ROYAL COMMISSION ON FARM MACHINERY

FARM MACHINERY SAFETY

Graham F. Donaldson

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ROYAL COMMISSION ON FARM MACHINERY

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PHYSICAL WELFARE EFFECTS OF THE MAN-MACHINE INTERACTION ON FARMS

by

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CONTENTS

APPENDIX A

LIST OF TABLES

LIST OF FIGURES

FOREWORD

This study reviews the salient features of the man-machine interaction on farms in Canada. It considers the interplay of man, machine and environment in so far as it influences the physical well-being of the farm machinery operator and others.

Farm mechanization has made a positive contribution to human welfare which is well recognized. It has reduced the time and effort required for many farm operations. It has played a part in increasing the productivity of agriculture, which has benefited the economic welfare of the whole of society, including the farm community.

But other effects of farm mechanization may be detrimental to man's physical welfare. These are the effects examined in this study.

Chapter 1 reviews some of the values held in relation to human safety and well-being, and outlines the various factors contributing to the man-machine interaction on farms. These include the epidemiological categories of environment, host and agent -- which in this case comprise the farm situation, the operator and the machine, respectively.

Chapter 2 discusses the main detrimental physical effects of farm machinery on humans. It reviews the nature of farm accidents involving farm machinery, and compares the accident rates in various other occupations and situations. (A more detailed analysis of fatal farm accidents involving machinery in Canada is presented in Appendix A.) Some of the chronic effects of farm machines on the health of the operator are then detailed.

After reviewing the mechanical operating features of farm equipment, the physiological and psychological effects they may have on the machine operator are discussed.

Chapter 3 presents a survey of the various means of improving operator protection and facilitating operating safety. Attention is focused on the role and contribution of human engineering in achieving this end, but consideration is also given to education and safety programs, and to means of encouraging preventive action. Some consideration is also given to the costs and responsibility for such action.

The study terminates with a bibliography of recent literature related to the various aspects considered.

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Graham F. Donaldson

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1. MAN-MACHINE INTERFACE

Machinery and Human Welfare

Technological progress and the changes that accompany it are familiar characteristics of our civilization. Evidence of it surrounds us, in new ways of getting work done, new sources of power, new and more efficient machinery and equipment, and in better ways of producing and marketing goods and services. These obvious features provide an expanding variety of new benefits -- better food, improved industrial products, easier work and more leisure. Consequently we tend to look benignly toward the process of technological change and to assume that its effects are generally beneficial.

From time to time, however, attention is recalled to some of the detrimental effects associated with the proliferation of technological applications. The recent concern over air and water pollution, due predominantly to waste by-products from highly technical industries, serves as an example. Similar examples of the impact of technology on individuals have been identified, varying from the effects of drugs at some stages of the human life cycle, to stress on airline pilots, and accidents in building construction.

Consequences of this type can in some cases affect a broad spectrum of society but, as with all events of an epidemic nature, those affected may vary from a relatively few isolated cases to a large proportion of the total population. From the sort of examples which are available, including those outlined above, it might be inferred that those effects of technology beneficial to the majority can be severely detrimental to a few. Such a situation is at least possible in the field of farm mechanization.

The continuing mechanization of agriculture has unquestionably contributed to increased farm productivity, and this has greatly benefited the community as a whole. But, mechanization has also extended the hours of work in association with farm machines, thus increasing the machine operator's exposure to the noise, vibration, heat, and the accident potential associated with farm machinery. By so doing, technological progress has at least increased the health risk of the people living within the farm environment. Consequently where the majority are likely to have gained, a few have potentially lost in terms of general welfare.

In terms of human welfare, however, such a situation need not be intolerable if it is recognized and if appropriate adjustments are made. As an ethical judgment, the welfare of a community can be said to be dependent entirely upon the welfare of the individuals comprising it. Hence if one becomes "better off" without loss to the others, then the welfare of the community as a whole might be considered enhanced. Alternatively, if those who become "better off" are, in their new situation, sufficiently "well off" to be able to fully compensate those who are left "worse off" by the change, then similarly total welfare may be considered increased.

Within our society, and in some parts of it more than others, it is generally considered that the individual is the best judge of his own well-being. Sometimes it is also held that the individual is largely, if not entirely, responsible for seeking the redress of any loss in well-being he might suffer. Such a position assumes, of course, that the person or persons involved are aware of their situation and comparatively that of others,

that they recognize the possibility of making changes, and that they have access to means for making changes to their relative position.

With this in mind, this study seeks to assess the ways in which the physical welfare of farm people might be adversely affected by continuing farm mechanization; to investigate the empirical or other evidence as to whether a loss of well-being has occurred in recent years; and, if so, to consider by what means it might most effectively be redressed.

Operating Environment

In day-to-day practical situations, there is, and has undoubtedly always been, a certain element of physical danger connected with the activities of physical existence, but it seems probable that this risk has increased with technological change. As primitive man moved from relatively blunt to sharper tools the risk of traumatic injury seems likely to have been increased. As man began to harness auxiliary power, first animal and then mechanical, to help him in his production activities the adverse effects were probably further increased. Since this power, almost by definition, exceeds the strength of man, it follows that unless it is perfectly controlled it can cause him great injury -- and such control is certainly not easily achieved.

Some of the adverse effects of the interaction of man and the machine became more obvious in the context of the Industrial Revolution in Europe. Though it is certainly possible that working conditions declined in association with the changing social order as people moved to the cities, the side effects of the machine dominated environment were one manifestation of this decline. They became the focal point of the humanitarian

movements and legislation of the time. It was as a result of pressures such as these that Factory Acts were introduced in Britain in the early nineteenth century. These sought, among other things, guards around machines, better lighting, shorter hours of work, and a minimum age for persons employed in factories.

Apart from its short-run deleterious effects, however, the Industrial Revolution wrought some far reaching effects of more positive significance in considering the man-machine working environment. Notable among these was the effective separation of production activity from the household. If expanding mechanization inherently increased the physical risk of workers, the danger was at least removed from the immediate environment where they ate, slept and raised their children. In farming, except in some specialized situations, this separation of activities has never occurred; in most parts of the world farming is still carried on by families.

The presence of the farm family within the working environment of the farm ensures that a wider range of people -- including the very young and the aged -- are exposed to the dangers of machinery. Whether participating in seasonal operations or as onlookers, it might be anticipated that more people in these categories will be subject to injurious effects in agriculture than in most other industries.

The fact that the work force on farms is comprised largely of the operator and his family causes their welfare to be regarded differently from that of the work force in other industries. In our society we tend to maintain the notion of a dichotomy between labour and management. Because the farmer is

both entrepreneur and manager he is placed in the managerial category. In view of this, and probably because farm family labour has no group organization, and the organization of hired hands is not strong, agriculture in North America is not strongly identified as an industry. Consequently, when considering the well-being of the work force the occupational health aspect of farming has been often overlooked by workers in that field. Similarly, the compensation arrangements that exist to offset some of the occupational hazards in most industries are often not extended to people working in agriculture. But, apart from these sociological aspects, there are many physical and economic features of farming which affect the farm operating environment of men and machines.

Since farming is, to varying degrees, land extensive there are inevitable location effects. Farms tend to be isolated in terms of distance from the supply and service centres in towns, and from the health facilities needed in emergencies. Also, when involved in field operations, the individual may be isolated from his headquarters. Because of this isolation there is a tendency to improvise rather than seek additional help, and to "extend the day" in order to complete an operation before returning to the home base. This is likely to increase the risk of accident. If an accident does occur, the potential time lag before those affected are discovered and reach medical attention increases the potential severity of the effects of the accident.

The inclination of the machine operator to carry on regardless, using makeshift repairs, working long hours, with poor lighting, is encouraged by critical timeliness effects of agricultural operations. Weather affects both the rate of work

and the time available to complete many operations. In order to avoid serious loss there is pressure to complete operations as soon as possible. This can obviously increase the risk of physical injury and damage to health.

Other, economic pressures may also be important. As a business, farming tends to have a high risk in terms of the variability of output. There is, therefore, a need to keep down production costs in order to avoid or minimize a loss in those years when returns are low. Since they are not directly productive, the cost of safety precautions and specialized safety devices are very often avoided -- with the purchaser accepting the possible danger of so doing without full consideration of the risk.

As the organization of agriculture adjusts, due to continually changing economic conditions and changes in the production relationships within farming, some marginal farms are economically squeezed. In particular these farms have difficulty in achieving the rates of capital formation needed to keep their mechanized plant up to date. Consequently, on some farms there is added pressure to "make do" with unreliable and inadequate machinery, and to economize on less directly productive protective devices. This again leads to high risk situations in the context of occupational health.

Similarly, these economic pressures lead farmers to keep down their labour costs. To do so there are occasions when inexperienced young people, often children, and less agile older men are called on to take part in seasonal and sometimes other operations. Due to such instances, and because they are frequently present as onlookers at the various activities (due to the close proximity of the household), the farm environment holds danger for virtually all members of the farm family.

All of this suggests that farming is inherently dangerous to the farmer, and all persons near him, during his use of farm machinery.

Human Component

As they work within this farm environment, the attitudes and physical characteristics of farm people could largely determine the extent to which they are susceptible to adverse health effects resulting from their use of particular machines. Their attitudes toward machinery seem likely to be of primary significance.

Since the progression of ownership in farming is typically from farmer to son, most farmers have since early childhood a long and continuing association with the various items of farm equipment. In some cases this can lead to a fearless familiarity with dangerous situations. As farm mechanization intensifies, it is possible for each new machine to be accepted and become familiar without any clear recognition that the situation has changed and the potential danger escalated. As most farmers get their training through apprenticeship within the family there is no real opportunity for formal instruction to even attempt to modify these attitudes.

In addition, because of the dispersed location of farms, farmers are not always made aware of accidents on other farms. Since the frequency of serious accidents within the small local community in which most farmers live is probably quite low, hence the real risk involved may remain unrecognized by individual farm operators.

Because the sight of an efficiently operating powerful machine is a satisfying one, there is a tendency for persons on the farm, other than the operator, to be attracted by its

operation. Their presence at a time when the operator is preoccupied with controlling the machine is not conducive to complete safety, particularly if their own familiarity with the scene does not induce caution.

Apart from these particular attitudes, farm people have in common with all humans certain physical frailties which leave them susceptible to accidents and to chronic health impairment arising from their association with machinery. Because machines are usually designed for normal able-bodied men there is increased risk whenever they are operated by anyone with impaired physical strength -- whether due to age, illness, permanent injury, or with strength or size less than normal due to sex or youthfulness.

There is also a limit to the physical endurance of competent and fit operators. Long hours of concentration in a repetitive operation, which is undertaken for not more than a few weeks in any one year, is likely to test the endurance and concentration of the most adept operator. Under such conditions the danger to health and well-being must be increased.

Similarly, the tolerance of the receptive faculties, for instance hearing, can be exceeded. Evidence to the Royal Commission on Farm Machinery by farmer organizations indicates some concern over temporary and partial permanent damage to hearing due presumably to prolonged excessive noise during tractor operation [28]. The eyes of tractor operators can also be affected by exhaust fumes causing irritation, discomfort, and the aggravation of chronic afflictions.

Apart from being detrimental effects in themselves, these irritations contribute to tension and lack of concentration on the part of the operator. This type of irritation along with continual vibration, long hours, cramped body position and

repetitive work would seem to combine ideally to cause distraction, reduce concentration, and heighten the risk of accident through inattention to machine control.

The recognition that human frailty can possibly play a part in causing machine accidents sometimes leads to the suggestion that "accidents are caused" and that responsibility lies with the machine operator. An understanding of the nature of these contributing human factors, however, suggests that the predisposition toward an accident is at least partly dependent on the nature of the operating environment and on the characteristics of the machine.

Machine Engineering

In machine design and development there appears to be at all times a "trade-off" between utility, in terms of effective operation and cost, and welfare, in terms of comfort and safety. Almost by tradition, machines are engineered first for function and are subsequently modified to provide tolerable limits of safety and comfort for the operator. In some circumstances, however, the two goals conflict.

For instance, for practical reasons tractors are designed with large wheels and with a high ground clearance. This causes the seating position of the operator to be high off the ground, and also gives the tractor a relatively high centre of gravity. Thus the operator has to climb up and down from his cockpit, sometimes with minimal provision in the way of steps and through impeded access, even though in the course of operation the need for machinery adjustment and other stops may require him to get on and off many times a day. This may predispose the operator to getting caught or falling, with the associated risk of injury. The high centre of gravity adversely affects the stability of the

tractor, both on sloping surfaces and at high speeds, thus creating a risk of the tractor overturning.

To facilitate additional functions, farm machines are increasingly fitted with an expanding variety of extra equipment, such as hydraulic handling devices on tractors. Each additional item increases the amount of attention required for control. Unless the control mechanisms are improved to maintain the manipulation required of the operator within certain levels, there is likely to be increased danger due to inattention to vital controls.

In order to provide power for additional equipment and to achieve faster rates of work, there is a trend toward longer and more powerful farm machines. This trend has several possible effects. It may increase the level of noise emitted by the machine, and thus increase the risk of hearing damage. It may also increase the level of vibration. This can indirectly cause physical damage, and when combined with noise and the need for continual concentration provides the ingredients for increased tension and operator stress. In turn this causes fatigue and again increased risk.

As the rate of operation is increased so is the amount of information the operator must digest in order to control the machine effectively and safely. Controlled studies have shown that added tasks reduce the effectiveness of operating performance, and consequently cause increased risk [50].

With increased power and speed there is greatly increased pressure on methods of control, many of which may be inadequate even on smaller machines. In particular, extra power and speed put greater stress on tractor stability, and on steering and braking mechanisms. Some of the shortcomings arise because

such mechanisms have a dual function. For example, brakes on tractors are designed primarily for turning, to supplement steering under heavy lugging conditions. Because of their design and the fact that they have two separate pedals these brakes are far from ideal when required to stop a tractor at road speeds.

A variety of other machine features either are, or can be, detrimental in their impact on the operator or those around him. Poor visibility from the operating position seems at least partly responsible for accidents in which small children are run over. Bad seat design is suggested as a primary cause of spinal damage. Cramped conditions and poor control layout are known to be significant in relation to the reaction rate in emergency situations. Exposed operating parts, particularly power-take-off shafts, are a serious source of danger.

All of these aspects, and those mentioned above, are subject to the attention of designers and particularly human engineers. The fact that manufacturers make some use of these skills leads to the assumption that machinery manufacturers do all that they can in regard to human welfare. But since welfare is recognized in relative terms it is necessary to consider how extensive these effects are, and what could be done to modify them, before assuming that what has been done is enough.

2. DETRIMENTAL WELFARE EFFECTS

Nature of Welfare Loss

The physical effects that may constitute a loss of welfare due to association with farm machinery can be recognized in two categories: the acute effects of injurious accidents, and the more chronic effects related to aspects of health. Apart from the basic differences in their impact -- the acute effects being physical, and the chronic largely physiological -- there is a difference in their incidence among the people within the farm environment. The more acute effects can generally impinge upon all persons on or near the machinery involved, which includes all members of the farm family and their employees, including short-term visitors in some circumstances. All of these people are susceptible to accidents. The chronic effects can usually accrue only to the machine operator. In most cases only the operator is in contact with the machine for sufficient lengths of time to be subject to the detrimental impact of the machine involved. For this reason the two categories are considered separately in the later discussion of their specific features.

While they are etiologically dissimilar, however, the distinction between acute and chronic effects is of less consequence in a welfare sense. Accidents and health deterioration both affect the physical well-being, economic productivity, freedom, comfort, and contentment of the individual. While this usually represents a loss in a real sense, both accidents and ill health can also be translated into an actual cash loss in the form of lost income, or costs of medical or other treatment. But in either form, they represent a deleterious welfare change which in some circumstances might greatly exceed

the positive gain obtained from the use of the machine. Consequently, the physical welfare effects associated with farm machine use would seem to warrant a continuing evaluation as the pattern of mechanization changes over time.

A survey of the literature relevant to these effects suggests, on the other hand, that consideration of these problems has previously been casual and incomplete. More recently, however, there has been a new and considerable interest in certain aspects of the general problem, as the attached bibliography will indicate. This attention may or may not be considered an accurate indication of the relative importance of these problems in a welfare sense. The various physical welfare effects are considered here under the headings: machinery accidents, general health effects, and hearing damage. The relative emphasis given to each area reflects recent concern and attention to the various problems rather than any more studied assessment of their relative significance in the spectrum of physical welfare effects associated with the man-machine interaction on farms.

Farm Machinery Accidents

Accidents are the most acute of the physical welfare effects involving farm machinery and consequently they are also the most obvious. Perhaps because of this, accidents receive more attention than the more chronic machine effects. On the other hand, they may be of greater significance in that, depending on the seriousness of the accident, the consequent welfare loss can be much greater from accidents than from other health effects.*

* The term accident is often used in reference to any unexpected or fortuitous event, but in this discussion an accident is considered to have some injurious or unfavourable physical effect on the persons involved. These can include, however, a broad spectrum of such detrimental effects. Consequently, it is convenient to classify accidents according to whether they cause temporary injury, permanent injury, or fatality.

Like all the physical welfare effects of farm machinery, accidents can be considered the result of the interaction of three elements -- man, machine, and environment. The three are necessary ingredients for the occurrence of the machine accident, and they represent the three aspects of an accident which might be investigated.

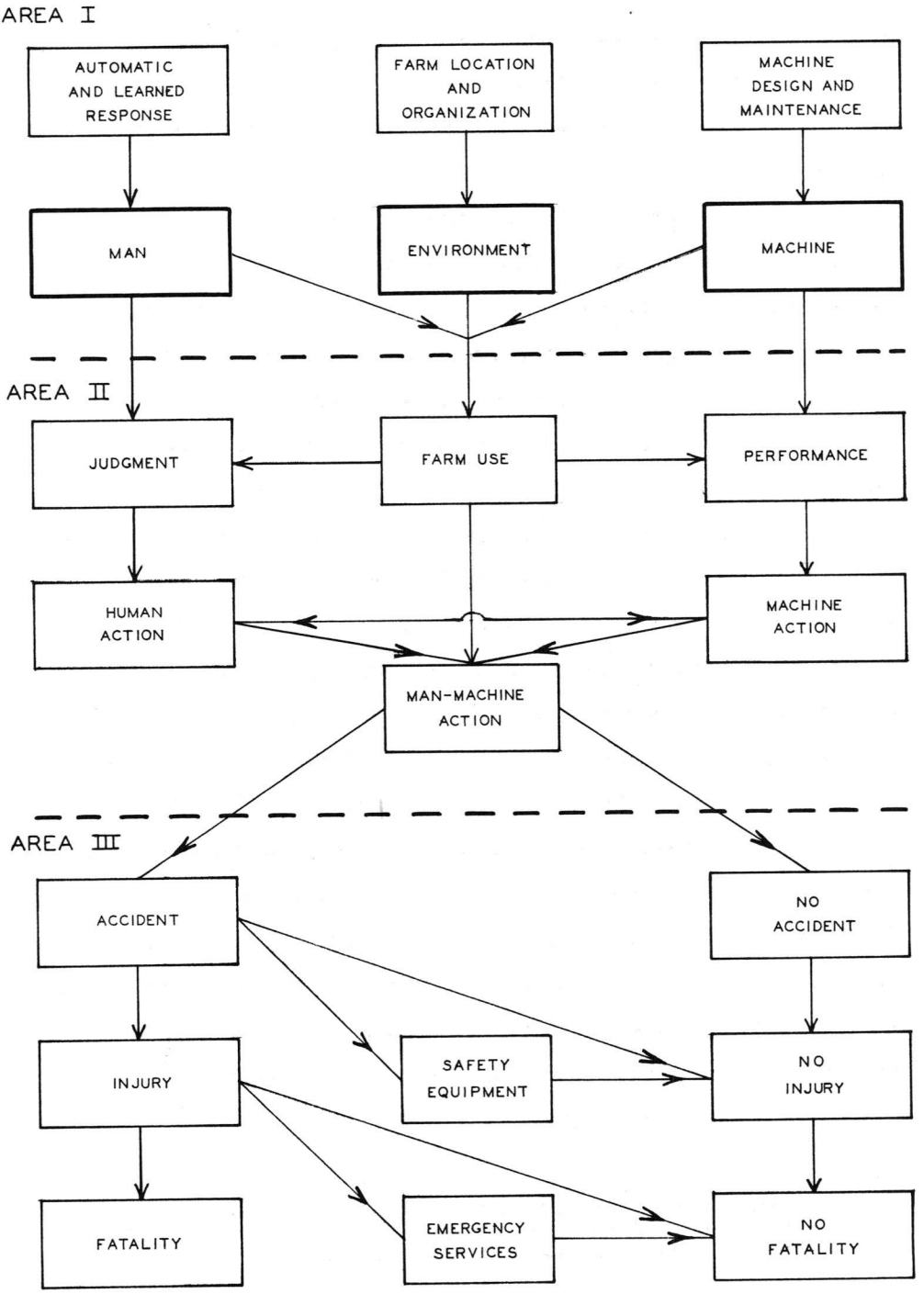
Exploration of their complex interaction is facilitated by a further division into three areas of involvement.** These areas and their interrelationships are outlined visually in Figure 1. Area I describes the factors inherent in the three elements involved; Area II relates the action taken by each element in an accident situation; and Area III indicates the results of their combination.

The environment determines the conditions under which the man-machine interrelationship takes place. As the farm population declines and mechanization increases, many aspects of the farm environment in which men and machines work are constantly changing. The nature of the farm environment, as indicated in Chapter 1, contributes to the risk of injury from an accident. As transportation amenities have improved some of the location effects have been mitigated, but as the population has declined the effects of isolation have increased. With less labour, larger farms and more mechanization, the machine operator spends increasingly longer hours working with machines. Other environmental changes occur as progressively more rugged areas are brought into production, and some -- such as weather effects -- change in an irregular cyclical pattern.

** This discussion is predominantly based on the material presented in various articles by Dr. L. W. Knapp, Jr., Agricultural Safety Engineer, Institute of Agricultural Medicine, State University of Iowa [22, 23, 24].

FIGURE I

MAN-MACHINE RELATIONSHIP IN FARM MACHINERY ACCIDENTS



The machine represents the culmination of the efforts of the manufacturer to fulfil the needs of the farmer in performing various agricultural tasks. Increasingly, such machinery has safety features built in, but the effectiveness of these features in promoting safety depends on the operating environment, the quality of maintenance, and the specific uses made of the machine. The quality of the machine is also changing over time to better meet the requirements of the changing farm organization.

Only man is unchanging in this context. The machine operator must be considered as the sum of his physical being, including all handicaps and susceptibilities, all automatic responses, and responses learned from personal experience and education. These features, and the underlying psychological and physiological aspects, must be considered as a given part of the operating relationship in modern farming. The operator, unlike the environment or the machine, is less capable of alteration or adjustment in the short run. Only by purposeful training can his responses and judgment be modified, and then it would seem only to a limited extent [9].

Many factors associated with the machine and the farm environment work to reduce the capacity of the operator to adjust correctly to situations which arise. The mental strains of getting the job done and preoccupation with other aspects of his decision situation reduce the alertness and reaction capabilities of the farmer. Physical factors such as the heat (or cold) in which he works, the dust he breathes, the vibrations to which he is subjected, and the fumes he inhales can further reduce his reasoning and reactions. In some instances these effects can lead to permanent physical damage which further reduces his capacity to adjust correctly. With all of these limitations man is placed

together with machines in an environmental situation involving machine use.

In Area II, farm use calls on man to make judgments which may or may not be adequate or appropriate. This may involve the use of the machine in many ways different than those envisaged by the designers. For instance, tractors are used not only to perform field operations but to act as a transport unit between farm units, to power a variety of labour-saving equipment, as a personnel carrier, a training device for young drivers, as emergency transportation in bad road conditions, and as a retrieval vehicle when other units become "stuck". In many instances the conditions these uses impose can radically affect the performance and stability of the machine. Such changes are not apparent to the user of farm equipment because he is not aware of the intent of its design -- in this regard he is at the mercy of the manufacturer.

A case in point is provided in terms of the longitudinal and lateral stability of farm tractors. As shown in Appendix A, of all fatalities involving farm machinery, 78 per cent were associated with tractors, and of these more than half were overturning accidents. The design of tractors predisposes their overturning in certain situations. The construction of orthodox tractors is such that if the rear wheels are held immovable, the power of the engine will attempt to wind the bulk of the tractor around the rear axle until the whole machine turns over on its back. When a tractor becomes bogged down in soft earth or in a shallow ditch the potential for such an overturn is very high. Since wheel tractors have a high centre of gravity and are usually lighter in front (often requiring the use of front wheel weights) they are also prone to "up-end" due to a high hitching point or an

excessive load on the rear, though the use of "weight-transfer" devices helps to offset this tendency.

Most overturning fatalities, however, are associated with the tractor rolling sideways. This type of accident is also predisposed by the high centre of gravity, though few such overturns occur simply due to the angle of incline. Usually an overturn is caused by dynamic effects associated with the momentum of the tractor and the position and direction of the wheels. In some cases the effect of the separate brakes on the rear wheels seems to be a contributing factor, because of the difficulty in getting equal braking effect on both wheels.

In these and various other predisposing situations the operator is the only part of the system which can react. The machine cannot react to the changing job situation. The whole burden of corrective action rests on the varying physical and mental limits of the operator. As the figures in Appendix A suggest, once his actions are further restricted by physical limitations, the accident potential is increased. In all such situations he is further subjected to such stresses as may be placed on him by the machine he is operating, and by environmental factors of weather and terrain which are changing within the period of the interaction.

As a consequence of the operating factors indicated in Areas I and II the man-machine reaction leads, in Area III, to either accident or non-accident situations which may or may not result in injury or fatality. Where there is an accident the consequences might be minimized by modifications to machine design (safety equipment) and to the environment (emergency services). In Area III, as in Area I, man with all his frailties is the given factor. The effects resulting from machinery accidents take many

forms, they are usually traumatic, and with tractors, particularly when they overturn, the results are very often fatal.

Accident Statistics -- The available data on farm accidents are generally incomplete. To some extent this deficiency may be attributable to some of the particular features of farming. In other occupations data are recorded or assembled from attendance records, company first-aid posts, worker compensation claims, hospitals, death records, and by various types of surveys. In agriculture there has been no program, official or otherwise, which has necessitated the organized collection of such data. Neither has there been any attempt to collate information from hospital records. In several provinces the only available statistics on farm accidents are in reports made annually within government departments, based on information obtained from newspaper clippings. Such data are clearly not very reliable.

Some data are available on farm accident fatalities. Minimal information on fatalities in various categories is extracted by the Vital Statistics Section of the Dominion Bureau of Statistics, and those figures on fatalities caused by accidents are published jointly with the National Safety League [37]. In the Province of Saskatchewan also, there is information available on farm accidents resulting in fatalities. Based on reports prepared in accident investigations by the RCMP, this information has been collected for some 15 years by the Saskatchewan Department of Health.

Using extended information extracted from the death records, together with the Saskatchewan data, a survey was made of various aspects of fatalities involving farm machinery in Canada. The detailed results of this survey are presented separately in Appendix A.

Farm fatalities in Canada directly attributable to machinery accidents increased by more than 30 per cent between 1957 and 1966, a period during which the farm population steadily declined. Consequently, the fatality rate per 100,000 farm population more than doubled in the ten-year period. This change seems to have gone unheralded and apparently unnoticed in Canada -- a fact that would seem to give little credit to safety associations, farmer organizations, government departments, manufacturers, or to anyone else interested in the welfare of farm people in Canada.

It is notable, too, that these figures refer to fatalities within a narrowly defined category -- specifically, machinery accidents on farms. All fatalities on public roads and those directly related to the farm household are excluded. If accidents involving slow-moving vehicles on public roads were included, the figures for Canada presented in Appendix A could be increased, judging by Ontario data, by some 10 to 15 per cent in any one year.

Further consideration of the data on fatalities highlights the susceptibility of the young and the old as the most frequent victims of farm machinery accidents deaths. It also shows a high frequency of overturn (39 per cent) and run-over (28 per cent) accidents causing fatalities on farms, and indicates that 78 per cent of fatal accidents involve tractors. The figures reflect the great variety of factors that contribute to accident situations, including all aspects of the man-machine interaction -- the man, machine and environment.

Unfortunately, much less information is available on the nature and frequency of <u>non-fatal</u> accidents on farms. What information is available tends to be collected through case study

or survey methods, and while these approaches both have their merits, particularly in studying the etiological aspects of accidents, they throw little light on the seriousness, or otherwise, of accidents across the broad spectrum of the farm environment. In all such studies the data are collected and classified according to criteria laid down to suit the specific circumstances, so that the published figures are not comparable from one study to the next. Thus it is difficult to make a broad evaluation of the impact of accidents within occupations or comparisons between them. There are, consequently, no general figures available in Canada which will permit a comparison with accident rates in other industries or in other countries.

On a provincial basis, however, some useful data have been collected by the Ontario Farm Accident Survey [39]. This survey involved a reporting scheme which covered the whole province in 1959, and certain counties in subsequent years. Unfortunately, because the survey has not covered any one area for a sequence of years, the data do not show any trends in the frequency or pattern of farm accidents. The survey does, however, provide some information about the nature of farm accidents and it gives an indication of the relative frequency of accidents causing temporary injuries, permanent injuries, and fatalities respectively.

Figures from the individual counties in 1959, and from those surveyed in subsequent years, show a steady relationship between the number of machinery accidents involving fatal, permanent and temporary injuries. Fatal machine accidents vary from two to six per cent of all accidents, while those involving permanent injury make up from 11 to 22 per cent of the total, and temporary injuries comprise from 75 to 85 per cent of the effects in all cases.

A separate survey conducted in Quebec and Manitoba by 4H Clubs provided data which were later summarized for Canada by the Canadian Chamber of Commerce. These figures show for Quebec four, eight, and 88 per cent respectively, and Manitoba four, three and 93 per cent respectively for fatal, permanent and temporary injuries. With slight differences, possibly due to differences in classification criteria, these figures are comparable with those for Ontario.

Using the ratio range obtained from the Ontario data, and the farm machinery fatality figures for all Canada in 1966, an estimate can be made of the frequency of non-fatal accidents in that year. On this basis it seems that there could have been some 500 to 750 accidents involving permanent injury, and from 1,900 to 5,100 farm machinery accidents involving temporary injuries. A total of some 3,000 to 6,000 persons might be expected, on the basis of these figures, to have been involved in a farm machinery accident of varying severity in that year, and the number seems likely to be steadily increasing.

Accident Patterns -- Using fatal accidents as an indicator of the accident trend, the limited data available suggest that accidents in "all industries" are declining. Figures published by the National Safety Council of the United States suggest, too, that in that country the number of fatalities per unit work force in all individual industries is also declining -- except in agriculture [36]. United States figures show that the death rate due to work accidents has declined in all industries from 31 per 100,000 workers in 1945, through 27 in 1950, 24 in 1955, to 21 in 1962. Over the same period accident fatalities in agriculture have <u>increased</u> from 53 per 100,000 in 1945, 57 in 1950, 55 in 1955, to 60 in 1962 [20].

Of all occupational categories in the United States only two have a crude fatality rate higher than in farming. For both of these, "mining and quarrying" and "construction", the fatality rate has declined markedly from 187 deaths per 100,000 in 1945 to 108 in 1962 for "mining and quarrying", and 126 in 1945 to 74 in 1962 for "construction" [36]. This is in marked contrast to the situation in agriculture.

In Canada, the figures are less easily compared, as the number of fatalities recorded in various categories cannot be related to the population in which they have occurred, due to differences in the categories used in each case. The absolute number of fatalities for both "mining and quarrying" and "construction" has, however, no trend either up or down. Since the number of persons employed in each industry has increased (particularly since the former includes oil rigs) it seems reasonable to argue that the crude fatality rate has declined in these industries. Concurrently, the trend of total fatalities in agriculture is also fairly even but the farm work force has declined by approximately one-third, thus foreshadowing the increase in fatalities in relation to people involved in agriculture, as shown in Figure 1 of Appendix A.

Two qualifications have to be made to these inferences drawn from data on fatalities. First, since the organization and the production processes of industry and agriculture have changed considerably over the last 25 years, it is by no means certain that time series data for any one industry are in fact comparing similar situations over time. On the other hand, data for all industries over time are indicative of the changing risks involved in all work situations. Second, fatalities may not be a reliable index of the frequency of all accidents. It might reasonably be

argued that, with better communications and continually improving medical knowledge and facilities, the number of accidents which become terminal might be reduced and thus the actual work accident rate may not have declined as much as the declining fatality rate in most industries would seem to suggest. If this is so, the accident frequency in agriculture may be even worse than the fatality trend suggests.

Similarly, it might be argued that the accident rate, like the fatality rate, may be declining in most industries. In industrial situations accident prevention and safety are given much attention. Apart from legislation requiring the use of protective guards and apparel, there are education programs and continuing attention to human engineering and safety aspects in layout and design. The upward trend of accidents in agriculture may suggest, therefore, that insufficient attention is paid to these aspects in the farming industry.

A large and variable proportion of the accidents which occur in agriculture are associated with farm machinery. Since the amount of mechanical equipment on farms varies from one type of farming to another, and consequently one region to another, it is not surprising that the proportion of accidents due to machinery also varies from place to place. Data collected from all areas of the United States show that, for the period 1960-1964, the proportion of fatal on-farm accidents involving farm machinery varied from a low of 27 per cent of all farm fatalities in the Southern Plains area to 48 per cent of all farm fatalities in both the Lake States and the Corn Belt [20]. This distribution reflects the relative level of farm mechanization in these areas.

In Canada, the proportion of all farm fatalities due to farm machinery has averaged 53 per cent over the last 10 years,

and has fluctuated little from year to year. The proportion of fatalities due to farm machines is slightly higher than 53 per cent for Ontario, Quebec and the Prairie Provinces, and slightly lower than that for all other provinces [10].

It is notable, too, that in each of the United States regions and in Canada, farm machinery fatalities were the largest of all causal categories of farm fatalities which include drowning, firearms, falls, blows, fires, electricity and poisoning.

There is also some evidence that machinery accidents are more serious in their impact on the victim than are other farm accidents. Of 2,562 persons hospitalized in Saskatchewan during 1966 due to farm accidents, a total of 670, or 26 per cent, were injured by farm machines. In the same area over the same year there were 45 fatalities as a consequence of farm accidents, and of these 22, or 49 per cent, were directly associated with farm machinery accidents. The same data show that 570 children under 15 years of age were also hospitalized and of these 103, or 18 per cent, were injured on farm machines. Of 14 fatalities involving persons in this age group, 5 or 35 per cent were fatalities caused by farm machines, showing the same trend as for the higher age groups [16].

The difference in these proportions suggests a much greater severity of farm machinery as opposed to other farm accidents. Since farm machines are built to cut, chop, grind, shake and otherwise dismember a variety of farm produce it should not be surprising that these mechanisms will be similarly violent with parts of the human body which stray into their grasp. The frequency of fatal accidents of this kind reflects the highly mechanized nature of the farm environment, but it also suggests that the man-machine relationship in agriculture is not functioning as favourably to man as might be expected.

Machinery Health Effects

Unlike accidents, the health effects of farm machinery operation are gradual and cumulative rather than sudden and traumatic. They generally affect only the machine operator, and because the effects involved are often not noticed or not identified with the cause they create little protest from farmers. In many cases, however, they are of consequence to medical practitioners and persons interested in occupational health.

Despite this, there is little evidence that machine health effects in agriculture have received any attention in Canada, and only slightly more work is evident in the United States. In some European countries, where tractor driving is often a specific occupation, there has been some research into these effects for many years. This research has typically been of two main types: the identification and measurement of potentially harmful aspects of the machine environment, and surveys of machine operators to investigate whether damage has occurred.

Various types of effects have been determined and investigated, varying from muscle pains, headache and fatigue to pathological changes in the gastro-intestinal tract. In general, the causes of health effects can be divided into physiological effects of physical and mechanical constraints of the machine, health effects due to exposure during operation, temperature effects, and the impact of noise.

Physiological Effects -- The detrimental health effects in this category derive mainly from the vibration of the machine and the postures that the seat and control layout require the operator to assume.

The vibration experienced by an operator is difficult to measure under field conditions, but it can be determined that the

engine causes vibrations of a small amplitude which are transmitted through the seat, steering wheel, and footrest. When a tractor is driven over rough terrain both axles vibrate, but the rear axle has the greatest effect on the driver. The vibrations can be of relatively large amplitude, and are transmitted through the seat. If the seat is poorly placed or suspended it may amplify the vibration at the rear axle [6]. Both the frequency and amplitude of vibrations vary with the speed of travel, but increased amplitude is considered to have the greater effect on the body. The vibration of tractors is mainly vertical in direction, but it also has horizontal and pitching motions, though these are much less fully investigated [30].

Recognizing that a tractor driver may be exposed to posture and vibration effects for several hours at a time, S. and R. Rosegger examined 371 drivers in Europe to assess whether the vibrations and shocks caused damage to health [44]. They observed that the human body tries to counteract vibrations by a constant contraction and relaxation of the muscular system. Over a number of hours this causes a change in the response of the autonomic nervous system, and this in turn affects the tone of the involuntary muscle system of the gastro-intestinal tract resulting in interference with normal digestion.

The same study, through X-ray examination, also revealed pathological changes of the thoracic and lumbar vertebrae far in excess of normal physiological degeneration. A comparison of occupations showed that only among truck drivers was there a higher percentage with spine damage. The percentage was lower among miners, bus drivers, and factory and construction workers.

It is also suggested that vibrations may have psychological effects manifested as a performance decrement. In

the United States a study was made of the effects on tractor operators of mechanically induced vibrations in vertical, horizontal and transverse directions for the critical frequency ranges found in a variety of farm operations. They found that disc-ploughed ground produced the most severe effects. The pulse rate, ventilation rate, oxygen consumption, and steering errors were all increased significantly when subjects were exposed to vertical vibration. Other vibrations had slighter effects. Although there were no drastic physical changes or performance decrements, the potential for physical effects due to many years of exposure, and the possible contribution to errors and accidents, were both noted [15].

Static, as well as dynamic, factors may be significant. Faulty posture due to the operating position held for long sedentary periods may result in later deformation (particularly if during adolescence), and can aggravate a variety of muscular conditions or affect the functioning of internal organs.

These effects, both static and dynamic, point to the need for careful attention to operator seating. This is complicated by the need for consideration to accessibility of controls, visibility forward and behind, a range of different sized operators, the need to allow for both sitting and standing, access for mounting and dismounting, and security of the operator for safety during operation. (Of the fatalities in the Saskatchewan data in Appendix A, most of the "run-over" cases older than 19 years were persons who fell off the machine during operation.) Most manufacturers have paid some attention to this aspect, and the standard of seating on tractors has consequently improved, but there is evidence that even the best seats available do not reduce vibrations to a completely acceptable level [66].

Exposure Effects -- As he rides on most farm equipment the operator, because of his restricted but unenclosed position, is exposed to both the surrounding climatic conditions and the dust, noise, heat and fumes produced by the machine in operation. For the best part of 60 years the drivers of cars and trucks have been protected from the elements and, at least in part, from many effects of the vehicles' operation, by some sort of cabin. Strangely, a similar pattern has yet to spread to the field of agricultural machines. Manufacturers have not until recently provided any type of enclosure on farm machinery and farmers have not demanded such protection. The myth of the hardy farmer seems to persist, at least among themselves. Evidence suggests, however, that apart from general discomfort there are a range of health effects which might be caused or aggravated by this exposure.

For instance, as the length of exposure to excessive heat levels increases, the health effects proceed through fatigue, a decline in working capacity, changes in perception and judgment, and finally exhaustion. A study of heat stresses in tractor operation showed that in summer in the American Midwest a tractor operator without shade is exposed to higher temperatures than a fit young man could normally be expected to withstand safely for an eight-hour day [33]. Heat generally has greater effect on older workers, a fact which is particularly relevant since almost 50 per cent of Canadian farmers are over 55 years of age.

Heat may also have psychological effects manifested in increased errors and slower reaction time. Controlled experiments have shown a significant impairment of ability to recall aurally presented messages as ambient temperatures increased from 90° to 95° F. [54].

While heat effects may be the most common (since heat can be due to both the seasonal weather and radiation from the machine) there may also be serious health effects due to cold. Direct effects of cold such as frost-bite are not unknown in early spring and late fall operations, and the effect of lost feeling and heavy clothing in reducing the precision of machine control, with consequent increased possibility of an accident, can only be guessed at.

Exposure to dust during certain field and farmstead operations may also lead to health effects of some consequence. The lung has an effective mechanism for removal of dust particles which are not filtered in the nose, but the efficiency of lung clearance appears to decrease with increasing lung dust burden [4]. The consequence of dust accumulation can be pneumonoconiosis -- a fibrous hardening of the lungs caused by irritation due to the inhalation of dust. This hardening is present in every lung and increases with age, but environmental conditions may increase it. In cases where the dust is finely divided it can cause a type of pneumonoconiosis known as silicosis. Both diseases cause a shortness of breath, a chronic cough, and chest pains, and they may predispose pneumonia or tuberculosis.

Studies in coal mining and construction have revealed that the duration of exposure to dust is significant in causing lung conditions [13]. Fortunately, therefore, the effects of machine-created dust on farmers may not be so serious in the short run (except as it affects vision and visibility). With repeated exposure over a lifetime, however, the effects in older age groups may be significant, but no clear evidence is available on this. Dust, in contact with the skin, may also cause or aggravate various types of dermatitis, but again no evidence is available on the incidence of this problem among farmers.

This existence of problems caused by temperature extremes and dust, together with exhaust fumes and the drift from toxic chemicals, all point to the desirability of protective cabs on farm tractors and self-propelled machines--for health reasons, even if they are eschewed on grounds of comfort! While this would not seem to present an insurmountable design problem, it is vital that a cab be designed and tested carefully so that it does not reduce one effect while simultaneously increasing some other hazard. For instance a cab which effectively provides weather protection may trap and crush an operator if a tractor overturns, or it may amplify the already substantial noise emission from various parts of the machine.

Noise-Induced Hearing Loss

One of the by-products of all types of machinery is noise -- unwanted sound of a level and intensity that creates annoyance and may cause cumulative physical damage. Machines have always made noise, and tractors have been generating high noise levels for a long time, but noise and its effects are relatively recent topics of scientific research.

At first, attention was focused on the discomfort and irritant effects of noise. Farmers operating powerful machines may initially be more concerned with the annoyance factor of noise than with the gradual physical damage to hearing. Probably, they correctly recognize noise as being distracting and fatiguing. In this sense noise may have serious effects in diverting attention, as do some other environmental factors, and this may lead to an increased risk of accidents due to inattention to controls.

Much of the more recent work on noise has been on physiological effects and noise-induced hearing loss. Despite the volume of work in this area (see bibliography), there is some

conflict in the ideas and information presented in the published work. It is clear, however, that farm machine operators are being exposed to noise levels that are likely to cause future hearing loss, but the amount of disability and the number of farmers affected are not established.

At least four factors interact to produce noise-induced hearing loss: the over-all noise level, its composition, its duration and distribution during the working day, and the amount of exposure during the working life of the operator.

Sound consists of pressure variations moving through the air (or some other medium). The essential elements of sound are the rate of pressure changes occurring -- the frequency, measured in cycles per second (c.p.s.); and the magnitude of the changes in pressure -- the intensity or sound pressure level, measured in decibels. The human ear detects intensity as loudness, and frequency as pitch.

Critical Noise Levels -- Hearing loss has been found to occur in a hearing band about half an octave below the frequency of the noise to which the subject is exposed. (An octave is the interval between frequencies having a ratio of 1:2, such as from 150 c.p.s. to 300 c.p.s., or 2,400 c.p.s. to 4,800 c.p.s.) Young healthy ears can detect sounds from 15 to 20,000 c.p.s., but the frequencies of most concern are those which occur in normal speech. A welfare loss could occur only if day-to-day activities are impeded, and it is considered that a person with measurable hearing loss in the critical frequencies, roughly 500 to 2,000 c.p.s., has a significant handicap. Consequently, considerable attention has been given to establishing damage risk criteria, that is, intensity levels and frequency ranges which should be guarded against in order to protect most of the population from hearing loss.

Numerous standards have been proposed, each of which is slightly different from all the others [1]. The most widely accepted of these is that proposed by the American Academy of Ophthalmology and Otolaryngology which states that when exposure to broad-band noise is habitual, and the noise is continuous for five hours or more during the working day, the average levels at 300-600, 600-1,200, and 1,200-2,400 c.p.s. should not exceed 85 decibels [2]. The relationship between this control, the speech frequencies, hearing threshold and tractor noise is shown in Figure 2.

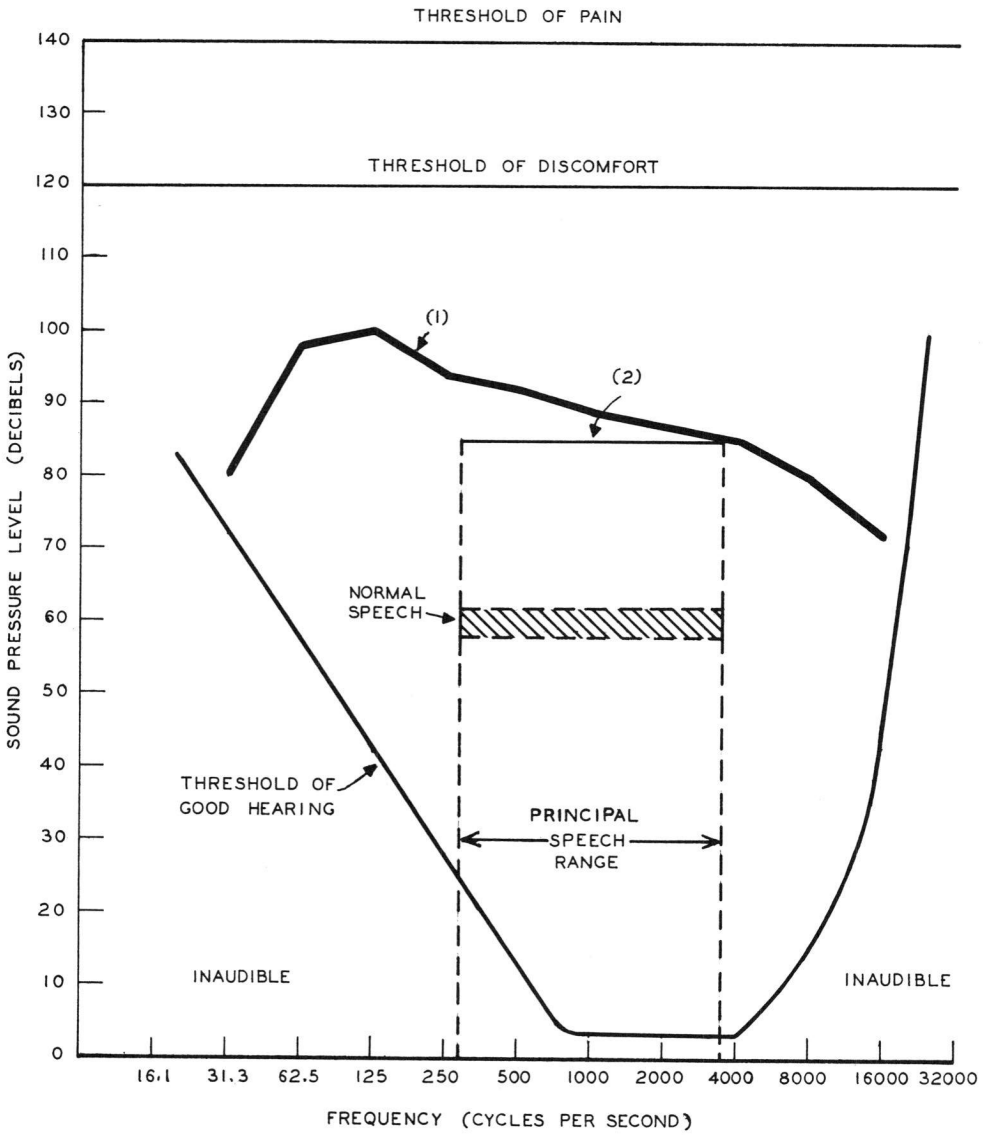
Since individual susceptibility to noise-induced hearing loss varies, this damage risk criterion will not protect everyone. Noise levels up to 90 dB in the speech frequencies are likely to be hazardous for 10 per cent of the population, and up to 95 dB may cause loss for 15-20 per cent. Consequently, these allowable levels of noise constitute rules for hearing conservation rather than deafness prevention.

Tractor Noise Emission -- Research in several countries has identified the frequencies and intensity of farm tractor noise emission. The most comprehensive of these is summarized in Table I. The measurements were made with standard equipment at the level of the operator's ear, and on tractors without cabs except where specified. In three of the surveys tests were made under operating conditions.

It will be noted that the lowest over-all level for a tractor was 92 dB, and the highest 113 dB. Both of these exceed the proposed damage risk criteria outlined above.

FIGURE 2

TRACTOR NOISE AND HEARING LEVELS



(1) MEAN SOUND PRESSURE LEVEL RANGE FOR A SAMPLE OF 58 TRACTORS

(2) HEARING CONSERVATION GUIDELINE (85 *dB* IN SPEECH FREQUENCIES)

TABLE I - MEASUREMENTS OF TRACTOR NOISE EMISSION

REFERENCE	SAMPLE	LOAD CONDITIONS	FINDINGS
D.M. Lierle and S.N. Reger (1958) Iowa[25]	14 measurements 11 tractors 7 makes 6 diesel 5 gasoline 35 to 60 h.p.	Tractors were operating under various work-load conditions	Over-all sound pressure level (SPL) ranged from 95 dB to about 107 dB 'C weighting' used Mean SPL in 300-600 octave band was 95 dB Mean SPL in 600-1,200 octave band was 90.5 dB
H.R. Weston (1963) Australia[53]	5 diesel and 1 gasoline tractor over 50 h.p. 3 diesel, 3 gas. under 50 h.p.	"Normal operating conditions"	Over-all SPL ranged from 92 dB to 106 dB Under 50 h.p. (mean SPL in 300-600 octave band was 80.3 dB (mean SPL in 600-1,200 octave band was 80.5 dB These tractors were not necessarily working at or near full power Over 50 h.p. (mean SPL in 300-600 octave band was 88.2 dB (mean SPL in 600-1,200 octave band was 85.5 dB
A.L. Riegert and T. Ireland (1967) Canada[42]	29 tractors 21 models 8 makes tractors ranged from 45 to 132 h.p.	"Actual working conditions"	Over-all SPL's without cabs ranged from 101 dB to 111 dB Over-all SPL's with cabs ranged from 95 dB to 113 dB C weighting used Without cabs (mean SPL at mid. freq. 500 cps was 91.3 dB (1,000 cps was 90.3 dB (2,000 cps was 86.4 dB
H.H. Jones and J.L. Oser (1968) Nebraska[19]	58 models 12 makes 18 gasoline 30 diesel	Measurements made at 50%, 75%, and 100% of full-load condition	Over-all SPL's ranged from 98 dB to 113 dB for tractors operating at 75% of full load Mean SPL at mid. freq. 500 cps was about 90 dB) 75% 1,000 cps " " 88 dB) full 2,000 cps " " 86 dB) load

The studies outlined in Table I all tested the effects of variables which might influence the over-all noise produced by a tractor including horsepower, fuel type, load condition and presence of a cab. In summary, their measurements suggest that noise levels will increase with horsepower, due to increased exhaust noise and larger fans; that they will vary little according to type of fuel used; and that individual design characteristics of different tractors will be of much greater consequence than either of the foregoing.

In general, the presence of a cab had little effect on noise, tending to reduce only low frequency noise levels [42]. There is no evidence to support the notion that cabs amplify the noise level, but it is contended that, unless specifically designed, cabs are likely to give little, if any, protection from noise. It remains possible that amplification could occur within a cab, or that cab vibrations may themselves produce noise as great or greater than engine noise itself [35].

Hearing Impairment -- Since the measured noise emission from tractors exceeds the conservation criteria in the critical frequencies, and is generally higher than the noise level that would be tolerated in industry, there would seem to be a real possibility that farmers will suffer from hearing loss. Whether they do or not will depend largely on their exposure to this noise. The duration and distribution of noise during the working day and through the working life of the operator can only be roughly estimated. The risk criterion is based on an industrial situation where exposure is regular from day to day for years. Farmers do not work so regularly or continually, but exposure to noise occurs in varying hourly amounts irregularly through each year. Though his total yearly exposure may thus be less, the

farmer may begin his working life years before that of an industrial worker and may continue until very late in life. Although specific studies have not been made, it appears that the amount of hearing loss experienced by farmers will not be reduced by their intermittent exposure, but rather that their hearing ability will deteriorate more slowly.

The measurement of noise-induced hearing loss is complicated because the effects of hereditary factors, blasts, infections, and aging cannot easily be distinguished from losses due to excessive noise. In two cases, however, measured hearing loss has been clearly identified. In Iowa, the audiograms from 91 full-time farm tractor drivers showed hearing losses greater than a control group [25]. They showed a sensitivity loss at about 1,000 c.p.s., and a greater hearing loss at 4,000 c.p.s., especially among men aged 30-49 years. The sensitivity of the left ear was generally worse than for the right ear, a difference which may be due to turning one ear toward the exhaust while watching a tractor-drawn implement.

In Australia, an examination of 53 tractor operators also showed measurable losses [53]. It was found that greater impairment occurred among those from inland farms where tractors are of greater horsepower, and where exposure periods are longer due to the large acreages. This effect might help to explain why concern over noise effects expressed at the hearings of the Royal Commission on Farm Machinery came only from the Prairie Provinces where similar farm conditions prevail.

In the future, larger tractors with fewer operators and increased numbers of mechanized operations, all associated with larger farms, seem likely to all contribute to greater exposure to noise and consequent hearing loss. This could create more serious hearing loss, more rapidly, for a smaller number of people.

Other Noise Effects -- The annoyance effect of noise is usually the only one of which the subject is aware. The response to this annoyance varies from person to person and from one situation to another. All noise can be distracting but generally the louder the noise the greater the nuisance.

While reaction to noise is an individual and subjective thing, "there is a consistent, and statistically reliable fatigue effect which arises from the fact that noise is a sensory input, devoid of information, that nevertheless demands attention to check this very absence of information" [7]. It has also been observed that "the presence of extreme noise requires a worker to expend more energy to perform a task than he would expend on the same task if the noise were not extreme" [6].

These annoyance and fatigue effects measurably affect performances and may increase the likelihood of accidents. One study of the psycho-physiological effects of noise on tractor operators showed that noise levels had only relatively small effects on problem-solving and steering ability [14]. But it also showed that tracking performance (steering) improved with decreasing noise and deteriorated under increasing noise. A second study supports the hypothesis of greater decrements in performance with greater changes in noise [47].

Thus the available evidence suggests that the level of noise emitted by farm machines is a matter justifying some concern. The discomfort caused by excessive noise might be considered a serious negative welfare effect in itself. There is some evidence, too, that continued exposure to high noise levels may help to jeopardize the operator's safety. The most serious effect, however, is the incipient hearing loss which, with prolonged exposure, can lead to permanent partial deafness.

3. IMPROVING PHYSICAL WELFARE

The extent to which the detrimental welfare effects associated with farm machinery can be diminished depends on the specific character of the interacting factors (man, machine and the farm environment) in any particular situation. This chapter considers how each of the contributing factors might be modified, the extent to which some modification has been attempted or achieved, and the avenues of adjustment that might be followed in future to mitigate the more serious losses in physical welfare.

Man-Machine Engineering

Since many of the detrimental welfare effects can be identified with specific features of various machines it would seem desirable that some effort be made to improve certain aspects of machine design. This might be achieved by adjusting the machine to better accommodate the operator in his use of the machine, and through specific attention to safety design and modification of those features found to have health effects. If this is feasible, what facilities and expertise are available to analyze this problem? Which various facets of the problem have been studied? How much use have farm machinery manufacturers made of this knowledge?

Within the engineering profession, the branch specifically devoted to improved man-machine design is known as ergonomics or human engineering. This field recognizes among its basic tenets the nature of man and machine and their interaction under externally determined operating conditions. It applies standard scientific procedures to define human behaviour in terms of operational characteristics, and it aims to locate and use man in any system in such a way as to maximize his efficiency in terms

of productivity and his utility in terms of physical welfare. The aim is to design in order to achieve, as nearly as possible, an optimum relationship between man, machine and environment in these terms.

The human engineer views man on the basis of four principles: (i) as an adaptive mechanism -- a complex system with a considerable adjustment capability, and many limitations; (ii) as the given factor in any design formula -- since he cannot be markedly modified, the physical system must be built to suit his characteristics; (iii) as having universal processes underlying his behaviour -- though the recognition of what processes are universal varies from time to time; and (iv) as an organism with determinate, though varying, physiological and social needs [55].

On the basis of these principles, the human engineer looks at the basic functions which man can perform in his role of machine operator. Six such functions are usually identified: (i) that of a multiple sensing unit which receives information from the physical world through sight, hearing, and other senses; (ii) a perception mechanism, converting physical stimulation into useful form; (iii) an information processor, analyzing the data perceived; (iv) a decision maker, selecting the appropriate response and its required rate and magnitude; (v) an operator, acting on the basis of decisions either by automatic or intellectual response; and (vi) a complex feedback organism, detecting and correcting erroneous responses. To the human engineer, it is through this sequence that man applies his powers of judgment and exercises those controls necessary for the effective operation of the machine [31].

This sequence is, of course, recognizably the same as that embodied in the human component identified as one of the

interacting ingredients in an accident situation, as shown in Figure 1 of Chapter 2. Exceeding the capacity of the operator to perform these functions, or preventing him in any way from performing them adequately will lead inevitably to inaccurate judgments or wrong actions which may under the "right" conditions predispose the occurrence of an accident. It is not difficult to perceive how this might happen. Consider, for instance, the vast and complex amount of information presented from a variety of sources to a tractor driver. He is virtually bombarded with a multiplicity of visual and auditory messages concerning both the operating environment and the machine. To keep track of this information in a dynamic situation, evaluate its significance, select the appropriate control actions, and execute them, repetitively over several hours, is likely to be more demanding than is apparently sometimes recognized.

Since he recognizes these functions, and the limitations of man in performing them, the human engineer is concerned about improving the key features of visibility and control mechanisms of a machine. Consequently, in farm machine design he is concerned with visibility beyond the operating position, both to the front and to the rear, by which the operator obtains information on the changing features of the operating environment and the performance of the machine. He is concerned, too, with the design and layout of dials and indicators, generally termed displays, which communicate information about the condition of the machine. Similarly, he is interested in the design and location of the various levers, knobs, and pedals, usually termed controls, through which the operation of the machine is regulated [8].

The human engineer is also concerned with the many other machine features which may hamper or facilitate the machine

operator in performing any of the operating functions required. The aim is to design the machine in order to (i) use human capacity to its greatest productive advantage, and (ii) yield greatest utility to the operator while he is performing these functions. In achieving the first of these the human engineer will endeavour to minimize many of those machine effects which may have chronic impact on man, since many of these indirectly reduce productivity. In pursuing the second goal, he will be specifically concerned with reducing both the chronic and acute machine effects on man. In these ways the interests of the human engineer are central to the problem of engineering machines to improve the physical welfare of those associated with them.

There are some physical welfare aspects of design, however, which seem to fall outside the ambit of the human engineer. These seem to be the concern of the safety engineer who, though he may be both interested and trained in human engineering, is also concerned with specific safety aspects. Very often these aspects may not involve reducing the frequency of adverse physical welfare effects, but rather with reducing the severity of their impact -- altering the nature rather than the frequency of their distribution.

Items which fall into this category include fail-safe devices such as emergency switches, protective guards for exposed moving parts, roll-bars, safety straps, warning lights, and reflecting signs for slow moving vehicles (SMV emblems). The safety engineer may also be interested in operator education. All of these items are closely involved with man-machine engineering principles, though they constitute a second level in the application of these principles.

Through the professional expertise of safety and human engineers there is available to a farm machinery manufacturer the means of improving his machines in terms of operator efficiency, utility and safety. Consequently, it seems appropriate to investigate the extent to which these facilities are utilized.

The recent published literature shows that certain relevant aspects of farm machinery design have been specifically studied, including tractor seats, safety frames (or roll-bars), protective cabs, hydraulic powered controls, and tractor stability [11, 32, 6, 57]. There is evidence, too, that many of the human aspects related to machine design have also been studied specifically in relation to farm machines -- for instance, vibration and noise effects. Some other relevant effects have been studied indirectly in relation to planes, automobiles and trucks, for example heat stress, visibility, driver concentration, and control and display layout. The publications of the Society of Automotive Engineers and the American Society of Agricultural Engineers indicate that there have been standards established for tractor seats, lights and light mountings, warning lamps, improved shields on the power take-off (PTO) and SMV emblems [48, 49, 3]. There have also been recommendations propagated concerning tractor tire inflation pressures and the improved safety of farm tractors, though both recommendations and published standards seem to lag considerably behind the relevant available knowledge.

A review of the descriptive sales literature indicates that design changes in farm machinery over recent years include the introduction of improved tractor seats, the adoption of hydraulic transmissions, power brakes and steering, better safety shielding of working parts, and the use of "quick-attach" hitching devices which reduce heavy lifting [52]. There are also available

safety frames, protective cabs, and certain other optional extras of this nature, and there are on the market several improved PTO covers, some fixed and some which turn with the shaft, improved driving and warning lights, and SMV emblems.

This would seem to be an impressive list, but none of these modifications is universally fitted to new machines, even within the production range of any one manufacturing company. Many are available only as options. The position varies from one to another but, generally manufacturers seem reluctant to introduce specific safety features even where evidence of their usefulness is overwhelming. Most concern for man-machine engineering features is registered when a production change, introduced for functional reasons, happens to yield some operator advantages. The general attitude indicated in both practice and in public statements seems to be one of some complacency.

In part, the attitude of manufacturing companies is reflected in the statement by the president of a major company to public hearings of a Royal Commission in Ontario [40], to the effect that: "Power assist devices, such as hydraulic control of implements and power steering, have made it possible for teenage children and farmers' wives to handle even the largest tractor safely. I submit to you that this is quite a valuable feature. There are more teenage children and farmers' wives on tractors today than you might think. If it were not for power steering and hydraulic attachments, they would not be able to operate tractors." Such a statement is surely notable for its complacency regarding safety, if not for its strange notions of social progress. There is certainly no evidence in Appendix A to lend support to his assertion as to the safety of such operators.

Some insight into the thinking which underlies their general attitude is provided by replies from the major manufacturers to an enquiry by the Royal Commission on Farm Machinery concerning the danger involved in unblocking corn-pickers. Previously, in evidence to the public hearings, concern had been expressed regarding the number of persons caught in the snapping-rolls at the front of this machine while attempting to unchoke the intake [5]. The nature of this not-uncommon accident is particularly traumatic. On occasions it is known to have shredded the arm of a man down to the bone along the full extent of its length from fingers to shoulder. Although they expressed some concern, none of the companies contacted who manufactured such a machine believe the suggested remedy (an emergency release) to be feasible, and none suggested an alternative, except stopping the machine before attempting to clear it -- even though the fastest and most effective, if not the only practical way of clearing it is by helping the machine clear itself.

Two of the companies contacted suggested that the provision of a fail-safe device "would probably encourage unsafe practices rather than reduce accidents" [5]. None recognized that the purpose of such a device would be to reduce the severity of such an accident rather than prevent it, and that consequently there would remain good reason for caution. A logical extension of the argument that fail-safe devices encourage unsafe practices is that safety straps in automobiles and safety frames on tractors will encourage more dangerous driving of these vehicles. In both cases, however, factual evidence is exactly contrary to this notion.

Convincing evidence of the effectiveness of tractor safety frames is provided by Swedish experience. The equipping of

tractors with safety frames on cabs became compulsory by law in 1957 and by 1965, 90,000 or 38 per cent of the 235,000 tractors used on Swedish farms were so equipped. From 1957 until 1962, when 40,000 tractors (20 per cent of the total) had safety frames, the number of overturns and the number of fatalities continued to increase. From 1962 onward, however, overturn accidents have declined by more than 50 per cent. Though this could obviously be due to some other change in the man-machine interaction there is no evidence of any such change. Concurrently, total overturn fatalities have been dramatically reduced, and those involving tractors with safety frames have been virtually eliminated [41].

Despite this evidence, and extensive research into alternative means of preventing a tractor from overturning more than 90 degrees, the manufacturers have only recently shown any interest in such devices. Most now provide frames as options but no company is fitting safety frames as standard equipment. What is even more culpable, some manufacturers are providing as optional fittings operator cabs which are not safety cabs. These light framed structures cannot be expected to withstand the crushing force of an overturning tractor; but they effectively restrain the operator within the danger area, removing the chance that he might fortuitously be thrown clear in the event of an accident. This situation does little to demonstrate the concern for safety expressed by these companies in hearings of the Royal Commission on Farm Machinery.

In many cases design changes, which greatly alter machine performance, are made with little consideration of the consequences. The data in Appendix A emphatically demonstrate the high frequency of tractor overturns as a cause of farm fatalities, and provide clear evidence that overturning accidents are

associated with higher tractor speed. The occurrence of overturn fatalities is more frequent for tractors in higher gear, and there is a strong indication that the tractor having the highest top speed has a large proportion of such accidents. Yet, the speed of tractors in top gear has been steadily increased by manufacturers without any attention to changes that might increase the stability of tractors at these increased speeds to counter the increased risk.

Nor does there appear to have been any attention to braking effectiveness. Tractor brakes are designed with separate brakes on the two rear wheels, operated by two separate pedals placed side by side, to facilitate the use of the brakes when turning under heavy load conditions. To stop the tractor in forward motion it is necessary to depress both pedals simultaneously. This is facilitated by a locking plate which can be placed over the shank of both pedals when full braking is required, but this requires a specific preparatory hand operation which cannot be done instantaneously and which can easily be overlooked. Even when it is used, this measure is often less than satisfactory, since the separate brakes, once worn by being used in turns, often require different pressures to give equal braking on both wheels. The use of power assistance in no way alleviates this necessity. Consequently, the brakes on tractors can only be used to any helpful effect by the most agile of operators. Thus the nature of tractor brakes constitutes a serious safety deficiency, and one about which the manufacturers have shown little discernible concern.

The farm machinery manufacturers all assert that they are aware of the nature of the man-machine interaction on farms, and there would seem to be little justification for them not

knowing what happens in the use of machines on farms. In the face of this, it seems incomprehensible that no tractor sold in Canada is equipped with a passenger seat. A little knowledge of farming operations and farm family activities will suggest numerous occasions when it will be necessary for additional persons, other than the driver, to ride on a tractor. The data in Appendix A indicate that persons in this category are frequently victims of fatal accidents. Yet no attempt has been made by manufacturers to make this activity less dangerous.

In Germany, all tractors sold must, by law, be fitted with a safety guard located on the mudguard. This guard provides a handgrip for both hands, and at least minimum protection from sliding or being brushed off. If such a guard was accompanied by an adequate foot-rest or platform the situation of the tractor passenger might inexpensively be vastly improved.

A similar situation exists in the seating position and controls of many tractors. Normal farm practice necessitates that persons of various physical size will, from time to time, use the tractor. Whether wives, children or otherwise, the provision of an easily hand-adjustable seat position would greatly facilitate their access to the controls and consequently their effective control of the tractor. Very often the operation of a tractor is made unnecessarily difficult, as in this case, by very small economies in production. In other cases there seems little reason at all. For instance, the clutch pedal on tractors is frequently heavily sprung, presumably to suggest sturdiness in construction. The effect is to make it difficult to declutch if one is either physically smaller than the norm considered in the design, less strong than the designer supposed, or for some reason displaced from the precise seating position necessary. This feature is

consequently an accident hazard. It could be modified for little more than the cost of the decision to do so.

A further example of the unwillingness of farm machinery manufacturers to adopt improved man-machine design is provided by the problem of tractor exhaust noise. Though noise is also emitted from the fan and the transmission of a tractor, the loudest source is the exhaust. It is well known that the exhaust noise can be effectively reduced to comfortable and safe limits (below the hearing conservation standard) without serious loss of effective power output from the engine. In fact, present exhaust muffling is designed to attenuate the higher frequency sounds while allowing through the lower frequencies. That they effectively do this is supported by the sound pressure measurements shown in Figure 2 of Chapter 2. The reason given for not reducing the lower pitch sounds is that farmers prefer the high noise level because, (i) they like to hear the "powerful sound", and (ii) they rely on changes in the noise level to detect how the machine is running [17].

The first of these may have some basis in psychological terms, though it is an attitude which can probably be modified, particularly if the farmer is made aware of the alternatives. The success in selling the advantages of lower noise levels in certain jet-engined planes used by some airlines, and in gaining acceptance of low-noise-level power boats, suggests that advertising could alter this attitude. There would seem to be sufficient concern among farmers over both the discomfort and the deafness effects of noise, as noted in public hearings of the Royal Commission on Farm Machinery, to provide a solid nucleus for the acceptance of quieter engines [51]. In addition, the possibilities of "Silent Strength" and "Whispering Power" would

seem ready-made for the publicity departments of tractor manufacturers!

The second point is fatuous. Clearly the machine operator can hear changes in the noise level just as effectively, if not more effectively, if the noise emission is less than 85 dB rather than above it -- providing he is not already prematurely deaf. At this lower level he may also be able to detect aurally changes in the function of other parts of the machine -- a point which might be used in selling this idea.

Farm machinery manufacturers argue that their raison d'être in not introducing many simple and readily available safety features and health-protecting modifications in their machine designs is that there is a low level of "buyer acceptance" of such machine design innovations [17]. In some cases this factor is likely to be real, but it seems that such a reaction must stem from a lack of knowledge on behalf of the buyer in relation to the possibility and probability of the side effects associated with farm machinery operation. As indicated earlier, there is no way that a farmer can know what sort of performance the engineers have allowed for in their design, unless he is told. It is argued that publicizing such information is detrimental as it emphasizes negative effects of the manufacturer's product. In this regard, however, the companies concerned seem to have overlooked the persuasive power and subtlety of the information media they have at their disposal, at least until very recently. It is interesting to note that in 1968 one of the major tractor manufacturers has begun to extensively advertise the advantages of tractor safety frames, though they are still provided only as an optional extra [18].

Many other shortcomings in machine design could be detailed, but it is not within the scope of this study to catalogue all of the deficiencies or particular excellences of various farm machines in terms of their physical welfare effects on farm people. These few examples are presented only to indicate that, despite the expressed concern and available competence of the farm machinery industry, the situation regarding safety and health effects is far from ideal and, it might be considered, not even up to reasonable expectations. It must be recognized that machine design changes are the most effective means of modifying the man-machine interface. The provision of safety modifications as optional extras is not enough. Since only the engineers know the characteristics of their machine design, and the expected limitations within which the machine was assumed to operate, only they know its tolerances and susceptibilities. The buyer is in no way able to assess what optional extra equipment is necessary for the safe performance of any machine. Since they do the designing, the farm machinery manufacturers also bear the responsibility for implementing all of the changes that research can produce and that the facts can justify.

Education and Safety Programs

Unlike machines, the extent to which the performance of man can be modified, in relation to any of the functions required of him as a machine operator, is limited. The nature of the physiological and psychological make-up of man is such, however, that some change is not precluded.

Physically, man can be changed in so far as it is possible to improve his physical fitness and thus indirectly his performance of control operations. By experience and training it is possible to develop in man learned responses which might

improve the accuracy and speed of his reactions. Similarly, by training and education it seems likely that it is possible to alter to some extent the perception and judgment of man in his role of machine operator. This might be achieved by improving the basic knowledge and information of the operator so that his awareness is increased, permitting observations to be more significant, analysis to be more comprehensive, the subsequent decision more accurate, and the action taken more appropriate.

Each of these potential adjustments necessitates the involvement of the operator if it is to be effective. This can only be realized if there is some awareness of the problem on the part of the operator involved. Once there is this awareness the necessary training or information must be available. Given that it is possible to adjust even partly the actions and judgment of a machine operator, it seems appropriate to consider the extent to which this approach has been used in attempting to improve the efficiency and well-being of the farm machinery operator. In particular, the extent to which facilities are available for education and training programs might be regarded as an indicator of the level of activity in this field.

A review of such activities in Canada reveals, on the positive side, some contribution by three groups of institutions: provincial governments, safety associations and manufacturing firms. The amount of activity in various individual units varies considerably, and there are no over-all planned programs or standardized procedures established.

Within government, the whole area of farm safety is regarded as a provincial responsibility. Despite this, many of the provinces have done little if anything of note in this area. In some provinces the total activity involves the collection of

data from newspaper clippings. In others, however, there has been some positive action usually through co-operation with the provincial safety councils or their equivalent. The most comprehensive of these programs is that in Ontario, where a program began in 1959 with a survey conducted through the Agricultural Representatives in each county [39]. In subsequent years a smaller number of different counties have been surveyed. This activity seems to have been effective to some extent in creating awareness of the problem. There is also an attempt to follow up this effect by an annual school, and through the activities of a field officer who attends farmer organization meetings. Unfortunately, in these activities they are largely "preaching to the converted", and the educational content of the material presented is limited by the short duration of the contact.

Activity in this field within the safety associations also varies considerably from one to another. Apart from the Ontario Farm Safety Council, which operates in co-operation with the provincial government, the next most active is the Saskatchewan Safety Council. Through its small but active Farm Division it regularly investigates the frequency of accidents and hospitalizations, and recently has evaluated the noise emission from tractors, both in conjunction with the Saskatchewan Department of Health [16, 42]. For their educational efforts all of the safety councils have relied on demonstrations and exhibits at country fairs and talks to farm groups.

The machinery manufacturers also take some action in this area. This is mainly in the form of decals bearing safety warnings strategically placed on new machines, and through instructions in operator manuals, and other circulated

publications. Frequently, the companies actively support the work of the safety councils, and farm youth and other groups who from time to time have safety projects. In these ways they follow a policy of "helping the dealer to educate the farmer" [29].

A less superficial review than the foregoing reveals, however, that the situation in this area is even less satisfactory than it seems. It must first be acknowledged that the educating of an adult group on psychologically unattractive aspects such as safety is an extremely difficult proposition. Though it is relatively easy to create some awareness, it is another thing to create the sort of awareness that will lead a farmer to seek the follow-up information required by either reading or attending courses, even if they are available.

In most cases the type of in-depth training which might do most good, such as on the frailty and relative susceptibility of man, on the nature of the machine, and on their interaction, is not available. Safety programs and exhibits are often given over almost exclusively to the type of propaganda known as the "scare technique", yet this is known to be of limited effectiveness. For such programs to be effective, the machine operator must identify himself as the victim and the culprit, and often as being irresponsible -- and this is an image with which the average individual will not identify [27]. There is some indication that too much fear, due to excessive use of "scare technique", may have undesirable effects in accident situations. There is considerable evidence that emotional factors are significant in situations where human error is involved, and fear may be a serious contributor [26].

The most serious omission from safety programs is information concerning the nature and reactions of the farm

machine. Rarely does anybody tell the farmer of the limitations or the inadequacies of his machine. Accordingly, he does not comprehend the dangers and therefore does nothing to avoid them. In many cases a real awareness of the problem is noticeably lacking among farmers. At hearings of the Royal Commission on Farm Machinery the president of a farmer organization stated his judgment (which was subsequently quoted in the brief of one of the manufacturers) [29] that farm safety "is the responsibility of the individual in more cases than not. I believe that the machines have adequate safety devices", and that "agricultural equipment in doing the job it was designed to do, is certainly safe in my opinion".* Such an ill-informed belief surely reflects a frame of mind rather than a knowledge of the facts.

Such a belief among farmers could obviously lead to a lack of concern for safe practices in machine use. Because they do not comprehend the shortcomings of a machine, it is not surprising that the introduction of a higher priced model that is safer, or of a safety device offered as optional equipment, is disregarded -- it offers no recognizable advantages. Through this innocence of their situation, and by voicing such views as that above, they leave manufacturers to assert unhindered that their products are adequate in this respect. Due to a lack of awareness of the inherent problems, farmers are "hoist with their own petard" so far as the safety of their machinery is concerned.

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* Royal Commission on Farm Machinery Transcript of Hearings, Volume 9, March 21, 1967, pp. 855-856.

Yet the safety programs of the safety councils are particularly deficient in information on machines. Possibly because of the need to raise funds from the manufacturers, they seem reluctant to consider this part of the problem. Instead they exhibit considerable zeal in seeking to improve the performance of man. Little heed is paid to the restraints on their possible success in doing this. Not only can man as a machine operator be modified to a limited extent, but it is very difficult to do so -- particularly on the voluntary attendance basis made necessary by virtue of the organization of the farming industry.

The activities of the manufacturer in this area are also rather limited. Decals on new machines do something toward getting information to the operator at the right time and place, at least until they eventually flake off or become coated with grime. Unfortunately, there is no way of ensuring that machine owners or operators will read the operator manual. The stated policy of "helping the dealer to educate the farmer" seems virtually futile. The dealers have no skills and are not equipped to carry out this function, and they are neither morally nor legally responsible for safe operation of the machines they sell. Though they are probably not entirely uninterested, it is difficult to see how they could undertake educational projects to the extent that would be necessary for any real effect.

Despite all of the difficulties, however, it should not be impossible to achieve some effect in the area of educating farm machine operators. It is not difficult to create some initial awareness, using accurate statistics and the mass media. Nor is it difficult to work up a comprehensive and effective educational program. The greatest difficulty lies in the step between these two -- in achieving participation, or involvement. The challenge

before the safety councils and other interested bodies is in establishing a philosophy that will encourage this involvement [46]. Even then, however, the achievement seems unlikely ever to be spectacular.

Changing the Farm Environment

As a focus for altering the man-machine relationship, the farm working environment seems even more intractable than man himself. The various features of the environment are such that they do not lend themselves to easy modification, yet they are themselves changing continually. These changes are largely due to adjustments in the organization and structure of the farming industry. The nature of the working environment is, in effect, mainly determined by the prevailing economic and technological situation of both individual farms and of agriculture as a whole.

Throughout this study the term environment has been interpreted in its widest possible sense. It has been used to encompass all of the facets of any farm operating situation that are not specifically identifiable with the entities of either man or machine. The effects it contains are both varied and numerous. They include the isolation effects of geographical location and settlement density, the physical effects of climate and terrain, the operating conditions imposed by changing husbandry and technology, the sociological effects of the proximity and changing structure of the farm family, and the broad organizational effects deriving from adjustment to economic change.

The isolation effects are inevitable, given the organization of agriculture based on the farming of broad acres by an owner-operator and his family. Clearly, this aspect is of greater significance in some types of farming, and hence in some areas, than in others. The problem of isolation from town

facilities and services and from contact with other persons in the case of emergency, is greatest where farming is most extensive, and is mitigated to some extent where agriculture is more intensive. As in other cases, the solution to this problem of isolation must come through improved communications.

On a regional basis, communication has improved considerably through the telephone and improved roads and road vehicles. Some further improvement is undoubtedly possible through the use of air ambulances, and similar services. Although some progress has been made along these lines, the situation in Canada remains far from ideal. In one documented case in 1967, a farmer whose arm was torn off in a PTO accident took six hours to reach full medical attention. This instance occurred in the more densely populated area of a province which boasts an air ambulance service, though it was not used on this occasion. Whether the ambulance was being used elsewhere or simply not considered is not certain, but this incident serves to emphasize the problems in making such a service effective.

Some of the dangers to the operator associated with working in relative isolation, often some distance from his home base, may also be counteracted by improving communications, in this case on the farm. The use of two-way radios on farms, with one on the tractor and another at the farmhouse, provides a possible approach to this problem. The present trend in farming, toward fewer and larger farms and fewer people, increases the potential of such a device -- particularly when a farm consists of segmented blocks of land.

The physical features of the terrain cannot be modified at all, but those that derive from the weather can be counteracted quite effectively by the use of protective operator cabs on

machines. Though this is a modification of the machine rather than the environment, it does effectively alter the micro-environment in which the operator works.

The operating conditions imposed by particular technology and husbandry practices, although they are frequently changing, are usually difficult to modify. Often technological innovations themselves reduce physical welfare hazards by changing the timeliness effects of some operations -- though they can do the opposite. Handling equipment, in particular, has greatly facilitated ease of work and physical well-being. Often the adoption of a specialized machine, such as a grain auger, has had this result. In other cases, however, some very hazardous operations continue to be undertaken because of the lack of appropriate specialized equipment to do the job. One example of this is the highly dangerous operation of compacting silage in pits or stacks using the farm tractor. Despite the use of evacuating processes, and the development of alternative ways of making silage with more finely chopped material, this compacting operation remains, in some areas, a not-uncommon practice. This might be one situation where a better knowledge of the stability limits of the farm tractor could encourage the farmer to change his fodder-conservation procedures.

The increased dangers associated with machinery working in close proximity to the farm family are similarly difficult to reduce. To some extent the adjustments within agriculture may increase the risks, by necessitating the use of younger and older members of the family in some operations. There seems no way of adjusting this situation except by the massive reorganization of farming. To some extent the problem is reduced by the increasing trend, in some locations, toward farmers establishing residence in

town and commuting to work at the farm. On the other hand, this may help to aggravate some of the isolation effects mentioned earlier. The only alternative approach is through continued attempts to educate farm people about the problem involved.

Finally, the operating exigencies created by economic pressures must also be recognized as being an unsatisfactory feature of the working environment. Agricultural adjustment is causing increased pressure on farmers to work faster, through longer hours, in order to cover larger acreages within the same time constraints as they previously covered smaller areas. To some extent this problem can be alleviated by larger machines, and by changes in husbandry practices. In other situations, where farm size does not grow, farmers are economically squeezed by increased capital costs and relatively stable product prices. This leads the farmer, in order to stay in business, to use older machinery and to economize on safety equipment -- both of which can lead to high-risk situations. Again, there is no easy solution, but this problem represents an aspect of farm welfare that would seem to be just as important in farm policy considerations as is the forced migration of people out of agriculture.

Encouraging Preventive Action

If the physical welfare situation, as outlined generally in the foregoing discussion, is considered to be less satisfactory than is acceptable, then the present largely voluntary approach to this problem must be recognized as being inadequate. If this is so, consideration must be given to a more concerted attempt to improve the relationship between man and machines on farms.

Such an effort might be based on a program of either promotion or compulsion -- or a combination of both. To foster

the safety and well-being of farm people by promotion might necessitate the use of research and education programs and facilities, and the establishment of appropriate standards for relevant manufactured items. An element of compulsion might be introduced, by legislation and effective administration, to compel both manufacturers and users of farm machines to adhere to certain standards. This aspect might be accompanied or enforced by a coherent attack through litigation under the established laws of tort, or under whatever laws might be passed relating to specific problems in this area.

A research program would seem to be imperative, whatever approach is followed. This might be fostered by either setting up a specific research fund to provide allocations for work in this area, or by establishing and financing a specific research unit charged to undertake the appropriate type of work. The aim of research within such a program would be to investigate the basic aspects of the man-machine relationship on farms, to relate the findings of the behavioural sciences and human engineering to farm machinery use, to evaluate the effects of the man-machine interaction on farm people, and to assess changes in these effects over time.

Through such a program it should subsequently be possible to seek solutions to actual and anticipated problems, and to devise effective modifications or alternative equipment for hazardous situations. By doing this it should enable all manufacturers, even those who are too small to do their own research in this area, to have access to the technology necessary for the improvement of their product in this regard. It should also facilitate the definition and establishment of standards relevant to the problem.

An education program might effectively accompany this research activity. It might, similarly, be fostered by provision of funds provided for specific purposes to existing instrumentalities, or by designating a specific unit to do this type of work. Rather than seek only to improve the performance of man as a machine operator, the program might usefully aim to create a broad awareness of the susceptibilities of man and the limitations or inadequacies of machines in relation to the physical welfare of human beings. By gaining such recognition it might help to build up pressure for effective action to improve the welfare situation, and create an effective demand for safety and health-guarding developments when they from time to time become available.

Based on progress in the research program, the material knowledge and measurements should be available for establishing effective standards for manufactured items and machines. Once established, such standards would provide a basis for legal action, an effective guide to manufacturers, and a focus for the agitation of interested parties seeking to improve the safety and welfare situation. Such a three-part program, together with litigation under existing law, could be developed with or without the intervention of government. Its effectiveness under these conditions might, however, be open to doubt, particularly because of the likely shortage of funds.

Apart from, or together with, this program for promoting the improved physical welfare of people associated with farm machines, there could also be introduced a program of compulsion or enforcement. Since the promulgation of effective legislation requires initial public awareness and a demand for action, some aspects of a promotion program might of necessity be an effective part of a program of compulsion.

A program to obtain the effective enforcement of basic improvements to physical welfare effects would also have three stages. The first requirement would be appropriate legislation, then effective and continuing administration (without which such legislation would be meaningless), and finally the possibility of eventual prosecution or, alternatively, litigation by affected parties -- depending on the nature of the legislation [34].

Possible legislation might include provisions to establish a legal framework for the recognition of relevant standards, thus clearing the way for their enforcement. It might seek to remove the competitive disadvantage that may accrue to a manufacturer who implements safety or health-guarding modifications while his competitors do not, by making the fitting of specific equipment compulsory. This might be achieved by establishing trade or commercial barriers against machinery which does not meet set requirements.

Concurrently, legislation might be introduced to regulate the use of farm machinery. An appropriate goal might be to compel farmers to use, and to leave in place, safety equipment. This might be effected by making this a required condition before worker compensation coverage can be applied for, or compensation for the owner-operator can be claimed. And it could be made mandatory where hired labour is employed. It might also be worthwhile to consider the registration of all tractors used on roads as motor vehicles, and to make them subject to the same road code as other vehicles -- including compulsory third party insurance.

Legislation concerning the compulsory adoption of certain minimum safety and health protecting modifications might be considered immediately desirable. This might include (i) the

compulsory fitting of safety frames or safety cabs on tractors, (ii) the outlawing of cabs not built to safety cab specifications, (iii) the required fitting of appropriate driving and warning lights, (iv) the compulsory fitting of rear-vision mirrors on tractors, (v) the adoption of the SMV emblem as compulsory across Canada (it is already legally required in Alberta, Manitoba and Ontario), (vi) the adoption of a passenger seat or safety hand grips on tractors (to avoid a conflict it may be necessary to modify regulations which make it illegal to carry a passenger on a tractor in some provinces), (vii) to require the provision of an additional single-pedal driving brake (this is already provided on some German tractors), (viii) the setting of a maximum limit on noise emission (appropriate muffling equipment is readily available), (ix) the fixing of a maximum speed that tractors are built to achieve, unless they have a sprung suspension, and (x) the compulsory fitting and use of guards and shields on moving parts, especially PTO covers, and auger shields.

Appropriate standards or information are readily available to permit the specification, and the fabrication, of all of these modifications. Since the larger manufacturing companies have already developed, or experimented with, all of these modifications it is likely that they would willingly co-operate in making such requirements effective. In addition, there is comparable legislation already in existence which might provide a precedent, if not a model, for similar legislation in Canada. Protective frames are legal requirements in Sweden and Britain, passenger seats are mandatory in Germany, SMV emblems are compulsory in three provinces at the time of writing, maximum noise emission standards for motor vehicles are in force in many countries, and the state of Michigan in the United States has a

law requiring the equipping of all machines sold in that state with "proper safety devices" [43].

Some types of legislation are likely to be less effective than others, as are some parts of other areas of the possible program outlined. In general, the possibility of laws to regulate farm work conditions have been disregarded by safety authorities as ineffective. They have been considered so because farmers are mainly owner-operators who employ little if any labour, and because farms are not effectively policed or inspected. There is some evidence, too, that safety legislation that regulates employers does not seem to be very effective in that, alone, safety legislation and enforcement in the construction industry "do not result in a significantly lower rate of injuries or seem to promote increased safety precautions" [45]. (The same empirical study indicated that those firms with the best safety ratings were those which had received "some form of assistance and education.") The fact that farmers are consumers of goods from a mass production industry, and that accordingly the appropriate direction for regulation might be toward the manufacturer, does not seem to have been recognized, and has certainly not been accepted. There would appear to be, however, considerable scope for adjusting this situation.

Similarly, there would seem to be strong justification for such action. The viewpoint that the individual is responsible for his own welfare is generally unacceptable because it assumes that he is fully aware both of the situation as it affects his well-being and of the alternatives available to him, and that he is in a position to recognize and make the necessary changes to improve his situation. Clearly, so far as the physical welfare effects of farm machinery are concerned, neither the machine

operator nor third parties near to him can meet these conditions. Consequently, if a welfare disadvantage is acknowledged to exist the action of organized groups, or of society as a whole, is not inappropriate. Effective action and "compensation", however, will only be achieved at some cost.

Costs and Responsibility

It has been argued, in the previous chapter, that it is the responsibility of the manufacturer to introduce such safety devices and health-protecting machine modifications as are necessary to promote the physical welfare of the people who work with farm machines. This argument is based on the reasoning that only the engineers who design and build a machine can know what modifications are necessary to promote both safety and utility in its operation. Only highly trained and informed personnel are in a position to make and interpret measurements which might reveal the operating tolerances of a machine. Similarly, only the designer knows the conditions and uses that a machine is built to stand. Consequently, it can be argued that the buyer is not able to assess what modifications, or optional equipment, are necessary for his protection.

Apart from this, however, the responsibility of the manufacturer for the effective and safe performance of his product has been clearly established in law. The liability of the manufacturer for ill effects caused by his product has been tested and proven for a wide variety of products [12]. Although most recent court action in this area has been in the United States, similar precedents of manufacturer responsibility have been established in many countries of the world. A case involving a claim against a farm machinery manufacturer has been cited as an example of the principle of design liability established by the

courts [38]. This case involved an unskilled worker who lost a hand when a mulching machine started up while he was cleaning the blades of the machine. The manufacturer was held liable because (among other reasons) he did not design the machine so that the blade would automatically disengage if the provided cleaning door was opened. [United States Courts, Tracy v. Finn Equipment Co., 310 F. 2d 436 (CA-6, 1962).] As a consequence of such court decisions the responsibility and potential liability of the farm machinery manufacturer would seem to be clearly defined. Though they bear the responsibility, however, manufacturers do not necessarily bear the cost of implementing improved design; whereas if they fail to implement a design improvement they may bear a considerable cost due to successful litigation against them.

If safety devices are fitted or modifications are made, the cost thus incurred can in many circumstances be passed on to the buyer in the form of a higher product price. This is particularly true if all manufacturers make such changes, either voluntarily or by compulsion. Consequently, the cost of better design in farm machinery might, in some circumstances at least, be met largely by the farmer.

At the same time, part of the cost involved is being paid by society as a whole. This is because the research activities of large firms receive an effective subsidy in so far as they are eligible for special taxation concessions in relation to research expenditure. Thus, it seems, part of the cost of design improvements might be borne by the manufacturer, some by the purchaser and some by society as a whole. The question remains as to who might reasonably be held responsible for the costs involved.

Society already bears the costs associated with the failure to counteract any increasing problem of safety or health effects, in the form of expenditures associated with the range of medical and health services which are provided for persons injured or otherwise affected. Consequently, some of the costs associated with preventing detrimental physical effects of farm machinery might be met by society as a whole on the grounds that it could be less costly to take responsibility for prevention than it is for cure. In logic there seems no reason why society, having assumed responsibility for health and medical services, does not hold equal responsibility for preventive services related to physical welfare.

From a different viewpoint, it can be argued that improved machinery technology is part of the continuing technological change which is fostered in agriculture through the policies of governments. In encouraging this technical progress through both an investment in research and the provision of funds to promote capital formation in agriculture, governments and thus society as a whole aim to increase and improve their supplies of food and farm products. The introduction of new farm machinery technology, while it is not directly or strongly supported by government-financed research, is nevertheless an implicit and accepted part of farm policy in Canada, as in many other countries. Consequently, the expanding quantity and size of machines on farms -- and its concomitant side effects on the structure of agriculture, and the welfare of farm people -- is the product of a policy designed to benefit the whole community.

In so far as such technological change is effective in increasing farm output and the quality of farm produce without increased costs, society in general must be considered to have

gained by its introduction. If the same technology, in the form of new machinery, has detrimental effects on the physical well-being of farm people then they clearly have suffered a welfare loss. If the development and introduction of safety equipment and health protecting modifications are an effective means of reducing this welfare loss, then responsibility for its introduction might appropriately be accepted by society as a whole, and governments in particular. In this way they might be making the compensation payments necessary to restore an optimum welfare balance, in the Pareto economics sense.

Accordingly, it would not seem inappropriate for governments to introduce and finance the research, education, and legislation programs that might improve the physical welfare situation vis-a-vis farm machines. This is not to say that they should directly subsidize the introduction of the desired machine modifications. Though the cost of these changes may be considered a burden on those parts of the farming spectrum that are already economically beleaguered, it would be difficult to justify a direct subsidy.

The actual cost of safety modifications to a single farm at any one time is likely to be small relative to total machinery costs on that farm. Any farm that is overburdened by the additional costs involved is likely to have its economic viability reduced by a very small margin of time. Also, since governments often take action to adjust the prices of farm products to guarantee the economic well-being of farmers, the cost of improving physical welfare would seem to be covered by such action.

Given acceptance of the need for, and appropriateness of, government action, the next concern might be "when?". The

available figures suggest that, among all accidental causes of mortality and morbidity in Canada, the rate due to farm machinery is already second to that related to the automobile (in the farm population and total population respectively) with the rate of farm machinery accidents increasing more rapidly than those involving automobiles. If the actual numbers of people exposed to potential accidents due to both causes are considered, the present rates might not be much different. Yet, just the general use of safety frames on tractors could be expected, on the basis of Swedish experience, to reduce the fatality rate due to all farm machinery accidents by about 50 per cent. This would save some 60 to 70 lives a year. It should not be necessary to await statistical proof that the detrimental impact of farm machinery on farm people exceeds that of automobiles on the whole community, before some action is taken.

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APPENDIX A

A SURVEY OF FATAL ACCIDENTS INVOLVING FARM MACHINERY IN CANADA

I MACHINE FATALITY TRENDS

Accident Characteristics

Accidents are the most acute of the possible side-effects of the man-machine interaction on farms. Their effects are more obvious, more frequent, and in many cases more devastating than any of the more chronic physical welfare effects of farm machinery.

Though each event is unexpected to any one individual, accidents in total tend to have a pattern, and a disconcerting certainty within the population as a whole. Because "accident" is a broad term embracing any unexpected event, there are included under this heading a wide variety of effects of varying seriousness. Consequently, it is useful to give more meaning to this term by sub-dividing the general category. The simplest classification might be based on the effect on the victim in terms of temporary injury, permanent injury or fatality.

Machinery accidents can involve varying degrees of traumatic injury. Because farm machinery is designed to cut, chop, grind and shake a variety of produce it is not surprising that its impact on man should be traumatic. On the other hand, data collected in the Ontario Farm Accident Survey in 1959 indicate that temporary injuries are by far the most frequent, representing more than 75 per cent of all accidents recorded. Accidents leading to permanent injury were somewhat less frequent, constituting 15 to 20 per cent of the total, and fatalities were a small minority of two to three per cent of all machinery accidents [39].

Fatal accidents are, however, the most extreme of the possible side-effects of farm machines on man, and as such they

might be studied as a significant feature of the physical welfare situation in their own right. But, since they are a part of the spectrum of accidents, fatalities may also be studied in order to obtain some insight into the nature and pattern of accidents as a whole. In doing this, however, some caution is needed since changes on the farm and elsewhere may be altering the pattern of fatalities, without this effect being reflected in the over-all accident pattern. As farm machinery design improves, a gradual reduction might be expected in the more serious accidents. As medical knowledge and services progress, it seems likely that some once-fatal accidents might cease to be so. In addition to these effects, given that the farm population is declining, it might be expected that the total number of accidents will have declined too.

Available Data

To investigate the trends in the frequency of fatalities associated with machinery on farms, and the incidence of this most adverse effect on the welfare of farm people in Canada, an analysis was made of the frequency of all fatalities considered to be due to farm machinery during the 15-year period 1952-1966. This information was obtained from the records of the Division of Vital Statistics, Dominion Bureau of Statistics, which in turn obtained the figures by classifying death records in all provinces. The data were classified according to criteria set down by the World Health Organization for Fatal Accidents -- On Farms -- Associated with Machinery [56]. This category does not include accidents in or around the farm home, or those involving farm machinery on public roads.

To assess the nature of these accidents, their impact on the farm population, their extent within various situations, and

the features of the machine involved, a more detailed study was made of fatalities caused by farm machines in Canada during the five years 1962-1966. This assessment was based on more detailed data, extracted from the death records for this purpose by the Dominion Bureau of Statistics. The information obtained is restricted by the limited amount of data recorded on the death certificates, and by the varied interpretation of the questions by those completing the record, which made the potentially useful replies to some questions quite unusable.

To supplement this analysis, a more detailed study was made of some 240 farm machinery fatalities in Saskatchewan during the 15-year period 1952-1966. This analysis was based on RCMP reports of post-accident interviews and inspections of the accident sites. Because of the nature of these reports the data available are more comprehensive than that available from the death records.

The data extracted from the death certificates by the Dominion Bureau of Statistics contain more detail of the accident effects on the victim, while the police reports provide more information on the machine and the working environment. Although basically the same type of information was sought from the two sources the data extracted are not fully comparable, because different facts were recorded in the basic documents. For this reason, different categories are used in the following tables, even when considering one aspect using data from both sources.

Since the five-year data for the whole of Canada include five of the 15 years considered in Saskatchewan, the Canada figures include about one third of the cases studied in Saskatchewan. A comparison of the figures from the two sources for the overlapping years suggests that the number of fatalities

estimated from the death records may slightly underestimate the total number of fatalities associated with farm machinery. This is possibly due to insufficient information being included on the death record to permit accurate classification. Alternatively, the cause of death may be wrongly stated in the event of a death occurring some time after the accident. Despite those limitations, however, these data are sufficiently comprehensive to facilitate the following analysis. The study considers the epidemiological aspects of host (victim), environment (farm situation), and agent (machine).

Annual Trend

The total number of deaths classified as farm machinery fatalities recorded in Canada over the years 1952 to 1966 are presented in Table 1. Together with these data are estimated figures for the total farm population, the total number of tractors on farms, and the computed fatality rate per 100,000 farm population. The proportional trends for these parameters are shown in Figure 1, where they are expressed as the percentage variation above or below the level occurring in 1951.

The number of farm machinery fatalities shows an irregular pattern with a definite upward trend. Had the base year not been a particularly bad year for fatalities, the proportional increase shown in Figure 1 would have been even greater . This trend is directly contrary to what might have been expected during a time of improving machinery design, better medical services, and declining farm population. Such an upward trend, particularly over the last 10 years of the period considered, suggests that the safety of the farm environment has declined so far as the risk of fatality is concerned.

TABLE 1

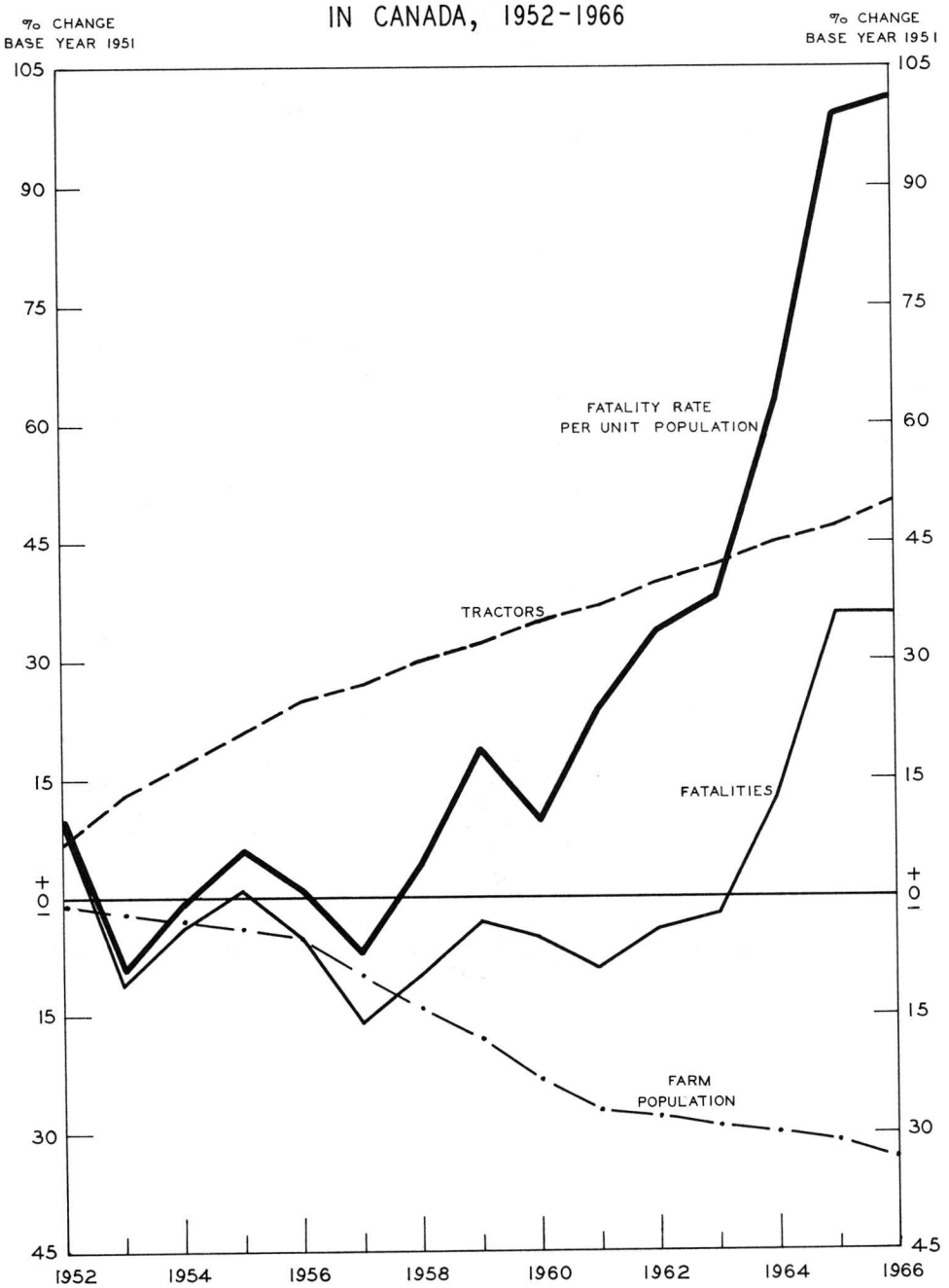
FARM MACHINERY FATALITIES, FARM POPULATION AND TRACTOR NUMBERS IN CANADA, 1951-1966

Year	Farm Tractors '000	Farm Population '000	Farm Machine Fatalities	Fatalities per Unit Population '00,000
1951	399.6	2,892	100	3.46
1952	426.1	2,860	109	3.81
1953	449.9	2,829	89	3.14
1954	466.1	2,797	96	3.43
1955	483.2	2,765	101	3.65
1956	499.5	2,734	95	3.48
1957	508.7	2,610	84	3.22
1958	518.5	2,487	90	3.61
1959	528.9	2,364	97	4.11
1960	539.3	2,241	85	3.79
1961	549.3	2,117	91	4.29
1962	558.4	2,084	96	4.62
1963	568.0	2,051	98	4.78
1964	577.6	2,018	113	5.59
1965	586.9	1,984	136	6.87
1966	597.9	1,951	136	6.97

Source: Figures supplied by Dominion Bureau of Statistics from published and unpublished material. Figures for census years 1951, 1956, 1961, and 1966 are published for: Farm Tractors - "Census Bulletin, Data on Census Farms and Commercial Farms"; Farm Population - "Census Bulletin, Farm Population, Tenure, Age and Residence of Farm Operators"; Farm Machinery Fatalities - "Accident Facts", annual bulletin published by National Safety League in co-operation with Vital Statistics Section, Dominion Bureau of Statistics. Figures for intercensal years for farm tractors and population are based on straight-line interpolation.

FIGURE 1

CHANGES IN FARM MACHINERY FATALITY RATE, FARM TRACTORS AND FARM POPULATION IN CANADA, 1952-1966



Over this same period, however, the farm population has been steadily decreasing. Thus farm machinery fatalities per unit of population have more than doubled in the last 10 years. This trend is in contrast with that in other industries where the fatality rate, in recent years, has steadily declined.

A similar trend exists for farm machinery fatalities in other countries. In the United States the total number of farm fatalities has been remarkably stable, showing no upward trend. Since the farm population has declined, however, the fatality rate has increased by some 75 per cent since 1950. As a proportion of this number, farm machinery fatalities have increased from 34 per cent of all farm fatalities over 1954-1959, to 38 per cent in the period 1960-1964. In Canada, the proportion of farm fatalities due to farm machinery has varied irregularly between 48 and 60 per cent of the total. The total numbers of farm fatalities, and tractor fatalities, have also been stable in Britain. But, again, the farm population has declined and the fatality rate per unit of population has therefore increased, though not to the same extent as in either the United States or Canada.

The underlying causes of this upward trend in farm machinery fatalities are likely to be quite complex, since accidents occur due to the interaction of numerous factors related to the activity of the victim, the nature of the working environment , and the characteristics of the machine involved. On the other hand, it is notable that this increase in the fatality rate in Canada has been accompanied by a continuing increase in the total number of tractors on farms. For instance, Figure 1 shows about a two per cent increase in fatalities concurrent with every one per cent increase in tractor numbers over the period 1956-1966.

Not surprisingly, a regression analysis of the figures set out in Table 1 shows a strong statistical relationship between the fatality rate and the number of farm tractors in Canada, though the relationship is not entirely straightforward. A comparison of the machinery fatality rate per 100,000 population over the period 1955 to 1966 for Quebec, Ontario, and the Prairie Provinces shows the average rates to be 4.51, 4.89 and 4.81 respectively, and for Canada 4.56. The annual rate for Quebec is significantly different from that for either of the other two sub-regions considered, at the one per cent level. From this, at first glance it seems that the significantly lower rate per unit of population in Quebec simply reflects the fewer tractors per farm in that province.

Comparison of the farm machinery fatality rate per 100,000 tractors (as opposed to farm population) gives figures for Quebec, Ontario and the Prairie Provinces of 39.8, 18.4 and 13.2 respectively, with a mean fatality rate for the whole of Canada of 18.7 per 100,000 tractors. In this case the annual rate for each area is significantly different from each of the others at the one per cent level. From this , clearly, there is not a simple relationship between tractor numbers and the frequency of farm machinery fatalities.

A multiple regression analysis of the data in Table 1 for the whole of Canada gave the regression equation:

$$Y_1 = -229.03 + .0035X_1 + .5857X_2$$

where Y_1 is the number of farm machinery fatalities in a year, X_1 the farm population (in thousands) in that year, and X_2 the number of farm tractors (in thousands) for the same year. If it was sufficiently reliable, this equation could be used to estimate the number of fatalities expected in any year for which the farm

population and number of farm tractors is known or can be estimated. The extent to which farm machinery fatalities are explained by the combined effect of these two variables is indicated by the coefficient of determination r^2 , which in this case is 0.75, suggesting that 75 per cent of the variation in the fatality rate due to farm machinery is explained by the level of the farm population and the number of farm tractors, or factors associated with these two variables.

In a further regression analysis, representing the population by two separate variables -- all under 20 years of age, and males of 50 years and over -- an even higher coefficient of multiple determination was obtained. In this case the r^2 value was 0.90, with individual coefficients of 0.48, 0.12 and 0.30 for tractors, population under 20 years, and males of 50 and over respectively. These values had standard errors of 0.25, 0.58, and 2.74 respectively, all of which are significant by T test. Although this analysis is based on a relatively small number of observations which may reduce its accuracy, it strongly suggests that a large proportion of fatalities can be explained by increases in the number of farm tractors, and in the number of older males on farms, or by factors associated with these changes.

If, over the next ten years, the farm population was to decline and farm tractor numbers were to increase at the same rates achieved over the last five years then, based on the above equation, there is likely to be 184 farm machine fatalities in Canada per year by 1974. Since farm tractors are likely to increase at something less than this rate due to the use of larger machines and fewer farms, this situation may never eventuate. On the other hand, if more machinery is used to replace labour on farms the hours of association of man and machines may increase

and the accident rate seems likely to increase accordingly. Thus the fatal accident risk may continue to increase even though the number of tractors ceases to be an even partly reliable indicator of the level of mechanization, as it has been used here.

The use of tractor numbers in the foregoing analysis should not be interpreted as suggesting that all such accidents are caused by tractors, though some 80 per cent are. Rather it suggests that an increase in fatalities is related to a concurrent increase in the level of farm mechanization as well as to changes in the structure of the farm population; an inference which suggests the need for further examination of the causes and impact of these accidents.

II MACHINE FATALITY VICTIMS

Age Groups

In order to consider the impact of farm machinery fatalities on the victims, a more detailed analysis was made of the data obtained from the previously mentioned sources. These data show the uneven incidence of fatal machinery accidents within the farm population. The age distribution of fatality victims in relation to the age structure of the farm population of Canada is presented in Figure 2. From the histogram the large number of child fatalities and the disproportionate incidence of fatalities in the older age groups are evident. In all, 37 per cent of the farm machinery fatalities analyzed were under 20 years of age, and of these 12 per cent were less than five years. A disproportionate 22 per cent of victims were 60 years or older, even though this age group is only 10 per cent of the total farm population. Perhaps not surprisingly, it is also apparent that, except as children, females are rarely the victims of fatal farm machinery accidents.

Types of fatal accidents by age groups are shown for Canada in Table 2 and for Saskatchewan in Table 3. In these tables, the similarity between the age distribution of fatalities in the two samples is noticeable. There is also a similarity in the accident pattern. In both cases more than 60 per cent of the fatalities were caused by persons being run over, or by machines overturning. Of those victims in the categories "Run Over", "Tipped Side" and "Tipped Back", 54, 54 and 17 respectively, or 75 per cent in each category, were associated with farm tractors as opposed to all other farm equipment.

FIGURE 2

FARM MACHINERY FATALITIES AND FARM POPULATION STRUCTURE IN CANADA,

1962 - 1966

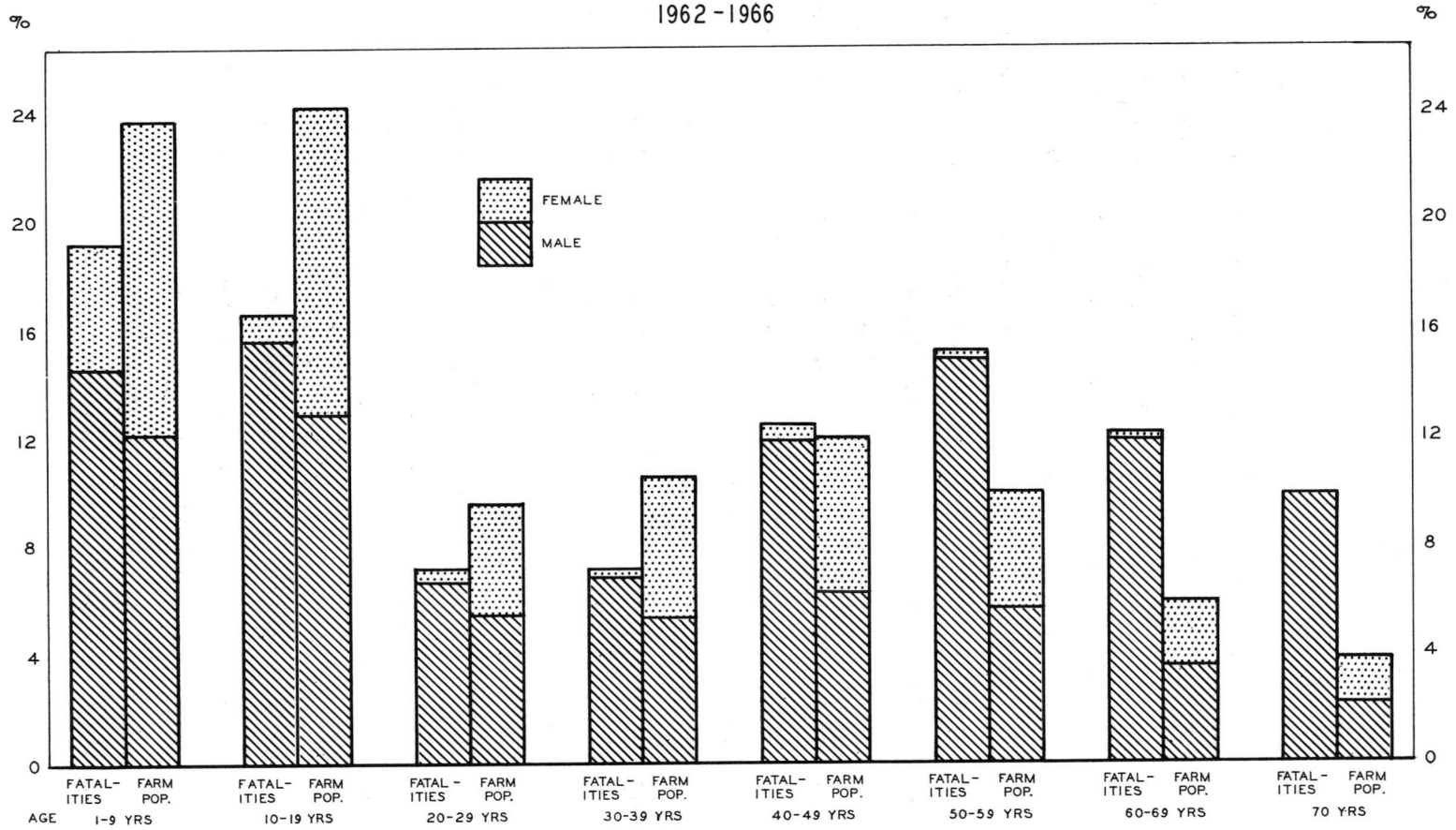


TABLE 2

FARM MACHINERY FATALITIES IN CANADA - ACCIDENT TYPE AND AGE OF VICTIM

Age in Years	Over-turned	Crushed by Tractor	Run Over Operator	Run Over Bystander	Run Over (Other)	Serv-icing	Caught P.T.O.	Caught Other	Miscel-laneous	Total	Percentage
1- 4	5	4	-	49	6	-	-	3	2	69	12
5- 9	9	2	8	13	5	-	-	4	5	46	8
10-19	46	15	6	2	11	-	3	2	14	99	17
20-29	20	4	-	1	3	1	6	3	5	43	7
30-39	23	1	1	-	3	2	1	6	6	43	7
40-49	35	5	3	-	5	4	2	6	15	75	13
50-59	36	8	10	-	9	5	5	8	10	91	15
60-69	31	3	4	-	12	3	5	3	12	73	12
70+	25	1	5	1	9	3	2	1	12	59	10
Total	230	43	37	66	63	18	24	36	81	598	100
Percentage	39	7	6	11	11	3	4	6	13	100	

TABLE 3

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND AGE OF VICTIM

Age in Years	Run Over	Tipped Side	Tipped Back	Pinned Under	Pinned Between	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
1- 4	22	-	-	-	-	-	1	1	24	10
5- 9	7	1	-	-	1	-	1	2	12	5
10-19	7	18	1	1	3	-	-	1	31	13
20-29	3	5	3	1	1	1	1	1	16	7
30-39	3	9	7	2	1	1	2	1	26	11
40-49	7	9	4	2	3	2	2	5	34	14
50-59	9	7	3	4	6	2	4	5	40	17
60-69	6	14	3	4	1	4	-	3	35	14
70+	7	10	1	1	2	-	-	2	23	10
Unknown	1	-	-	-	-	-	-	-	1	
Total	72	73	22	15	18	10	11	21	242	100
Percentage	30	30	9	6	7	4	5	9	100	

Also outstanding are the large number of children under five years who are run over, and the large number of overturn accidents involving teenagers. Including those classified as "Crushed by Tractor", which were probably largely overturns, some 35 per cent of fatalities in this category were under 20 years of age. The young, including the very young, are also mainly those in the "Run Over" group of fatalities, both as pedestrians and as passengers.

Apart from teenagers, the other group most prominent is that which includes men over 60 years of age. Farm machinery fatalities in this age group include a large proportion of "Overturned" and "Run Over" accidents. Although in the other categories, including "Miscellaneous", the numbers are fewer, a large proportion of these fatalities also involve relatively older people. In relation to the total numbers in this age group the fatal accident rate is very high, though perhaps not so high in relation to the number doing active work on farms. The general impression, however, is of the great susceptibility of both the young and the aged.

Work Category

The figures in Table 2 suggest that a large proportion of fatal accident victims were the machine operators, and this is not unexpected. More remarkable is the number who are clearly not operators nor involved in the operations in progress. All victims under the age of five years, the bystanders who were run over, and many in the "Run Over (Other)" category (mainly non-participating passengers) were not machine operators.

Of the cases in the Saskatchewan sample, 37 per cent of all fatalities involved persons other than the operator, and more

than half of these were children under 10 years of age. In the Canadian sample 20 per cent of all victims were identified as not the operator, but some 50 per cent of the victims were not categorized.

Of the 598 victims in the Canada sample eight per cent were hired workers not identified as members of the farm family, and 18 per cent were not identified as farm residents but included retired members of the family, tradesmen and custom operators working on farms. In the same sample, 10 per cent of the accidents were known not to have occurred at the victim's place of residence, but again 35 per cent of the cases were not classifiable. Some of the 10 per cent were farm operators visiting neighbouring farms.

Though this evidence is fairly inconclusive, it is apparent that a wide variety of people within the farm environment are potential fatality victims. On the other hand, it seems that in most cases -- 63 per cent in the Saskatchewan sample -- it is the machine operator who is killed.

Circumstances

Having considered the age group and work category of victims, there remain some personal circumstances that might be significant. The first of these is the number of hours worked by the operator at the time of the accident. The figures in Table 4 show, for the Saskatchewan sample, the number of hours worked and the type of accident involved in each case.

From the table it is evident that a large number of accidents occur when the operation has been going only a few hours. A fatal accident would, however, seem almost equally possible at any stage of a normal working day. But, the figures

TABLE 4

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND HOURS WORKED

Hours Worked*	Run Over	Tipped Side	Tipped Back	Pinned Under	Pinned Between	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
0- 2	3	6	4	2	1	4	-	4	24	13
2- 4	10	10	1	2	7	1	1	4	36	20
4- 6	8	11	4	-	4	2	3	2	34	19
6- 8	5	10	4	6	-	3	1	-	29	16
8-10	5	11	2	2	3	-	2	2	27	15
10-12	7	6	1	1	2	-	1	4	22	12
12-14	1	4	2	-	-	-	-	-	7	4
14-16	-	-	-	1	-	-	-	-	1	1
Unknown	33	15	4	1	1	-	3	5	62	
Total	72	73	22	15	18	10	11	21	242	100

* If the number of hours worked fell on the hour the case was classified in the later interval.

for the lower hours worked probably reflect the higher frequency of short operations; consequently the table gives no indication of the frequency of accidents for the fewer occasions when long hours are worked, and so there is no clear evidence that fatigue operates as an accident causing factor. The five per cent of cases when more than 12 hours had been worked prior to the accident suggests that fatigue could be a factor in these extreme circumstances.

Apart from age and fatigue, another possible predisposing factor could be the physical agility of the operator, or the victim, even if not the operator. In the Saskatchewan sample it was found that 11 per cent of the accident victims suffered some disability. The disabilities varied from an amputated limb, previous injury, and epilepsy, to impairment from alcohol. Each of these is clearly capable of limiting the ability of the individual in reacting effectively to meet a dangerous situation, and hence could be an active factor in an accident situation.

Injury Type

In considering the victim within the accident epidemic it is possible to discern some of the physical susceptibility of the human being by looking at the type of injury involved. The accident type and the nature of the injury in broad categories are shown for the Canada sample in Table 5. With rare exceptions, the injuries caused are, in a medical sense, traumatic in nature. Sixty per cent of all fatalities involved either a fractured skull or a crushed chest -- both typical of the overturn and run-over accident. Of the overturn accident, 47 per cent of the deaths were due to asphyxia caused by a crushed chest. Of pedestrians run over more than 70 per cent died due to a skull fracture.

TABLE 5

FARM MACHINERY FATALITIES IN CANADA - ACCIDENT TYPE AND NATURE OF INJURY

Type of Injury	Over-turned	Crushed by Tractor	Run Over Operator	Run Over Bystander	Run Over (Other)	Serv-icing	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
Skull fracture	46	13	11	48	13	7	4	9	18	169	28
Crushed chest	107	15	10	7	23	7	3	2	15	189	32
Limbs caught	-	-	-	1	-	-	-	3	-	4	1
Multiple injuries	19	7	10	3	3	-	7	8	10	67	11
Internal injuries	24	8	4	5	13	2	2	3	9	70	12
Other	34	-	7	2	6	2	8	11	29	98	16
Total	230	43	42	66	58	18	24	36	81	598	100

Though a large proportion of fatalities are apparently associated in this way with the weight and force of the machine involved, there are other effects in some cases. For instance, in 14 per cent of the overturn accidents death was due to a variety of injuries and effects, including shock and exposure, bleeding to death, drowning while pinned by the machine, and in some cases subsequent gangrene or tetanus. Some 20 per cent of all cases are also classifiable as multiple injuries and internal injuries. It is notable that skull fractures are frequently the cause of death in the "Caught" categories, which are usually associated with torn limbs. Evidence from some sources suggests that more accidents in rural areas tend to be fatal because of the delay in getting the victim medical attention. These data suggest, however, that in many cases this is of little consequence due to the extreme nature of the injury. In other cases, perhaps up to 40 per cent of the total, the timeliness and quality of medical attention could be a matter for real concern.

In general, regardless of the specific nature of the accident or the type of injury, and without attributing the cause to either the individual, the machine effects, or the accident environment, there is strong evidence to suggest that - in terms of the most extreme of the detrimental effects of the man-machine interaction - the old, the young, the halt and the weary, are the ones bound to pay the price.

III MACHINE FATALITY SITUATIONS

Location

Among the environmental effects of the farm accident situation there might be included aspects of location, time and light effects, and other physical conditions. The effects of location might be of two types --geographical, in the sense of the location of the farm, and operational, in the sense of the operating position on the farm.

From the data presented in the section on fatality trends it is noticeable that there is a difference in the fatality rate from one geographic region to another within Canada. This could reflect topographical effects on the stability of field machinery, the level of mechanization on farms, or some sociological effects associated with the farm family and the family farm.

There is some evidence that topographical effects may be important. The overturn fatality figures for Alberta, with fewer tractors than Saskatchewan, are almost 50 per cent higher (37 as opposed to 25), than the figures for Saskatchewan. This seems to be due to the greater steepness of the land in Alberta, and this thesis is supported by the fact that tractor fatality figures for some parts of Alberta are higher than for others, with the higher rate occurring where the terrain is more hilly. To some extent this pattern tends to disguise the fact that micro-topography is also important in determining the stability of farm machinery. Overturn accidents are prevalent as a proportion of all accidents on the supposedly flat prairies, where the actual surface is far from flat and even.

The higher relative number of farm machines in some areas seems to give rise to more fatalities. The figures for the Maritime Provinces, with fewer machines, show a fatality rate per unit population less than 50 per cent of that in Canada as a whole. Similarly, in Quebec the fatality rate per unit of population is slightly less than that for the whole of Canada. However, the fatality rate per tractor unit in Quebec is more than double the rate for the whole of Canada (39.8 per 100,000 tractors versus 18.7 per 100,000). This fact rather diminishes the argument that with fewer machines there will be less exposure to them and thus fewer accidents. It suggests that sociological factors may be of far greater importance in this regard.

Some further evidence of the effect of the structure and organization of the family farm on farm machine fatalities can be obtained from a breakdown of the fatalities for each province by age group. Although there are some smaller inter-provincial differences, the figures for Quebec are completely different. In the age groups 1-4, 5-9, and 10-19 years the number of fatalities were respectively 33, 46 and 50 per cent of all the farm machinery fatalities in the whole of Canada. This contrasts with approximately 20 per cent of the total for the older age groups.

The simplest explanation of this would be to note that farm people have larger families in Quebec. But the number of fatalities in the young age groups is far more than proportional to the number of children in the population of the province. Clearly the relationship is not simply explained, but it seems possible that this phenomenon is explained by special activities involving children. It may be that they tend to follow the machine operator more closely, or they may become machine operators at an earlier age. Alternatively the explanation may be

in the stage of the mechanization process. Tractor numbers are increasing in Quebec at a faster rate than in other regions. It may be that the tractor is not as well understood by the operator or the bystander, because of its newness in the farm environment. In other words, there is evidence that the operating environment varies from one location to another.

Within any region and on any farm there are also likely to be locational effects. Different types of accidents occur in the different places. The type of accidents in relation to the place of occurrence is shown for the Saskatchewan sample in Table 6. Although the largest number of fatalities occur in the field, a larger proportion occur either on roads or in the farm yard. The Saskatchewan sample includes machinery fatalities on roads, but not those involving collisions with other motor vehicles. The most outstanding figures are the larger number of over-run fatalities which occur in the field, and the large proportion of side-tipping accidents which occur on farm roadways. In general, it might be observed that the three locations in which farm machines are most used seem to be equally dangerous given the expected pattern and duration of machine use in these situations.

Time

Another aspect of the machine operating environment is the changing conditions throughout the day. The pattern of occurrence of farm machinery fatalities for the Saskatchewan sample is shown in Figure 3, and the type of accidents occurring at various times are shown in Table 7.

The pattern shown in Figure 3 has three peaks, at about 10-11 a.m., 1-2 p.m. and 6-7 p.m. In some other studies a mid-morning and a mid-afternoon peak have been observed, and these have been attributed to the fatigue of the operator who is

TABLE 6

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND PLACE OF OCCURRENCE

Place of Occurrence	Run Over	Tipped Side	Tipped Back	Pinned Under	Pinned Between	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
Field	35	18	13	6	5	8	5	9	99	41
Road	11	44	4	2	1	-	-	3	65	27
Yard	22	7	2	5	9	2	4	7	58	24
Other	4	4	3	2	3	-	2	2	20	8
Total	72	73	22	15	18	10	11	21	242	100

FIGURE 3

TIME OF OCCURRENCE OF FARM MACHINERY FATALITIES IN SASKATCHEWAN

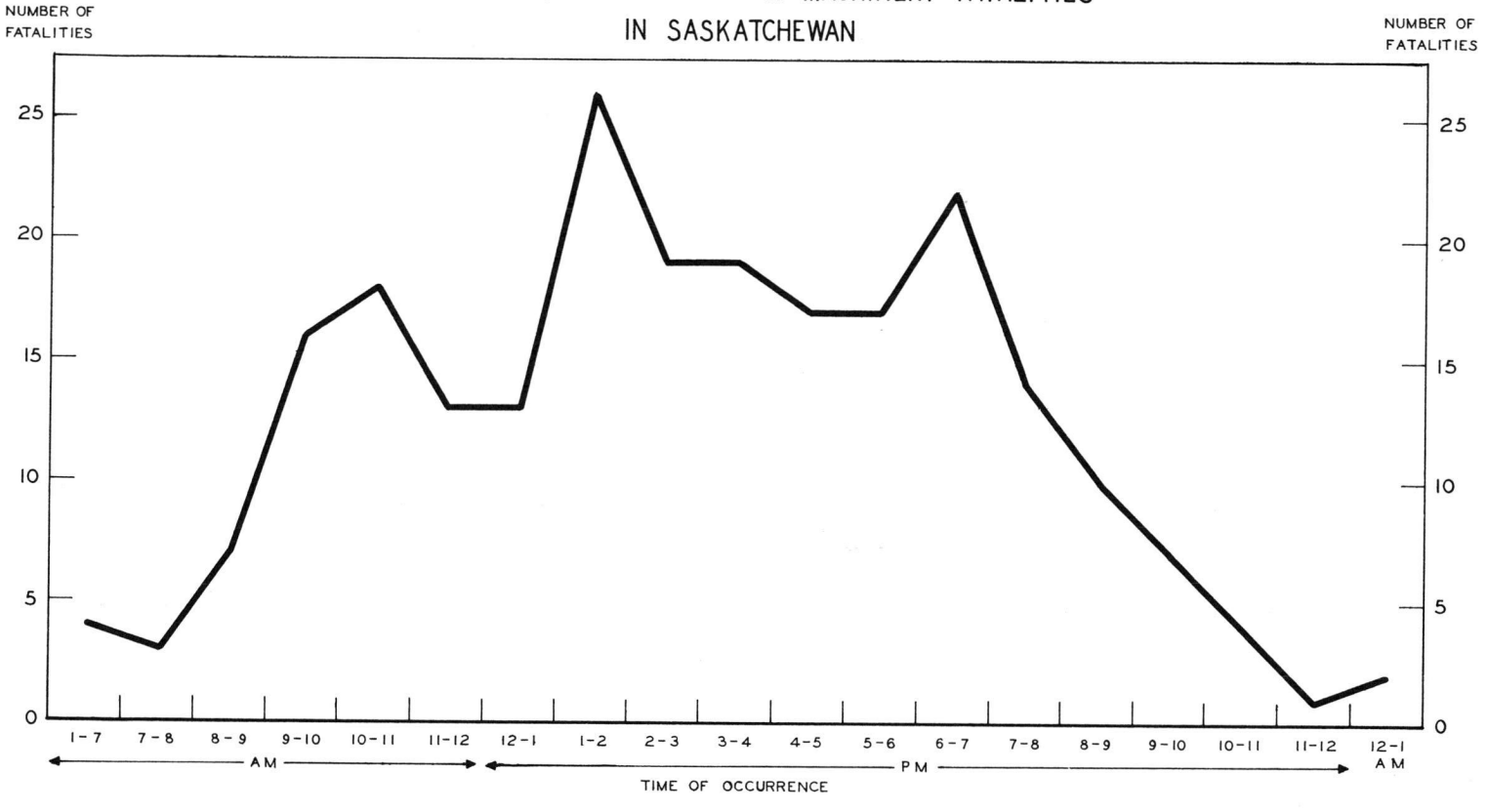


TABLE 7

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND TIME OF OCCURRENCE

Time	Run Over	Tipped Side	Tipped Back	Pinned Under	Pinned Between	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
0001-0900	4	6	5	-	-	-	-	-	15	6
0901-1200	14	8	6	2	8	3	-	6	47	19
1201-1400	10	11	4	2	1	2	3	6	39	16
1401-1700	15	19	3	5	4	2	4	3	55	23
1701-1900	13	15	2	4	1	1	-	3	39	16
1901-2400	13	11	2	1	4	1	1	3	36	15
Unknown	3	3	-	1	-	1	3	-	11	5
Total	72	73	22	15	18	10	11	21	242	100

presumed to have been doing the same repetitive job continuously for some hours by this time [39,21,5]. On the other hand, it might also be argued that these peaks simply reflect the peak operating hours, and that more machines are working at these times. The largest peak, which occurs in the early afternoon, may also be affected by the post-midday-meal torpidity. This effect is an observable phenomenon and it tends to be emphasized by the almost traditional practice of the farmer taking a nap in the early afternoon in the times outside the peak work seasons.

From Table 7 it can be seen that the evening fatalities are frequently caused by side-tipping accidents which in turn are identified with the use of high gear. Fifty per cent of fatalities between 6 p.m. and 7 p.m. were overturn accidents, presumably associated with returning from the field using road gear, perhaps in poor light, with the operator probably in a state of fatigue. That it is the machine operator who is killed in these cases is supported by the fact that all but six of 35 fatalities occurring during that hour involved persons over the age of 19 years.

While this evidence is not conclusive it does clearly indicate that the different conditions existing at various times of the day are a significant part of the man-machine operating environment on farms. But other aspects are also important, including the time of the year.

Of the fatalities recorded in Table 7, 80 per cent occurred in the six months May to October inclusive, and 35 per cent occurred in the two months of May and August. These two months represent the peak seeding and harvesting periods in Saskatchewan, and so can be assumed to reflect the increased machinery use in these two periods. These figures may, however,

be reinforced by the fact that the operations performed in these two periods are subject to time constraints due to biological and weather effects, which may cause the operator to be hurried at those times.

Despite these seasonal activities, however, there are a few accidents in almost every category, that occur even in the months of least activity. To some extent, the risk of accidents in the very cold season might be increased by the cold affecting the dexterity of the operator and the stability of tractors being used in outside operations. This type of effect is, of course, likely to vary from year to year but no trend is observable in the available data, except for the over-all trend shown by the total figures. There remain, however, some individual environmental features which need to be considered.

Conditions

Apart from the more regular environmental effects which contribute to fatality situations, such as time and location effects, there are some irregular effects which may be important. These include weather, light and surface conditions.

The prevailing weather conditions at the time of each fatality included in the Saskatchewan sample were recorded, and the data showed that 83 per cent of accidents occurred in clear conditions. Fifteen per cent happened in cloudy weather, leaving less than two per cent which took place in inclement conditions of fog, snow, rain or sleet. Thus, there is no evidence that observable weather effects in any way influence the occurrence of fatal accidents, but the fact that farmers are less likely to be doing field operations in inclement weather may obscure the possibility of increased danger.

The natural light conditions were also recorded for cases in the Saskatchewan sample, and of all cases 84 per cent happened in full daylight. Of the rest, six per cent occurred at dawn or dusk and 10 per cent in darkness. Though this evidence is far from conclusive there is a suggestion that light effects could be significant in some cases.

In the case records for the Saskatchewan sample the exact surface conditions were not detailed but the outstanding features of the situation were indicated. These indications are summarized in Table 8. Of the categories used, two are favourable surfaces, that is either "Dry" or "Flat", and three are unfavourable, either "Wet", "Hilly" or "Rough". From the table it can be said that 65 per cent of fatal accidents in the sample took place in generally favourable surface conditions, and almost 30 per cent in rough or hilly conditions. Not surprisingly, a higher proportion of side- and back-tipping fatalities, just less than 30 per cent in each case, occurred in hilly conditions. For the other accident categories there seems no clear surface effect on the frequency of the accident.

TABLE 8

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND SURFACE CONDITIONS

Surface Condition	Run Over	Tipped Side	Tipped Back	All Other	Total	Percentage
Dry	32	26	1	32	91	42
Wet	2	4	4	3	13	6
Level	18	6	2	23	49	23
Hilly	7	20	8	6	41	19
Rough	8	5	4	4	21	10
Unknown	5	12	3	7	27	-
Total	72	73	22	75	242	100

Thus, although the evidence is not so complete as might be desirable, there is a suggestion that surface conditions are of some significance in causing farm machinery fatalities. The full significance of this effect, and of all other environmental effects depends, as has been mentioned, on the individual involved and on the features of the machine concerned.

IV FATAL MACHINE CHARACTERISTICS

Machine Type

The type of farm machines associated with the fatality cases in the Canada sample are shown in Table 9. Of all fatal machinery accidents, 78 per cent involved tractors, and of those more than half were overturn accidents. This large proportion due to tractors is a reflection of the ubiquitous nature of the tractor in farming, and the central position it holds in mechanized operations.

After tractors, the machines most commonly involved in fatal accidents were combines and balers -- representing six per cent of all fatalities, with 17 cases each. A number of these accidents occurred when parts of the mechanism, usually the cutting table, fell on the operator during repairs or adjustments. No other single machine was involved in as many fatalities but collectively other field machines were involved in six per cent of fatalities. Almost every type of field machine was involved in one or more fatalities. After combines and balers the machines most frequently involved were corn pickers (five cases) and forage harvesters (three cases) in that order. Those machines which might be expected to be more dangerous, such as mowers and swathers, were apparently no more dangerous than disc ploughs and cultivators. More than half of the field machine fatalities involved the victim being caught in the machine, and 20 per cent were passengers or operating assistants run over. Both of these types of accidents reflect the nature of the machines involved, which have in all cases exposed working parts such as tines, blades, cogs and chains.

TABLE 9

FARM MACHINERY FATALITIES IN CANADA - TYPE OF MACHINE AND NATURE OF INJURY

Nature of Injury	Tractor	Combine	Baler	Other Field Machine	Farmstead Machine	Transport	Other	Total	Percentage
Skull fracture	130	2	8	8	5	6	10	169	28
Crushed chest	166	6	1	11	3	1	1	189	32
Limbs caught	1	-	2	-	1	-	-	4	1
Multiple injuries	50	1	4	3	5	-	4	67	11
Internal injuries	55	3	-	4	2	4	2	70	12
Other	64	5	2	12	5	3	8	98	16
Total	466	17	17	38	21	14	25	598	100
Percentage	78	3	3	6	4	2	4	100	

A variety of injuries resulting in death were caused by farmstead machines. Machines in this group include handling equipment such as grain and bale elevators and grain and forage augers, but a variety of other equipment powered by stationary motors was also involved. The transport category includes almost exclusively farm wagons and trailers, usually tractor-drawn. The accidents in this category probably reflect the danger to passengers from unsprung vehicles without provided seats, since 8 out of 14 of the fatalities were passengers run over. The group identified as "Other Machines" included equipment such as power saws, post-hole diggers and other specialist items, but it also includes some fatalities where the machine was not sufficiently identified to be classified accurately. Consequently the pattern of injuries in this group is probably not significant.

The make of farm machine, particularly tractors, was recorded for each of the cases in the Saskatchewan sample but, because the population of tractors in the province cannot be accurately classified according to brand, it is not possible to draw conclusions about the frequency of accidents involving different makes. On the other hand, it is notable that one make of tractor was involved in 29 per cent of all accidents, and 38 per cent of side-tipping accidents. Another make was involved in 18 per cent of all accidents and was in 23 per cent of the run-over fatalities. There is some suggestion, therefore, that a brand difference does exist in terms of specific types of accidents.

In the case of the tractors involved in the side-tipping accidents it was noted that the use of high gear was frequent at the time of the accident. On checking the rated speed in road gear of all tractor models involved in tipping fatalities it was

found that the average speed for the make involved in 38 per cent of side-tipping accidents was 13.9 m.p.h. as opposed to 11.8 m.p.h. for the next fastest make. This suggests a possible thesis as to why this make of tractor seems to overturn more frequently. Apart from brand differences, however, there are likely to be other machine differences with some bearing on their accident pattern, including the mechanical performance and state of repair of the particular machine.

Machine Condition

The various aspects of machine operation which might differentially affect an accident situation include the state of mechanical repair, and the use or non-use of fitted safety devices. For the Saskatchewan sample a small number of cases, about eight per cent in all, were recorded as involving a machine in bad repair. No specific details of machine condition were recorded.

Similarly, the use or non-use of protective devices was fully recorded only in some cases. Of 10 PTO accidents, when death was due to persons being caught in the power-take-off shaft, eight cases showed that the PTO shield was not in place while in two cases it was. For other accidents involving persons caught in machines one third did not have the protective cover in place. The evidence suggests that even if the devices used are in place this type of accident can still occur.

Machine Operation

Both the type of operation under way and the purpose for which a machine is being used may influence the accident pattern. From the Saskatchewan sample some observations were made on the operation in progress, the gear used, the position of the operator, and his activity, at the time of the fatal accident.

This analysis showed that 60 per cent of the fatalities occurred while the machine was operating and in motion. A further 13 per cent involved a machine that was operating and stationary, and six per cent had the motor running and were temporarily stationary. A surprisingly large proportion of nine per cent involved the machine moving unexpectedly, such as during hitching or cranking to start. Another nine per cent occurred while the machine was stationary and stopped. In view of the proportional time spent in operating other activities, the general conclusion must be that the activities other than straightforward field operation are likely to be more dangerous.

The gear being used at the time of the fatality was varied, but 20 per cent of moving accidents occurred in each of second, fifth (road), and reverse gears. Some 45 per cent of the side-tipping accidents occurred in road gear, suggesting that high speed reduces machine stability. Twenty five per cent of the run-over fatalities occurred while using reverse gear, suggesting visibility problems, and 60 per cent of backward tipping accidents took place in first or second gears, presumably when pulling heavy loads.

To further explore this aspect, the age of the operator was considered in relation to the gear being used. Although the distribution was fairly even, it was noted that 50 per cent of operators under the age of 20 years were using top gear at the time of the fatality. This is double the 24 per cent figure for all cases, which suggests that the judgment and machine control of youthful operators may be insufficient to enable them to handle the situations they can encounter or create.

The position of the fatality victim in relation to the machine at the time of the accident is reported for the

TABLE 10

FARM MACHINERY FATALITIES IN SASKATCHEWAN - ACCIDENT TYPE AND POSITION OF VICTIM

Position of Victim	Run Over	Tipped Side	Tipped Back	Pinned Under	Pinned Between	Caught P.T.O.	Caught (Other)	Miscel-laneous	Total	Percentage
Operator (Riding)	18	70	22	4	5	3	-	6	128	53
Operator (temporarily off machine)	9	-	-	-	7	4	5	-	25	10
Passenger	20	3	-	-	2	-	-	1	26	11
Pedestrian	20	-	-	-	-	-	-	-	20	8
Servicer	2	-	-	10	1	3	2	9	27	11
Co-worker	3	-	-	-	2	-	-	2	7	3
Other	-	-	-	1	1	-	4	3	9	4
Total	72	73	22	15	18	10	11	21	242	100

Saskatchewan sample in Table 10. This relates closely to the machine operation at the time of the accident which was mentioned previously. The largest proportion of the accidents occurred while the operator was riding on the machine. But a large proportion occurred while the operator was off the machine, or while the machine was being serviced. This suggests that danger is involved in the processes of maintenance and adjustment and in clearing an overloaded machine, as well as in machine operation. A further 11 per cent of victims were passengers, which indicates the frequency and vulnerability of passengers on machines where generally no provision is made for them.

This evaluation is, unfortunately, less complete than might be desired. It is, however, the best that seems possible given the existing data limitations, and it does represent a more complete analysis than has been published anywhere previously. Two points emerge from the analysis. First, that the number of fatalities associated with machinery on farms in Canada has increased very sharply over the last decade. This suggests some changing relationship within the man-machine interface over this period. Second, there are clear indications that various changing features of the operator, the machine and the environment can all contribute to the creation of an accident situation. Although the relative importance of the individual features in such situations remain rather indefinite, this analysis does provide sufficient evidence to indicate the need for more thorough research in this area.

BIBLIOGRAPHY

Bibliographical Notes

The following brief literature review and bibliographic list are divided into sections, covering farm accidents, machinery health and hearing effects, engineering and design, and safety research and education. Although the divisions correspond approximately to those used in the study, the number of bibliographic entries in each section is in no way intended to reflect the importance of any topic. The amount of available information varies considerably from one subject to another.

Farm Accidents -- Information on farm machinery accidents is not easily located. There are relatively few published statistical reports, analyses of the problem, or suggestions for improvement. A few people, in both the United States and in Canada, are notable for their close attention to the problem and for their efforts to direct public attention to the need for change.

Of particular note is the work of Dr. L.W. Knapp, which includes, in research reports and papers, a comprehensive discussion of epidemiological aspects of farm accidents.

Often, epidemiological studies of farm injuries are reported by medical practitioners who first note the seriousness of the problem through their patients. For instance see the articles by Cleary, and Powers.

Some detailed surveys have been undertaken, in various locations, as reported in publications of the Ontario Department of Agriculture and Kansas State Department of Health. The statistics kept by the Kansas State Department of Health provide a model for those which might be kept elsewhere.

The most detailed statistics available are in bulletins by Jones, Rush, the National Safety Council, and National Safety League of Canada.

The article by Crosbie, and the Food and Agriculture Organization working paper, contain some comparative accident statistics for different countries. Some other similar data are presented by Hansen, Renntun and Wilson, respectively.

Reports dealing specifically with tractor overturning or tractor-motor vehicle accidents include those by the FAO, Knapp and Hindman, Knapp (1967), McClure et al., Rees, Renntun, and Wright (1966). Articles by Cavender, Knapp and Piercy, McConnell and Knapp, and Wright (1966), describe accidents involving other machinery including power-take-offs, power lawn mowers and hay balers.

A variety of statistical information is available from provincial safety councils, and in some cases from the provincial departments of agriculture or health. The following is a list of statistical material, mostly unpublished, and the organization from which it was obtained.

Alberta Safety Council. Accidental Deaths of Farm Residents, Alberta 1955;
Farm Safety Facts and Ideas; Farm Resident Fatalities 1958-1964.

Ontario Department of Transport, Drive Control Branch. Farm Tractors Involved in Motor Vehicle Accidents - 1965, 1966.

Province of British Columbia, Department of Agriculture. Farm Accident and Farm Fire Reports for 1965, 1966, 1967.

Province of Manitoba, Department of Public Utilities. Accidents Caused by Machinery.

Saskatchewan Safety Council. Accidental Deaths, Saskatchewan, 1966 by type and age; Fatal Farm Accidents in Saskatchewan, 1955 - 1966; Number of Farm Accidents Requiring In-and-Out-Patient Hospital Care and rates per 100,000 Farm Population by age, sex and type of accident.

University of Alberta, Department of Agricultural Engineering. Tractor Fatalities in Alberta 1952 - 1966.

Health Effects -- Many bibliographic entries listed under other headings contain a few sentences on machinery health effects. The most informative of these are the articles by Knapp, and by Stephanson, both of which are concerned primarily with traumatic farm accidents. Manby, and Barger et al. comment on the whole range of health effects; Barger et al. in considerable detail. Other articles tend to have specific areas of concern.

The most comprehensive study of the physiological effects of tractor vibration is contained in the article by German researchers Rosegger and Rosegger. Christ, and Dupuis have conducted later similar research using varying seat types.

Articles by Marik and Sekyrova are typical of Czechoslovakian research reports, in that the effects on the spine and digestive tract are discussed as a recognized occupational disease. Czechoslovakian research has included studies of agricultural health problems for at least ten years. In 1966 the Institute of Industrial Hygiene and Occupational Diseases in Prague published more papers dealing with agriculture than with any other industry. This contrasts markedly with the situation in most other countries.

The detailed research report by Huang and Suggs describes several psychological effects of vibrations. An article by Bachynski suggests that "whiplash" injuries are likely to be rare in farming. The advertising brochure of the Board of Chiropractic indicates some incidence of back complaints among Canadian farmers.

Many of the articles, including Drechsler, Dupuis, Kiene, Koshman, Matthews, the SAE Riding Research Committee, are mainly technical, describing the mechanics and measurement of vehicle vibrations.

The article by Morris, Liljedahl and Wiebers is possibly the only published research on the topic of tractor operation and solar heat. Articles by Fuller and Brouha, and Wing and Touchstone deal with the physical and psychological effects of heat respectively.

The articles by Cook, Harris, and an anonymous article in National Safety News, describe generally the industrial health problems of airborne dust. Williams et al. have studied grain dust specifically. Henry and Zoerb, in turn, propose solutions to heat and dust problems.

Articles by Kay, and Rispler and Ross, have as their topics environmental toxicology and exhaust gases, but they do not describe the possible effects of these on farm tractor operators. Wienesch and Wallace describe a model engine which reduces the dangers from exhaust gases.

It is evident, from reports by the World Health Organization and Valkenburg et al. that there is little relationship between occupation and rheumatic diseases. Problems specific to an older working force may apply to farm machinery operators and the article on aging, by Stokoe, describes some of these problems.

Hearing Effects -- Most of the conflict in the published work on noise-induced hearing loss has to do with establishing a maximum safe level of noise. General information on the topics of noise characteristics, industrial noise, and hearing loss is contained in anonymous articles published in National Safety News, and in Therapeutic Notes , and in publications by Bell, Cohen, and Farr -- the first three of these references are particularly useful. Acton includes the work of Kryter et al. in his review of varying damage risk criteria. Further discussion of guidelines is contained in articles by Van Gierke, and Scott.

Measurements of farm and industrial noise levels, using various controls, are contained in papers by Cox, Huang and Suggs, Hutchings and Vasey, Jones and Oser, Jensen, LaBenz et al., Lierle and Reger, Ottoboni and Milby, Pavlov and Kolmakov, Riegert and Ireland, Valchetel, and Weston. The measurements by Jones and Oser, and Riegert and Ireland are the most comprehensive and useful.

The effects of cabs are discussed by Cox, LaBenz et al., Ottoboni and Milby, Pavlov and Kolmakov, Riegert and Ireland, and in a test report by the National Institute of Agricultural Engineering. Hearing surveys of farm and industrial tractor operators are described by LaBenz et al., Lierle and Reger, Ottoboni and Milby, Siroky, and Weston.

The psychological and performance effects of noise are the topics of the studies by Huang and Suggs, and Shoenberger and Harris. Three of the articles, Clark, Fox, and one in Canadian Occupational Safety Magazine, deal with the compensation of occupational hearing loss. Many of the articles on noise measurement also include suggestions for reducing noise or protecting the operator.

Machine Engineering and Design -- The articles in this section suggest changes in farm machinery designs to save lives, prevent injuries and increase operator comfort. Stephanson deals briefly with all of these problems.

Many authors stress the need for human-factors engineering in the farm equipment industry; see Wokoun, Wokoun and Kalen, and Michaels and Stephens. The book by Chapanis, and paper by Thomas provide a good introduction to this relatively new branch of engineering.

Overturn protection has recently received the most attention of all proposed changes. The large number of articles attests to this: see those in the Farm Safety Review, and by Bucher, Hansen, Lamouria et al., and Stephenson. Tractor stability is measured and described by Sack, and by Worthington. Standards and testing procedures for overturn protection in other countries are described in publications by the British Standards Institute, Moberg, Organization for Economic Co-operation and Development, and Persson.

Cabs without overturn protection is the topic of Harbeck and Gardner. Several of the articles in other sections include suggestions for design changes, for example Henry and Zoerb discuss cab design, and Rowley deals with designs for noise control.

Better lighting, shielding of moving parts, safer hitches and tractor suspensions are considered by Long, Van Syoc and Lemmon, and by Zezula, as well as in a report by the Ontario Department of Agriculture, and in several SAE standards.

The concern of farm machinery manufacturers for safety is defended by the Farm and Industrial Equipment Institute reports, the Massey-Ferguson brief to the Royal Commission on Farm Machinery, 1967, and by Zink.

Several of the papers, Johnson, McFarland, Tanquary, and Zink, were written due to concern with the growing trend in the United States for the manufacturer to be considered responsible for the performance of his product. Hahn and Inshaw discuss aspects of the responsibility for safety.

The books by Nader, and O'Connell and Myers, describe the consequences of the refusal of the automotive industry to engineer automobiles with the safety of the operator and passengers as a prime design consideration. Robb and Philo, and Grimaldi, very concisely describe the legal position of farm machinery manufacturers who ignore elementary principles of human factors engineering.

Safety Research and Education -- Several articles present analyses of why accidents occur, including recent psychological theories of accident causation, and methods for motivating or training people to act safely.

Several articles discuss the causes of accidents and the problems of effective safety education in industry; including those by Anderson, Conte, Ferguson and Daschbach, Lipinski and Winslow, MacPherson, Peters, and Simonds and Grimaldi.

A number of articles criticize existing safety education methods; see Malfetti, Sands, and Scott.

Three articles, one by Pyle, and two from the Saskatchewan Safety Council, deal very generally with safety in farm operations. Specific safety recommendations are contained in the Farm Safety Review, and in FAO and ILO reports, and also in articles by Gienger, and Wright.

The slow moving vehicle emblem is considered to be largely a problem of education. It is discussed by the National Safety Council, the Saskatchewan Safety Council, and by Patterson, and Stuckey and Harkness.

Some of the more interesting and useful publications within this whole field are set out in the following list.

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