather particles. Diseases and disorders are most likely to appear in workers who have worked for several years in such buildings.

## Controlled-atmosphere Storage

Controlled-atmosphere (CA) storages are found on farms in those parts of the country where large quantities of fruits and vegetables are stored. A CA storage is designed to retard the metabolic processes of horticultural crops to extend the time perishable seasonal products will retain acceptable eating qualities such as flavor, texture, color, etc. The metabolic process can be slowed by lowering the temperature of the storage, and by reducing oxygen ($O_2$) and increasing $CO_2$. This means rooms must be sufficiently airtight to exclude oxygen entry and maintain wanted concentrations of $CO_2$. The desired levels of these two gases vary according to product, but as a rule, $O_2$ levels are always below levels immediately hazardous to life (6%). Normally, once a CA storage is sealed, entry is not made until the end of a specified time period when the structure is opened and completely ventilated with air, and entry is safe. There may be exceptions when entry is required for system repair or to obtain samples. This is when the insufficient-oxygen hazard is present.

When fossil-fueled atmosphere generators are used to initially establish the low-oxygen atmosphere, a high carbon monoxide (CO) concentration may be produced in the CA storage. This is harmless to the produce, but, when the room is vented prior to produce removal, CO may seep into adjacent work areas. There is no CO danger if nitrogen gas (N) is used to create the atmosphere.

## ANIMALS

Interactions between farm animals and their caretakers provide the possibilities of both health and traumatic injury hazards to the caretaker. Many of these interactions are in the context of production agriculture work, but not all. Injury and health hazards also occur from pleasure-oriented activities such as pleasure riding of horses, and showing farm animals in 4-H and FFA contests. In terms of understanding hazards associated with farm animals, it makes little difference whether the animal and person interaction is work or pleasure oriented. Broad categories of animal-related hazards include animal handling and zoonotic diseases.

Many traumatic injuries, ranging from minor bruising and crushing injuries to death, occur during the routine handling and treatment of animals. The conditions and activities involved in routine handling and treatment vary widely, from moving rabbits between cages during cage cleaning, to separating small pigs from their mothers for vaccinations, to branding cattle unaccustomed to human handling. Several factors influence the chance of a person becoming injured while handling or treating animals. One obvious factor is exposure: the more contact there is between an animal and a person, the more likely that animal is to eventually cause some injury. This is true even though some animals become more docile as they are routinely handled. Some animals by their nature invite exposure, such as dairy cows and horses. Exposure may also be substantially increased by the method of feeding. Some feeding methods are heavily oriented to manual and individualized feeding while others are mechanized and involve large groups of animals.

Other factors that influence the chance of traumatic injury from animals include:
1. Size: The larger the animal, the more probable it is to injure a person, and injure him or her severely.
2. Familiarity with human touch: The less an animal is handled from birth, the more it will resist being handled later in life.
3. Haste in transporting the animal: The more rushed an animal is when moved, and the more excited it becomes, the more likely it is to resist movement.
4. Handling animals without proper restraints or handling devices such as halters, ropes, squeeze shoots, kicking straps, etc.
5. Trusting an animal to the extent you turn your back when in close quarters with the animal, or commit similar careless acts.
6. Remaining unaware that all farm animals have predictable behavioral characteristics.
7. Handling beef, dairy, hogs, and horse newborn animals in the presence of their mothers; any handling of bulls and stallions.

## Zoonoses

*Zoonoses* is the term that denotes diseases caused by infectious agents common to both animals and man (Steele, 1979). A person may become infected by both direct and indirect contact with diseased animals, their manure, urine, and bedding, or through animal products (meat, milk, hides, hair, etc.). Indirect contacts include soil, plants, and water contaminated by animal waste products. Intestinal diseases, respiratory disorders, general feelings of ill health, and skin rashes and diseases (dermatoses) are the most common manifestations of zoonotic diseases. Deaths to livestock producers or workers in the United States from zoonoses are rare. Less rare, though still not particularly common, are treatable dermatoses cases.

## PRODUCTION AGRICULTURE CHEMICALS

The term *pesticide* is generic for chemicals that kill, attract, repel, or otherwise control pest plants, animals, and microorganisms. A wide range of compounds are used in pest control including: acaracides (mites), algicides (algae), avicides (pest birds), bactericides (bacteria), fumigants (nonselective pesticides in gaseous form), fungicides (fungi), herbicides (weeds), insecticides (insects and related anthropods), molluscides (snails and slugs), nematicides (worms), predacides (vertebrate pests), pesticides (fish), and rodenticides (rats and other rodents). Pesticides are used in nearly every type of production agriculture operation, though total use has decreased in recent years.

Exposure to a pesticide does not, in and of itself, cause harm to humans, though this effect is often implied. The effect or influence a pesticide has on humans depends on various factors such as: physical and chemical properties (toxicity, degradation, volatility, etc.) of the pesticide; the dose or concentration of the pesticide; the duration

of the person's exposure; susceptibility of exposed persons; and the type of exposure (inhalation, ingestion, dermal). Poisoning effects from pesticides may result from short-term overexposures and/or long-term, low-level exposures. Short-term overexposures may result in immediate serious illness or death. More common are minimal overexposures that lead to headache, sweating, diarrhea, dizziness, fatigue, muscle ache, nausea, and other common human maladies. These symptoms mimic many other illnesses. Because minimal overexposure incidents are difficult to identify, they may often be underreported.

Multiple episodes of long-term, low-level exposure to pesticides are reportedly associated with many health risks to farmers. Cordes and Foster (1988) listed cancers, birth defects, sterility and infertility problems, genetic damage, and neurological and behavioral abnormalities that reportedly result from overexposure to pesticides. However, reported associations between pesticide overexposures and diseases are subject to controversy and disagreement. Diseases and chronic health problems may neither appear, nor be detected or diagnosed by physicians, until months or years after pesticide exposure. It is often difficult, if not impossible, to precisely attribute the disease or health problem to the pesticide exposure. Confounding factors include smoking, alcoholism, other occupational disease exposures, aging, poor personal hygiene habits, a lack of medical care, and other conditions that contribute to an unhealthy lifestyle.

Pesticides have three primary routes of entry into the human body and one less frequent route. The primary routes are through dermal (skin) absorption, by inhalation (breathing), and ingestion (eating, drinking). The less frequent route is eye absorption. In production agriculture, the most common form of poisoning is by dermal contact. The exceptions to this are small children, who are most often poisoned by ingestion. The handling of pesticides when they are at full strength, such as the opening of containers and pouring during the mixing operation, are prime times for overexposure incidents to applicators. Children can be poisoned when they drink pesticides or pesticide mixtures stored in soda bottles, milk jugs, coffee cans, etc., and when they put contaminated products, such as dirt, weeds, paper, etc., in their mouths. Field laborers may be overexposed from mixing and spraying operations, pesticide residue on treated plants, or drinking, bathing, or cooking with contaminated water. These are only a few of the ways in which acute overexposures and chronic, low-level exposures may occur. For more complete listings, check the references at the end of this lecture.

**Fertilizers**

Production agriculture makes use of many types of fertilizers to enhance or restore soil composition, and to increase crop yields. Nitrogen, lime, potash, and potassium are the major fertilizers. They may be applied singularly, or in combination mixtures, and in various forms. For instance, nitrogen may be applied either as anhydrous ammonia, aqua ammonia, urea, or ammonium nitrate. Most fertilizers are applied in granular form and present only low to mild hazard exposure to the eyes and respiratory tract and to the skin as skin rashes. The exception to this last statement is anhydrous ammonia ($NH_3$). Anhydrous ammonia is an efficient source of nitrogen fertilizer for crops and is widely used throughout most regions of the country. This fertilizer exists at atmospheric pressure as a gas but is converted to liquid form when put under pressure. Anhydrous ammonia is handled and stored through pressurized systems. It is applied by injecting it directly into the soil through injection knives. Once in the soil, it converts to a gaseous state and is immediately absorbed by soil moisture.

Anhydrous ammonia is a severe irritant of the eye, skin, and respiratory tract. It can cause damage by freezing the skin and destroying (chemically burning) eye and

respiratory tract tissues. Permanent eye damage is the most serious hazard of $NH_3$. Inhaling an excessive amount of $NH_3$ vapors could also result in asphyxiation, but situations where this might happen on the farm are unlikely. The risk of injury is greatest during transfers of $NH_3$ between supply tanks and applicator tanks. Ruptured or leaking valves, cross-threaded hose connectors, damaged hoses, over-filled tanks, or hoses that become disconnected are the main sources of accidental $NH_3$ release.

**Other Chemicals**

Many other chemicals are used regularly in production agriculture. Some may be used only in certain types of operations, while others are found in almost all operations. For instance, a variety of fuels, oils, lubricants, and degreasers are found on many farms. These products may be flammable or explosive, and harmful to the respiratory tract, eyes, and skin. Dairying operations use detergents, disinfectants, and sanitizing agents for cleaning animals and equipment. Harmful vapors, chemical burns, and skin diseases are possible hazards. Because disinfectants are not always stored properly, small children are at particular risk. Another example includes several types of chemicals, including acid formations, applied to forages to promote field drying and forage preservation in storage. Eye and skin chemical burns are the primary hazards.

**OTHER HAZARDS**

Hot weather hazards include sunburn, skin cancer, and heat-related illness such as heat cramps, heat exhaustion, and heat stroke. Production agriculture work is often done outdoors in sunny, hot, and humid weather, and may involve long continuous hours and strenuous, physical labor. These conditions increase the seriousness of hot weather hazards. Repeated sunburn episodes contribute to the development of skin cancer. Two types of skin cancer, basal cell and squamous cell, are seldom life-threatening, but a third type, melanoma, may become life-threatening if left untreated. Of the heat-related illnesses, heat stroke is the most serious and is a true medical emergency. Heat stroke occurs when the body's heat regulating mechanism goes out of control, and the body's core temperature rises to life-threatening levels.

Frostbite, which is frozen body tissue, is the most common cold weather hazard and usually happens to the nose, ears, fingers, or toes. Hypothermia, which is a lowering of the body's core temperature, is less likely occur. Air temperature, wind, dryness or wetness of skin, and length of exposure are the critical variables. Frostbite damage ranges from mild incidents where recovery is complete, to severe incidents which may lead to amputation of the body part. Cold weather hazards in production agriculture are most common among livestock and dairy producers and workers. Watering animals, wearing insufficient clothing, and looking for lost range or pasture animals in a snowstorm are examples of reasons persons suffer from cold weather hazards.

**Musculoskeletal Injuries**

The term *musculoskeletal* refers to our body's system of muscles, bones, joints, and related structures (tendons, connective tissue). Many musculoskeletal injuries are known as cumulative trauma disorders (CTD). Cumulative trauma disorders often result from the repetitive motions of specific body parts associated with working movements. These working movements often involve tools and equipment, lifting, turning, straining, etc. Some of the many types of CTDs are: carpal tunnel syndrome, Raynaud's syndrome, bursitis, tendinitis, hip joint arthrosis, and milker's knee. Other types of musculoskeletal injuries include low back pain and muscle strains and sprains. These types of injuries are most common among those working in crop production, particularly workers in horticultural specialties, fruits and tree nuts, and vegetables and melons (Bobick et al., 1991).

The production agriculture work environment is conducive to many types of musculoskeletal injuries. Tractor operation, milking cows, lifting and throwing bales

of hay, lifting containers of produce above the head to dump into trucks, stretching across mushroom beds, and bending over low-lying crops (cucumbers, strawberries, etc.) are just a few examples of common work activities that may result in musculoskeletal injury. To the extent the work environment involves vibration, cold or dampness, a fast work pace, and forceful exertions, the hazard is increased.

## Dermatoses

*Dermatoses* refers to skin diseases. Information on production agriculture occupational dermatoses is sketchy. Nevertheless, it is considered a leading agricultural occupational health hazard. Among the agents that may cause dermatosis are pesticides, zoonotic diseases, ultraviolet radiation, and the various farm chemicals mentioned earlier. Other sources include inedible plants (poison ivy, oak, etc.), crops (lettuce, celery, strawberries, and others), and animal feed additives. Hands are the most commonly affected body part. Dermatoses are most closely associated with migrant and seasonal farmworkers. One reason is the nature of their work: hand and field work results in a high exposure to plants. Dairy farmers, from their use of sanitizers and cleaners, have also been identified as a susceptible group for dermatoses.

## Slips and Falls

One of the most common causes of minor injury on the farm, and an occasional serious or fatal injury, is slips and falls. A variety of circumstances cause these falls, including: ice around farm buildings, wet surfaces in the barn, including manure, stepping up onto machinery that is wet or the boots are muddy.

## Electrical

Electrical power usage on the farm is still growing. Electrical hazards are created if the electrical wiring and electrical motors are not installed according to the National Electric Code. The other electrical hazard on the farm is contact with the high-voltage electrical wires that supply electricity to the farm. Contact with these overhead electrical wires can occur from moving a portable grain auger under these wires, handling aluminum irrigation pipe, pivoting an extension ladder under these wires or contact from unusually high farm equipment.

## Flowing Grain

The flow of grain inside the grain bin when the grain is being emptied from the bottom of the bin can readily trap anyone who is on the surface of the grain. The force created by the unloading grain is so great that once a person is waist deep in the grain, he or she is unlikely to be able to escape, even with the aid of a safety rope. Typical unloading rates will bury a person in less than a minute (NIOSH, 1993), and if not removed, the person is suffocated. A similar hazard occurs for children who are inside a grain wagon when the wagon is unloaded.

Other variations of this hazard occur when the surface of the grain has caked or crusted as a result of moisture at the surface. The grain can bridge at the top or cake to the walls of the bin. Once the bin has been partially emptied, a person entering the bin can fall through this bridged surface or be trapped by grain that is dislodged from the bin walls.

The risk of suffocation increases if grain spoils, because it gives off carbon dioxide, which may displace the oxygen in the bin. Even if the worker is not completely buried, he or she can suffocate because of the lack of oxygen above the grain surface (NIOSH, 1993).

## Long Work Days

The seasonal nature of farming creates the pressure to work quickly and work long hours during the planting and harvest periods. During these periods, the operator who is working long hours "to get the job done" may engage in risky behavior that would not be acceptable in less stressful periods.

**Miscellaneous**

The most common hazards associated with production agriculture, identified by nearly 30 years' worth of injury and illness reports, studies, and investigations, were addressed in the sections above. However, these hazards are only a part of the story, as a complete listing of hazards would be much longer. Indeed, a complete listing may not even be possible because nearly everything associated with production agriculture, including ground surfaces, is a potential hazard. Many hazards overlap. For instance, silos were discussed in relation to toxic dust particles and gases, but falling off silos, or down silo chutes, was not. Other hazard areas not discussed include high-pressure injections, electrical shock, fires, mental stress, drownings, and hazards from work uses and of all-terrain vehicles, to name a few.

There are also a multitude of consumer and industrial products used in agricultural production. Examples include chain saws, lawn mowers, power tools, welders, ladders, etc. These products all have hazards that may produce as serious an injury or illness as the hazards that were discussed in more detail. Readers should consult the references and bibliographies to become familiar with the multitude of hazardous conditions and situations that may exist at some point in production agriculture.

**SUMMARY**

Hazards and "agents of injury" are numerous and commonplace in production agriculture. Hazard characteristics associated with the operation of tractors include tractor stability, PTO operation, and runovers; tractor age, maintenance, and alterations; and operator variables such as age and training. Many farm machines, whether used for stationary or field work, involve multiple hazard points. The types of machine hazards that often result in the most serious injury include wrap point (PTO drivelines), pull-in point, and shear/cutting point hazards. These hazards are closely associated with the functions of farm machinery. Some hazards, such as noise and PTO, are associated with both tractors and machinery.

Respiratory hazards include silo and manure gases, toxic dust, and oxygen-deficient atmospheres. These hazards usually involve crop and animal storage and housing structures. Two toxic dust hazards, farmer's lung disease and organic dust toxicity syndrome, have been found, particularly among dairy farmers and swine confinement workers. Animal, weather, and chemical hazard exposures are also common among farmers and their families, as well as with migrant and seasonal farm workers. Production agriculture health-related hazards are difficult to identify because of the delayed appearance of symptoms or ill effects, confounding exposure variables, and unhealthy lifestyles or behavior patterns.

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## SAMPLE QUIZ QUESTIONS

1. Obtain farm/agricultural statistics reports from several different sources. Review any accident descriptions that are available from newspaper articles. Determine if the agricultural hazards as described here accurately reflect the events described in the newspaper articles and accident statistics.

2. From the best reports available, analyze the hazards encountered on a farm about 100 years ago and today. Was it safer to work on a farm then or now?

# Unit III
# HUMAN FACTORS

**PURPOSE**

To introduce students to the concepts of human error and human limitations.

**OBJECTIVE**

After completing this unit, the student will be able to:

1. List the four principles for the application of the human factors design philosophy as defined by Meister.
2. Explain the significance of people being different, people being adaptable, and people being goal oriented.
3. List five categories of human error.
4. Define and calculate anthropometric values for a 95th percentile man or woman.

**SPECIAL TERMS**

1. Behavior
2. Human error
3. Anthropometry

**INSTRUCTOR MATERIALS**

1. Lesson plan
2. Chalkboard

**TRAINEE MATERIALS**

1. Participant outlines made by instructor
2. Supplementary materials

**INTRODUCTION**

A hazard was defined in unit II as a condition or changing set of circumstances that presents a potential for injury, illness, or property damage. An injury to a person on a farm usually involves the interaction between an agent of injury and the person. There is the opportunity to reduce the probability of injury by considering the agent of injury or, separately, considering the person. The person in the human-machine system is the subject of this lecture. The general discipline for analyzing the person in this human-machine system is human factors.

One definition of the discipline of human factors is the application of behavioral principles and data to engineering design to do two things: to maximize an individual's contribution to the effectiveness of the system of which he/she is a part and to reduce the impact of that system on the individual (Meister, 1971). The reduction of the probability of personal injury is one element of human factors analysis.

**BASIC CONCEPTS AND PRINCIPLES**

The basic concept in the application of human factors in the system design process is that of the "human-machine system". Figure III-1 depicts a model of a human-machine system. This model shows the closed-loop relationship between the human operator and the equipment. For example, the operator of a corn harvesting combine receives information from the equipment through information displays in the cab or from the external environment in which he is operating (e.g., the position of the header with respect to the corn rows or the amount of grain observed on the ground behind the combine). The operator processes the information and makes certain decisions involving it and then operates the equipment controls (e.g., turns the steering wheel or reduces ground speed) to change the equipment status to achieve some desired goal. The equipment consequently provides new information (feedback) about its changed status to the operator and this cycle continues. The interaction between the operator and the machine creates the system relationship.

**Four Basic Principles of Human Factors**

Inherent in the application of the human factors design philosophy is the acceptance of four principles that have been given by Meister (1971). The first principle states that the functional effectiveness of equipment is related to the efficiency with which people can operate and maintain the equipment. Thus, any reduction in the operator's performance will lead to the equipment failing to perform its function or cause the equipment to perform that function less effectively than planned. For example, although a self-propelled forage harvester may have been given the capability of traveling at 9 mph (15 kph) through a field, it will fail to perform its function if the operator feels uncomfortable traveling at that speed (i.e., is disconcerted by the vibration, noise, and complexity of performing required tasks that are affected by the vehicle's speed) and selects a slower, more comfortable ride.
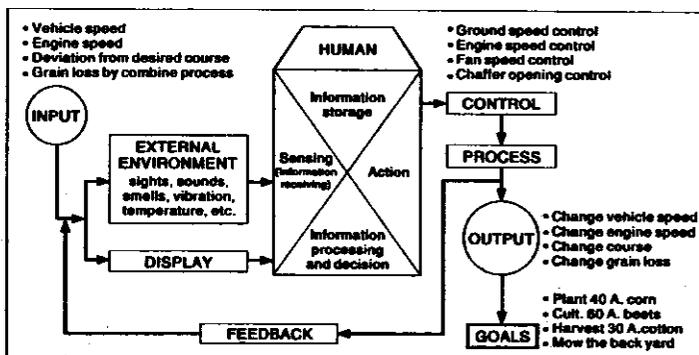


Figure III-1. A model of a human-machine system.

The second principle is that people operate and maintain equipment in a manner influenced by the equipment design. Thus, characteristics of the equipment design such as the responsiveness of the steering system or brakes, or the visibility of information displays in sunlight, or the force required to loosen a drain plug, act as stimuli to which the equipment user must respond. If the equipment characteristics require more from the operator than the operator is willing or capable of providing, the operator can respond incorrectly, out of sequence, or not at all. These equipment stimuli demand selective attention of the user; the operator cannot respond to all of them at the same time. Thus, at any given time, the user must pay more attention to some features of the equipment than others. Stimuli can also take the form of procedures for operating and maintaining the equipment, such as those given in operator's manuals, that impose loads on the operator's memory. Just as physical materials have certain tolerance limits within which they function effectively, the capabilities of people are set within certain natural limits within which they function best.

The third principle is derived from the second. Since equipment design characteristics act as stimuli to the user, then it follows that users will respond more efficiently to (or will accept as more preferred) certain arrangements of these characteristics over other arrangements. Thus, if equipment characteristics are designed to match the capabilities and limitations of the operators, the performance of the operators should be more efficient. Because uncomfortable whole-body resonances, which are inherent with humans, occur in the frequency ranges between 3 and 6 Hz and between 10 and 14 Hz, a seat or cab suspension design that greatly limits a vehicle operator's vertical acceleration in these frequency ranges will be better than one that does not (assuming that significant vibration inputs occur in those regions).

The fourth principle is that it is easier to modify equipment characteristics to match human capabilities than it is to modify (or select) human capabilities to accommodate equipment requirements. It is easier to select displays with larger alphanumeric characters or to arrange displays so that they are closer to the user than it is to add more sensitive visual acuity to the human. It is easier to design controls to be actuated within "human" force capabilities and to locate them within "human" limits of reach than it is to endow the operator with greater strength or to change his physical dimensions to a more desirable geometry.

**People are Different**

People are different in their size and shape (anthropometric dimensions). Because of this fact the human-factors design philosophy leads the design of a vehicle seat to permit the operator to independently adjust the vertical and fore-aft position. This allows the operator to determine the best viewing position for reading displays and observing the tasks, and choosing the best position relative to the machine's controls.

They are different in their perception of "comfort". This fact motivates designers to provide adjustability in the operator's work environment (e.g., seating, foot/leg room, air conditioning, etc.) to accommodate these differences.

They are different in their motor capabilities (e.g., reaction time, strength, etc.). They are different in their sensory capabilities (e.g., visual acuity, hearing ability, smell, sensitivity, etc.). They are different in their mental or cognitive capabilities for storing and processing information and for making decisions (e.g., learning rate, memory, retention of skills, etc.).

They are different in their experiences, "native-training", motivation, cultural background, perception of risks, and many other characteristics. Even the same person may be different at different times. Thus, the truth is: there is no "average man" or

"average person" for any measure of man. The lesson is: design to accommodate the differences (not the mythical average man). In this same regard, it should be noted that human performance (e.g., the interval of time to recognize and respond to an emergency) is not distributed "normally" with equal variance around a central mean. Thus, the mean of the distribution of a performance measure is not a very useful design parameter. It is better to view the "whole" distribution and design to accommodate as much of the whole as is feasible.

## People are Adaptable

When systems are designed for the "average person" the real people working in those systems must exercise perhaps one of their greatest attributes, their adaptability. People can accommodate system deficiencies to the point that those deficiencies are transparent or unrecognizable. As the tasks get more demanding (up to some "point") we just apply more effort and make judgments and adjustments to "get the job done". Common measures of operator or system performance such as productivity may detect no difference between an "inconsiderate" design (one with low commitment to human factors requirements) and a "good" design. Questionnaires and interview techniques can be designed that are helpful in soliciting operator responses to identify subtle, but significant, differences between alternative system designs.

Our adaptability can be observed in the way that we compensate for unwanted system characteristics and behavior. Compensating behavior (i.e., human actions in response to interferences to achieving a goal) can be observed in many settings, but perhaps the most fruitful one (for teaching someone what to look for) is in the use of personal computers. For example, in the situation where a computer user is trying to create a simple x-y graph using a widely used spreadsheet software product, it is common to observe the user finally "give in" to the product and accept the graph in the form that the product (really, the software designer) constrained it. This compensating behavior generally stems from the user having expectations of the system that will not be fulfilled—such as believing that the computer graphing program is as flexible as pencil and paper. The lesson is: although people are adaptable, their adaptability can compensate only to a limited degree before system performance is degraded or before the user becomes dissatisfied and either tolerates the system as it is or searches for another alternative.

## People are Goal-Oriented

Somewhere in the general sequence of performing a task a human operator may be faced with choosing among alternative goals or perhaps coordinating conflicting goals. For example, in operating a system, the goal of continuing to operate may conflict with the goal of avoiding compromises in safety. A case where human behavior, directed by a goal, has affected the performance of a safety device concerns the removal of power take-off shields. A recent article in *Successful Farming* summarized a survey conducted by Purdue University in four midwestern states. They found that the power take-off shield is more likely to be left in place if it is of the flip-up type (i.e., hinged at the back so it lifts up out of the way and then flips back down). The flip-up shields were found in place 89% of the time. The bolt-on, fixed shields were found in place 58% of the time, and the quick-attach shields (easily removed) were found in place only 31% of the time. Reasons that were found for removing the shields included: interference with the use of centrifugal spray pumps, interference with fully mounted equipment such as posthole diggers, and interference with the tasks of connecting and disconnecting drivelines.

Humans are agents of errors; they propagate error-likely conditions. An important element in the system design process is to analyze the tasks performed by the equipment operator and to classify potential human error associated with those tasks. This analysis will likely suggest possible equipment design or operator training
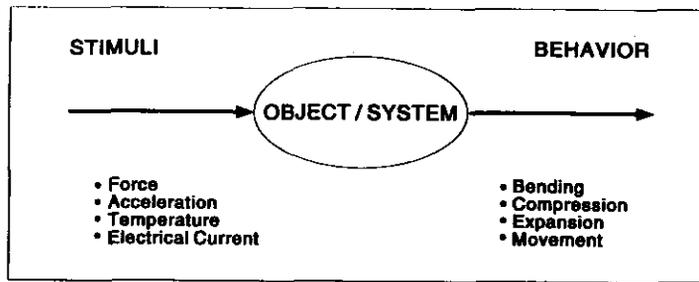
**Figure III-2a. Relationship between stimuli and behavior in objects and systems.**

remedies either to reduce the frequency of errors or to make the system more tolerant of the errors.

People will accept or take risks to achieve goals. Their experience (i.e., behavior learned from past occurrences with the same or similar systems) affects their current decisions. The operator's application of knowledge from one system to another has led system designers to use population stereotypes (e.g., pushing forward on a lever to go forward or faster, etc.) to minimize operator training time and reduce the likelihood of "negative transfer" of training.

**Behavior Defined**

Before we proceed to a specific example of an interruption to a hypothetical machine, behavior and human error need to be defined and discussed. The word *behavior* is used to describe responses (i.e., actions, conduct) to stimuli. It refers specifically to responses that can be observed. Commonly used statements like, "the operator was inattentive" or "the operator was careless", do not describe the observed actions of an operator and, therefore, are not descriptions of behavior. Every engineering discipline is concerned with the behavior of objects or systems. Understanding the behavior (i.e., response) of objects or systems such as bridges, vehicles, buildings, and motors to stimuli of force, acceleration, temperature, and electrical current is an important part of the engineering discipline. Examples of these are shown in figure III-2a.

When people are included in the system, other stimuli, such as hunger, thirst, personal goals, threats, and "barriers" to goals, etc., in addition to the stimuli of the physical environment, become important design considerations. The human behavior (really, the system behavior, because the operator's behavior is united with the rest of the system) resulting from these stimuli may be described only by the observed actions of the system and by the operator's decisions inferred to have occurred because of observed actions. This is illustrated in figure III-2b.

As shown in figure III-3, the behavior that a system displays reflects on: how comprehensive the designer was in considering the stimuli that affect the system, and
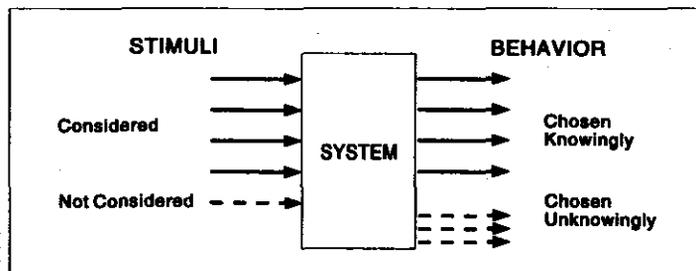


**Figure III-2b. Relationship between stimuli and behavior of humans.**
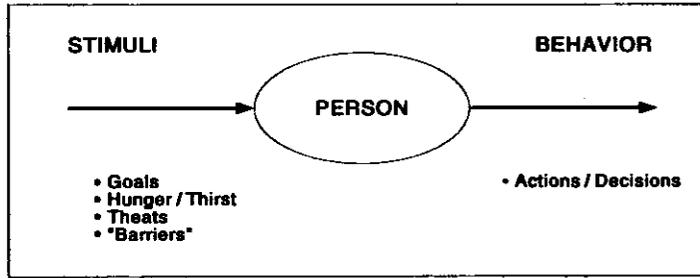
**Figure III-3. System design considers the stimuli affecting the system and the desired system behavior.**

the choices made by the designer regarding the responses that the system is permitted to make. In this context, the designer includes all the representatives that influence the system design (i.e., legislative, judicial, producer, customer).

To change the behavior of a system, we can either modify the stimuli (redesign the environment in which the system operates) or control or limit the responses that are permitted to occur following the stimuli (redesign the system). In "human-machine" systems, the human is one element of the system that generally is not within the designer's control. Even in military systems, where selection and extensive training of system operators is possible, the system designer still cannot completely specify the operator's characteristics to match the design of the other system elements. The operator's behavior, however, is strongly influenced by the system design. Individual actions and the sequence of actions permitted of, or performed by, the operator are dictated by the system design. As such, operator behavior can be excluded or included, as shown in figure III-4, as is done with other design parameters.

## Human Error Defined

The other term requiring definition is *human error*. With regard to system design, the definition of human error offered by Rigby (1970) is most appropriate, "Human error is any member of a set of human actions that exceeds some limit of acceptability". Swain and Guttmann (1980) state that an error (human or otherwise) is merely an out-of-tolerance action where the limits of tolerable performance are defined by the system. There is no connotation of blame or fault. By convention, the definition of human error excludes malevolent behavior but does include intentional errors. An intentional error is one that occurs when the operator performs some act believed to be correct or to represent a better way of performing a task but, in fact, is incorrect or wrong. Most errors are unintentional . . . they just happen . . . such as activating the wrong control because controls similar in appearance are nearby.

## Five Categories of Human Error

A human operator in a system can perform an out-of-tolerance action, that is, make an error if the operator does something incorrectly, fails to do something, or fails to do
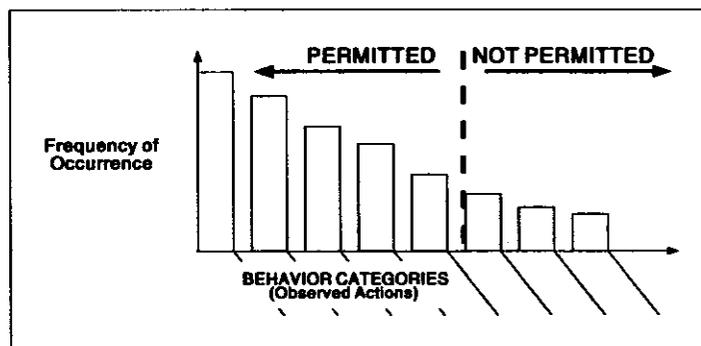


**Figure III-4. Behavior can be excluded or included.**

something in time. There are five major categories of human error, according to Swain and Guttmann (1980):

1. An error of omission that occurs when a person fails to perform a task or part of a task.
2. An error of commission that occurs when a person performs a task or part of a task incorrectly.
3. An extraneous act that occurs when a person introduces some task or step that should not have been performed.
4. A sequential error that occurs when a person performs some task or part of a task out of the proper sequence.
5. A time error that occurs when a person fails to perform a task or part of a task within the allotted time, either too early or too late.

**Reducing Probability of Error**

Human performance is highly variable; we never do anything exactly the same way twice, and no two people perform a task exactly alike. As long as the variability of the human performance stays within the acceptable limits defined by the system, no error will be noted. It is only when a response is outside these specified tolerance limits that an error occurs. The narrower the limits, the more likely it is that they will be exceeded. Thus, human variability can contribute to human error, and the greater the variability, the greater the potential for human error. Figure III-5 depicts a hypothetical distribution of time observed for human operators performing a task, along with a specified tolerance limit. In this case an error occurs if too much time elapses. In such a situation, the probability of error can be reduced two ways:

Reduce the variability of performance by selecting the operators or by intensive, periodic training of operators so that only those people who can perform the task as required by the system will be permitted to operate the system.

Enlarge the acceptable tolerances by redesigning the system to accommodate the existing variability in the population of operators so that, in the case shown in figure III-5, even the slowest operator can perform the task without an error.

Human tolerance limits, that is, limits placed on human responses to keep the variability of human behavior within acceptable tolerances, must be used in trying to control the potential for human error. Swain and Guttmann (1980) offer the following list of tolerance limits arranged from the most effective to the least effective: 1) Barrier limits physically prevent unacceptable performance (e.g., interlocks, shields); 2) Fixed limits are clearly and permanently established limits (e.g., detentes on controls, color coding of instruments); 3) Empirical limits are limits checked by observation or measurement during or after performance (e.g., checking an instrument panel to see that a gauge is within tolerance); 4) Reference limits are standards to be
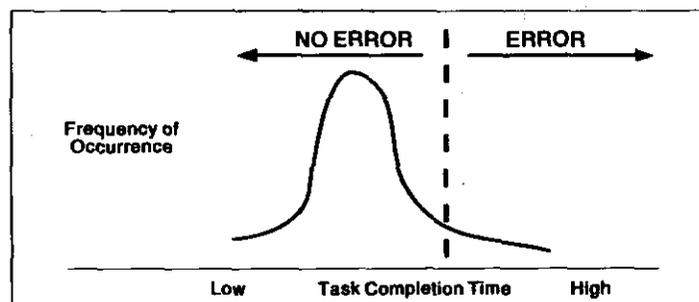


Figure III-5. A hypothetical distribution of time observed for human operators to perform a task; also shown is a system-specified tolerance limit.

compared with an output in time of doubt (e.g., samples of "good" and "bad" welds used in quality control inspections); 5) Caution limits are limits given by warnings, signs, etc. They are not very effective because they often are not present while the related action is being performed or, if present, they are a familiar part of the operator's environment and are no longer attention-getting signals; 6) Conventional limits are limits instilled by training or custom (but which may not be reinforced in the work situation); 7) Forensic limits are limits subject to debate and are often defined after some incident has occurred to assess blame.

## HUMAN VARIABILITY

The discipline of human factors encompasses such diverse human characteristics as work physiology (the strength to push, pull or turn controls, the ability to lift materials, etc.), cognitive skills and processes, and anthropometry (the physical dimensions of people). These and other elements of the human factors discipline are used to select the people that the Air Force will train to be jet aircraft pilots, to design the control panels and instruments that are used by the operator to control a nuclear power plant, and to design the operator controls for an agricultural machine. Time permits only a brief introduction to one of these areas, anthropometry.

Human beings come in only two basic models, male and female. This would seem to simplify the task of gathering data for design purposes. However, there are still wide variations due to size, age, sex, body type, race, and country of origin, and even some professions emphasize certain characteristics rather than others. For example, people who do strenuous physical work are apt to be bigger and stronger than those who have desk jobs.

The wide range in size and ability of humans makes the designer's task challenging. The designer must consider the great variation of users and attempt to accommodate as large a proportion as possible. This is particularly true in the design of agricultural equipment. Rather than working with a specific population, such as might be found in an industrial situation where the workers range from 20 to 65 years, the agricultural designer knows that the design will be used by a wide spectrum of users. It will be used by youngsters as young as 8 to 10 years of age, by older people, well into their eighties, by women as well as men, and by people of all sizes and abilities. The equipment will be used at night and in bright sunlight, in summer heat as well as winter cold. It must accommodate heavy clothes, jackets, and gloves on the hands, and have foot controls with sufficient clearance for winter boots (fig. III-6). The designer's task to accommodate as many people as possible under extreme conditions is difficult and requires good anthropometric data.

A study by Casey (1989) gives evidence that, in addition to the wide range of people and their sizes who use agricultural equipment, U.S. farmers tend to be significantly
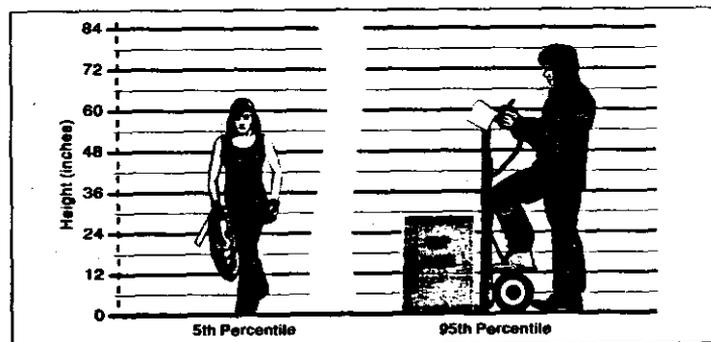


**Figure III-6. Equipment should fit the smallest operator in light clothing as well as the largest in bulky clothes.**
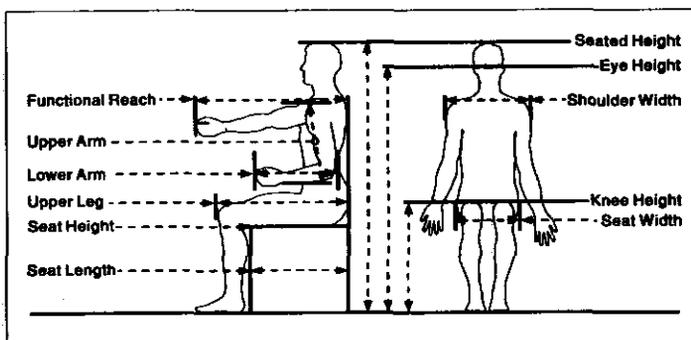
Figure III-7. Conventional anthropometric dimensions.

larger in size and weight than the corresponding general population. These data argue that engineers/designers need to provide increased dimensions and adjustability to accommodate these larger individuals, while still providing for the smaller user in the population.

**ANTHROPOMETRIC DATA**

Measurements are made of many different parts of the body. These measurements form a data bank for the design of most equipment that interfaces with a human (fig. III-7).

The conventional anthropometric measurements include the following:

| | |
|---|---|
| Standing height | Seat or popliteal height |
| Seated height | Functional arm reach |
| Seated eye height | Upper and lower arm length |
| Upper leg height | Shoulder width |
| Knee height | Hip or seat width |
| Seat length | Weight |

However, human beings must not only fit spatially in a man-task system, but they must also be able to move and function dynamically. This requires additional room for the operator to ingress, egress, move, turn, reach, and operate controls. Although static body dimensions are useful for certain design purposes, the dynamic or functional dimensions are probably more useful for most design problems (fig. III-8). The dynamic or functional dimensions must consider the location and movement of operating controls as well as the forces to be exerted and the direction and frequency of the movements.
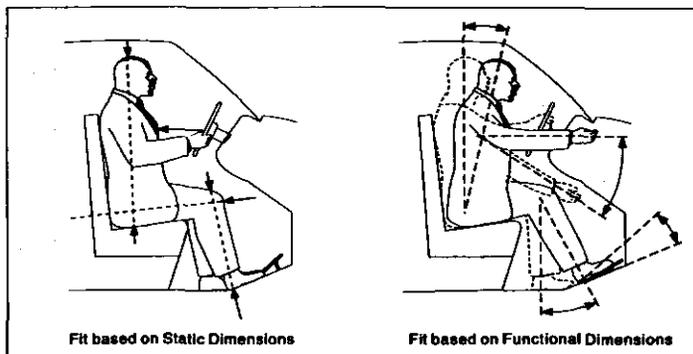


Figure III-8. Static versus functional body dimensions in vehicular cab design (from Damon, Stoudt, and McFarland, 1966).

Anthropometric data are a powerful tool for the designer of man-task equipment; however, it is important that the data used for design are based on samples of subjects similar to the end users. There are large amounts of data available for young men, most resulting from military service activities. Data on people at large or the general population exist, but data on some groups of interest are much less available. Examples of groups whose data may be scarce are small children, elderly people, women, and ethnic groups.

Because the number of humans that may use a particular piece of equipment is so great, it is not reasonable or possible to measure each one. Rather, a sample that is representative of the whole is selected and measured. If the sample is sufficiently large, sample errors will be insignificant and the resulting design will give a reliable fit.

As the body dimensions are measured and compiled for our sample, a data bank is developed, ranging from the smallest measurement for each dimension to the largest. This range represents 100% of the total with 1% the smallest size and 100% the largest size. If the sample is sufficiently large, the measurements fall into a normal bell-shaped probability density function, with the maximum number of measurements occurring at the mean (or 50th percentile) (fig. III-9).

This provides a very convenient way to refer to the size of a particular dimension with respect to the rest of the population. For example, a man whose standing height measures at the 70th percentile point would be larger than 70% and smaller than 30% of the men. He would be referred to as a 70th percentile man in height. The same procedure is used for all other dimensions.

Anthropometric data for engineering use are best presented in percentiles as discussed above. These tables provide a faster, more convenient method of determining a percentile equivalent of a dimension than does the use of normal probability density functions. Typically, the extremes below 2% or 5% and above 95% or 98% are disregarded for most designs, and a useful range covering the middle 90% to 96% is used.

The percentile can be determined arithmetically using the standard deviation (SD) and the mean value. The standard deviation is a measure of the scatter or dispersion about the average:

$$\text{Standard deviation (SD)} = \sqrt{\frac{\Sigma(D^2)}{N}}$$
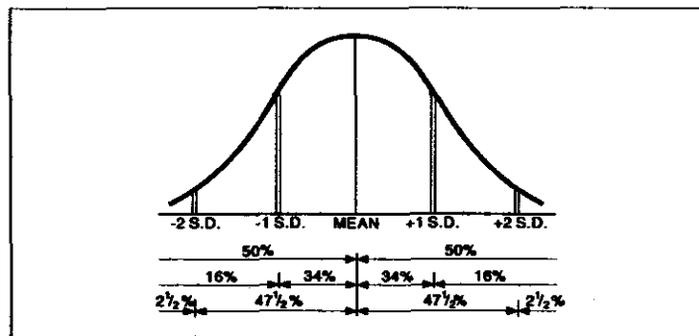


Figure III-9. Gaussian probability density function. Definition of percentile and standard deviation.

where

Σ — sum of

D — deviation of each value from the mean

N — number of subjects

In normal distribution, the mean (or 50th percentile)

±1 Standard deviation includes 68% (16 to 84 percentile)

±2 Standard deviations include 95% (2.5 to 97.5 percentile)

±3 Standard deviations include 99.7%

The computation of a specific percentile is done as shown in the following examples:

1. To obtain the 75th percentile value when the mean value is 35.1 in. and the SD is 1.5 in., use $K_1 = 0.674$ (see table III-1).
   Multiply the value 0.674 by the SD (1.5): $0.674 \times 1.5 = 1.01$ in.
   This value is added to the mean value to give the dimensions of the 75th percentile: $35.1 + 1.01 = 36.1$ in.
2. To obtain a value below the mean, the calculated value is subtracted from the mean value. For example, to find the value of the 10th percentile when mean value is 35.1 and SD is 1.5, use $K_1 = 1.282$: $1.28 \times 1.5 = 1.9$ in.
   The 10th percentile value is: $35.1 - 1.9 = 33.2$ in.

3. To find the adjustment needed for the middle 90% of this group, use the factor $K_2$ times the SD. $K_2$ for the central 90% = 3.29
   The adjustment required is: $3.29 \times 1.5 = 4.9$ in.

## FALLACY OF DESIGNING FOR THE AVERAGE PERSON

When a normal distribution is fitted to the anthropometric data, it is observed that the most likely measurement for any dimension is at the mean. A designer might conclude that equipment designed to fit this 50th percentile person or average person would accommodate the largest number of persons, but designing for just the 50th percentile person is a serious error. A control or device designed to accommodate only the 50th percentile person will be too large or out of reach for the small half of the population and too small to fit the large half.

Designing for the 50th percentile is also an error when the design involves muscular strength, because a control designed for average strength could not be operated by the weaker 50% of the users. In general, maximum control resistances should be based upon the strength exertion of the weakest potential user. If the weakest person can operate the control, all others will be able to do so as well. The designer should

Table III-1. How to compute percentiles from standard deviations (from Roebuck et al, 1975)

| Percentile | | $K_1$ | Percent Confidence Interval on the Mean | $K_2 = 2K_1$ |
|---|---|---|---|---|
| 30 | 70 | 0.524 | 40 | 1.045 |
| 25 | 75 | 0.674 | 50 | 1.349 |
| 20 | 80 | 0.842 | 60 | 1.683 |
| 15 | 85 | 1.036 | 70 | 2.073 |
| 10 | 90 | 1.282 | 80 | 2.563 |
| 5 | 95 | 1.645 | 90 | 3.290 |
| 2.5 | 97.5 | 1.960 | 95 | 3.920 |
| 1.0 | 99.0 | 2.326 | 98 | 4.653 |
| 0.5 | 99.5 | 2.576 | 99 | 5.152 |

remember that even power-assisted controls may have to be manually operated in the event of an emergency power failure and should be designed accordingly.

There are situations where a compromise design or average is acceptable. Things that are not adjustable and are used by the general public fall into this category. Examples are the height of the checkout counter at the supermarket, the height of drinking fountains, and stair tread height. These are examples of equipment that would be designed to inconvenience the fewest number of people. Designing these facilities for the average-size person will be acceptable to more people in general than would be the case if the equipment were sized for an extremely small or extremely large person.

Because the force that the human body can exert depends upon the position of the body or limb, as well as the muscle strength, the engineer/designer must consider what the equipment design requires the operator to do. A repositioned control can be the difference between a control that is easy to operate and one that is not acceptable. Biomechanical design data and criteria are given in texts such as *The Human Body in Equipment Design* by Damon et al., *Biomechanics of Ergonomics* by Tichauer, and *Human Engineering Guide to Equipment Design* by Van Cott and Kinkade.

It is not unusual to find even new equipment that is designed and marketed with operating forces that are excessive. An understanding and application of anthropometrics will correct many of these situations.

## Design for the Extremes

When an engineer/designer designs equipment, he or she must consider the total population that will use the item. This involves careful study of the population that will affect the design. Usually there is some limiting anthropometric dimension requiring a design that will accommodate individuals at this extreme on the anthropometric scale. The logic follows that if the design will accommodate the extreme individual, virtually the entire population can be accommodated. For example, a design requires a minimum dimension, such that the height of a door or passageway would be based upon the upper percentile sizes. If large individuals (in the 95th percentile) can pass through the opening, then certainly smaller individuals will be able to as well. Dimensions requiring a "maximum" specification, such as the maximum height to reach, need to be designed to accommodate individuals at the lower percentiles, typically the 5th percentile person. If individuals of this size can reach the control, the larger person should have no difficulty.

## Design for a Range Adjustment

Some equipment requires adjustment in order to accommodate people of varying sizes. Some examples are: the forward and backward seat adjustment in vehicles, the height of desk chairs, the seat suspension setting for tractors, and steering wheel and control locations in vehicles.

Usually it is not reasonable or economically feasible to try to accommodate the total 100% of the size range in the design. A decision is made to include a range of the population that will accommodate the maximum number of individuals with a reasonable design and cost. This is the designer's choice and, typically, the cut-off points on the range of population are at the 5% and 95% points. With this choice the design will accommodate the middle 90% of the population with only the smallest (those below 5%) and the largest (those above 95%) outside the design range.

Because there are relatively few persons that fall into the extreme size categories, the number of people inconvenienced is small. Studies have shown that from the perspective of design economics, the range of adjustment needed to accommodate the middle 90% is reasonable. To include the first 5% and the last 5% may require a greater range of adjustment than is required for the middle 90%; the design is much

more difficult and the cost is excessive. In most situations, the added complexity and cost is not justified by the small numbers who benefit. A seat adjustment of 10.7 cm will accommodate the middle 90% of users. Including the top and bottom 5% will require a total adjustment range of 26.2 cm.

## Design for a Worldwide Market

Increasingly, equipment is being designed and marketed for use by worldwide clientele. Thus, the engineer/designer must choose the anthropometric data carefully. People of different countries and races vary in size, conformation, and characteristics. These variations may affect the design. For example, when people with a generally smaller stature are expected to use the same equipment as people with a predominantly larger size, the range of adjustment may need to be extended, or other modifications may be needed. Foot pedal control must be spaced differently for operators with larger feet, and so on. The engineer who is aware of this full-spectrum target market will be interested in anthropometric data with an international base.

## SUMMARY

The interaction between the operator and the machine creates the human-machine system relationship. The functional effectiveness of the machine is related to the efficiency with which people can operate and maintain the machine, which is influenced by the equipment design. Operators will respond to the design characteristics that act as appropriate stimuli, and it is easier to modify the machine characteristics than it is to modify (train or select) the operator. The operator in a system can perform an "out-of-tolerance" action, i.e., make an error, by omission, commission, an extraneous act, a sequential error or a time error.

Anthropometric issues are only one of the many human factor issues to be addressed in the design of a human machine system.

## REFERENCES

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1. Analyze the most complete narrative information available for several farm injuries to determine if there was a component of human error leading up to the injury. What type of error was involved (error of omission, error of commission, etc.)?

2. Review a combine or tractor manufactured 20 to 25 years ago and compare with the newest tractor available. Identify design changes that will reduce the probability of human error and human stress and fatigue.

3. Obtain a recent publication of anthropometric data. Compare your measurements with that data and compute the approximate percentile for each value.

# Unit IV
# HAZARD ANALYSIS

**PURPOSE**

To introduce students to analysis strategies for evaluating hazards.

**OBJECTIVE**

After completing this unit, the student will be able to:

1. Perform a failure mode and effects analysis (FMEA)
2. Perform a fault tree analysis
3. Perform a risk score analysis
4. Perform a task analysis

**SPECIAL TERMS**

1. Failure mode and effects analysis
2. Fault tree analysis
3. Risk score analysis

**INSTRUCTOR MATERIALS**

1. Lesson plan
2. Chalkboard

**TRAINEE MATERIALS**

1. Participant outlines made by instructor
2. Supplementary materials

**INTRODUCTION**

Reducing the probability of an injury on the farm requires that the hazards in a new design for a machine or structure be analyzed to identify the hazards and prioritize the response to those hazards. The analysis should identify the extreme conditions, from the high probability of a fatal injury to the low probability of a minor injury, and the continuum in between these extremes. This analysis is improved if those who participate in the analysis have a good understanding of the hazards likely to be encountered and of the injury frequency associated with these hazards.

**HAZARD ANALYSIS**

Studies of hazards have shown that they can be divided into three broad categories: inherent properties or characteristics of the products; failures, material or human; and environmental stresses (Hammer, 1985). Hazard analysis is required to: identify such hazards; determine which hazards can be eliminated through the design process; and determine the best approach for reducing remaining hazards to an acceptable degree. A sound analysis helps to prioritize hazards for corrective actions and demonstrate the adequacy of subsequent safeguards. There are many different methods for conducting hazard analyses. The textbooks of Brauer (1990) and Hammer (1985) provide many examples. Four hazard analysis procedures are discussed to provide examples of how hazard analysis is used in safety engineering.

**FAILURE MODE AND EFFECTS ANALYSIS (FMEA)**

Failure mode and effects analysis (FMEA) is a systematic, analytical tool that will help the engineer, to the extent possible, identify potential failure modes and their associated causes, analyze customer, and develop design alternatives. In a pure sense, all items, including sub-assemblies, should be evaluated. A rigorous FMEA is a summary of the collective experience of the total design and development team. The FMEA document parallels and formalizes the mental discipline that engineers normally go through during the process of product development.

An FMEA reduces risk, supporting the design process by:
• Objectively evaluating design requirements and alternatives.
• Assuring that potential failure modes and their effects on customers have been considered throughout the development process.
• Providing valuable information to the engineer to assure adequate testing and development programs.
• Prioritizing product optimization efforts, based on impact to the customer.
• Identifying risk and aiding in developing contingency plans for failure prevention.
• Providing a reference to aid in the analysis of design changes, concerns, and developing advanced technology.

The customer in an FMEA is understood to be the end user of the product being studied. However, parts and subassemblies may have some hidden customers which, if ignored, could be severely impacted by product failure. Such customers are other design engineers of higher-level parts, manufacturing engineers, machinists, assemblers, reliability engineers, and field service. These customers are most impacted by nonmanufacturable and nonserviceable designs and should be considered in the process of product development.

The conduct of the FMEA is guided by the form that is commonly used to complete this analysis (fig. IV-1). Following the form makes the mechanical process of completing the FMEA relatively simple. Several of the people most knowledgeable about the design, manufacture, design evaluation, and service of the component reviewed should be asked to participate in the FMEA. The challenge in completing an FMEA is to achieve consensus of the participants on the values to be entered on the form.

(1) This section of the FMEA form will vary from manufacturer to manufacturer depending on the complexity of the products being evaluated. Many manufacturers have the form loaded into the PC database.

## FAILURE MODE AND EFFECTS ANALYSIS

Part or Process Name _____   Model Year/Vehicle(s) _____   FMEA Date (Orig.) _____   (Rev.) _____

Engineering Release Date _____   Prepared by: _____

| Part Name & Number Part Function | Potential Failure Mode | Potential Effect(s) of Failure | S e v | Potential Cause(s) of Failure | O c c u r | Design Verification | D e t e c | R P N | Recommended Action(s) | Area/Individual Responsible & Completion Date | Actions Taken | Action Results S e v | O c c | D e t | R P N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | | | |
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Figure IV-1. Typical FMEA form.

**Potential Failure Mode**

Step 1. Complete top section of the form to provide a record of this FMEA.

Step 2. Identify the part number to be analyzed and list all the functions of the part.

Step 3. Identify the *potential failure modes*. A potential failure mode is defined as the manner in which a part or assembly could fail to meet the design intent, performance requirements, and customer expectations. The potential failure mode may also be the cause of potential failure mode in a higher-level assembly, or be the effect of one in a lower-level part. A recommended starting point for listing potential failure modes is a review of available failure data, such as past FMEAs, engineering test reports, quality reports, any other available documents, and cross-functional team brainstorming.

Examples of potential failure modes:

| | |
|---|---|
| Cracked | Sticking |
| Deformed | Short circuited (electrical) |
| Worn | Open circuited (electrical) |
| Corroded | Vibrating |
| Loosened | Dirty |
| Leaking | Fractured |

Note: Potential failure modes should be described in technical terms, not as symptoms noticeable by the customer.

**Potential Effects of Failure**

Step 4. Identify the *potential effects of failure*. Potential effects of failure are the effects of the failure modes on the customer. Potential effects of failure are described in terms of what the customer might experience. These should be expressed in terms of product performance.

Examples of potential effects of failure:

| | |
|---|---|
| Poor appearance | Insufficient power |
| Hydraulic lines fracture | Excessive operator fatigue |
| Noise | Poor gradeability |
| Won't start | Lighting failure |
| Vehicle control impaired | Leaks oil |
| Poor stability | |

It is important to obtain data from customers. This could be in the form of warranty reporting, service reports, dealer questionnaires, focus groups, manufacturing improvement efforts (troubleshooting), vehicle final test reports, and cross-functional team brainstorming.

**Severity**

Step 5. Estimate the *severity* of the effect of the failure. This is a numerical evaluation of the seriousness of the effect of failure to the next operation in manufacturing/assembly, the vehicle, or the customer. The severity rating applies to the effect of failure only. It is important to note that to reduce the severity ranking there must be a design change. Severity is evaluated on a 1 to 10 scale (fig. IV-2).

| Severity of Effect | Ranking |
|---|---|
| Minor: Unreasonable to expect that the minor nature of this failure would cause any real effect on the vehicle or system performance. Customer will probably not even notice the failure. | 1 |
| Low: Low severity ranking due to nature of failure causing only a slight customer annoyance. Customer will probably only notice a slight deterioration of the system or vehicle performance. | 2 3 |
| Moderate: Moderate ranking because failure causes some customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure (e.g., engine misfire, compressor rumble, sunroof leak). Customer will notice some subsystem or vehicle performance deterioration. | 4 5 6 |
| High: High degree of customer dissatisfaction due to the nature of the failure such as an inoperable vehicle (e.g., engine fails to start) or an inoperable convenience subsystem (e.g. air conditioning system, power sunroof). Does not involve vehicle safety or noncompliance to government regulations. | 7 8 |
| Very High: Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulations. | 9 10 |

**Figure IV-2. Evaluation criteria for selecting the severity value (SEV).**

Step 6. Identify the *potential causes of failure*. A potential cause of failure is an indication of a design weakness, the consequence of which is the failure mode. Every possible cause of failure should be listed which is assignable to each failure mode.

Examples of failure causes are:

Incorrect material specified                Over-stressing
Incorrect assembly instruction            Insufficient hydraulic capacity
Insufficient torque specified               Inadequate B10 life
Insufficient lubrication capability         Permissible material impurity level
Insufficient horsepower specified
Allowed casting inclusions

Step 7. Estimate the *occurrence*. Occurrence is an estimate of the likelihood that a specific cause will result in a failure mode. The occurrence ranking number has meaning rather than value. A design change is the only way to improve the occurrence ranking number. Estimates of the likelihood that a cause will result in a failure mode is on a 1 to 10 scale (fig. IV-3). In determining this estimate the following questions should be considered:

- How adequate is the proposed design verification (or test) program?
- Is part carry-over similar to a previous-level part or assembly?
- How significant are the changes from previous-level parts or assemblies? Is the part radically different from the previous-level parts? Is the part completely new?
- What is the service history or field experience with similar parts or assemblies?

| | Probability of Failure | Ranking | Design Life Possible Failure Rates |
|---|---|---|---|
| Remote: | Failure is unlikely | 1 | < 1 in $10^6$ |
| Low: | Relatively few failures | 2 | 1 in 10,000 |
| | | 3 | 1 in 4,000 |
| Moderate: | Occasional failures | 4 | 1 in 1,000 |
| | | 5 | 1 in 400 |
| | | 6 | 1 in 80 |
| High: | Repeated failures | 7 | 1 in 40 |
| | | 8 | 1 in 20 |
| Very High: | Failure is almost inevitable | 9 | 1 in 8 |
| | | 10 | 1 in 2 |

Figure IV-3. Evaluation criteria for selecting the occurrence value (OCCF).

Step 8.   Identify the steps in the *design verification* process. Design verifications (DV) are all validation methods employed to verify that the design prevents potential product failure.

Examples of design verification methods:

Design reviews                Prototype testing
Proving ground testing        Lab testing
Mathematical studies          Computer simulations
Feasibility reviews           Design of experiments

Step 9.   Estimate the *likelihood of detection* of the failure. Detection does not relate to inspection techniques in production. Detection in the sense of FMEAs describes the ability of the proposed design verification program to identify a potential design weakness (fig. IV-4). The detection ranking number is used to evaluate the design verification program. In order to achieve a lower (more desirable) ranking the planned design verification program must be improved.

| Likelihood of Detection by Design Verification Program | | Ranking |
|---|---|---|
| Very High: | DV program will almost certainly detect a potential design weakness | 1 |
| High: | Program has a good chance of detecting a potential design weakness | 3 |
| | | 4 |
| Moderate: | DV program may detect a potential design weakness | 5 |
| | | 6 |
| Low: | DV program not likely to detect a potential design weakness | 7 |
| | | 8 |
| Very Low: | DV program probably will not detect a potential design weakness | 9 |
| Absolute certainty of nondetection: | DV program will/cannot detect a potential design weakness, or there is no DV program | 10 |

Figure IV-4. Evaluation criteria for selecting the likelihood of detection value.

Step 10. Calculate the *risk priority number*. The risk priority number (RPN) is the product of the severity, occurrence, and detection rankings. RPNs are relational, therefore they have no individual value or meaning. An example of calculating the risk priority number is:

- Product A:

| | | | | |
|---|---|---|---|---|
| Severity | - | Engine misfire | - | Ranking 5 |
| Occurrence | - | Repeated failures (1 in 20) | - | Ranking 8 |
| Detection | - | High (good chance) | - | Ranking 3 |

Risk priority number (RPN) = 120
    Severity (5) × Occurrence (8) × Detection (3) = 120

Step 11. Identify *recommended actions*. After the RPN has been calculated, corrective action should be directed at the few critical characteristics. The intent of the corrective action should be to reduce any one or all of severity, occurrence, and detection rankings.

A reminder:

- To reduce the severity ranking the team must make one or more design revisions and verify through testing.
- To reduce the occurrence ranking the team must remove or control one or more of the causes of failure.
- To reduce the detection ranking the team must improve the design verification system.

    - Design of experiments
    - Dynamic product simulation
    - Revised test plans
    - Revised design
    - Revised material specifications

Step 12. Identify the *responsibility* for recommended actions. Enter the person(s) or area(s) responsible to facilitate corrective actions. Include the completion target dates.

Step 13. List the *actions taken*. After an action has been completed successfully, enter a brief description of the actual action, the results, and the effective completion date. Again on complex projects, project management techniques are a must to assure timely completion of actions that could postpone an important FA.

Step 14. Calculate the resulting *risk priority number*. After each corrective action has been successfully completed the FMEA must be updated. A reevaluation of the severity, occurrence, and detection rankings should be made. The next step is to recalculate the risk priority number. A newly prioritized list should be circulated to the individuals and/or areas responsible for the design and corrective action.

The FMEA has been completed. Remember that the risk priority number has no absolute value but is used to rank the priorities of the design changes that result from the analysis. When the process is taken to its ultimate conclusion, design changes or

design verification changes reduce the risk priority number. The probability of any failure is reduced and the severity of any failure is reduced.

## FAULT TREE ANALYSIS

Reliability engineers have long employed a failure mode and effects analysis to predict the probability of a mechanism meeting the design goals for reliability. The FMEA is based upon known or projected failure rates of individual components, how each part could malfunction, and the ultimate effect on higher-level subassemblies or the entire product. It is a tool for analyzing hazards that result totally from the failure of a mechanical part, but it does not consider human or environmental factors. To overcome this limitation, the fault tree analysis technique was devised (Hammer, 1985). The fault tree analysis technique is based on the assumption that most unintended incidents are the result of one or more sequences of events, which can be represented in a fault tree diagram.

## Logic Symbols Used

Beginning with the unwanted event (injury incident), a diagram is constructed backward through prior actions that could cause the event. This task is done with the use of fault tree logic symbols. Figure IV-5 is a diagram and explanation of fault tree analysis symbols. Events in a sequence are connected by gate symbols that indicate whether all of the preceding conditions must be fulfilled to cause the event (AND gate), or whether any one condition will trigger the event (OR gate). The event symbols, because they have particular meanings, also give some indication of the type of event. The process is continued for each branch of the tree until all available information is applied. The lowest level of each branch is a failure or error initiating the event.

Fault tree construction for a product can be very complex. However, a simple example is given in figure IV-6. In this example, the operator of a farm tractor starts the engine by shorting across terminals on the starter motor while standing on the ground in front of the drive wheel (an unsafe practice). If the transmission has been left engaged in gear and the engine starts, the tractor may run over the operator. This is the top event which is to be avoided. When bypass starting is tried on a tractor that has the conventional dry, spring-loaded clutch, there is an immediate but slight movement of the drive wheel when the starter is engaged. This slight movement may warn the operator and allow him or her to move out of the way. However, when the tractor is equipped with a hydraulically actuated clutch, there is a brief time delay while hydraulic pressure is building up. This permits the engine to reach full speed before the clutch is suddenly engaged, resulting in a rapid lurch of the tractor, potentially running over the operator.

Examination of the fault tree diagram suggests various actions that may be taken to reduce the risk of bypass starting. For instance, improved reliability of the key switch and other components in the electrical system may reduce the need for bypass starting. Another engineering solution is to cover the starter motor terminals. A third solution is to install a hydraulic valve that bypasses hydraulic pressure until the operator depresses the tractor's clutch at least one time. Clutch depression is a procedure normally done from the operator's station, thereby removing the operator from in front of the tractor wheel. A less effective, but still helpful measure may be to utilize a hazard warning at the starter motor. Carefeul study of the sequence of events in the fault tree diagram shows that each of these preventive steps has some merit.

AND gate. A logical AND relation. Output A exists if and only if all of $B_1, B_2, \ldots B_n$ exist simultaneously.

OR gate. A logical inclusive OR relation. Output A exists if any of $B_1, B_2, \ldots B_n$, or any combination thereof, exists.

Inhibit gate. Permits applying a condition or restriction to the sequence. The input and condition or restriction must be satisfied for an output to be generated.

Identification of a particular event. When contained in the sequence, usually describes the output or an input of an AND or an OR gate. Applied to a gate, indicates a limiting condition or restriction that must be satisfied.

An event, usually a malfunction, describable in terms of a specific circuit or component.

An event that is normally expected to occur; usually an event that always occurs unless a failure takes place.

An event not developed further because of lack of information or of sufficient consequence. Could also be used to indicate further investigation is intended when additional information becomes available. Symbol W with a numerical subscript is sometimes used also.

Indicates and stipulates restrictions. With an AND gate, the restriction must be fulfilled before the event can occur. With an OR gate, the stipulation may be that the event will not occur in the presence of both or all inputs simultaneously. When used with an inhibit gate, stipulation is a variable condition.

A connecting symbol to another part of the fault tree within the same major branch. Has the same functions, sequence of events, and numerical values.

A connecting symbol to another part of the fault tree within the same major branch. Has the same functions and sequence of events, but not numerical values.
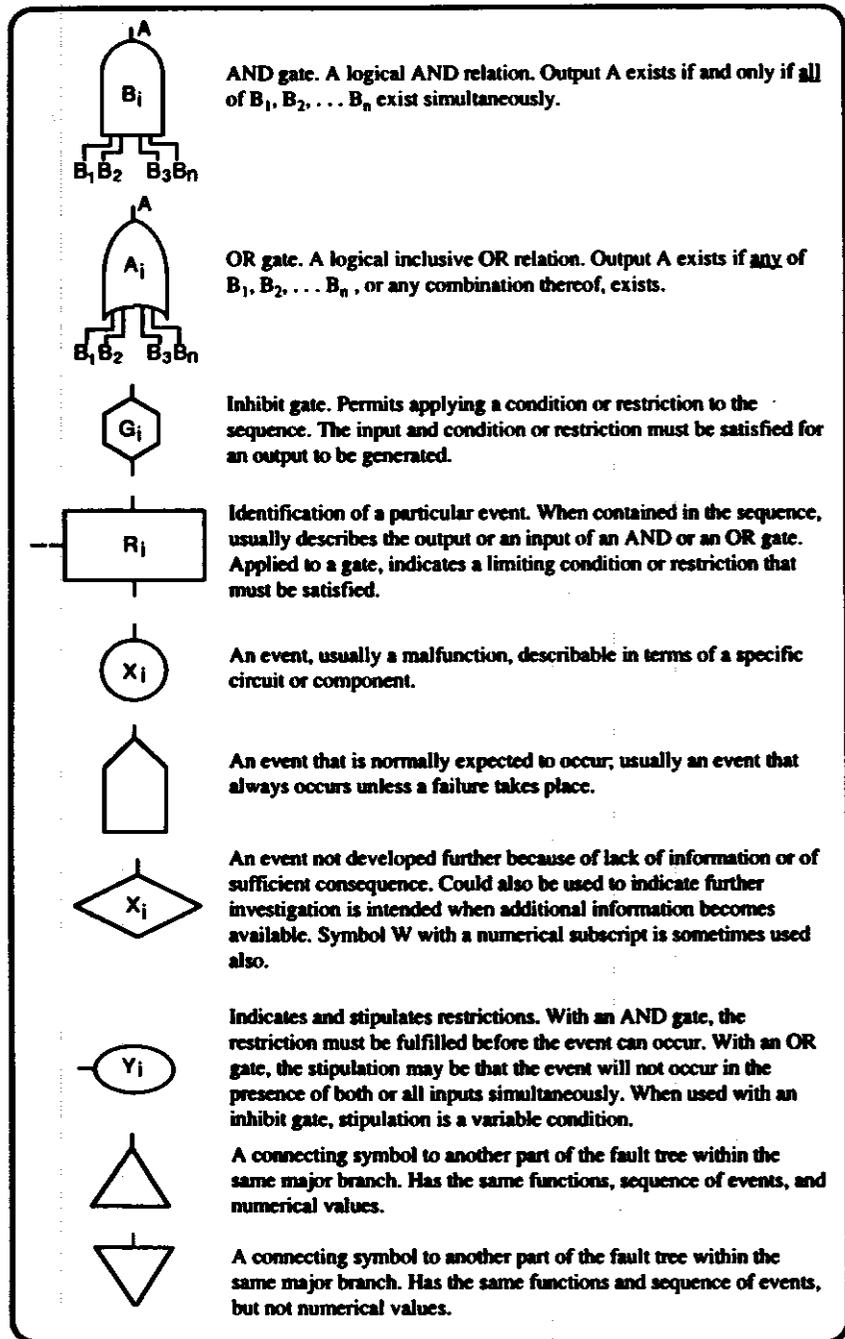
**Figure IV-5. Fault tree analysis symbols and explanations (Source: Hammer, 1980).**
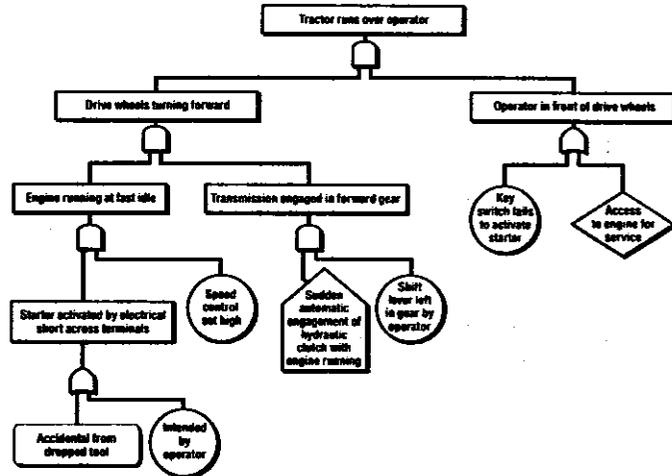
Figure IV-6. Fault tree analysis of tractor bypass start hazard. Example developed by K.C. Anderson, P.E.

| General Exposure Scale | | General Likelihood Scale | | General Consequences Scale | |
|---|---|---|---|---|---|
| Rating | Descriptor | Rating | Descriptor | Rating | Descriptor |
| 9 | Continuous exposure | 9 | Almost certain to complete accident sequence | 9 | Death or complete disability |
| 7 | Once daily | 7 | Very possible, but not assured | 7 | Permanent partial loss in work capacity. Increased work difficulty |
| 5 | Once per use season or once annually | 5 | Some conditions favorable to completing accident sequence | 5 | Hospitalization. Up to one month lost time. No permanent loss in work capacity. |
| 3 | Only once in life of a small percentage (10%) of product | 3 | Remotely possible, but not likely | 3 | Doctor's office or emergency room treatment. Up to one week lost time. |
| 1 | Theoretically possible, highly unlikely during life of product population | 1 | Practically impossible to complete accident sequence | 1 | Minor first aid. Immediate return to work. |

Figure IV-7. General scales for hazard elements (Source: Madsen, 1985).

**RISK SCORE ANALYSIS**

A different technique of hazard analysis is to score hazards by considering the importance or impact of three hazard attributes: exposure—an estimate of how often an operator or bystander is exposed to the hazard; likelihood—the probability that an unwanted event will occur once there is exposure to the hazard; and consequences— the most probable injury that might result. Each of these attributes is assigned a value based on predetermined scales similar to those shown in figure IV-7. A composite score is found by multiplying the values; this total score becomes the risk score for the hazard. As shown in figure IV-7, a risk score could vary from 1 to 729. Risk scoring is somewhat subjective because equally qualified experts may assign different

scores to a given product. Therefore, the technique is best used by teams of experts, so that each expert's composite score can be averaged to find a final hazard risk score.

To illustrate this procedure, an example of the development of a gasoline-powered golf cart is used. A prototype golf cart, model XN, has been assembled. The hazard analysis team has reviewed the machine and operated it on a local golf course. The team has identified four potential hazards and has reached a consensus quantification for the risk score on each hazard. The results are summarized on a hazard analysis worksheet similar to the one shown as figure IV-8. Typically, the summary sheet also lists the hazard type and a description, factors contributing to the hazard, potential injury effects, and additional comments. This example suggests that the hazard analysis team considers the risk of overturn as the most significant hazard, and thermal or fire as the least significant.

**TASK ANALYSIS**

Another area for human factors involvement in system design is that of task analysis. Task analyses may be performed to identify error-likely situations, to describe what should happen, and to analyze what might happen when a system is operational. A task analysis may also be performed to document what is required of a person to operate a system and to make judgments about whether an operator can perform what is required.

In addressing the first question, a detailed analysis of the tasks, equipment, and work environment is generally performed. Task performance goals are evaluated and workloads measured. Equipment and workstations are evaluated to determine whether they accommodate the human operator they serve. Likewise, the work environment is evaluated to determine what it imposes on the people within it. With knowledge of the physical, mental, social, and psychological characteristics of the population from

| Product: Model XN Golf Cart | | | | | | | Date of Review: 30 Sep 1991 |
|---|---|---|---|---|---|---|---|
| Hazard Type and Descrip- tion | Hazard Analysis | | Quantification | | | | |
| | Factors Contributing to Hazard | Effect/Injury Potential | Expo. | Like. | Cons. | Comp. No. | Comments |
| Impact Rolling Machine | Worn park brake latch - Inadvertent release of brake - No adjustment on latch | Bystander injury - Bruises - Contusions - Fracture | 7 | 4 | 3 | 84 | Engineering - consider redesign. Manufacturing - consider heat treat of part. |
| Thermal- Fire and Ex- plosion | Gasoline line may wear through, spilling fuel. Routed near electrical components, potential ignition source. | Operator - 1st and 2nd degree burns | 4 | 3 | 3 | 36 | Engineering - consider rerouting line. |
| Overturn Lateral Stability | Sharp turn radius. Excessive top speed. Insufficient strength of canopy frame. | Operator injury - Fractures - Possible death | 6 | 5 | 6 | 180 | Engineering - consider design changes to reduce speed, strengthen canopy. Publications - consider safety message in manual. |
| Crushing Falling Object | Carts are stacked on end for shipment, held in position with steel banding. End unit may fall over when banding is cut. | Injury to truck unloader - Bruises - Possible fractures | 3 | 4 | 5 | 60 | Shipping - consider different stacking pattern. |

Figure IV-8. Typical hazard analysis worksheet. Example developed by K.C. Anderson, P.E.

**Figure IV-9. An example task analysis format.**

which the system operators will be selected, judgments then can be made about whether the operators will be able to perform as expected.

The task analysis procedure includes a step-by-step description of tasks to be performed by the system and the operator interaction with the system. Each step generates demands for successful completion, and these demands are compared with what operators can do.

A typical task analysis format includes a portion for describing the task behaviors and another for analyzing the task components (fig. IV-9). At some stage in the development of a new system, it will be possible to define human tasks to be performed and groupings of these tasks that will be defined as individual jobs. This effort is normally considered to be the descriptive half of task analysis. In a task description, operations in a system are listed. Time baselines may also be used. When first done the data will be fairly gross; probably identification of gross tasks is all that can be done. As the system becomes more definitive, more detail will be possible. Ultimately, the task descriptions must be rather detailed, with each stimulus and response identified in each single step in each task for each job. This level of detail allows the analyst to describe the factors influencing performance in each task and job. The main purpose of the descriptive material is to provide the necessary inputs for identifying error-likely situations, helping personnel who prepare the written job and task instructions, and serving as the basis for determining the selection and training requirements for each job and task (Swain, 1974).

Each task may be analyzed to identify potential sources of error. The analysis involves determining whether there are any conflicts among the various factors of tasks, environment, equipment, and personnel. Such conflicts may result in errors. The ultimate objective of the task analysis is to suggest system design changes. The potential errors of greatest concern are those with an intolerable combined possibility of occurring, going undetected or uncorrected, and causing an unacceptable system consequence. A possible design change may reduce the possibility of an error; it may increase the likelihood that the error, if made, will be detected or corrected; or it might involve some way that the system could tolerate the error. The design changes may involve changing any of the factors associated with the potential error. The changes may be addressed to equipment design, methods of use, formal training, or personnel selection criteria. This step is crucial, and it must be shown that any recommendation for change represents an optimum accommodation of all the various system criteria (including cost).

**EXAMPLE OF A TASK ANALYSIS**

Figures IV-10, IV-11, and IV-12 depict a "synthesized" flow of actions and decisions, both required and possible, of an UPSAT machine operator following an interruption caused by some material clogging the shredder unit. An UPSAT machine is a hypothetical machine, its name an acronym for urban paper shredder and transport machine. It is a self-propelled vehicle operated by one person and is driven along city

streets collecting prepackaged containers (specifically made for this purpose) of paper trash/refuse set out along the curb by residents. The machine is built to shred the paper refuse in a collection chamber with rotating drum knives. The shredded paper is collected and compressed in a large holding tank that periodically is transferred to a transport vehicle. The shredded paper is sold by the city to various customers needing this raw material for their enterprises.

The problem to be studied is: "In what way will the operator behave (or can we expect him to behave) when the shredder unit becomes clogged?".

The flow charts of figures IV-10, IV-11, and IV-12 provide a means of analyzing this problem. The beginning of each flow chart, or "event chain" as it would be for any other kind a machine interruption, is an event that represents a functional problem of the human-machine system. For whatever reason, the system became clogged (for our example, some old asphalt shingles were placed in the collection container), and the behavior of the operator stems directly from the occurrence of the interruption. Thus, it is necessary to recognize that interruptions to system function are characteristics of the system. Operator activity (i.e., behavior) in response to those interruptions depends on:

- equipment design
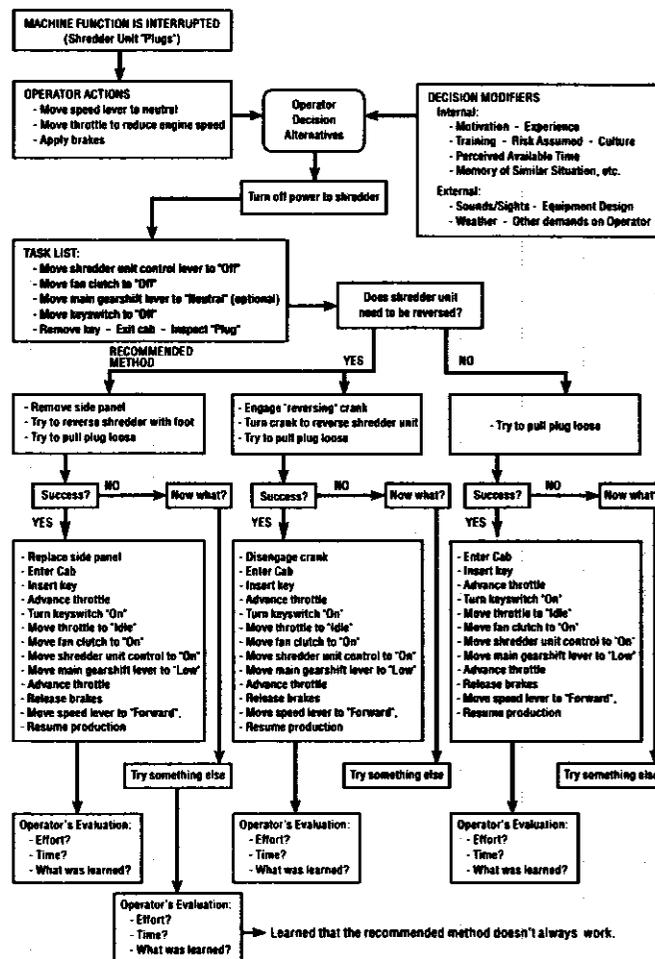- other external modifiers of behavior



**Figure IV-10. Synthesized flow of actions and decisions required and possible of the operator of an UPSAT machine when the shredder *unit plugs and the operator turns off the power* to the shredded unit.**

- internal modifiers

Thus, as is shown in figures IV-10, IV-11, and IV-12, the operator activity immediately following the interruption basically is dictated by the equipment design. That is, there are certain actions that the operator must do before production can be resumed. After these immediate actions are taken, the operator may then have a number of decisions alternatives from which to choose. (Note: the more alternatives available, the greater will be the variability of performance and, therefore, the greater will be the potential for human error.) The choice taken by the operator is affected by other "external modifiers", such as the sounds or sights just prior to the interruption, the weather, or other demands on the operator, and by "internal modifiers", such as motivation, experience, training, and memory of a similar situation, etc. Although it is hoped that each item shown in the flow chart contributes to the understanding of how operator behavior can be "synthesized", special notice should be given to the last box, operator evaluation. This item is a key element in each of the event chains because the evaluation conducted of the time and effort required by the operator and what that person learned forms the basis for subsequent decisions.

Figure IV-10 shows a flow of action and decisions required and possible by the UPSAT machine operator when the shredder unit becomes clogged and the operator turns off the power to the shredder unit. Figure IV-11 shows the flow of actions and decisions, both required and possible, by the UPSAT operator when the shredder unit becomes clogged and the operator leaves the power on to the shredder unit. Figure IV-12 shows the flow of actions and decisions required and possible of the UPSAT
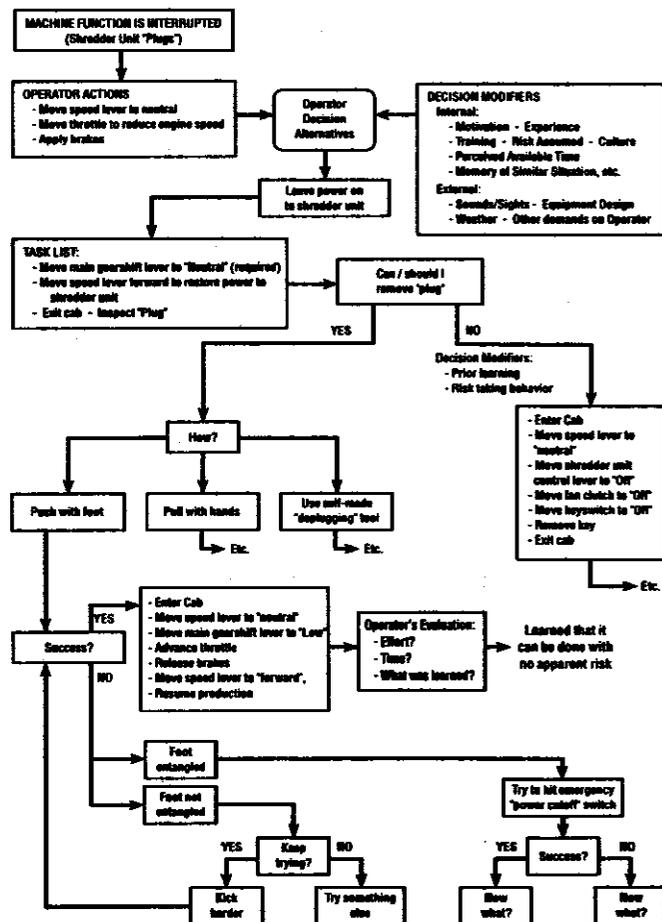


**Figure IV-11. Synthesized flow of actions and decisions required and possible of the operator of an UPSAT machine when the shredder *unit plugs and the operator leaves the power on* to the shredder unit.**

operator when the shredder unit becomes clogged, but the operator reverses the rotation of the shredder unit using controls within the cab to eject the clog.

**SUMMARY**

Four approaches to the analysis of a machine or system were presented. The FMEA is best suited to analyze reliability issues. The fault tree analysis and task analysis are methods of examining detailed operator-system interactions. A risk analysis is a systematic approach to evaluating hazards in any system. The use of these techniques provides an organized method of identifying and prioritizing hazards in the system such that system modifications can reduce the probability of personal injury to an acceptable level.

**REFERENCES**

This lecture was primarily condensed from chapter 9, *Safety and Health for Production Agriculture*, Dennis J. Murphy, ASAE, 1992, and *Human Factors: A Series of Quality Instructional Materials*, No. 1 Human Factors Concepts. An Overview, Jerry R. Duncan, ASAE, 1991. No. 11 Operator Behavior: Responses to Interruptions of a Machine Function, Jerry R. Duncan, ASAE, 1991.

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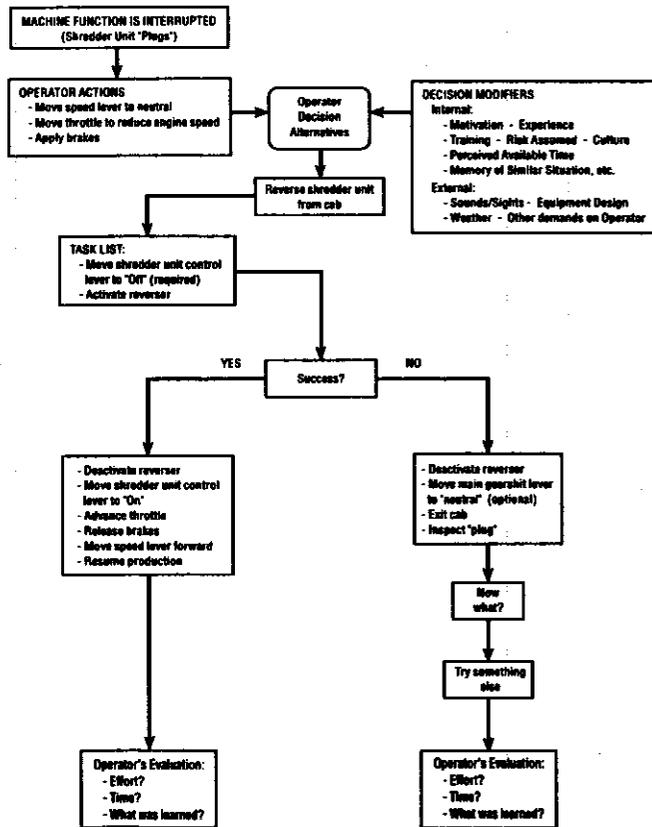


**Figure IV-12. Synthesized flow of actions and decisions required and possible of the operator of an UPSAT machine when the shredder *unit plugs and the operator reverses the rotation* of the shredder unit from within the cab.**

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**SAMPLE QUIZ QUESTION**

1. Select a system that you know in detail and for which you can identify hazards in the system. Select one of the analysis techniques to review the system. Perform the analysis. Explain why you chose the particular technique and explain the choices made in using the technique.

# Unit V
# ENGINEERING FOR HAZARD CONTROL AND INJURY PREVENTION

**PURPOSE**

To introduce students to the principles of safe design.

**OBJECTIVE**

After completing this unit, the student will be able to:

1. List the steps in the system design process
2. Explain the essential elements of the identified safety engineering principles
3. List and explain the safety hierarchy

**SPECIAL TERMS**

1. Fail-safe design
2. Failure minimization
3. Redundancy
4. Passive protection
5. Defeatability resistance

**INSTRUCTOR MATERIALS**

1. Lesson plan
2. Chalkboard

**TRAINEE MATERIALS**

1. Participant outlines made by instructor
2. Supplementary materials

**INTRODUCTION**

A brief discussion of the system design process will precede the development of a few safety engineering principles that are relevant to agricultural equipment and structure design.

**A SYSTEM DESIGN PROCESS**

An organized product development requires that a well-planned design sequence be followed. This sequence typically includes:
- Identifying a human need and creating product ideas to satisfy that need
- Evaluating alternative design ideas
- Designing and building prototypes
- Testing and evaluating the prototypes
- Performing a preproduction "pilot" run of the product manufacturing processes
- Full-scale manufacturing of the product
- Conducting product evaluation

Evaluating alternative designs is an important step in the process. Because of ever-present financial pressures to be competitive, it is imperative that products be introduced into the marketplace on schedule and within the specified budget. The importance of meeting scheduled introduction dates is clearly recognized in highly competitive industries. For example, a missed availability date for the Christmas buying season can result in vast inventories that are susceptible to being outdated in a relatively short period, possibly creating financial disaster for a toy manufacturer. Thus, it is very important for the manufacturer to develop and evaluate alternative designs prior to their introduction.

The evaluation of design ideas may include functional requirements review, design group reviews, analytical methods, economic analyses, and others. A functional requirements review includes techniques that basically work in reverse of "brainstorming" sessions. During this type of review the soundness of the design is scrutinized, impractical ideas are eliminated, and a check is made that the original functional requirements are satisfied.

Design group reviews are particularly valuable in finding potential deficiencies in the design or considerations that had been overlooked. Experienced members of the design review group can draw upon knowledge of similar designs that can be very valuable. On satisfactory review of design ideas for function, a general specification for the product is established. Often, this is a joint effort between marketing and product engineering functions. The publication and distribution of a general specification helps ensure that the development of the program starts and ends in a product of well-defined specifications that are mutually agreed upon by all appropriate segments of the manufacturing firm.

The analytical methods available include mathematical models and computer simulations that provide information about concerns such as stress within a structure for a given load condition. Other computer programs are available for simulating the fatigue life of components, bearings, gears, shaft deflections, forces, and geometric analyses of how parts fit together within a product. These analytical methods are valuable because they permit the engineer to consider design changes and to evaluate the effects of those changes with considerably less time and expense compared to methods requiring physical testing.

Another crucial test of the product design is its cost. Since the product engineer's responsibility can be defined as the organized development of an idea into a profitable product that satisfies a specified need, it will be of little consolation if a product has superior appearance, unmatched performance, and high reliability if it cannot be sold

at a profitable price. To ensure profitability, a number of steps can be taken to determine the anticipated selling price and the cost to produce the product. Market surveys are made of historical total sales of a similar product that is currently being manufactured and what percent of market penetration can be expected with the new product. Engineering and development costs can be estimated. The cost of capital expenditures for machine tools and buildings can be calculated. The unit cost of the product is compiled from calculation of the materials, labor, and overhead required to produce the product. All of these economic studies become inputs to the decision of whether or not a particular product design will be selected for manufacture and marketing.

There are many design selection criteria operating simultaneously during the design process. Each of these criteria is important, and many of them can conflict. If we consider them to be system criteria, it is obvious that it is impossible to maximize all of them. One could make an item very easy to produce, for example, but at the expense of size, selling price, operability, or styling. The design selection criteria in the following list are representative of those that are generally balanced against each other:

1. Functional performance
    Speed
    Maintainability/Serviceability
    Producibility
    Safety
    Human factors
    Accuracy
    Operability
    Reliability

2. Compliance to standards/regulations
    ASAE, ISO, SAE, OSHA,
    DOT, EPA
3. Styling
4. Cost

Once a system design has been selected and prototype units have been built, the next step in the design process is a major one. A thorough test and evaluation program requires a major commitment in work force, facilities, and time. It generally includes activities of component testing, field stress testing, durability testing, and a complete system evaluation. During this period, further safety reviews and human factors evaluations are conducted.

In summary, the system design process can be characterized as being 1) Multi-faceted: There are many factors that are considered. 2) Interactive: Many different disciplines and groups of people are involved. 3) Iterative: Many cycles occur in which ideas are proposed, developed, tested, modified, and tested again before a final design is established. 4) Evolutionary: As a design proceeds, it evolves into a product that best satisfies all of the influencing factors.

The following quotation from an editorial in the December 1979 issue of *Product Engineering* summarizes the system design process and the task of the design engineer very concisely:

> The design engineer must anticipate every need of the user, every stress of the product, every economic alternative to keep costs low, every conflicting patent, every manufactured complexity, every operating hazard, and every maintenance problem. NOT one at a time, but all at once.

A few broadly stated principles that typically govern the application of engineering to the safety of the user and bystander are presented. Additional principles and details are presented in the listed references.

**SAFETY ENGINEERING PRINCIPLES**

Product design and product reliability go hand in hand because the reliability of a product is built into its design specifications (Vinogradow, 1991). Product reliability relates to safety engineering in two ways. First, if a product is not functioning the way it is intended, or it breaks down from a component or system failure, work goals become compromised. This may cause frustration or anger, which in turn, may result in hurried and reckless work procedures, inappropriate risk taking, or an enraged behavioral act (e.g., kicking a control). All of these actions may lead directly to an injury incident. A smoothly flowing work process often means a worker's exposure to hazards is reduced because the person can remain in a safe location (e.g., on a tractor seat, on the outside of a silo, standing back from operating machinery, etc.). Field crop harvesting machinery, farmstead machines to move or process crops and feeds, and manure storage equipment are among those items for which proper product functioning is an important means of reducing product hazards.

**Product Reliability**

Product reliability also relates to safety engineering through direct failure of product parts. For example, breakage may occur with a kicking chain being used on a young cow or the snap on a lead shank tying a horse. In either case an injury to the handler may result. Another example is the possibility of being injected by hydraulic oil if a high-pressure hose ruptures.

**Fail-Safe Designs**

Some safety engineering designs are referred to as *fail-safe*. The goal of a fail-safe design is to ensure that a product failure will not result in damage to people, the product itself, or the environment. There are three types of fail-safe designs (Seiden, 1984).

A *fail-passive design* reduces the product to its lowest level of energy so that the product cannot operate until corrective action is taken. No further damage will result from the hazard causing the inactivation. Electrical circuit breakers and fuses are common examples of fail-passive designs.

In a *fail-active design*, the product remains energized but in a safe mode until corrective action can be taken. Products that use monitoring systems to warn of failure, or potential failure, have fail-active designs. A battery-operated smoke alarm that beeps when the battery charge becomes low is one example.

A *fail-operational design* allows the product to continue to operate with reasonable safety until corrective action is possible. Many view this as the most desired type of fail-safe design because it allows the product to continue with its functional purposes. An airplane that is capable of flying with half of its engines shut down is one example of this type of design.

**Failure Minimization**

Fail-safe designs are not possible or feasible for all hazards (Hammer, 1985). In such cases, engineering can still be used to minimize the consequences of failures of products. The four principal methods are:

1. Monitoring devices. A specific parameter, such as temperature, noise, or toxic gas, is kept under surveillance to ensure that it stays within acceptable limits. Monitoring devices check operating conditions to keep dangerous situations from developing or reaching the imminent stage. A valued monitoring device entails four steps: detection, measurement, interpretation, and response.
2. Warning devices. This method is similar to monitoring but more directly involves a person as the monitor. The intent of warning devices is to focus the attention of the person on the item that constitutes the hazard or potential hazard. Warning devices work by alerting at least one of a person's five senses. Figure V-1 illustrates how the five senses may be used as warning devices.

3. Safety factors and margins. This refers to the process of designing products to withstand stresses over and above the normal functional requirement. For example if the structural strength of a step is required to hold 300 lb (136 kg), a safety factor of 2 would result in the step being designed to hold 600 lb (272 kg). Safety factors are intended to handle unexpected events that could possibly occur, even though it cannot be predicted when or if the event will actually occur.

4. Failure rate reduction. No operating component lasts forever. Therefore, designs attempt to limit failures while the system is operating, the rates of failure, and shut downs of the system from component failures (Hammer, 1985). This is achieved by using components with life expectancies much longer than their usage would normally require; by timed replacements, using quality control measures to ensure that only quality components are used; and through redundancy. Redundancy means having two methods to achieve the same objective within the same system. Automatic standby electrical power generators in the case of normal power failure is one example of redundancy.

## Redundancy

Redundancy is a common and important safety engineering technique for improving product reliability. The concept of redundancy cuts across many of the fail-safe design and failure minimization principles discussed above. The two primary types of redundancy are parallel and series. Parallel redundancy can be achieved by having backup systems (e.g., standby generators), or by having two or more parallel subsystems. To have parallel subsystems (components, circuits) means to have two or more subsystems operating at the same time, each capable of functioning independently. If one subsystem fails, the other subsystem carries on. A twin-engine airplane, capable of flying with only one engine, is an example. Series redundancy means that subsystems are arranged in a series in which all units must operate or fail to allow functioning. Series redundancy is most often used to prevent damage from inadvertent or premature operation of systems (Hammer, 1980). With series redundancy, all units in the series must fail if the device is to activate inadvertently. The probability of this occurring is low, lowering the overall risk of damage.

Some systems may involve only partial redundancy (Brauer, 1990). For instance, a single pump may be supplying fluid to two sets of hydraulic lines to actuate one cylinder. A failure with the pump would cause the entire system to go down. However, a failure in one set of hydraulic lines would not cause the system to go down because of the presence of the other set of lines. Hence, the system is only partially redundant.

Redundancy is most commonly thought of in terms of hardware and automatic equipment. However, it can also involve human operators. Cruise control devices on automobiles provide speed control, as does the operator's foot on the accelerator. The use of pilot and copilot in an airplane is another example of humans as redundant devices.

## Passive Protection

Passive protection means to provide engineered protection from hazards irrespective of the behavior of the individual being protected. Conventional wisdom indicates it is the ideal type of hazard protection: it utilizes the more reliable and predictable engineering sciences, rather than the less reliable and predictable human sciences. The automobile air bag and motorized seat belt shoulder harnesses are perhaps the most readily recognized passive protective systems. However, automatic fire extinguishing systems, in-line ground-fault circuit interrupters, and gas line shut-off valves for extinguished pilot lights are other common examples. Passive protection has proven to be especially effective, in comparison to other types of hazard protection, with hazards that are individually and routinely encountered by consumers and the public. Important to remember, though, is that the need for passive protection still signifies

| Sense | Means | Description | Example |
|---|---|---|---|
| 1. Sight | a. Illumination | a. A hazardous area is more brightly illuminated than nonhazardous surround areas. | a. Having well-lit highway intersections, obstacles, stairs, and transformer substations. |
| | b. Discrimination | b. Paint a physical hazard in a bright color or in alternating light and dark colors. | b. A structure (such as a pole), piece of equipment, or fixed object which could be hit by a moving vehicle is painted yellow or orange. OSHA standards require that the inside of the door to an electrical switch box be painted orange so that the fact that it is open can be recognized easily. |
| | c. Notes in instructions | c. Warning and caution notes are inserted in operations and maintenance instructions and manuals to alert personnel to hazards. | c. A warning in a car owner's manual to block the wheels before jacking the car to change a tire. |
| | d. Labeling | d. Warnings are painted on or attached to equipment. | d. "NO STEP" markings on hydraulic or pneumatic lines; high voltage; jacking points. |
| | e. Signs | e. Placards that warn of hazards. | e. Road signs indicating hazards; "NO SMOKING" signs; EXPLOSIVE, FLAMMABLE; or CORROSIVE signs on trucks carrying such material. |
| | f. Signal lights | f. Colored or flashing lights (or reflection) attract attention to a hazard or indicate urgency. | f. Red flashers on construction barricades at night; swinging red lights at railroad crossings; yellow caution lights at intersections; traffic lights. |
| | g. Flags and streamers | g. Tags or pieces of cloth are used to warn of danger. | g. A tag on a switch to indicate circuit is being worked on; a red streamer at the end of a long load protruding over the rear of the vehicle; colored strips of cloth on wires, ropes, and cables to make them more easily visible; flags used by flagmen at road construction sites to warn motorists when it is safe to proceed. |
| | h. A set of hand motions to pass instructions, warnings, and other information from one person to another. | h. Hand signals | h. Signals to the crane operator from a man guiding a load being lifted into place. |
| 2. Sound | a. Alarms | a. A siren, whistle, or similar sound device provides warning of existing or impending danger. | a. A siren indicates that there is a fire in a plant; a siren or whistle warns personnel to clear an area where blasting is to take place. |
| | b. Buzzer | b. Alerts a person that a specified time has passed or that time has arrived to take the next step in a sequence of actions. | b. Some compressed air packs contain buzzers that sound when the pressure in the tank has decreased to a predetermined level, or after a preset time has passed. |
| | c. Shout | c. Voice action to warn of a danger. | c. One person warns another of an obstruction. |

Figure V-1. How the five senses can be used as warning devices. Adapted from Hammer, 1985. (continued).

| Sense | Means | Description | Example |
|-------|-------|-------------|---------|
| 3. Smell | a. Odor detection | a. Presence of an odorous gas can indicate the presence of a hazard. | a. An odorant is added to refined natural gas (which has no odor) so that leaks can be readily detected. |
| | | b. Burning materials give off characteristic odors. | b. The presence of an unseen fire can sometimes be detected by characteristic odors of products of combustion. |
| | | c. Overheating equipment can be recognized by the odor generated. | c. Vaporization of oil can permit detection of a hot bearing; odor of hot, steaming water can warn a car driver of a broken radiator hose. |
| 4. Feel | a. Vibration | a. Rough running of equipment can indicate the presence of a problem and impending failure. | a. Vibration of a rotating shaft can signal a loss of lubrication, wear, and damage. |
| | | b. Corrugations or vibration inducers in a road can warn a driver of a hazard. | b. Land shoulder markers in a road can warn a sleepy driver when he is going off the road or out of his lane. |
| | c. Temperature | c. Excessively high temperature can warn of a problem. | c. A maintenance man may be able to detect by its temperature a bearing that is acting abnormally; a temperature increase in an air-conditioned space may warn of equipment problems; excessively high temperature of a cooling fluid may indicate a possible problem in the equipment being cooled. |
| 5. Taste | a. Ingestion | a. May indicate that material taken in the mouth is dangerous. | a. Acid, bitter, or excessively salty taste may indicate that material is not proper for consumption. |

Figure V-1. (continued) How the five senses can be used as warning devices. Adapted from Hammer, 1985.

the presence of a hazard that may cause harm. Hence, it is not an engineering solution that should take precedence over hazard elimination or exposure reduction.

Passive protection is an effective safety engineering technique for hazard situations that previously relied almost solely upon individual compliance with safety and health practices and rules. Passive protection can be combined with an active measure to significantly reduce the consequences of some hazards. A case in point is tractor stability. Before the advent of rollover protective structures (ROPS), avoiding the consequences of tractor rollover relied exclusively upon the safe operating practices of the operator. A factory-mounted ROPS, a passive measure, combined with fastening the seat belt, an active measure, provides very effective protection against the crushing hazard of tractor rollover.

Even without the active measure of fastening the tractor seat belt, substantial protection is afforded the operator by the passive portion of the protective system. The presence of the ROPS prevents the tractor from crashing completely against the ground during an overturn. In most cases, this is enough to prevent a life-threatening crushing of the operator. Thus, the passive protection concept, even though not 100% passive, can provide a relatively effective amount of protection from some hazards.

**Defeatability Resistance**

Effective product safety engineering considers reasonably foreseeable misuse of products. This is a concern closely connected to product liability. For instance, it is reasonably foreseeable that some farmers will misuse farm tractors as transportation vehicles for more persons than the operator. Another aspect of reasonably foreseeable misuse is less well recognized. This aspect has to do with reasonably foreseeable misuse of safety engineering features and devices.

Seiden (1984, pp. 136-138) has grouped safety engineering measures into six classes according to their safety-defeatability quality or content. Seiden's classes refer to actions the product user would have to engage in to defeat the safety feature. Class 1 represents the most easily defeated safety measures and class 6 the most undefeatable. Thus, class 6 safety engineering measures are more likely to remain in place and serve their intended function. The classes are:

Class 1. Change in standard operating procedure to defeat product and/or safety function; revert to prescribed procedure to restore safety function
Class 2. Use of simple tools and/or contrivances to defeat safety
Class 3. Use of special or complex tools or equipment to defeat safety
Class 4. Major product redesign, remanufacture, alteration, or rebuilding to defeat safety
Class 5. Product function disruption, impairment, or damage required to defeat safety; product repair necessary to restore function
Class 6. Product function destruction necessary to defeat safety irreversible; impractical to reasonably reset, restore, or restart function and/or safety

Class 6 is the ideal safety-defeatability resistance class. With class 6, the engineered safety device or feature cannot be defeated without destroying the product itself: hence there are few actual examples of this class. This is why it represents the ideal. At the other end of the scale, with class 1, the safety-defeatability resistance is very low. Safety devices that can be removed or made ineffectual by hand or by changing the way a job is completed represents class 1 safety-defeatability resistance. Many modern walk-behind lawn mowers contain an example of a class 1 defeatability safety feature. Modern walk-behind lawn mowers are required to utilize quick blade-stop technology to reduce hazards to operators that leave the area behind the mower.

One way manufacturers have achieved quick blade-stop is to install an additional control lever on the mower's handlebar connected to a shut-off switch on the mower's engine. To operate the mower the control lever is hand-held in the appropriate position by the operator. If the operator leaves the rear of the mower, the shut-off control must be released. This shuts off the mower's engine and stops the blade. This safety feature is easily defeated by tying the shut-off control lever to the mower's handle bar with a short strap. This keeps the shut-off switch from operating as intended.

Farm machinery guards and shields that are removable by hand tools, and that do not affect functional use of the machine, are an example of class 2 safety-defeatability resistance. Another example is the use of a screwdriver to short across starter motor terminals to bypass safe tractor start-up procedures. Cutting off tractor ROPS with a torch would be an example of class 3 safety-defeatability resistance. These last two examples (as well as the lawn mower example) obviously raise questions about the role of operator responsibility for complying with and maintaining original equipment safety devices.

An old safety proverb declares that "there is no smarter fool than he who figures out how to beat a safety device". Nevertheless, the point here is that effective safety engineering recognizes people have tendencies to ignore or defeat safety features, and more may do so when it is easy to do.

**Emergency Shut-off Devices**

One issue of safety engineering that doesn't fall neatly into the normal categories of safety is that of machinery emergency shut-off devices. This issue has particular relevance in production agriculture because it is already being used in some instances, and some see an expanded role for such devices. Some machinery-related incidents between a person and a machine's hazard point result in the person becoming entangled or entrapped by the machine, with the machine continuing to run. This situation sometimes results in additional or more severe injury to the victim. For instance, a person's leg may be pulled into a pinch point by a running machine. If the machine continues to operate, another limb of the victim may become ensnared as the person struggles to pull free. Even when only part of a victim is caught, the continuing action of the machine sometimes inflicts considerably more damage to skin, muscle, and bone of the victim.

An emergency shut-off device would presumably allow an immediate stopping of the machine once a person becomes caught by the machine. The simplest way to utilize this technology is to have some means near enough to the point of entanglement that the worker or a helper could activate the emergency shut-off device once a victim is entangled in the machine. There are important factors to be considered, including:
- Does the emergency shut-off device encourage workers to be unnecessarily near the hazard area? If the emergency shut-off device becomes a convenient way to stop and start machine operation, the emergency shut-off device may create additional risk to the operator and others nearby.
- A person working alone may not be able to activate the emergency shut-off device no matter how convenient it is because of the way the person becomes entangled or caught. For example, the incident may happen too quickly.
- A victim may not have the presence of mind to activate the emergency shut-off device because of excitement or panic. On the same machine, one victim's entrapment position may be such that the emergency shut-off device can only be activated by a pushing action, while a second victim's position may be such the emergency shut-off device can only be activated by a pulling action.
- In some instances, the continuing action of the machine results in a complete severing of a digit or limb, in essence freeing the victim. In cases where the person

is working alone, this may allow the person to seek emergency help. The alternative — a stopped machine with a trapped victim — may result in death from loss of blood or shock.

* Some machines have several high-hazard areas (e.g., a PTO drive line, other powered mechanisms, and crop intake, processing, and discharge areas). This may require several different emergency shut-off devices on a single machine because the action in each hazard area is different.

These considerations are not easily resolved. An emergency shut-off device must have a very high degree of reliability before it is used. Assuming that technology can solve any problem given sufficient resources and motivation, satisfactorily engineered reliability may raise the cost of machinery to prohibitive levels. On the other hand, there are already some examples of simple emergency shut-off devices in use on machines. Some activities involving the filling of silos result in workers being near moving parts of the self-unloading ensilage wagon and the ensilage blower. Some modern ensilage wagons use a combination of wire rope and grab bars as an emergency shut-off device, and modern ensilage blowers have a handle or bar that acts as an emergency shut-off device. Some emergency shut-off devices, of course, do not eliminate or reduce a hazard prior to the injury incident, but only attempt to minimize damage once the injury event occurs.

## THE SAFETY HIERARCHY

The safety hierarchy represents a conceptual prioritizing of ways to reduce hazards and risk. Generally, some combination of priority methods are used to combat a single problem. The safety hierarchy is:

1. Eliminate hazard or reduce risk.
2. Apply safeguarding technology.
3. Use warning signs.
4. Train and instruct.
5. Prescribe personal protection.

Safety engineering principles further identify how these priorities may be accomplished with products. This unit is most directly concerned with the first three priorities of the safety hierarchy, and in particular the first two. These are the priorities that utilize the engineering sciences most directly. Before looking again at the safety hierarchy, we will address another safety engineering concern.

Safety engineering discussed within the framework of the safety hierarchy demonstrates how engineering principles and priorities combine to solve real problems. Numerous examples from production agriculture are given to illustrate how theory is translated into practice. Some wording of the safety hierarchy terms are altered slightly to reflect common usage of the ideas that the safety hierarchy represents.

## Eliminate Hazards or Risks

This is the most fundamental principle of safety engineering. However, it may not be possible to apply this principle in real situations as directly as might be assumed. To actually eliminate a hazard or risk means to do away with it completely. This may often only be achievable by doing away with the product itself. Product substitution is possible, but the product that is substituted is also likely to have associated hazards and risks. For example, the hazards of coal mining can be eliminated by switching to nuclear power. However, nuclear power is not without its own set of risks. In most instances, when hazard or risk elimination is spoken of, what is really meant is significant hazard or risk reduction. This reduction may be accomplished in many different ways.

For instance, suppose there may be a requirement for a service operation under a raised element of a machine. The designer could provide a built-in swinging block that could be positioned by the operator to positively assure that it would not fall. This is an example of active protection. The operator must participate by positioning the swinging block to be protected. A more passive solution is to equip the hydraulic control with a valve that would not release oil to lower the element unless the engine were running. This automatically protects the operator against the element inadvertently falling even though the operator doesn't have to take any specific actions to receive the protection. Even with some types of passive protection, a problem can arise. For example, the operator could unintentionally sever a hydraulic line while performing the service work. Or, an operator may intentionally open a hydraulic line because he or she doesn't fully understand how the hydraulic lock system works. Therefore, it sometimes is best to incorporate redundancy by providing both the manual block and the locking hydraulic valve.

Another example of a passive safety device is one that reduces the tractor bypass starting hazard. A valve bypasses the pressurized hydraulic oil, which activates the clutch until the operator cycles the clutch pedal one time. Thereafter, the clutch actuation mechanism functions in the normal manner as long as the engine continues to run. Since the operator must normally mount to the operator's station to actuate the clutch pedal, this movement removes him/her from the position of risk in front of the drive wheel. The valve does not interfere with any tractor function, it requires no action on the part of the operator, and in fact, it may never be noticed by the operator. Assuming adequate reliability, these are the optimum characteristics for any safety system (Anderson and Smith, 1988).

One method of significantly reducing hazards is to change or improve the operation of the product so the operator isn't required to be in an exposed position. Tractor-mounted corn pickers that were commonly used during the 1930s and 1940s are an example of this method. Under some crop and climatic conditions the machine clogged at the crop intake area, particularly if the picking mechanism was worn or out of adjustment. As operators became impatient with the chore of removing corn stalks with the power disengaged, they sometimes attempted to pull the stalks loose with the engine running and the power take-off engaged. A sudden release of the clog would then pull an arm into the rotating mechanisms. The advent of the corn head for combines resulted in widespread replacement of pickers by combines for corn harvesting. The corn head of a combine uses a solid steel plate on the snapping roll, instead of raised ribs, to help separate the ear of corn from the stalk. Many corn heads are also able to run in reverse. This allows these machines, in effect, to unclog themselves in many instances. These changes and improvements have reduced this corn harvesting hazard to a great extent.

Another example is to replace a potentially harmful mechanism with one that does the same job but is much less threatening. The substitution of a nylon filament for a steel cutting blade made use of the hand-held power grass trimmer feasible for general use by the public. If the whirling filament inadvertently strikes the leg of the operator, it might sting or cause a bruise, but it is not likely to cause a serious wound. Yet it is still able to perform its intended function. External chain or belt drive mechanisms, with their attendant nip points, may be replaced by an internally concealed gear drive, which provides improved reliability of machine operation, along with the reduced exposure to risk.

Access to large tractors and self-propelled field equipment generally involves ascending a number of built-in steps to reach the operator's platform. An accumulation of mud or debris can lead to a slip and injury from the resulting fall.

The use of slip-resistant materials, steps with widely spaced bars to allow mud to fall through, and the strategic placement of handholds significantly reduce the probability of slip and falls.

## Use Safety Guards and Enclosures

Sometimes it is not possible to eliminate a hazard. The second-priority design solution is to interpose a guard between hazards and exposed persons. A guard is any device intended to minimize the possibility of inadvertent contact with moving machinery parts, or to restrict access to a hazardous area of the product. Guards and shields are important devices for reducing hazards in production agriculture. This is because of production agriculture's use of field and mobile powered equipment, and the functional requirements of machinery and material handling equipment for raw products.

Some machinery hazards may be guarded by location. Guarding by location refers to two things. For one, it means that there are enough other machine parts (not designed as guards) interposed between the hazard and the operator in such manner that a safe distance is maintained. Or secondly, there is enough distance between the hazard and normal operation and servicing paths that risk to the operator is minimal. The construction of a well-designed guard includes the following characteristics (Brauer, 1990):

- Permanently attached to the machine
- Prevents access to the danger zone
- Strong and durable
- No additional hazards created
- No interference with the operation of the machine
- Allows easy access to perform service without removal of guard
- Easily opened and closed, or easily returned to the proper position

Experience has indicated that farm machine guards which are perceived as a nuisance are often removed and discarded. Research conducted by Purdue University (Campbell, 1987) showed that more than one half of all agricultural tractors inspected did not have a power take-off master shield (the shield over the tractor PTO stub shaft) in place, presumably because the shield made it more difficult to attach the PTO drive line. Tractors originally equipped with bolt-on or quick-detach-type PTO master shields had the highest percent missing, while those tractors with hinged shields that could be raised for easier access to the PTO stub shaft were more likely to have the shield in place.

Guard or shield materials may have openings, such as those found in expanded or pierced metal or wire mesh, for a number of reasons. It may be necessary to allow air circulation for cooling, monitoring machine action, or permit cleaning of the area. When guard openings are necessary, a safe distance must be provided relative to the size of the opening. This is referred to as safety distance guarding. The ASAE Standard S493 contains specifications for safety distance guarding for agricultural machines. Figure V-2 is an example of the specifications for safety distances involving mesh or grille-type guards.

The agricultural environment is severe and dictates that guards must be designed for heavy duty service. The ASAE Standard S493 (ASAE, 1991) specifies that "guards shall remain functional under forces that could be applied by a 270 lb (123 kg) person leaning on or falling against them in normal operation". Guards must support such weight where the guard may be used as a step. There is the possibility of corrosive action on such machines as manure spreaders and chemical distributors. It is also possible that physical contact between machines or dumped loads could damage the

guard and reduce its effectiveness. Guards, as well as other exposed machine parts, are to be free from sharp edges and corners so that they do not create new hazards.

If a guard covers an area that must be accessed for lubrication or other service, a hinged guard to discourage removal and discard is needed. If the guarded parts continue to rotate or move for several seconds after power is shut off, a visual or audible warning is needed to indicate continued machine action. These are issues covered in the voluntary consensus standards of ASAE. When the guarded area is out of sight of the operator's station, some method to prevent power engagement by a second party should be provided. Removing the engine key or other power source (fuel, electrical fuse) is one way to protect against machine hazards. A more passive measure is to include an interlock that prevents power start-up when the guard is open or removed. In some respects, such interlocks have advantages and disadvantages similar to emergency shut-off devices.

Human presence-activated systems are closely related to the concept of guards and shields (Anderson and Smith, 1988). The objective of a human presence-activated system is to detect and respond to a person entering a hazardous area. In effect, it tries to prevent such entry. Such systems are typically equipped to sense the presence or absence of operators in either a hazardous or safe (e.g., the operator's station) location. The seat switch incorporated in some lawn tractors, combines, and cotton pickers is an example of this concept. The human presence-activated system device is activated when the operator rises from the seat; it declutches the power train or shuts off the engine before the operator has time to reach an area of danger. This circuitry can have a time-delay mechanism, which would reduce the aggravation of power train interruption caused by momentarily lifting off the seat. A complicating factor with a human presence-activated system and cotton pickers is the periodic need to observe the picker drums while they are functioning. This is resolved by a tether switch to allow momentary, slow movement of the drums for observation from the ground; the action will stop when the remote control switch is released.

Some combinations of machines are used in a stationary position while the operator is on the ground. One example is a small tractor with a front-mounted log splitter. To allow operation, an override switch permits the log splitter to operate while the operator is on the ground. The override switch is installed in such a manner that it will deactivate when the operator sits down on the seat and resumes a mobile work mode.
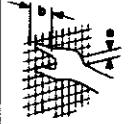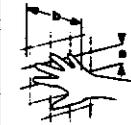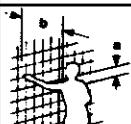
| Limb | Illustration | Width of Aperture (Diameter or Lateral Length, a, mm) | Safety distance to Hazard (b, mm) |
|---|---|---|---|
| Finger Tip | | 4 < a < 8 | b > 15 |
| Finger | | 8 < a < 25 | b > 120 |
| Hand | | 25 < a < 40 | b > 200 |
| Arm | | 40 < a < 250 | b > 850 |

Figure V-2. Dimensions for openings through mesh or grille guards (adapted from ASAE Standard S493. 1991).

The use of tethers and override switches illustrate the trade-offs common to safety engineering problem solving. On the one hand, these devices reduce risk taking by allowing workers to achieve work objectives in a relatively safe manner with a minimum of effort and inconvenience. On the other hand, such devices may increase risk if workers fail to follow appropriate safe operating procedures.

## Use Safety Warnings

There are some hazards that cannot be designed out of a product and cannot be effectively guarded. A common example is the crop intake area of any harvesting machine. An attempt to effectively guard this area will interfere with the basic function of the machine. In such situations, the third-priority safety engineering strategy is appropriate. Warnings should be strategically placed in close proximity to the hazard.

Safety messages should not be used indiscriminately or the "billboard effect" may result. The billboard effect is a confusing array of instructional material displayed on the machine. The use of safety messages should be limited to those major hazards that pose the threat of death or disability, or to denote reminders of safety practices. The temptation to overuse safety messages (the billboard effect), and to overstate hazards, is strong. Safety message hazard classification refers to the use of the signal words DANGER, WARNING, and CAUTION. Overclassification occurs when a more serious signal word, such as DANGER, is used when a lesser one, such as WARNING, is more appropriate. ASAE Standard S441 (ASAE, 1993) governs hazard classification for safety messages, but the process is not an exact science. This, and the nature of product liability case law, encourages overuse and overclassification of safety messages. That is, to protect themselves from charges of negligence, manufacturers and dealers may place more numerous and serious warnings on products than otherwise is needed, based on more objective criteria.

When safety messages are needed, an effective safety engineering strategy is to limit the use of the DANGER signal word to the most serious one or two hazards on a product. This preserves the impact of the DANGER signal word. Both DANGER and WARNING signal warnings should be located as close as possible to the hazard point. CAUTION signal warnings, which are usually safety practice reminders, are more appropriately located at the operator's station as a reference. The use of pictorials as a part of a safety message is both popular and relatively effective (see Aherin et al., 1992). The amount of text is minimized, comprehension is faster and may last longer, and pictorials can be effective for persons with limited reading or language ability.

## Train and Instruct

Most equipment sold today is provided with an owner's manual or operator's manual. This manual provides another way that warnings and instructions can be conveyed to product users. How owner's manuals are organized with respect to safety messages is primarily a concern of instructional materials and communications professionals. However, engineers have a critical role in developing owner's manuals because they have the most intimate knowledge of the product, including its actual and potential hazards. The owner's manual provides opportunity for a fuller explanation of those hazards, which are identified by warnings on the product. A section on safety at the beginning of the manual should reproduce warnings on the product, include a diagram of the product to identify hazard and warning locations, and give full safety- and health-related precautions and instructions.

Specific safety messages should be repeated in different sections of the manual that may involve the hazard area. For example, a safety message from the beginning section may be repeated in the service or maintenance section. This process is particularly important for products used in environments that render safety messages unreadable over time. Safety and health information in owner's manuals also provides

a way of communicating hazard information when products are repainted but safety messages are not replaced, and when older products with unreadable safety messages are resold on the secondary market.

**Prescribe personal protection**

Occasionally, the operator will be exposed to hazardous conditions, such as noise from operating a chain saw, handling anhydrous ammonia, pesticides in the air during application of the pesticides, the absolute requirement to enter a manure storage pit, or the requirement to enter a controlled atmosphere storage. Whenever the engineer has the opportunity to communicate to the operator regarding these issues, instructions should be provided that include specific information concerning the type of personal protective equipment that is required and the general limitations of that personal protective equipment.

**SAFETY ENGINEERING STRENGTHS**

The strengths of safety engineering as a strategy for hazard and injury prevention and control cannot be over emphasized. Safety engineering is the most important deterrent to unanticipated injury and death. The following summary statements and examples represent both current and forward-looking applications of safety engineering without regard for unresolved liability or other feasibility (costs, cultural traditions, etc.) issues. With this caveat, safety engineering:

*Utilizes the "hard" sciences rather than the "soft" sciences.* The distinction between hard and soft sciences is important because what is known about the hard sciences is more precise, reliable, predictable, etc., than what is known about the soft sciences. The essential difference is between understanding physical objects and things versus the thought processes and behaviors of people.

*Alleviates incentives to take risks.* Examples: automatic coupling systems for hitching implements to tractors eliminates the need for a second person during hitching; stirring augers help to keep grain from bridging inside bins, reducing the need for humans to enter the bin for that purpose.

*Eliminates or significantly reduces hazards and risks.* Examples: the hydraulic valve to prevent tractor bypass starting and runover incidents; closed systems for transferring pesticides between original containers and mixing containers prevent exposure to pesticides in their most concentrated form.

*Offers automatic protection against hazards and risks.* Examples: ROPS and a passive seat belt restraint on tractors; human presence-activated systems or devices that stop moving parts if a person is in a hazardous zone.

*Provides relative permanence.* When engineered protection becomes a part of original design, the protection is more likely to stay in place. Examples: hinged guards on farm machinery; built-in ground-fault circuit interruption for electrical systems.

*Provides relative efficiency.* One engineering oriented solution or device may be applicable to all or many similar products or situations. Examples: fire-resistive coverings for cellular plastic insulation in farm buildings, oxygen level indicators in all confined spaces (silos, manure storages, grain bins, etc.)

*Combines solutions to increase protection.* Examples: mechanical guards with interlock controls to prevent operation of hazardous machinery parts without the guards in place; viewing port holes in grain bins, along with stirring augers, eliminate the need to climb and enter the bin for observational purposes.

*Implements solutions regardless of a complete understanding of the causes of injury events or levels of risk.* Examples: animal restraint systems can make animal handling safer without a complete understanding of animal behavior; an ability to reverse a machine's crop intake mechanism can reduce the risk of an entrapping incident without understanding why people take risks with running machines.

## SUMMARY

The challenge for any new product design is to find the effective balance of competing issues of product performance, styling, safety, and cost. A few broadly stated principles that typically govern the application of engineering to the safety of the user and bystander were presented. A safe product design includes considerations of the quality of the product. A reliable product reduces the probability of injury because the operator is able to remain at the controls of the machine, operating the machine. Priority should be given to designs that ensure that a product failure will not result in an injury, a fail-safe design. Failure minimization, redundancy, passive protection, and defeatability resistance are concepts that should also be considered in a new design. If you address the safety hierarchy, eliminate the hazard, apply safeguards, warn, train, or recommend personal protective equipment, you will have addressed the priorities of a strategy to deal with safety issues in a new product design.

The safest possible machine design begins with an understanding of the accident data associated with similar machines. The analysis of this data provides some understanding of hazards encountered in agriculture. The designer of a new machine should consider the broadest possible application of human factors principles. Analysis techniques such as task analysis, failure mode and effects analysis, fault tree analysis, and risk analysis provide methods to systematically review new designs. Safety engineering principles provide methods to resolve issues that are identified. The application of these concepts will lead to the safest possible design.

## REFERENCES

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**SAMPLE QUIZ
QUESTIONS**

1. Review a relatively new agricultural machine.
    (a) Determine whether there are examples of the safety principles being applied to the machine, i.e., fail-safe designs, failure minimization, redundancy, passive protection, and defeatability resistance. List them.
    (b) Are there examples of the safety hierarchy being applied to this machine? List them. Is it necessary, in part, to compare this machine to early versions of the machine?
    (c) Are the guards on this machine in conformance to ASAE S493 (fig. 2)? List them.