ROYAL COMMISSION ON FARM MACHINERY

FARM MACHINERY TESTING

Graham F. Donaldson

Study No 8

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ROYAL COMMISSION ON FARM MACHINERY

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SCOPE AND PURPOSE IN THE MEASUREMENT AND EVALUATION OF FARM MACHINERY

by

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While this study was prepared by a staff member of the Royal Commission on Farm Machinery and is being published under its auspices, the views expressed therein are those of the author and not necessarily those of the Commissioner.

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Queen's Printer for Canada
Ottawa, 1970

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FOREWORD

This study assesses the need for a more empirical approach to the analysis of decisions concerning farm machinery. It considers the possible applications and uses of various types of measurements by manufacturers, farmers, and by others involved in making decisions about farm mechanization. Within the scope of the projected usefulness of these measurements, their adequacy and availability are subsequently considered in relation to their intended use.

It is widely accepted that new farm machinery technology has bestowed many benefits on manufacturers, farmers, and on society as a whole. What is less well recognized, however, is that it has also made the decisions relating to farm machinery vastly more complex. It is in the context of the increasing complexity of these decisions that this subject is analyzed.

An empirical approach to these problems is not new, since numerous measurements and tests have been made for many years in order to evaluate the characteristics of farm machines. But, in the course of this activity, there has been almost continual dispute as to the desirability of doing more or less of this work. Similarly, there has been recurrent debate as to the validity of methods used and the quality of information obtained. As a result, the policies followed concerning machinery evaluation, both within the manufacturing industry and in agriculture, have seldom been unequivocal.

In view of this, the aim of this study is to provide a broad assessment of the role of measurement and testing in the manufacture, distribution and use of farm machinery. The study considers both the purpose and use of measurements and information, and the means and procedures for obtaining them and making them more available.

Chapter 1 presents the general case for the formal evaluation of farm machinery. It contains a summary of the uses of information in decisions concerning farm machinery, and considers the potential types and sources of measurements and their relative availability.

Chapter 2 discusses in greater detail the data useful for and obtainable by manufacturers and farmers, and by others working to facilitate and regulate the operations of these two groups. It identifies the various kinds of data and where they fit in terms of use.

Chapter 3 concentrates on practicalities. It deals more specifically with the problems, procedures and desirability of alternative programs of farm machinery evaluation.

The author gratefully acknowledges the very considerable assistance given by the staff of the Commission in the execution of this study. Such a review would be almost impossible without the patient help of library staff in particular, but also of those involved in administration, typing, proof-reading, photocopying and numerous other activities.

Acknowledgement and thanks are also due to various colleagues who, from time to time, contributed ideas and made helpful comments. Special recognition is given to Donald G. Russell, Research Assistant with the Royal Commission on Farm Machinery, who assembled much of the factual and discursive material on which this review is based. Grateful thanks are also due to Dr. John P. McInerney, University of Manchester, who provided great assistance in clarifying the ideas presented herein.

Notwithstanding this considerable help, all errors and omissions remain the clear responsibility of the author.

April 1969 Graham F. Donaldson

TERMINOLOGY

When discussing the dimensions and properties of farm machinery, a series of general terms is often used with more specific meaning than is generally attributed to them. Unfortunately, this usage is not uniform in the technical literature relating to this area. In order to avoid confusion, therefore, the following terms are used throughout this study as defined below:

Specifications -- Static physical dimensions as may be used in fabricating a machine -- lengths, masses and volumes.

Performance -- Dynamic dimensions referring to standard operating properties -- drawbar horsepower, fuel consumption, capacity ratings.

Quality -- Design characteristics -- tolerance levels and assumptions allowed.

Production Characteristics -- The specifications, performance and quality measurements, together with details of service and warranty characteristics.

Capacity -- Operating capability in actual functional operation.

Efficiency -- Effectiveness in relation to costs incurred in specific operation.

Reliability -- Resistance to mechanical failure or malfunction during operation.

Adequacy -- Effectiveness or quality of operation in specific situations.

Safety -- Quality of machine in terms of operator well-being.

Operating Characteristics -- The capacity, efficiency, reliability, adequacy, and safety properties of a machine.

Durability -- The persistence of the operating characteristics over time, in terms of hours of use.

1. INFORMATION REQUIREMENTS

> When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*.1/

Changing Information Needs

The use of information is a commonplace part of modern life, in business, government and elsewhere. Everyone is familiar with the flow of information, and even more aware of the means of conveying it -- from place to place, time to time, and person to person -- in the form of books and papers, radio and television, telephone and telex, and other media. In recent years the widespread use of computers has heightened our awareness of information use in the guise of data acquisition, analysis, and communication. So significant is this trend that a whole new field of science has emerged, dealing with information gathering, analysis, and exchange.

All this development has not been without point or purpose. Information has long been recognized as an essential constituent of economic activity through its role in all levels of decision-making (23, 65, 81, 97). Decisions involve the weighing of alternatives to make a choice, and this process of comparison requires information about the alternatives in order to permit the selection of the one that is most satisfactory. All activities

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1/ William Thomson, Lord Kelvin, Popular Lectures and Addresses (1891-94).

involve decisions, from the individual's choice of what time to get up in the morning and what to wear or eat, to the manufacturer's decision as to what goods to produce, their size, shape and selling price.

The decisions involved in all situations are both numerous and repetitive. This repetitive frequency derives from the need for continual adjustment to change. If there were no change, if things continued as they were or proceeded as they were expected to, then no situation would arise which required either a decision about adjustment, or the formulation of a new plan of action. But in the real world, change is both normal and continuous, and so consequently is the need for new information.

The nature of decisions, and the information desirable to facilitate them, also vary according to the complexity of the choice to be made. Thus the selection of a particular garden spade or fork is simpler than the choice between alternative mechanical tillers or garden tractors. If the type of goods available remained the same, at least the type of information and the analysis to be made of it would remain constant. But as we apply new technology and develop more sophisticated equipment, so the complexity of decisions and the type of information required both change accordingly. In this regard, alterations in the nature and process of farm mechanization have interesting implications.

If mechanization is defined so as to include the use in production of all tools and equipment, then the mechanization of agriculture is clearly as old as organized cultivation itself. In this sense, the mechanization of farming has been a slowly evolving process from the beginning of organized agriculture (as early as 5000 B.C.) through to the present. In its earliest form it involved the innovative activity of individuals who fashioned their own tools to suit their specific needs. In this, and even in the adjustment to the use of draught power, the farmer working alone was largely self-contained. In such a situation the necessary simple information could be acquired by the user through the observation of trial and error procedures. Few measurements were required for either decision-making or communication in such self-contained production units.

As the structure of economic organization evolved into more complex patterns, with the growth of specialization, the activities associated with the manufacture and use of farming equipment became separated. Initially, the specialist maker of tools was closely associated with the user, in direct communication. As the situation developed, and each became more specialized, it seems likely that the need for measurements was increased. Even so, since the process of mechanization proceeded very slowly in this phase, with such innovations as the plough and seed drill being refined slowly over several centuries, the amount of new information required at any one time was probably never very great (41).

With continued development towards the complex, structured, interdependent economic organization of the present day, however, the need for information and its communication have become increasingly important. The machines used in agriculture have grown considerably more complex. Although the process is still largely evolutionary, the rate of change in mechanization has recognizably increased. The specialization which has grown up within the sequence of manufacturing, marketing and utilizing farm machinery has placed considerable emphasis on the need for the communication of information, both between firms and within the stages of the production process, in order that the system might function effectively, if at all. As a consequence, the need for communicable information is almost certainly greater now than ever before.

Along with these changes there have been associated adjustments in the significance of machinery on farms. Agriculture has become more highly mechanized, with both larger numbers and more complex machines being used. This complexity tends to make the decisions involved in machine purchase and use more difficult. Concurrently the combination of higher capital costs, changes in the relative importance of machinery as compared with other inputs, and associated changes in the structure of agriculture, have increased greatly the rewards associated with making decisions more accurate. This increased precision can only be ensured by using larger quantities of more reliable and accurate information.

As a consequence, without any identifiable revolution, the need for greater amounts of more specific information regarding farm machinery would seem to have steadily increased. In so far as this need has grown up, the nature of the item and of the situation is such that the need is for information in the form of measurements, rather than any other kind. In view of this, the purpose of this study is to consider in some detail the scope for, and the purpose in, making measurements related to farm machinery, and in making them readily available.

Measurement Uses and Applications

Measurements are the most precise form of information. They represent estimates of the magnitude, duration or value of definite items, ascertained in relation to some standard. As the various items with which the decision-maker is concerned -- whether physical, temporal, or economic -- can be reduced to measurements, the precision of his analysis can accordingly be increased, though this assumes, of course, that adequate analytical tools are readily available and that the measurements obtained are appropriate to their use. In so far as this increased precision is desired, there must be a continual effort to acquire additional and more accurate measurements. In practice, the increased attention to data acquisition in government and business might be considered a reflection of concern in this direction.

Measurements also play a significant role in the process of communication. Though they can have a subjective content, measurements are essentially objective estimates of magnitudes expressed in terms of some standard scale, such as centimetres, hours, or dollars. It follows, therefore, that if the standard used is known and accepted by all persons involved, then these measurements can become the form in which information is communicated from one user to another. As communication increases in importance, so the need for measurements can be expected to increase.

In their separate activities, both manufacturer and user require measurements relating to farm machinery. In the process of machine production a manufacturer is confronted with a series of decisions related to the planning and development of his product, and subsequently another series concerning its manufacture and distribution. Similarly, a farmer encounters a decision sequence associated with assessing machine requirements and availability, then with the evaluation, selection and purchase of a machine, and eventually with its operation and maintenance. Since they both work in a dynamic decision situation, where people, prices, physical conditions and technology are all changing, both manufacturers and farmers continually need new information on which to base their decisions.

Though many of these decisions can be made independently, there are some which necessitate the communication of data from the maker to the user and vice versa. While the manufacturer needs to know the mechanization requirements and operating restraints on the farm before he can develop an appropriate piece of equipment, the user needs information on how, where and when it might best be used in order to fully exploit its capabilities. Thus some measurements are sought by both makers and users concerning the decisions and operating conditions of one another. Very often this exchange can be facilitated by effective communication, though in many cases when information is sought by both groups regarding the same item, the measurements required are different in detail. In addition, some measurements may also be required by other parties involved in the mechanization of agriculture, though again the specific needs may be slightly different.

The measurements sought by the manufacturer in his machinery production process are determined by the specific features of his decisions related to product planning and development, design consolidation and production, marketing and distribution, and provision of support services. With few exceptions, none of the decisions in any one of these stages can be made without taking account of those decisions made before and after it, as is shown more fully in Chapter 2. Similarly, they must also be made with reference to the continually changing decision environment. Very largely, this is created by (1) a trend towards the production of an increasingly complex equipment package, (2) a dynamic state of machinery and farming technology, and (3) the competitive situation that exists within the manufacturing industry.

In particular, the type of information required by manufacturers is greatly influenced by the fact that they are no longer producing just a simple physical entity. Along with increasingly complex mechanical hardware the manufacturer today provides a variety of ancillary features. These include an undertaking as to the quality of machine performance, service and repair parts for the machine, a guarantee backed by a warranty, and responsibility for its adequacy and safety in operation. At all stages of the manufacturing process the nature of the "package" being produced influences the information required.

Information requirements are also affected by the dynamic state of technology. A manufacturer of farm machinery has to cope not only with new methods of producing his goods, but with changes in the mechanized, electrical and hydraulic components and systems that are built into his product, and with changes in production processes on farms that require new and different machines. In order to take these adjustments into account they need to be quantified and thus measurements concerning these changes are necessary.

Farmers similarly face a sequential series of machinery decisions. These are related to the activities of production planning, machine selection, purchase and replacement, equipment operation and usage, and machine servicing and maintenance. The decisions in any one phase are similarly interrelated, and they too have to be made in a dynamic decision situation. For the farmer, this involves an increasing level of mechanization made necessary by his changing production processes, more complex machines designed to do a more detailed operation, and increased economic pressures which compel him to maintain his farming operation at an efficient size and level of technology or submit to failure. Since these adjustments cause a growing number of increasingly complex decisions, which place a premium on increased accuracy, they in turn necessitate additional machinery measurements and information of various kinds.

But neither manufacturers nor farmers face these changes alone since a variety of outside groups are also involved. For instance, research staff in universities and public research institutions provide professional insight and discoveries -- particularly in biological, applied mechanical and economic aspects -- which can be drawn on by manufacturers during product development. For their efforts to be constructive, however, these research groups need information from both the maker and the user.

Similarly, the dealership plays a vital role in the manufacture and distribution process, since the interchange between the manufacturer and the farmer is largely through this intermediary. But since his activities are influenced by the decisions and problems of both suppliers and customers, detailed information regarding their decisions is needed by the dealer in order to facilitate his own operating decisions. As well as this, he requires data from both maker and user in order to facilitate the transfer of information from one group to the other.

Farmers also draw increasingly on outside expertise -- from formal advisory services, research groups, and independent consulting services. To be effective, these bodies similarly require an expanding variety of accurate information concerning machine characteristics and usage. The variety and precision of the formal tools of analysis they use tend to increase in order to match the complexity and required accuracy of the decisions involved, and the availability of analytical techniques often outstrips the availability of requisite data. In so far as this occurs, the data required by members of this group continually expand.

Again, since agriculture is a highly regulated sector of the economy, a variety of information is sought by those concerned with guiding technological progress and the orderly development of farming through such means as technical regulations and credit provision. The data they require are usually of a more general kind, but as the effects of technical change become recognizably more far-reaching, the interest and the data needs of this group increase accordingly.

Consequently, there would seem to be a demand for a wide variety of measurements by both manufacturers and farmers, and by a large group of other data users who are also involved in the process of farm mechanization. To a large degree, the measurements that interest all groups are related to specific decisions that confront either the manufacturer or the farmer. Since the nature of these decisions is various, so are the types of data required. As the types of measurements required are diverse, so are the means of acquiring them.

Types and Sources of Measurements

Many different measurements can be made of farm machines. The characteristics of a complex modern machine are such that its physical specifications alone may fill several hundred pages. Add to this the fact that in its purposeful operation every machine has both a static and a dynamic dimension, and that both of these might be evaluated in physical and economic terms in any number of operating situations, then clearly the volume of possible measurements is of almost astronomical proportions.

Making *all* these measurements is clearly not feasible. Since the resources used in the process of measurement all have a cost, it would be prohibitive to do so in such terms even if it were physically possible. Nor is it useful; not all of the possible measurements would be of any practical use. Implicit in the opening quotation by Lord Kelvin is the requirement that the measurements concerned be related to "... what you are speaking about, ..."2/ In other words, the measurements involved should be relevant to the specific context which is being considered. In this sense the number of measurements that are desirable in any one situation would seem to be rather more manageable.

Since they are to be used primarily to facilitate various types of decisions, the measurements that are needed will be determined by the particular decisions to be made, and by the type of analysis used in making them. An increasing number and variety of different decisions are involved in the manufacture and use of farm machinery, and they vary in relative importance from one situation to another. In general, however, they all relate to one or more of the interdependent production or operating characteristics of farm machines.

Measurement Categories -- Concerning any one of these features there will be several types of possible measurements. First, there will be physical specifications, including such items as the overall dimensions and power, and the size and quality of components. Second, there will be measurements of dynamic or time-related features, including rates of work, length of life and durability. Third, there will be cost measurements, such as fuel consumption and maintenance costs, which are necessary for evaluating the economic aspect of all decisions. In every case these measurements are needed in a form that will facilitate comparative evaluation and subsequent choice by either the

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2/ Ibid.

manufacturer or the farmer. This means that in order to be of greatest use they need to be made in standard terms by standardized procedures. This is necessary in order to enable comparisons to be made between alternatives and to permit projections concerning the features of innovations.

Perhaps the greatest constraint on the type of measurements required is imposed by the need for decisions to be made *ex ante*, or before the fact. Positive measurements are available only *ex post*, after a machine has been in use for some time. Thus, in the initial stages of the life cycle of a machine model, most of the information used in decisions must inevitably be in the form of predictions. Since no two machine units are exactly alike, many of the measurements concerning a particular machine unit must be expected values, right through to the time when the machine ceases to be used. Because of this, it becomes necessary to make many decisions on the basis of expectations and to collect measurements in a form that will permit the formulation of such expectations. This might be achieved by making measurements of prototypes (providing they bear a definable resemblance to the production model) in certain conditions to provide a basis for projections relating to the function of similar machines in other locations. Alternatively or concurrently it may involve the collection of actual performance parameters to permit new machines to be evaluated on the basis of experience with earlier ones. In addition, measurements recorded in the process of maintaining repair parts, services and warranty programs might be useful in predicting reliability and cost patterns for similar machines or comparable subsequent models. When all of these predictions are later validated by comparison with actual recorded data, they then form the basis for further predictions.

Evaluation Methods -- The data used for these purposes might be obtained from various sources. The most common ones can be grouped into categories of testing, surveys and records. Testing is comprised of laboratory tests, simulated trials and field trials; surveys include both case studies and field samples; and records encompass data collected by research farms and stations, service centres and warranty programs. In this order these methods reflect a gradation from the most highly specialized and specific type of measurement activity based on a small sample, to the most general and non-specific data collection taken from the whole population. The sources are summarized in Table 1.

TABLE 1

FARM MACHINERY MEASUREMENTS

Category	Procedure	Source	Measurement Characteristics
1. TESTING	Controlled Measurement	Laboratory tests Simulated trials Field trials	Based on small sample; tests reproducible and thus data are comparable from one machine to another; detailed information can be obtained; test procedures can be standardized so that measurements relate to set "standards"; data available before sale.
2. SURVEYS	Information Feedback	Case studies Field samples	Based on sample; data refer to actual practice not controlled conditions; amount of detail often limited; observations frequently not on scientific basis since personnel not trained; quality of information also affected by skill of enumerators or investigators; data available only after machines have been in use on farms.
3. RECORDS	Data Retrieval	Experiment farm records Service centre records Warranty program records	Based on whole population (except those from experiment farms); type of data restricted to repair pattern; data series limited to in-warranty period and those measures taken by service staff only - omits farmer maintenance and repair activities; experiment farm data more complete than farm surveys and case studies, but may be atypical of commercial farm use pattern; data available only after machines in use for prescribed period.

Laboratory trials are usually carried out on small samples of machine components and on component systems. The measurements obtained are usually in physical terms, and they are made primarily for use in the design and production process. Simulated trials are generally used to obtain data on the behaviour of component systems or operating segments of a complex machine (68). The data obtained are primarily in physical terms but they relate to dynamic qualities of the machine and have some relevance to farm operation. Field tests are done on the whole machine in actual operating conditions. Usually, prototypes are evaluated in a variety of tests in all three of these test categories. Testing is possibly the primary source of measurements used by the manufacturer, and an important source of those useful to farmers, but obviously it is not the only source.

Many measurements relating to machine use in actual field conditions (thus not subject to the supervision of engineers) are obtained from case studies and surveys of farms. These studies provide data of the 'feedback' type which are equally useful to the machine manufacturer and to the user or potential user (if he happens to be a late purchaser). Very often this type of activity provides the only measurements available that will indicate physical and cost changes for any machine over time.

The process of obtaining measurements from records kept for other purposes is sometimes termed "data retrieval". Detailed information may often be obtained from farms with a high level of management and from various research stations. These sources may yield comprehensive data of greater detail and complexity than random case studies and surveys, though it may be less representative of general field situations. Data extracted from service centres and repair parts depots, and those obtained from warranty records, are often in less detail. They have the advantage, however, that they come from the whole population of any one machine type and not from only a sample of machines of that year.

Although information from any one source will have its particular uses and inadequacies, data from all of these sources are likely to be useful in making the numerous decisions that have to be made at various stages in the development and utilization of any machine. In spite of their usefulness, however, there is often a shortage of measurements for use in the decision processes that require them. Not all of the potential sources are utilized. When they are, the measurements obtained are often made in such a way as to limit their usefulness to some users. Those data most useful to many individuals are not always disseminated. Thus the relative availability of measurements to users varies from one situation to another.

Relative Availability to Users

Although they share a common interest in obtaining measurements regarding farm machinery, the relative capabilities of the manufacturer and the farmer in obtaining the specific measurements they want are by no means equal. A number of different factors influence the respective capacity of each in this regard. The manufacturers, since they develop the prototypes and can test the final products before they are released, have a virtual monopoly over the available forward information. Though they may not be able to obtain all of the measurements they may wish because of the costs involved (particularly on short lines), the opportunity to do so is open to them. Farm machinery users on the other hand, have (collectively) in their possession much of the positive data on actual machine performance that might be desired by manufacturers, though often its usefulness to either party is not exploited.

Relative Access -- Of the several measurement sources suggested in Table 1, the manufacturer has direct and preferred access to all but three. All of the measurements obtained through testing can be readily acquired by the manufacturers involved. They can also obtain all of the data that might be extracted from the records of service-repair and warranty schemes. In addition, they may also obtain data from case studies, surveys, and experiments on farms and research stations. In this latter group, however, they have no preferred advantage in terms of access, except in so far as an individual manufacturer may be able to allocate more resources to the acquisition and analysis of the data concerned than can a farmer.

The farm machinery user has the double disadvantage that he does not have direct access to most of the data sources, and that the measurements which he might make within his own operation are of limited use. This is due to the information being available only after the primary decision (the purchase decision) has been made, and to the data being specific to one machine in one set of (or very few at most) seasonal operating conditions. To the data available from farms and stations the farmer has equal access along with the machine-maker. But, as with data from the other sources, he has at all times a greater limitation on the resources he can individually allocate to information collection and processing as compared with most manufacturers. It is probably for this reason that farmers are interested in the collective allocation of resources, on their behalf, through the establishment of official testing stations.

On the other hand, because of these constraints on farmers, and since there is in principle a mutual interest in measurements concerning farm machinery, it would seem to be to the manufacturer's advantage to make relevant information available to farmers. This happens only to a limited extent, probably because there are several problems involved. First, there is a communication block between the two parties in that the maker and the user do business through an intermediary. The existence of dealerships means that unless the dealer organization is effective in its role, there is an interrupted flow of data from the manufacturer to the farmer, and a check in the feedback of information from the farmer to the manufacturer.

Second, there is a difference in the frame of reference of the two potential data users. The manufacturer is concerned with a wider range of machine operating conditions, and, of course, there are in manufacture some decision problems that are quite different from those confronting the farmer. Thus the manufacturer will seek some measurements that will be of little or no use to the farm decision-maker. In order to provide information useful to farmers, the manufacturers would need to collect some additional measurements and to modify the form in which others were collected. This is not often done, partly because there is some expense involved but largely because there is scepticism as to the amount of use that would be made of such data by farmers.

In addition, much of the data of use in the machine development process would require specialist interpretation before it could be useful in a specific farm location or decision situation.

Because this specialist interpretation must inevitably exceed the resources of the relatively small farm business, it can only effectively be provided for groups of farms. Again, this is seldom done. The manufacturers do not provide a technical field advisory service, even though such a service has been provided by many other industries serving agriculture, in particular the chemical industry. Responsibility for the effective transfer of new machines, and the technology they embody, from the factory to the farm is left with the dealership. The dealerships, in most cases, have no expertise or resources which they can devote to this "extension" process, and they receive little aid from the manufacturers in so doing.

Nor is the desired expertise available from other sources. Though government-supported advisory services have provided detailed information to farmers on the management of biological innovations, the introduction of mechanical innovations on to farms has been left mainly to the machinery manufacturing industry and to the farmer's own initiative. Neither government nor independent institutions have done very much in the way of either developing or evaluating new machinery technology. This contrasts with the fairly extensive investment and subsequent activity in applied research and development work concerning other aspects of agricultural technology.[3/] As research and development work has been neglected, so the subsequent phase of field evaluation and assessment (leading to advisory activities) has also been overlooked.[4/] In his machinery management decisions the farmer is largely dependent on such information as the manufacturer is prepared to make available to him, or that distilled from his own and fellow farmers' experience.

3/ Typically, the research budget of the Canada Department of Agriculture shows that in 1967-68 only $250,000 out of $36 million was allocated to agricultural engineering projects. With occasional exceptions, the budgets of the provincial departments in Canada show a similar imbalance. Most work is done within university departments and because of size effects, this tends to be fragmentary.

4/ The one exception in Canada has been the activities of the Saskatchewan Agricultural Machinery Administration which, between 1960 and 1965, undertook a small but thorough testing program for field machinery. This program provided a considerable amount of useful data on the machines they evaluated.

The measurements so provided tend to be limited in both quantity and value. Apart from the ignorance or scepticism about the farmer's needs in this regard, the machinery companies are faced with a conflict of interest in their actions in this area. At all times such firms feel the need to be prudent about the possibility of publishing data that may be to their competitors' advantage. Similarly, they are most circumspect about broadcasting anything that might constitute a "performance claim" to which they might be legally held. Apart from restricting the information made available, these reactions may lead one to question the objectivity of such information as is made available. The information gained from experience is of limited value in that it is available only after the purchase decision (that is, the decision of greatest magnitude) has been made. Similarly, the experience gained often relates only to one specific machine in a limited set of circumstances, so that it may not necessarily be transferred to a new model or to subsequent circumstances. Consequently, it can be argued in general terms that the farmer is at a strong relative disadvantage in obtaining the measurements he may need in his farm machinery decisions.

Evident Problem -- At the same time, there is evidence both from their own expressed concern (see Appendix A), and from field studies, that farmers do encounter difficulties in making accurate decisions concerning their farm machinery. A detailed study of the number and size of combines held on a sample of farms in England in relation to acreage to be harvested showed that, with "average" expectations for machine capacity and available harvest days, only 50 per cent of the farms examined had combines well suited to their needs (30). Of the rest, about equal numbers had inadequate and excess capacity repectively. Similarly, a review of the acreages handled with different-sized combines on survey farms in Saskatchewan shows a wide range of "expected capacity" for machines of one size, with considerable overlap in the acreage covered from one size group to another (see Appendix B). That is to say, the same acreage was sometimes handled by three different-sized machines on three different farms. Though to some extent the tendency towards inadequate or excess capacity is a reflection of the attitude to risk of the individual farm decision-makers, the extremes of under- and over-capacity strongly suggest difficulty in formulating reasonable expectations. In many ways this difficulty is not surprising since it has been demonstrated that the harvest machinery capacity decision is a complex one to make. It has also been shown that, with a relatively simple analysis of some relevant measurements, the decision could be made more accurately (28).

In summary, the usefulness of measurements in aiding farm machinery decisions made by both manufacturers and farmers can be shown to increase with progressing economic and technical change. When considered in comparison with those of the manufacturers, the limited evaluation capability of farmers has been highlighted. On the other hand, data on the special needs of farmers are supported by some empirical evidence, as summarized above. Consequently, in the following chapters in which data uses and acquisition are discussed, some special consideration is given to farmers' requirements in this regard.

2. DATA USE AND AVAILABILITY

Machine Characteristics and Decisions

A major proportion of the many decisions made by a manufacturer concerning his product relates to the process of machine development. It is at the stage of product planning and development that assessments have to be made of the physical and cost characteristics of the machine that are likely to be encountered in the production of the final design, in marketing and distribution, and in the provision of after-sales support services. Since these characteristics are an integral part of the manufacturer's output, they have to be evaluated in relation to the developing machine design.

Once it has been developed, a machine prototype has a set of physical features built into it which (unless modified) will largely determine the production characteristics of the final product. These *production characteristics* may be identified as five interdependent features: the physical specifications, the related performance parameters, the design quality, the service requirements, and warranty features. These characteristics are interdependent to the extent that a change in any one of them will almost invariably change one or more of the others. The problem of the design engineer is to adjust all five characteristics in order to reach some predetermined goal within certain acceptable limits.

When the machine is brought into purposeful operation, the production characteristics will react with the operating environment to give rise to a set of *operating characteristics*. These may similarly be identified as an interdependent set of five distinct traits: operating capacity, cost efficiency, mechanical reliability, adequacy of function, and safety in use. As with the production characteristics, the operating characteristics are completely interdependent in that a change in any one parameter will cause changes in some or all of the others. The farmer and machine operator are concerned with selecting and using machines so that all five characteristics are kept within some tolerable range.

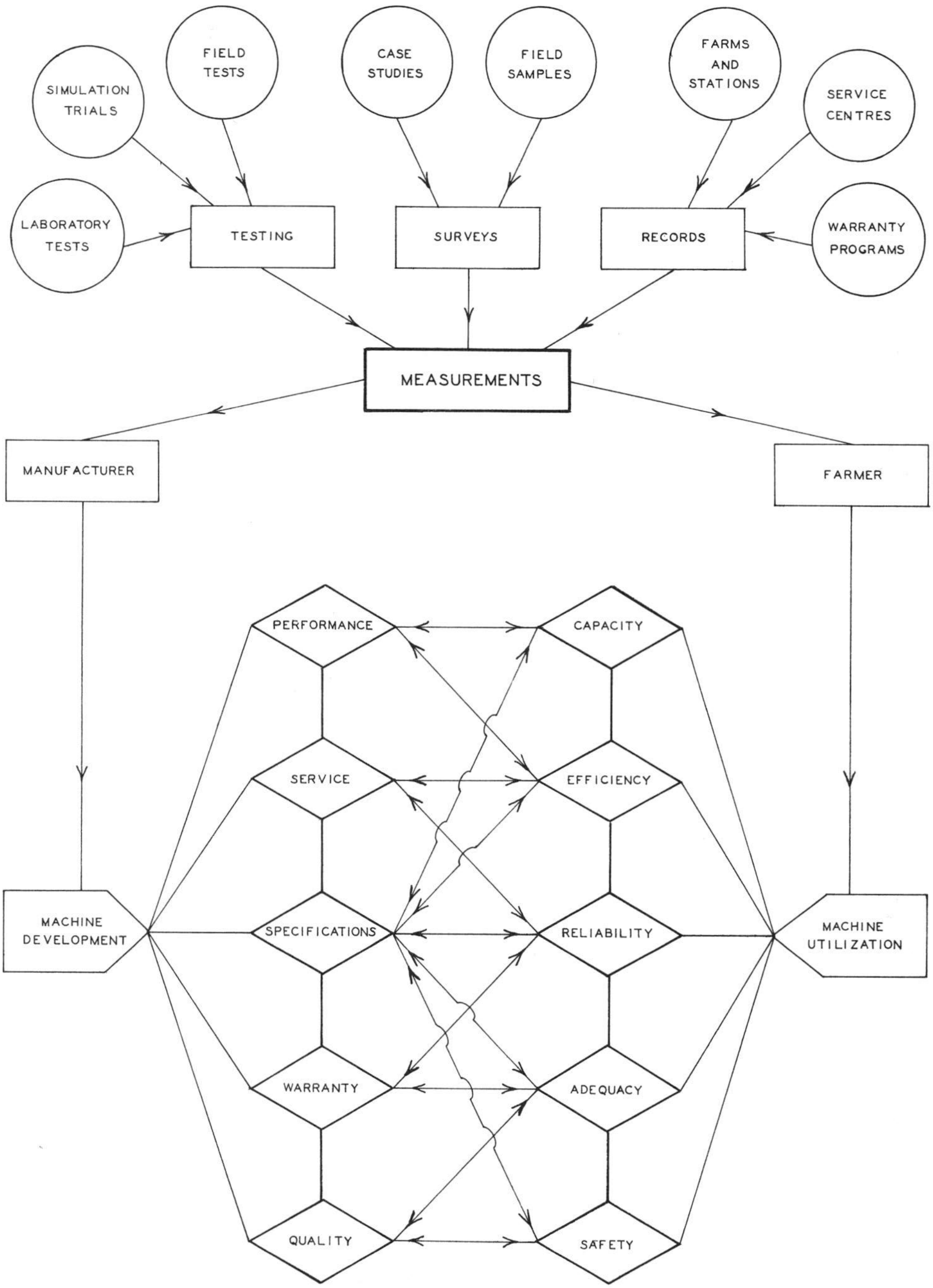
Multiple Interaction -- As the production and operating characteristics are interdependent within their respective categories, they are also interrelated one with the other. Some aspects of this interrelationship are represented in Figure 1. It is the operating characteristics of a machine, generated as it reacts to the farm use environment, that in practice determine the limits within which the engineer has to optimize the production characteristics of his new machine. This relationship is of primary concern to the manufacturer, since the operating characteristics achieved reflect the effectiveness of the machine in ultimate use, and this in turn largely determines the number of machines that will be sold and where they will be sold. Thus, in the process of product development, the production characteristics might be adjusted until the expected operating characteristics are considered satisfactory over as wide a range of operating conditions as possible.

Conversely, the farmer has to select machines so as to achieve the operating characteristics he desires in his particular farm situation and for his mode of operation. Just as the manufacturer can adjust his design to get certain production traits, so the farmer can select from the available machines and adjust his operating procedures to get the operating features desired. But the operating characteristics which the farmer can realize in his particular farm situation are effectively restrained by the production characteristics of the alternative machines available to him. Since no amount of operator skill or adjustment will remove these ultimate restraints, the production characteristics of a new machine are of vital interest to the farmer.

Thus, in none of the decisions and adjustments which the manufacturer or the farmer may make can any individual characteristic be considered independent of any of the others.

FIGURE I

SCOPE AND PURPOSE IN MAKING FARM MACHINERY MEASUREMENTS



Rather, the various characteristics can be likened to variables of two sub-systems which interact within a larger system of the machine development and utilization complex. A change in the specification of a machine may change the mechanical performance and, say, the warranty features. Indirectly these alterations may induce changes in the capacity and efficiency of the machine, and may affect the reliability and adequacy of the machine's operation. Similarly, a change in the operating capacity of the machine by increasing its rate of work may directly alter the efficiency and the safety of the machine performance. Conversely, these may influence the performance and service features of the machine, and may necessitate changes in its specifications and safety features.

In this way the interests and the actions of the manufacturer and the farmer are mutually dependent within the machine development and utilization "system". Consequently, it is quite impractical to collect data from only one point of view or from one half of the system, since it will show only a part of the overall situation which is not independent of the rest. Though the particular measurements they require may differ, both the manufacturer and the farmer need information concerning all of the machine characteristics in order to fully assess their decision alternatives.

Because all of the characteristics within the system are variables and their interrelationship is so complex, detailed measurements and specialized tools of analysis are necessary to enable decisions concerning them to be made with precision. Increasingly, these problems are being handled through the use of "systems analysis", and data are being sought to enable these tools to be used effectively. It is only by determining the measurements required in relation to the decisions involved and the techniques used to analyze them that the vast volume of measurements which might be made can be reduced to manageable proportions.

Measurement Activity by Manufacturers

In order to take effective account of these numerous related and interacting machine variables, manufacturers are making increasing use of a "systems approach" to engineering and design.[1/] In a farm machinery context the systems approach can be used to study criteria related to each of the various machine characteristics for the machine as a whole rather than consider the component parts of the system in isolation. This approach was first used in problems relating to complex aircraft, space and defence equipment, but it has since been effectively used in farm machinery design and development (18, 35, 46, 71).

Machine Development -- Machine development may entail either the working-up of a new design or the modification of an existing one -- or sometimes part of each -- in that new component systems can sometimes be integrated with existing ones in a complex machine. In either case, the general specification of a machine is usually evolved through consideration of the production and operating complex of which the machine is to form a part. In framing this specification, all of the relevant variables have to be identified and information obtained as to how they interact within the system as a whole. Then the procedures of "systems analysis" can be used to find the optimum values for those variables which can be controlled.

In practice, a large development problem may often be divided into a number of separately resolvable sub-problems. Once the system and its sub-systems have been identified, data are obtained relating to the specific features required in machine performance and operation. The aim is to examine in quantitative terms the most promising systems in order to seek the combination of specifications that will give the best overall solution of the operating objectives. This process may involve evaluation of design features, environmental effects, biological tolerances and economic constraints, all as variables in formal relationships.

1/ A systems approach can be briefly defined as the identification and study of interacting functional units and the mechanisms between them. These may include biological, mechanical, human, information and other elements, all integrated in a particular environment to achieve some desired objective. Thus many familiar organizations or processes might be studied as systems -- including a farm, any industrial process, or, as shown in the previous section, the manufacture and utilization of a machine. All systems are characterized by interdependence and interaction of their elements. The term systems analysis usually refers to the use of models, particularly computer models, to study the working relations of such systems.

Design carried out in this way employs not only the traditional activities of invention and engineering but also draws on the tools of operations analysis and mathematical programming. Through the use of computer technology, these tools can handle variables in a probabilistic form and allow interpretation of the output in terms of decision theory. To do this ideally, however, data need to be available in the appropriate form. Consequently, a large part of the activity in any design and development project concerns data acquisition and information processing (15, 103, 107).

On the other hand, because a systems approach is of relatively recent origin, there are often large gaps in the data required. Thus another strength of systems analysis tools is that, when employed with the aid of a computer, they can be used to some effect on the basis of normative approximations and estimated ranges of variables. A valuable feature of the systems approach when used in this way is that, once the problem is properly formulated, the systems model specifies very precisely the measurements necessary for its most effective use. As a systems approach is being increasingly used, the measurement activity related to it is also increasing. The nature and progress of some of this work is reported in the professional literature (22, 38, 86, 103).

But measurements are not used solely in the design process, nor is the design process an entirely separate and discrete operation. The processed data are manipulated for analysis and subsequent decision-making, and are then used to establish design standards against which the machine can be built and modified. By using parameters from the systems output as standards against which performance and other features are checked, the data obtained can be used in quality control as well as in product development.

Production Control -- Numerous measurements, other than those employed or generated in the systems approach, may also be made in the process of controlling production. Manufacturers are aware that the production characteristics of a machine vary not only with the design specifications, but also with the quality of materials and components used and the manner of their assembly. Therefore, they make extensive tests and measurements of these ingredients, whether supplied by sub-contractors or within their own firm. Not all of the parts, components or completed machines are tested, but efforts are made to test a representative sample for performance, specification, quality and durability.

In doing this, specified standards are often used, and these are sometimes formalized through adoption by the Society of Automotive Engineers (SAE), or some alternative institution, as "standards" for use across the whole industry (3). It is possible, too, that in some situations these standards might be legally enforced. It is in the control process of manufacture, and in the communication activity associated with the ordering and collection of parts and components, that standards play their most specific role. Though they are no substitute for more detailed measurements, when formalized they do provide a guarantee to buyers of certain minimum characteristics. It is on this basis that standards may be legally enforced by government action. To be fully effective in this role, however, the standards used have to be continually adjusted in order to relate to actual use requirements (36).

Though many measurements may be produced from the control procedures used in this way, they are generally of specific use only in control, and are seldom used except in decisions to accept, reject or modify the particular parts or components involved. Thus they are not oriented to the machine user's requirements, though they indirectly provide the purchaser with some protection. Other control procedures, such as those for completed machines, however, may provide more useful information.

Once a design has been developed, prototypes are usually built and are tested as a complete unit, sometimes using forecasts from the systems model as standards. The test measurements are also compared with those obtained for other models, both of the same make and those of other manufacturers, under standardized testing procedures and conditions.

On the basis of these standard tests, projections can be made as to the operating characteristics of the machine in various working environments. This can be done by simple extrapolations or by use of simulation procedures. In addition, prototypes or early production models are often subjected to field trials in selected operating situations. This provides further measurements relating to the operating characteristics of the machine. Finally, once production models are in general farm use, some further measurements are often made, both by specific activity towards that end and indirectly through the records of service and warranty schemes.

Special Programs -- Although, in this testing and measurement activity, detailed information is sought relating to all of the machine characteristics shown in Figure 1, special attention is sometimes given to certain features. Recently, problems "machine reliability" have been singled out by manufacturers for such attention. Reliability is a key characteristic among the various operating features of a machine, as Figure 1 suggests. A change in reliability directly affects all of the other operating characteristics, particularly working capacity and costs. In addition, it indirectly influences warranty and service features, which in turn affect the manufacturers' costs. Due to some change in relationships, concerning reliability, perhaps through the increased complexity and sophistication of farm machinery, or due to inter-manufacturer competition or to changes in production costs on farms, several companies have taken action to improve the reliability of their products in recent years.

To do this they each instituted specialized "reliability programs", the aim of which was to assess and upgrade the reliability of all component parts and systems, as well as that of total systems as a whole. The purpose was to reduce service costs, increase warranty periods and provide a higher quality (more reliable) product. The programs were assigned to measure reliability levels, follow up on items needing engineering attention, establish reliability goals, assist in test planning, and measure progress towards achieving reliability goals. The actual procedures employed are outlined in the published literature (7, 8, 108). The emphasis on reliability led to the development of several new design tools and accelerated testing methods, and to the adaptation of other techniques first used in air transport and space programs (21, 33, 99, 106). Considerable success has been reported by several companies who have introduced such programs (84, 87). They record increased operating life for machines, increased reliability, and reduced warranty expenses. Each of these gains, of course, benefits the manufacturer, but they are also of direct benefit to the farmer-user, since all changes in operating characteristics will inevitably affect both parties.

Comparative Activity -- Of all the testing and measurement activity relating to farm machinery characteristics, probably most is conducted by the manufacturers. The quantity of this, and the thoroughness with which it is done, varies considerably from one machine to another and from one firm to another. In the orderly development of a new machine the amount of measurement may, as previously intimated, be considerable. Alternatively, in the hasty assembly of a new design necessary to meet the competing product of a rival company, the amount of measurement and evaluation might sometimes be minimal. Generally, the larger manufacturers tend to do more testing than the smaller ones. Since all of the procedures involved in controlled measurement and testing are labour-intensive -- and intensive in terms of a most expensive type of labour, the skilled technician -- it is often only those firms with a large volume of output that can afford to make all the measurements that might be considered desirable. On the other hand, the level of activity devoted to information is effectively a matter of choice on the part of management. To a large extent the decision to make certain measurements will depend on the use to be made of them, which in turn may depend, among other things, on the complexity of the product being manufactured and marketed. Thus there are a few smaller firms which manufacture complex and specialized machines that make extensive use of measurements and employ large amounts of equipment and expertise to acquire and use them.

To a large extent this aspect of communication seems to have been overlooked by manufacturers. It is well recognized that those measurements used for analysis and decision-making are also used for communication. Because of the complexity of modern farm machines a team of specialists is often employed in their development. Consequently, measurements for communication are important in themselves. In the process of transferring a design from the development unit to the production factory, and from the drawing board to actuality, extensive use is made of measurements data. Yet in moving the machine from its production to its operating environment, the usefulness of measurements is disregarded. Few details are made available to either dealerships or to farmers. Despite the acceptance of a systems approach, the recognition of the manufacturer's role in a larger system seems not well recognized.

Information Useful to Farmers

Farmers require measurements for use in analyzing their decision alternatives just as do manufacturers. Both types of firm are confronted with numerous decisions arising out of progressive change, though the sources of this change are different in each case. The manufacturer faces decisions related to changes in the technology he builds into his product, alterations in his competitive position, and changes in the organization and needs of agriculture. The farmer, on the other hand, needs to make decisions concerning adjustment in his farm organization due to technological changes in agricultural practice, and to economic changes arising both from these and from various external effects.

Farming Changes -- The decisions facing the farmer regarding purchase and replacement, and concerning operation and use of his machinery, have to be made in a dynamic situation where many related operating factors are variable, and where the economic and technological features of both farming practice and of the economy as a whole are continually changing. For instance, virtually all farm production is susceptible to a variety of biological effects such as pests and diseases. Agriculture is also characteristically subject to the almost random effects of weather variables at most stages of the production cycle. Coincidentally, there are often irregular price changes for both inputs and outputs of farm production. Over the longer term the upward movement of wages in the economy, and the resulting emigration of labour out of agriculture, leads to larger and larger acreages being farmed with more and larger machines. This same effect results, too, in more complex and sensitive operations, such as fruit-picking, being handled by machines. It is this type of change that creates the need for a flow of information on which to base the expanding range of decisions that follow.

Some of these changes may create the need not only for larger amounts of information, but perhaps for a different kind than has been required in the past. An example has arisen in the case of grain-drying on the Prairies. The introduction of artificial grain-drying has caused a demand for detailed technical information on the physical and physiological process of drying, and on the resulting chemical and biological changes in grain qualities. Associated with these relationships there are complex cost, market and price implications that need to be taken into account. In this particular case, the changes affect not only farmers, but machine manufacturers, government agencies, market authorities, and food processors as well. Consequently, in assessing the information needs of different firms and the usefulness of measurements in various decisions, it is necessary to make a regular reappraisal of the type of decisions involved, the value of achieving increased precision in the decisions, and the analytical tools available to facilitate the increasing of accuracy.

Machinery Investment -- Of the two types of decisions that confront the farmer concerning farm machinery -- those involving machine purchase or investment, and those relating to machine operation -- investment decisions are the most complex. They necessitate some consideration of all the individual operating characteristics of the machine and of the choices relating to them. Characteristically, investment decisions also involve the greatest magnitudes in terms of cash expenditure. Accordingly, these have been much studied. General aspects of these decisions have been outlined from time to time by numerous writers (see, for example, 29, 37, 79). Various individual aspects have also been considered (5), and in Canada, guidelines are frequently published by both federal and provincial Departments of Agriculture (50, 100), as well as by agricultural engineering and farm economics departments of universities (26, 53).

In analyzing a machine investment decision, the first step involves the assessment of requirements -- the size of the job, the thoroughness required in the operation, and the various restraints that might influence it, such as weather effects, crop conditions, and competing jobs to be done. To these requirements has to be compared the various machines available so as to facilitate a choice of the most suitable type, make, model, size and age (new or used). In some cases a vast range of alternatives may be available from which to choose. Each alternative is likely to have different capacity, cost efficiency, reliability, operating adequacy and safety features -- and these are each likely to differ for different farm situations. In order to provide better comparative and absolute measurements and assessments of these characteristics, and to facilitate work towards their improvement, a large number of studies have been made.

Amongst recent work these include comparisons of tractor performance (85, 92, 98), traction effects (25, 27, 39), tractor operating features and efficiency (95), combine operation and efficiency (6, 14, 70, 94), machine durability (43, 51), fertilizer spreader performance (52), and the effects of surface and soil conditions on machine operation(62, 89), and many others. A great variety of aspects is also covered by the activities of various "testing" authorities (58, 63). None of these features can be completely evaluated in isolation, but the various studies provide information that might be included in more comprehensive assessments of decision alternatives.

In addition to these varying features, the need for farm level decisions to include analysis of ancillary farm equipment, or machinery systems, and of work procedures and sequences, has been emphasized (64, 82). Further to this, the farmer in his machinery selection is likely to be influenced by the service facilities, warranty coverage and the quality record, integrity and reputation of the maker and his agents -- all of which need to be assessed on a more objective basis.

Consideration of all these factors makes machine investment decisions very complex. This complexity is compounded by the fact that some such factors cannot be defined as a single value, even for a specific farm situation. Many variables involve risk and can only be quantified as probabilities. Others may not be measurable at all. In particular, decisions as to the quantity of investment needed -- the capacity decision -- involve assessment of weather and biological probabilities, as well as those relating to machine performance and reliability. Even when these can be assessed, the farmer has to decide how much he can afford to reduce risk by increasing his capacity, and this is dependent on other factors, including his financial situation. Several attempts have been made, with varying success, to take account of the cost effects of these variables in different situations. These include work on optimum machinery combinations (44, 45, 47, 56, 61) and on harvesting systems (31, 40, 48, 54, 55). Each of these studies has advanced certain formal procedures that could be used in analyzing machinery capacity decisions, providing certain measurements are available.

Decisions as to the time of investment -- the replacement decision -- involve particular dimensions of risk that are associated with time effects. In particular they involve an assessment of the durability of the operating parameters with use over time, including some time into the future. Thus the decision involves consideration of changes in variable costs with increasing hours of use, in relation to fixed costs over time. But since these decisions are made in a dynamic world, the replacement decision also involves evaluation of any improvements in technology that have taken place which might increase the returns to making an earlier replacement. The need to assess changes in machine operating characteristics and changes in technology -- in other words, the operating characteristics of new machines -- makes the replacement problem similarly quite complex. Notwithstanding this, however, various attempts have also been made to formulate this decision problem in a readily analyzable form. These include the tractor replacement models outlined by various workers (17, 20, 32, 83, 96).

Machinery Usage -- Operating decisions are, on the other hand, relatively more straightforward. However, some expertise may be required to assess certain aspects of machine function, and many usage decisions can be made more accurate if specific information is available regarding the production and the operating characteristics of a machine. Thus a farmer may, for instance, be able to make a better decision about starting combining if he knows the grain losses associated with harvesting crops of different grain moisture contents. Similarly, he may make a better choice of operating speed if he knows the grain losses being incurred at various working rates. In general, however, machine use decisions are less complex and require less-detailed information to permit an increase in their accuracy, and the results of bad decisions are less profound.

The more complex decisions on farm machinery appear capable of being made more accurately provided the measurements can be obtained, and the means of analysis are made available -- and both can be obtained at a cost. There is in all situations a "trade-off" between the cost of the measurements and their analysis, and the cost of making a wrong decision. Fortunately, the choice is not between absolutes, such as making no measurements and no analysis or, alternatively, complete measurements and exhaustive analysis. Rather, there is a spectrum of levels of precision that might be achieved, and as the precision increases, so does the cost. Thus the vital question is -- does the possible cost involved in making a wrong decision warrant the expense of making the measurements required and analyzing them?

An assessment of various cost items over time for different types of farms in Canada shows that investment in machinery is a continually increasing proportion of total investment in almost all situations. (The exceptions are those farms where increased livestock intensity has caused an expansion of capital expenditure on livestock that has masked the change in machinery investment.) Similarly, both machinery operating expenses and overhead expenses have increased as a proportion to total costs for almost all farm types and locations. Some of these data relating to Prairie farms are shown in Table 2.

In practice, as the magnitude of farm machinery costs increases, the farmer has a growing incentive to try to increase the accuracy of his decisions and so seek additional and more accurate information and measurements. To some extent this fact seems to underly the interest in measurement and testing expressed by farmers in evidence to hearings of the Commission, which is summarized in Appendix A. The extent to which farmers might seek additional measurements will depend on the savings they anticipate from more accurate decisions, and on the cost of obtaining the data required. The cost of obtaining the information depends on the nature of the items being measured, and on how, when, and by whom it is collected -- alternatives which are discussed later. The cost of analyzing the data obtained depends on the tools and expertise available, and these also determine the type of measurements required.

Decision Procedure -- Despite the relative importance and overall complexity of these decisions, and the apparent usefulness of the various analytical procedures available, farmers generally have made less use of these formal methods than might be expected. For generations they have made decisions concerning their mechanization -- as they have made most other farming decisions -- on the basis of their judgment or intuitive feel. A recent study in Canada has suggested that, in relation to farm machinery, this remains the type of approach that is adopted in most cases (93).

TABLE 2

MACHINERY STOCK AND EXPENSES ON FARMS IN PRAIRIE PROVINCES AND CANADA

Year	Machinery Stock per Improved Acre		Machinery Expenses* per Improved Acre	
	Prairies $	Canada $	Prairies $	Canada $
1931	5.96	7.59	1.41	1.60
1941	4.85	6.50	1.56	1.80
1951	15.90	19.46	4.31	4.82
1956	16.16	21.86	4.85	5.75
1961	18.78	24.81	5.04	6.37
1966	21.85	29.03	6.36	8.21

* Includes "depreciation on machinery".

Source: Derived from data published in Dominion Bureau of Statistics Catalogue No. 21-511, Part 2 for 1931, 1941, 1951, 1956, 1961. Dominion Bureau of Statistics Catalogue No. 21-202 for 1966.

Other studies have shown that for major decisions many farmers will use deductive methods including budgeting procedures, and that they will in many cases make use of estimates of costs and returns (49). It has also been noted, however, that farmers usually do not seek the type of information of most use to them in this approach. Several explanations have been projected for this behaviour, but in spite of these, it remains arguable that the real reason lies in their experience that the type of information they want is not available! It seems also likely that the level of training of farmers precludes recognition or use of the full potential that might derive from the use of formal analytical tools.

More recently, there has been an observable movement away from informal towards relatively formal procedures in decision analysis. This may be related to a rise in the level of formal training among farmers, as well as to the increase in farm size and capital investment which has greatly increased the magnitude of individual decisions. The trend has been evidenced, and greatly facilitated, by the emergence of private and governmental farm management advisory services (and the skilled personnel to operate them), which can effectively utilize the tools of operations research and systems analysis that are available. Coincidentally, there has been an expansion in the use of computers, so that the necessary computational facilities are now accessible to almost every specialist who might use them. The use of systems analysis techniques for analysis of farm decisions is thus a feasible proposition -- but their use necessitates measurements to permit their effective application to real decision problems. In view of the scarcity of these measurements, and of the relative shortage of skilled personnel, it would seem at this stage unlikely that formal decision techniques will be widely applied to many individual farmers' decision problems. On the other hand, there would seem to be considerable scope at present for the development of generalized models and analysis designed to provide decision materials for a wide range of farmers, perhaps in localized areas or relatively comparable situations. At this stage, it can be safely argued that the techniques and procedures exist whereby government, university or commercial services could implement specialist programs to meet the needs of those farmers who desire them in making machinery decisions. The only technical limitation is the shortage of data.

It is along these lines that the need for more measurements relating to farm machinery can be most strongly argued. It is on the basis of the various analytical formulations relevant to the decisions involved that the type of measurements needed can be specified. Since the tools likely to be of most use in these situations will be fundamentally the same as those used by manufacturers, the measurement needs of farmers and manufacturers would again seem likely to coincide, to at least some extent. At present, however, very few measurements made by manufacturers are accessible to farmers, and in general the data they can obtain is quite inadequate to permit effective use of the available tools. Since the cost of acquiring all of the measurements necessary exceeds the expenditure that might be tolerated by any farm unit, the farmer is therefore restricted to using those limited data that are readily available to him.

Data Available for Farm Decisions

In terms of volume, the amount of information and number of measurements that are available to farmers regarding farm machinery seems very large. Measurements and tests are made in relation to farm machinery by manufacturers, by official testing authorities, by various research bodies, and by farmers themselves. Since they collect the information, these people are also the sources from which it is made available -- at least to the extent that it is made available. In addition to these primary sources, however, there are others that acquire and disseminate this type of information, sometimes in an analyzed or partly processed form. Bodies that do this include farm machinery dealerships, farm extension or advisory services run by various government and other authorities, and certain farm consultants. In spite of this level of activity, however, the amount of information available in relation to that required is less satisfactory than might be expected.

Manufacturer's Data -- The largest stock of measurements potentially useful to farmers is that held by the manufacturers. Limited amounts of this information are made directly available along with machines that are purchased. Most of it is presented in operating manuals and instruction leaflets, or on the machine itself in the form of decals which indicate maintenance requirements, initial starting procedures and sometimes safety precautions (91). Generally, this information is aimed at increasing the adequacy of the machine's operation, and facilitating the most effective operation of warranty and service programs, including the supply of replacement parts. In most cases the data provided are useful in aiding operating or machine use decisions only -- not selection and purchase decisions -- except in so far as the above considerations are important in the selection process.

Additional measurements and information are frequently made available, similarly oriented to facilitating the effective operation of after-sales services, including repairs and maintenance procedures. But in some cases it includes information on machine specifications and performance for both the manufacturer's machines and for those of competing lines. This information is of more use in pre-purchase assessments, but it is seldom sufficiently detailed to provide much insight into the operating characteristics of machines in the local operating conditions, let alone on individual farms, nor is it entirely adequate for comparative assessments in economic terms. To permit this, in any case, it would be necessary to undertake some analysis of the various machine and individual farm features, and in most instances the dealer is no better equipped to do this than is the farmer himself.

In spite of the recognized complexity and cost of their product as a farm input, no effort has been made by manufacturers to introduce any form of technical field representatives -- even though such a system has been operated for many years by agricultural chemical and fertilizer companies, and other industries supplying agriculture with technical inputs. Consequently, the bulk of those measurements held by manufacturers which might be useful to farmers is not made available to them. Furthermore, there is no formal structure for the feedback of information from the farmer to the manufacturer, such as a technical service would provide. There are many ostensible reasons why data are not made available to farmers -- notably the cost of making them available, and the competitive pressures that make an "open information" policy hazardous in existing business procedures. But given the cost affecting "feedback" obtained, together with the fact that costs can fairly readily be passed on through price increases, and since the machines can be, and are, tested and evaluated thoroughly by competing firms anyway, these arguments seem rather hollow. The fact remains that the manufacturers hold most of that information which might be useful to farmers, and they are the only ones who have this information prior to the actual purchase and use of the machine. All other data sources can provide measurements only after machines have been on the market and in use for some time.

Test Information -- The next most active group in the field of machinery measurement and testing, after the manufacturers themselves, is the various "testing" authorities. Official testing agencies exist in some 29 countries, including Australia, Britain, Finland, France, Germany, Italy, The Netherlands, Sweden, United States, and the U.S.S.R. (59). Of these, in terms of the volume and quality of their work, those of Germany and the U.S.S.R. are outstanding (11). In Canada, the Agricultural Machinery Administration, operated by the Province of Saskatchewan in the period 1960-65, also undertook field testing of farm machines. The activities of many of these testing stations are oriented towards the testing of machinery purchased on government contract, and several do not pursue any policy of distributing information to users.

The best known of these various organizations in North America is the Nebraska Agricultural Experiment Station in the United States. This unit, operating under the authority of State legislation, undertakes a comprehensive set of compulsory standard tests on all tractors sold in that State, which in practice encompasses virtually all tractors sold in North America. The Nebraska station tests and reports in detail only on tractors, and the tests relate only to the production characteristics of the tractors. The information generated is widely distributed in pamphlets, bulletins and summary sheets (69).

The largest organization in this field is the National Institute of Agricultural Engineering in Britain. As part of its activities, this institution tests a large variety of machines, including tractors, combines, balers and other harvesting equipment, cultivating and seeding implements, and a variety of other farm machines. The measurements are made in standardized tests relating to production and some operating characteristics, and the test information is made available in detailed technical reports and in less-detailed "Test Reports for Users". In this form the information gained is widely and freely available (66). This Institute also carries out research over a wide range of agricultural engineering problems, the results of which are made available to manufacturers. It also undertakes confidential tests of prototype machines on behalf of manufacturers.

The various other machinery testing authorities in different countries tend to make measurements that are largely similar though not made on a fully comparable basis (1, 9, 67, 75). In all cases the greatest emphasis is on the production characteristics of the machines, which can be assessed most easily using standardized and reproducible test procedures. Many of these tests have been standardized to coincide with those "test standards" agreed under the auspices of the Organization for Economic Co-operation and Development (OECD) (73, 74, 76, 77). As all such testing units publish their measurements, they are usually readily obtainable, and in so far as the reports are based on standard comparable tests, duplication of basic tests from one country to another may be, to some extent, avoided.

Research Measurements -- Many additional and complementary measurements are made, relating to various items of equipment, by numerous state and university research units in different countries, including Canada. Often these units make tests of certain component systems rather than whole machines, and sometimes they deal with only specific characteristics or modifications of the standard machines. In other cases, their work relates to specialized systems or whole machines, developed for use in specialized local crops or conditions. The data obtained are usually made public as in other cases, but since the features being measured are often specific to a certain set of conditions, these data are frequently less widely circulated (for example, see 26).

These same organizations also make use of survey methods to collect information. Through their field survey activities a wide variety of measurements are often collated. These relate particularly to operating characteristics rather than the production features of machines, and are valuable for this reason. Because these data are obtained by skilled research personnel, it is often possible for them to be analyzed in some detail, and for the information to be made available in a processed form. As these units often work in conjunction with farm advisory services, these data, together with the unit's interpretation of test data from other institutions, often form the basis of the information made available through official extension and other advisory services. This source is often also used by consultants. In Canada, as mentioned previously, this type of work is done by the Canada Department of Agriculture, some provincial Departments of Agriculture, and by several agricultural engineering departments in the universities.

Some data are often also extracted from farm records. Though most farmers keep few records, some record a surprising amount of information relating to all aspects of their business, including their machinery. Because of the probabilistic nature of many of the variables measured, the data collected by any one farm in any one year are often of limited use to the individual farmers involved. When these data are compiled to reflect a distribution of observations, they become more useful -- not only to the individual farmers concerned, but to many others near them as well. Frequently this type of recorded data is used by applied research and advisory specialists, and in some cases the information obtained by farmers' experimentation and experience constitutes evidence as valuable as that produced by expensive research procedures. In rare cases the data available are very comprehensive, though they often require some analysis for their full usefulness to be realized.

Generally, however, the information in the form of measurements that is available from any of these sources is insufficient in terms of that needed for use in specific analysis. Most data that are available suffer from the problem that they have not been specified to suit the requirements of any particular decision or analytical procedure. Rather, tests are made and measurements recorded to assess various machines in terms of some physical quality criteria. Often the intention is simply to verify that the specifications meet some previously agreed or accepted standard. Clearly these measurements are of little direct use in analyzing a capacity or replacement decision!

Needs and Facilities of Other Groups

Agriculture in the present day is a complex industry that contains many people in addition to farmers. Within its organization there are numerous groups who are involved in regulating and supporting the effective operation of farms. Though their interests are usually specific to some aspect of agricultural production, a large number of different individuals or groups makes use of empirical data relating to farm production, including those relating to various features of farm mechanization. The various interested parties might be classified in the categories of technical services, farm suppliers, and regulating agencies.

Technical Services -- The groups most deeply involved are perhaps those concerned with providing technical services to farming. These include research workers in various related disciplines, including agricultural engineers, farm economists, biologists and plant breeders, and many others. In this category, too, must be included numerous field specialists involved in educational and advisory work in farming. The activities of these groups vary widely, but the type of data they need can be indicated by looking at certain examples of their interests. The agricultural engineer is concerned, among other things, with the adequacy of machinery for various farm operations or tasks. The farm economist is interested in the cost efficiency of this equipment. Thus these two groups seek information concerning the operating characteristics of the range of machinery available -- the engineer so that he can make modifications and improvisations to existing machines or develop better ones, the economist so that the best available alternative can be selected and used to greatest effectiveness.

Biologists, particularly plant breeders and geneticists but others as well, have become more interested in mechanization in comparatively recent times. Today it has become clearly apparent that the increased mechanization of agriculture can be achieved effectively only by joint efforts to change the biological characteristics of crops as well as by developing new mechanisms. Often the fruits of this co-operation can be gathered only if there is improved quality of management at the farm level to match the changes in technology, and for this reason extension specialists and farm advisers are often also involved.

Technical service activities of this nature are carried on by government institutions, universities and machinery manufacturing firms -- often with co-ordination of the activities of all three. Generally, these teams have access to data collected from all of the sources listed in Chapter 1. Where the measurements are not readily available, at least the resources necessary for their acquisition are usually available. Thus the needs of these groups can normally be met, even though there may be a time lag and perhaps some considerable expense involved in meeting them. In some cases, however, the adequacy of communication and co-ordination is insufficient to permit the required information to be available as readily as it might be. Data pertaining to mechanical innovations seem to be seldom as freely available nor as comprehensive as that relating to agronomic or other biological innovations. To some extent, the information that is available appears to be roughly proportional to the level of public expenditure in the particular field.

Farm Suppliers -- A second group concerned with farm machinery innovations and the measurements relating to them can be designated as farm suppliers. This category might include most other manufacturers and firms supplying production inputs to farming, such as agricultural chemical and fertilizer companies, fuel and oil suppliers, and to some extent those concerned with farm credit, insurance and other services. In some cases the data needed are complex and detailed -- as, for instance, those required by a herbicide manufacturer who markets a new product that necessitates specialized equipment. In such cases this information is probably sought directly from farm machinery manufacturers. A similar situation would seem to arise with specialized manufacturers who make modifications and additional fittings for machines made by the long-line companies.

The needs of most other parties in this category would seem to be less specialized, and in many situations the information they seek is general in nature and therefore more easily obtained. On the other hand, there is no easy point of reference where the data they require might readily be obtained. Since those firms that are in this category seldom have their own primary source of information, they depend on secondary sources, and the data available from these sources are found very often to be incomplete.

Regulatory Agencies -- The third category in this broad group of data users are the regulatory agencies. In this class we must include institutions responsible for the quality control of farm produce, groups responsible for farm policies relating to technological innovation, and those concerned with welfare aspects, both physical and economic. The information needs of these groups are sometimes detailed and specific but mainly of a more general nature. Examples of cases where more detailed measurements are required are the quality regulation problem, related to grain and certain aspects of machine operator welfare, both of which are discussed more fully in separate studies (30a, 31). In certain cases there is some indication of a need for a continuing analysis and appraisal of some measurements in order that changes over time in patterns of parameters relating to farm machines might be recognized more readily.

Since most of the parties in this group are government instrumentalities, they tend to have preferred access to the data and measurement facilities of official research stations and government services. In many instances the official testing units have been set up to aid the decisions of these parties, at their own behest. It is therefore paradoxical that, while finding the information thus obtained necessary in their own case, these regulatory agencies have often not subsequently accepted nor even recognized the same need on behalf of those decision-makers who happen to be farmers. Since they have access to these official test data, the situation of government agencies is perhaps comparable to the relationship between various commercial firms who need data *vis-à-vis* the machinery manufacturers' facilities. The shortage of comprehensive data, as required by these official bodies, arises, therefore, not from lack of a possible data source, but from the limited resources at the command of that source at any one time.

In summary, it seems that changing technology and economic adjustments are creating a need for more thorough analysis of farm machinery problems, and through this a demand for more measurements. These measurements are sought by various groups, but most of the data required are similar to those needed by manufacturers and farmers. The general needs of these two parties would seem to coincide in many cases. Concurrently, an increasing amount of data is being collected, particularly by the farm machinery manufacturers. Though much of the same data would be useful to farmers, they have limited and insufficient means of acquiring it, and little of that held by the manufacturer is made available to them. Given the existence of many advisory sources, official and otherwise, the relative ability of farmers to use measurements is not a real constraint on their usefulness. Since farmers have, through their changing situation, a real though unquantified need for more information, it seems appropriate to consider the alternative means, difficulties and costs involved in obtaining it. Given some assessment of these procedural problems, the associated costs and the anticipated benefits from an increase in the availability of data might be considered in relation to one another.

3. MEASUREMENT ACQUISITION

Problems of Measurement

The desirability of a more empirical approach to farm machinery decisions, and the trend in that direction, presage the need for increased measurement activity. The shortage of existing measurements, and the relative disadvantage of certain groups in acquiring them, further suggests the need for an organized program to increase their availability. Such a program does not seem infeasible. The review of measurement sources, presented in Chapter 1, suggests that a range of procedures is available. The summary of existing data sources in Chapter 2 indicates that several institutions are already using one or more of these methods to provide data on farm machinery. The extent to which a program could be developed, therefore, seems to be restricted only by the operational problems involved and the availability of resources.

The difficulties encountered in the operation of such a measurement program will represent a combination of conceptual and procedural constraints. These arise from the complex nature of the variables to be quantified, and from the fact that measurement is not a simple matter. In particular, they are influenced by the dynamic aspects of change in which all activity takes place.

Conceptual Problems -- These include the decisions as to what measurements should be made, where, and in what form. This necessitates identification of the problem and formulation of the decision so that the form of analysis can be specified. The measurements that are ideal will be those that permit the analysis necessary for the decision to be made with greatest accuracy. Those that are feasible will depend on the nature of the decision situation to which they relate, and on the procedural limitations in making the measurements.

The identification of the decision problem is generally more straightforward than specifying the analysis that is appropriate. Identification can usually be done either from practical experience or from field investigation of the problem area. Formulation of the decision analysis, on the other hand, necessitates an assessment of the techniques available and of the data they require, in relation to the problem situation and the data that can be acquired. The problem situation is very often characterized by change. Change creates uncertainty, and decisions can be classified according to the way that uncertainty is handled in their formulation. Thus, in situations where there is imperfect knowledge, there may be decision analysis on the basis of assumed certainty, objective risk, subjective risk or acknowledged uncertainty (88). Each of these employs different analytical techniques, and they in turn require different measurements. This has particular relevance in farm machinery decisions.

Agricultural production is characterized by having a large number of variables that are stochastic -- that is, they vary over time according to some frequency or probability pattern. Thus there is a need to take account of risk in farm decisions. To do this, a large number of observations may be required in order to forecast likely outcomes. For example, in assessing farm machine capacity a number of variables, including available operating time, weather, surface conditions, crop yield, rate of work, number of breakdowns and many others, can all be assessed as probabilities. Thus for decision-making purposes data are required in the form of frequencies of values concerning these variables -- and this often means making measurements over time and in different locations.

Even when the measurements that are desired have been specified, however, there are some further conceptual problems that can restrict their being made. These arise from the fact that the simple definition of measurement used in Chapter 1, while not of itself inaccurate, is a gross simplification. Far from measurement being the assessment of magnitudes according to some scale, the scientific empiricist distinguishes between at least four different kinds of measurements, and at least as many different types of scales (34). The four kinds of measurements form an hierarchy, from simple identification to the combining of constants and laws, in which the conditions for their application are progressively more stringent. Once the type of measurement to be used is decided, the relevant procedure that can be employed in making the measurements required has effectively been specified. Conversely, once the procedure to be followed is laid down, the type of measurement has usually, thereby, been specified.

Quantities measured in any of these four ways may be assessed in various units, depending on the choice of scales. Again, four different types of scales are regarded as being in common use. They range from the allocation of numbers, as identifying marks, to ordinal scales, which indicate order of magnitudes (such as, for example, Moh's scale of hardness, or one used in the ranking of machine operation ability), interval scales, which preserve interval as well as order (like those used for measuring temperature, and the Rockwell scale of hardness), and ratio scales which preserve order, interval and ratio (such as the common scales of length, mass and time). Given a knowledge of the type of scale used in obtaining a given set of measurements, then the statistical procedures appropriate in assessing the results are considered to be defined. It follows that, conversely, once the analytical procedures are chosen, the type of scale to be used has also effectively been specified.

The conceptual problems involved in a measurement program involve, therefore, the identification of these different variables and the relationships between them. In some cases the type of measurement will be determined by the measurement source and the procedures employed, such as in a farm survey of, say, reliability. Here the measurements obtained can only be in the units in which the farmers have recorded or recalled them. Alternatively, the fact that the nature of a system is not fully explored and the laws and constraints not established, as say, in certain aspects of hydraulics, may limit the measurement procedure that can usefully be employed. Again, once the decision problem has been formulated and the appropriate form of analysis selected, the type of scale will be specified. Thus, in a problem concerned with the scheduling of field operations, time may be measured in minutes; costs, in cents per hour; and operator skill, by ordinal ranking. On the other hand, if for some procedural reason (such as limitations on the repeatability of a measurement) the types of measurement and scale are restricted, so also will be the type of analysis that is possible in making use of them.

In addition to measurement and scale, however, the empiricist is also concerned with probability. Two different forms of probability are recognized in terms of the different kinds of procedures used for determining probability relationships. The *relative frequency* is used to describe positively identifiable events. For instance, over time the probability of a machine part failure is measured in terms of an array of relative frequencies. Similarly, *subjective probability* is an empirical measure of the frequency of events, but this time measured in terms of subjective expectations. For example, farmers' expectations for the range of grain loss through shelling over several years might be measured subjectively. The use of subjective probabilities in analyzing decision alternatives subject to risk is a current vogue of decision theorists.[1/]

As with the different types of measurements and scales, each of the forms of probability are of conceptual consequence in making measurements of farm machinery and in analyzing them. Given the relative complexity of these various concepts, it is not very surprising, therefore, that there are conceptual difficulties of practical significance in any program involving measurement. It may be partly because these fundamental conceptual problems are either not well recognized, or not well handled, that the data available are often limited, both in quantity and usefulness.

Procedural Problems -- The procedural problems encountered in measurement often involve the reconciling of conceptual constraints and practical difficulties. They include the problems of how, when, and where evaluation is to be made. Though many problems of procedure arise in farm machinery evaluation projects, special attention has been given to two aspects -- measurement technique and sampling procedure.

1/ A third probability concept -- that of the degree of confirmation -- is used in statistical tests of validity. Since it relates not to how the world is, but to how it is described, however, it is not included as an empirical concept.

Measurement technique refers to the actual taking and recording of measurements. It is of concern because measurements need to be made under specified conditions. It is in the nature of things that some situations can be more easily specified than others, and this leads to the generalized statement that some measurements are easier to make than others.

Related conditions have to be specified in order that measurements have meaning in a relative sense. Since the items being measured are always variables, their condition at the time of measurement needs to be made explicit. This aspect is of particular concern when measurements are to be used in comparing one machine with another. Fair comparison depends on the conditions affecting the variable being comparable from one situation or machine to another. Consequently there has been great emphasis placed on the need for "repeatability" in measurement technique and much attention given to the definition of "reliable" specified measurements.

This emphasis seems to have led to a somewhat narrow and simplistic approach to farm machinery evaluation. The type of measurements made available, particularly in test reports, appears to be determined more by their reliability and repeatability, and by the relative ease of their acquisition, than by any consideration of the use to which they might be put. The general orientation of test data seems to be towards defining the machine rather than defining the alternatives involved in any particular decision. Thus the test reports from all existing agencies provide considerable information on the production characteristics of machines in specified conditions, but little on the way in which these are translated into operating characteristics once they reach the farmstead or field. Consequently they provide data that are of limited value in many farm decisions.

The data presently available appear to be provided by engineers, to engineers, for engineers. This emphasis on narrow positivistic measurements no doubt arises from the engineers' emphasis on design and development rather than on management and utilization. Happily this emphasis is changing, so that currently more attention is being given to machinery management (5, 57, 72, 80). Coincidently there is a trend towards seeking economic rather than technical efficiency in building, adapting, and evaluating farm machinery.

Just as there is the need to specify the conditions under which a measurement is made, so there is a need to select samples. In the same way as it is impossible to assess a characteristic in relation to all of the variable conditions that might occur in operation, so it is infeasible to test all machines that are produced or all of the components that go into them. Consequently it is necessary to select samples on which to undertake tests, and to make measurements on a basis that facilitates the projection of values that might be expected in various use situations.

Sampling procedures have been studied in some detail to the extent that once the nature of the parameters being studied and the size of the population and anticipated variability have been identified, the size of the sample required and the sampling procedure can be decided quite readily (16, 19). Thus in sampling to enable the testing of small machine components, or for field survey work, the appropriate procedure is relatively straightforward. In situations where measurements are to be made on large or complex mechanical systems or on complete machines, however, the cost associated with making the large number of measurements involved, and possibly in acquiring the machine, may often preclude the use of a reliable sample size. Though as large a sample as possible is preferred, it is not uncommon in practice to be limited to a sample of one in some situations. The adequacy of such a basis for measurement is clearly open to question. In particular, the use of restricted samples in the evaluation procedures of certain consumer testing organizations has been criticized (12, 78).

More constructively, since this limitation is not easily overcome, there has been some discussion as to means of ameliorating the limitations of the bias imposed when only a restricted sample can be used as a basis for measurement. The two main lines of thought in this area both hinge on the fact that manufacturers build machines to identifiable specifications.

In this regard it is important to note that each component of a final product will have not only a physical specification but also a range of tolerance, this variability being inherent in modern manufacturing processes. When assembled, each mechanical system will have, as a consequence, its own set of tolerances. While it may be possible to reduce the extent of this variability in assembled systems by matching parts whose idiosyncrasies cancel one another to varying degrees, the final products must each have a unique set of production characteristics, and consequently differing operating characteristics. This reality is well recognized by production engineers who take action to limit the range of this remaining variation. This is done by working to detailed specifications and by using quality control processes to ensure (as near as possible) that a minimum tolerance level is sustained in the units sold. These limits are established, and are clearly known, by the manufacturer.

Given that this is the case, it has been argued, on the one hand, that any single unit chosen at random will be as representative of a machine of that model as will any other single unit (10). In particular, it is argued that such a randomly selected machine will be above the minimum tolerance standard, and that it is unlikely (though possible) for it to be in the few that are at the "tail" of the distribution which, it might be assumed, will be skewed towards the higher values for any characteristic. Thus it is strongly held that a randomly selected unit is the "best" limited sample to use. In advancing this argument, its proponents are strongly critical of the practice of evaluating a machine that has been specially selected and prepared, on the grounds that such a unit will almost certainly be in the thin upper end of the frequency distribution for most characteristics.

On the other hand, it is argued that, in evaluating a specially prepared unit which is "known" to be in the upper regions of the distribution of machines, the assessor at least knows where in the frequency distribution the sample is from. Further to this, it is suggested that since the minimum values for each machine characteristic are known (from the maker's specified tolerances), a knowledge of the upper limits means that the expected range of values for any model has thus been defined.

On the basis of these arguments, each of these policies is followed by different organizations working under differing restraints. The first is used widely by manufacturers themselves in relation to purchased components or component systems (though they seldom test as few as one!). It is also used by certain testing units, notably the Australian Tractor Testing Authority. While this policy is far from ideal, it seems the more appropriate of the two in cases where the minimum standard to which the item is built is either not known (though known to exist) or, alternatively, not accepted as having been met.

The second policy is endorsed by several testing authorities, particularly those of Nebraska State and the British National Institute of Agricultural Engineering (60). This seems the more appropriate policy -- though still far from ideal -- in those situations where the minimum standards are known and where the related data are readily available. It would seem to be most defensible in a situation where some of the component tolerances were also known. Though such a situation is not inconceivable, there is no evidence in the test reports published by either of the establishments mentioned that any of these conditions are met. While it is known that detailed specifications often *are* provided by the manufacturers when their products are tested, the fact that the expected range of values is not intimated in their reports might be considered to invalidate the claims of these centres regarding their "sampling" procedure.

The existence of these two approaches serves to emphasize that even the detailed procedure followed in measurement is determined to some extent by the way in which the activity is viewed or conceptualized. It also serves to emphasize some of the limitations involved in using testing as a means of acquiring measurements. The key point that remains is that only a limited number of units can be tested, and on this restricted sample, the formulation of estimates or expectations must always be hazardous to some extent.

It is in this way that the procedural and conceptual problems of measurement might act as constraints in a farm machinery measurement program. To the extent that they exist, they can affect the way in which a program is organized. Thus, indirectly, the problems of measurement have a determining influence on the type of program that is most effective.

Alternative Means of Acquisition

The kind of measurements needed and the methodological problems surrounding their acquisition point to the necessity for a structured, organized program to obtain data and make them available. The limited resources of various interested groups suggest the need for some joint, co-operative, or centralized service. Moreover, the existence of agricultural research and advisory services relating to other aspects of farming, and of machinery evaluation programs in other countries, provides a precedent for government action in this area. Consequently, it is worth considering how such a program might best be organized.

In assessing the form of organization that is most suitable, it is necessary to consider both the constraints on evaluation outlined above and the particular aims of the program. In practice, the purpose and ideals of the organization might be manifold. In particular, they might include the function of protecting the farmer, and in some cases the manufacturer or dealer, as a consumer. They might also include both an educative and research role to increase the efficiency of resource use in the area of farm mechanization. But virtually every purpose that can be envisaged will be served if the organization follows the dual policy of acquiring relevant measurements and disseminating them in a usable form.

In pursuing this policy, four alternative proposals seem worth considering. The first might be to develop a supplementary program based on expanding the existing work being done in this area by various units throughout the country. The second might be to set up a system of compulsory requirements and standards, so that machine manufacturers are compelled to make more data available. The third alternative might be to establish an independent authority with sufficient resources to initiate a full program of measurement and information distribution. Or, a fourth proposal might embrace certain aspects of each of these approaches.

Supplementary Program -- The most likely form of supplementary program would be one implemented by the provision of additional funds to existing institutions active in the field of machinery measurement and information dispersal. This implies the provision of research grants or contracts to university departments, and to various branches and research stations of both federal and provincial government departments. The provision of these funds might increase the amount of work undertaken by allowing existing work to be expanded. It might result in machinery measurement being substituted for other activities, and in the long run attract additional resources, including skilled personnel. In this way, a system of grants might reorient the emphasis of existing institutions towards taking more account of farm mechanization problems, and this might be considered desirable.

Such an approach would have the advantage, by utilizing places across the country, of providing facilities in a large number of locations close to the major farming areas. Because of the existing ties between the universities and research stations, and the advisory services, there would be an established base for increasing the flow of information. In view of the close association of university research and teaching, the provision of project grants might also facilitate the training of personnel for further work in this area.

On the other hand, a major disadvantage of this approach seems to lie in the fact that the program would be piecemeal. The complex interrelationships of machine charactersitics and the involved problems of measurement procedure suggest that the first (and continuing) project ought to be the evaluation of data needs and priorities. Without clearly established directions, it is difficult to see how any major improvement can be wrought in the existing system. The only condition under which a piecemeal approach would be satisfactory would be if the existing measurement activity were presumed to be of the type required.

Since many of the existing centres of activity are widely distributed and largely independent of one another, there is also likely to be considerable duplication of measurement work (which may or may not be useful), particularly of the standard measurements of production characteristics that are usually part of any detailed project. In view of these two disadvantages, some central co-ordinating machinery would seem desirable, and this unit would need to have a basic program of its own. In this way a central co-ordinating unit could ensure an equitable and effective cover of subjects in terms of location, machine models and decision problems.

Compulsory Requirement -- Since it is known that many machinery manufacturers make a large number of measurements on their products, it seems reasonable to argue that the farmer might be greatly aided by requiring manufacturers to make information available to him. To some extent, however, this argument is based on a fallacious supposition -- that is, that the manufacturers' data would be useful to farmers. In many cases this would not be the case. Though similar, the actual measurements made for their own purposes by manufacturers are likely to be of limited value in farm-level decisions. What is unquestionably true, however, is that all the larger machinery manufacturing companies have both the facilities and the expertise with which to make measurements, and their activities could easily be extended to obtain the kind of information the farmer needs. It can also be argued that they have a responsibility to facilitate the most effective utilization of their product. Thus a program requiring manufacturer action in measurement provision should be neither impracticable nor unreasonable. Small firms unable to maintain their own independent measurement facilities could probably be accommodated (and benefited) by provision of services on a contract basis by either a central testing authority, an agricultural engineering department of a university, or a specialist commercial firm.

Such a compulsory requirement would have a precedent in the provisions required of the pharmaceutical industry. This industry is legally required to make standard tests and to make the results available to regulatory agencies, in several countries. (It is not suggested that the further precedent of established standards be followed in this case.) To achieve effective implementation of such a program, it would probably be necessary to impose some restriction on sales until such time as the required information was made available. It would also be necessary to formally specify both the measurements to be made available, and their mode of acquisition. This could be done on the basis of the standard test procedures used by various institutions around the world. They would, however, need to be continually updated in order to be fully effective. The need to establish such standards for measurement, and to review them on a continuing basis, again suggests the need for some central co-ordinating unit.

In attempting to make this approach effective, several unsatisfactory features are likely to arise. For instance, since measurement activity is costly, any requirement of makers to evaluate machines before sale is likely to put a heavier burden on short-line companies, who have fewer sales and less opportunity to spread the costs involved over a large volume of output. In this way, such a requirement might create an additional barrier to entry into machinery manufacture, unless it were overcome by the availability of an official agency that might undertake this work on a contractual basis. Further, because of the need to specify procedures in detail, there are likely to be many rigidities involved that could affect the usefulness of the data provided. In addition, these requirements must almost inevitably restrict the freedom of action of manufacturers both in modifying models, once on the market, and in introducing new models, and again this might not be desirable.

In addition, there may be restrictions on the usefulness of data arising from rigidly specified requirements. In particular, it will be very difficult to specify any regional coverage requirement, since this is likely to impose an almost impossible time constraint on the market introduction of the machine. If such a requirement were imposed, it could result in Canada being the last of the world markets to get new technology, with subsequent diseconomies becoming inevitable.

Independent Evaluation -- The development in Canada of a new and independent institution devoted to research and measurement concerning farm machinery would permit the greatest freedom in expanding information availability. A program based on this idea would have some useful precedents. The notion of independent testing is embodied in various institutes and testing units around the world, and was implicit in the nature of the ill-fated Agricultural Machinery Administration in Saskatchewan. Such an institution could be established under federal legislation, operating independently much as the National Research Council. Alternatively, it could be established as a special agency of the Department of Agriculture. This latter alternative would ensure use of existing regional facilities at research centres, but might restrict the type of relationship that could be developed with outside organizations, particularly the machinery industry.

Once established, a separate institute could be located either in Southern Ontario, in close proximity to the major manufacturing activity, or on the Prairies, where more than 60 per cent of all new farm machinery is used. Wherever it was located, it would need to have branch units located in a variety of areas and probably in each province. This would allow the authority to evaluate those machines of greatest significance in the farmers' budget in each location, and to measure those variables of greatest significance in the decisions involved there. The freedom of action of such an institution would also allow it to provide services to manufacturers, and to the whole range of other individuals or organizations that may need better information regarding farm machines.

On the other hand, this alternative would have the disadvantage that it would probably be more costly than the other alternatives, and that it might duplicate some of the facilities and activities already in existence.

Combined Program -- A program based on a central co-ordinating unit but involving various features from one or all of the alternatives outlined above might be considered. Such an approach might have all the advantages of the individual programs and might effectively overcome some of the limitations that are associated with them. It could be based on a separately established central body with freedom to organize its own measurement and related research activities. In addition, it might be given freedom to deal directly with the manufacturing industry in obtaining their co-operation in providing or exchanging data and results. Further, it could have funds at its disposal with which to foster specified projects on certain machines in various areas, by allocating grants to provincial universities and research stations.

The central unit might operate by using its "good offices" and its project funds to influence the work being done in all other organizations. By building up a body of useful data it might also have a regulating influence over the relationship between manufacturer and farmer. Alternatively, it might be delegated certain powers, supported by legislation, to allow it to intervene directly in the maker-user relationship. While having certain advantages, this latter alternative may imply much more direct intervention in the manufacturing sector of the economy than is acceptable or desirable. However, since the effective operation of either a supplementary or a compulsory requirement program suggests the need for a central co-ordinating body of some sort, the possibility of a combined program seems attractive. That the central body should have activities of its own is also an interesting possibility.

Desirability of Independent Evaluation

Many of the goals of a machinery evaluation program might be met by any one of the foregoing alternatives. Indeed, each has its particular advantages. On the other hand, it might be argued that certain goals will be fulfilled only by a program incorporating an independent evaluating unit. Two particular goals that might be met more effectively in this way concern the provision of consumer protection and manufacturer service.

Consumer Protection -- The concept of consumer protection has become of increased importance in western society generally, and particularly in North America, within the last decade. A feature of the changing interest has been the growth of a movement, the aims of which are to hold manufacturers and their agents clearly responsible for their products, particularly with regard to basic specifications and design quality, and to the resulting adequacy and safety of products in their end use. The movement received identity in the four points promulgated by the U.S. President in 1962, which stated the consumer's rights: -- to safety, to be informed, to choose, and to be heard (104).

Examples of the impact of this movement are seen in the publicity and subsequent legislation concerning the quality and safety of automobiles and tires, and in the expressions of concern and regulatory activities relating to medical drugs and certain chemical domestic products. There has also been legislation concerning packaging, food inspection and consumer credit conditions (13).

Of course, to some extent there has always been some concern about the desirability of a "fair deal" in business transactions, particularly when the economic power of one of the contracting parties clearly exceeds that of the other. Consequently, there has been, for many years, a steady growth of regulatory legislation and of "accepted" business standards relating to commercial practice in general. Government activities in this area range from consumer protection by enforced standards, through consumer assistance activities such as training programs, to information-gathering (13).

In some ways protective legislation relating to farm machinery purchases has created interesting precedents, which have yet to be followed in any other area of producer-consumer interaction. The previously mentioned State of Nebraska law regarding agricultural tractors enforces conditions that apply to no other similar manufactured goods. *The Saskatchewan Agricultural Machinery Act* and the *Farm Implement Acts* of Manitoba and Alberta provide consumer protection to an extent unprecedented in relation to any other goods, or, so far as can be ascertained, in any other country of the world (102). These provide for licensed distributors and dealers, minimum stocks of repair parts, and a statutory contract of sale which specifies, *inter alia*, the right to return a machine with full reimbursement under certain conditions, and also minimum warranty guarantees. The Acts also provide for supervision of the trade by government inspectors, and specify manufacturer's liability to fines for enfringements of the law. Thus, in relation to the effectiveness of machine function, and to spare parts supplies, these Acts afford considerable consumer protection.

In view of the existence of these often one-sided safeguards, it is surprising that much less attention should have been given to other aspects of consumer protection concerning farm machinery in Canada. For instance, the existing legislation provides no safety standards, does not require the provision of information on specifications, or regarding capacity and efficiency of machines in operation, nor is there any guarantee or assessment required of the operating adequacy of farm machines in Canadian conditions. This last aspect might be considered very important in that a large proportion of farm machinery used in Canada is imported, and that the particular combination of farm size enterprise mix and climatic conditions under which Prairie farms operate are unique to Canada. Yet in only one province have machine operating characteristics been evaluated -- by the activities of the Saskatchewan Agricultural Machinery Administration.

Thus the existing legislation only partially satisfies the requirements suggested by the tenets of consumer protection. It does not promote safety; it does not guarantee the right to choose; it does not facilitate or encourage the provision of information; and it permits the farmer to be heard only in regard to specific matters. Nor does this legislation provide any protection for the manufacturer or distributor, such as, for instance, against payment default. On the other hand, it enforces certain rigid conditions and requires consumer participation only to the extent of administrative procedure. Thus it might be regarded as a good example of the paternalistic type of consumer legislation which manufacturers might fear most (104).

A broader and more constructive level of consumer protection might be realized by instituting, either separately or as part of a broader program, an independent evaluating authority. By following a concerted plan of measurement activity, possibly using all of the methods available, such an institution should be able to provide both standards and information that would enable all of the consumer protection tenets to be met. It would in this way be operating much as the testing and rating agencies of consumer's organizations. Consequently, it is likely to have all of the strengths and limitations of these organizations (12).

The difficulties and disadvantages may be numerous. In particular, they will reflect all of the conceptual and procedural problems of measurement discussed previously. There is likely to be considerable difficulty in keeping up with all of the technical changes instituted on farm machines, even without model changes. There will always be problems regarding non-typical and varying use conditions, since no program could ever cover them all. On the other hand, once well-established, such an agency should be able to make rapid projections of the expected operating characteristics of a new machine or a modification. It could also provide a clearing house for similar information from all other sources. Forecasts of performance should be possible for a wide variety of the more likely operating conditions throughout Canada. With the aid of some applied research, various standards should be easily established for any machine, particularly safety standards.

On the other side of the coin, such an institution would not have all the disadvantages of a consumer-financed unit. It would be dealing, in the main, with clearly defined, branded goods -- though assessing comparable brands fairly could provide some problems. The performance characteristics of interest can readily be specified, and the choice of the alternative that is preferred might usefully be left to the farm manager, so that there would be no problem of assessing "best buys" subject to conflicting criteria. In addition, if it is government-sponsored, the institute should not have the constraint of inadequate or fluctuating funds. Thus it should be able to employ the best staff available and not have to resort to assessment by untrained personnel.

Of course, the effectiveness of this approach depends upon the data being used by the consumer, and there will always be difficulty in reaching all of those machine users who might profitably utilize the information available. However, a certain degree of protection is likely to derive from the fact that such an institution is in existence. If the evaluating unit disseminates its findings without prejudice, it would seem unlikely that manufacturers should be prepared, knowingly or unwittingly, to run the risk of having an inadequate machine publicly exposed. Thus they are likely to make market release decisions more carefully, and to tighten up their quality and design control procedures. In this way, and by improving the accuracy of their own decisions, farmers as consumers are likely to gain directly from a program of independent evaluation. In addition, they may also make some indirect gains from such a program in so far as it helps manufacturers.

Manufacturer Service -- Even if established primarily to afford consumer protection by facilitating better purchase and use decisions, an independent evaluation unit is likely to provide some direct assistance to manufacturers. Given some recognition of the interdependence of the machinery manufacturer and the farmer, the unit might purposely be oriented so as to extend this assistance. This might be achieved in various ways.

For instance, in addition to testing machines available on the market, the unit might undertake, on a fee-charging basis, confidential tests of prototype machines. By doing this, it might enable smaller manufacturers to have access to the skills and facilities similar to those which larger manufacturers provide for themselves, but which for smaller firms would be uneconomical. This might be a significant aid to short-line manufacturers who perhaps may provide specialized machinery specially suited to Canadian conditions. By providing such facilities, it may aid the entry of new companies into farm machinery manufacture, thus promoting competition in the industry and providing a wider range of goods from which to choose. In both ways, farmers may gain as a consequence.

The availability of evaluation skills and facilities of an independent unit may also be useful to larger manufacturers. It might be used to provide management with an assessment independent of that provided by the development team working on a particular project. It might also be used as additional capacity to supplement the company facilities in times when they are overloaded, such as when development work reaches a bottleneck or load peak.

Apart from these activities, an evaluation unit might also provide some services and facilities that manufacturers cannot feasibly provide for themselves. For example, since most machinery manufacturers buy in many components, the unit might provide independent evaluation of component performance or suitability. In this way, it may provide some degree of "consumer protection" to manufacturers in so far as they are consumers; it could also act as an arbiter in disputes over component quality. Similarly, it might provide independent assessment of manufacturers' finished products in cases where a specifically independent evaluation is desired by the buyer, such as is often required by overseas government contracts.

The unit might also provide very specialized or seldom used facilities that might not otherwise be available for many manufacturers' development programs. In particular, this might include newly developed specialized techniques which themselves may still be in the evaluation stage. By facilitating the work of the manufacturers in these various ways, the evaluation unit might give benefit not only to them, but indirectly to farmers and the community as a whole.

Co-ordinated Research -- Although the basic justification for an independent unit lies in the functions outlined above, the same body might usefully be involved in applied research related to agricultural engineering and mechanization. In practice, many major evaluation activities would constitute applied research projects. Consequently it is difficult to see how such a unit could operate without a recognized research function. In addition to this, however, it might also act as the co-ordinating unit for a broader program.

Both the supplementary and compulsory requirement proposals outlined previously needed a central co-ordinating unit for their full effectiveness. Though neither of them provides an ideal alternative, some aspects of both proposals could usefully form a part of an overall program. In particular, the provision of some data by manufacturers would greatly facilitate the making of projections based on test data. Once workable predictive models were developed, the provision of data from manufacturers' test programs would allow projections to be made of performance and operating characteristics, for Canadian conditions, before the release of the machine on the market. This seems to be the only way that such pre-sale predictions could be made. It would be essential, therefore, that the unit do sufficient research to enable it to develop the necessary models.

Further to this, an independent authority could play a vital role in facilitating applied research and development work by providing a central data bank. Applied research is wholly dependent upon the availability of data. Very often the major restraint is not the existence of such data but their availability. The availability of computer facilities makes it now possible to collect and store considerable volumes of information. There exist at present sufficient data to warrant such a collection and storage program. As measurement activity continues, or increases, more and more data will need to be stored, ready for use. These data could come from a variety of sources, remembering that many measurements useful in decision analyses, such as weather data for instance, may not relate only to machines and mechanization. Similarly, the data stored are likely to be useful to various groups, including manufacturers, research centres and farm advisers.

Finally, the research role of the central unit could include the use of funds, in the form of grants or contracts, to foster research in other institutions. Clearly the research necessary in the farm machinery field will extend further than simply research into evaluation, and some of this work may be better undertaken by some other organizations. Full consideration of the issues involved in securing the most effective organization of machinery research exceeds the scope of this particular study, but since measurement is a significant part of research particularly at an applied level there might usefully be a tie-up between the work of the central unit and other research centres. Apart from encouraging the growth of work related to farm machinery, this might be an effective means of obtaining regional coverage without the expense of establishing multiple sub-stations for that purpose. In this, as in other aspects, the creation of a relatively independent institution seems highly desirable. Nevertheless, the ultimate desirability of such an organization should properly depend on the costs and benefits that are anticipated in relation to it.

Costs and Benefits

The nature and scale of any program of evaluation that is instituted will ultimately be determined by the expected costs and anticipated benefits to the nation. As with all investments, the measurement program that is selected should be that which gives the maximum net benefit without reducing investment in alternative activities that might be giving greater benefits. The net gain from farm machinery evaluation will depend, on the one hand, upon the total benefits derived from increased efficiency in machinery manufacture and usage, and, on the other, upon the direct and capital costs involved in running the program. Assessing the magnitude of both of these, however, presents a measurement problem quite complex in itself. Not only are the costs and benefits difficult to identify, but also they are likely to redound upon different persons or groups in the economy and to be spread over widely different time periods. Thus, in practice, they might not be separately identifiable and are certainly difficult to quantify.

Of the two, the benefits are the greater imponderable. Clearly, the gains from a program of farm machinery evaluation can arise only from better decisions, facilitated by the more empirical approach that extra data will allow. This may lead to more efficient resource use by either manufacturers or farmers. However, a more accurate decision made by a manufacturer may provide benefit only to the farmer's efficiency, and the end gain may be that of the consumer who consequently gets either better quality or cheaper food. The distribution of gains, whether or not the better decision relates to new or existing technology, is explained in terms of the economics of innovation. A different decision, made through benefit of better knowledge, constitutes a type of innovation within the working environment to which it relates.

An innovation will be adopted in production only if it: (i) increases the total output from an existing level of inputs, or (ii) reduces the cost of producing the existing level of output.

It is also apparent that an innovation might be introduced if it effectively reduced the variability, or uncertainty of production. The end effect of doing this, however, is usually to increase output by giving a less fluctuating pattern of production. It can be argued, too, that since a reduction in cost of production will make the production of that good more profitable, this will lead to a further increase in output as profit maximizers expand their output. Thus all innovation in production processes may be considered output-increasing.

For example, the selection of a better cultivation procedure for a particular soil type might directly increase yields. Alternatively, a machinery decision (made by either a farmer or a manufacturer) that results in either better cultivations or faster harvesting may cause a reduction in yield fluctuations due to weather effects. In the same manner, the selection of a machine that will do a comparable job for a lower capital investment than the alternative procedure can give a lower unit cost of production. In all cases, the decision is likely to increase total output, but it will also involve substituting one type of input for another.

The benefit from more satisfactory farm machinery decisions and the adjustments that accompany them could go to manufacturers, farmers, consumers, or to the economy as a whole. To the extent that such decisions lead to substitutions in resource use that are, at the aggregate level, commensurate with increasing productivity and economic growth, the benefit will accrue to the economy as a whole. To some extent, too, some general benefit might be obtained by government action to divert some excess profits to society in general through various taxes. They may also seek to ensure that some benefits are passed on to consumers by fostering increased competition through facilitating ease of entry, and preventing amalgamation or collusion, or by fostering wage increases.

Where a manufacturer is enabled to make a better decision, resulting in reduced costs through, say, a reduction in service requirements or in spare parts inventory, the benefits may not necessarily be passed on. Depending on the level of competition in the industry -- and, in an economic sense, this seldom equals that in farming -- the manufacturer is usually able to retain some or all of his increased profits. That this is so, is the basic rationale behind the existing policy of leaving most (virtually all) of research and development relating to farm machinery to the manufacturer -- the argument being that the manufacturer can cover the cost of this activity by the extra profits he can make. But a change such as that instanced above may also provide some benefit to farmers, and indirectly to consumers (with or without government intervention).

The distribution of gains associated with increased farm output are, on the other hand, even more problematical to forecast. The extent to which benefits are passed on depends largely on the elasticity of demand for the product concerned, and on discrete movements in demand -- unless there is institutional regulation, such as through marketing boards or guaranteed prices. Since the elasticity of demand for many farm products approaches unity, and since sudden expansions in demand are exceptional, it is reasonable to expect that increased output will cause prices to fall and that the benefit will be passed on to the consumers. However, in practice there are regulatory devices used in relation to many products, and others are sold on world markets where Canadian farmers may well face a more elastic demand for their share of the total market than exists for the product as a whole. Thus the benefits of innovation seem likely to benefit farmers and consumers, both.

From this discussion it is apparent that where the division of gains from innovation favours one segment of the economy to the exclusion of others, the government can and does redress this imbalance by playing a regulatory role. Similarly, by providing facilities for innovative programs, such as farm machinery evaluation, the government can foster the making of cost-reducing or output-increasing decisions. Thus to a considerable degree the whole process is determinable by government action, though the actual gains and their distribution will depend inevitably on the characteristics of many individual decision situations, and on the nature of the government action that is taken.

In view of this, and despite the difficulties in doing so, it seems desirable that the likely benefits be assessed, in order to estimate the amount that might reasonably be spent on farm machinery evaluation in Canada. This might be done in absolute or relative terms, for either individual farms or for the country as a whole. Though the projected figures vary widely from one method to another, the assessment can be approached on four different bases.

The first is to consider farm machinery costs as a proportion of total farm costs and to relate this to present expenditure on research into non-machinery aspects. In the short run, the level of costs might be accepted as a useful indicator of the importance of various resources in the farm business. In the long run, it is desirable for research funds to be spent where the marginal return is greatest, and this may bear no relation to the level of existing expenditure on any one facet of farm production. However, without the assessment of marginal costs and returns for each project, the proportion of total farm costs attributable to mechanization could serve as a broad indicator of the relative order of savings that might be achieved, and thus of the evaluation and research expenditure that is justifiable.

On this basis it is noted that expenditure on agricultural research and development, including that on farm machinery and mechanization, by the Canada Department of Agriculture exceeds $30 million per year. Since machinery costs on farms vary from about 40 to 60 per cent of total farm costs, and average, say, 50 per cent, it might be argued that approximately half of the research budget should be spent on farm machinery research and development, including evaluation -- that is, $15 million per year (it is presently about 1 per cent of this). Alternatively, if extra funds are available, an amount equal to that spent on biological research might also be spent on projects related to farm machinery -- that is, some $30 million per year.

A second assessment might be made on the basis of anticipated savings arising from the application of applied research and evaluation work. To do this it is necessary to consider some estimates. The fuel consumption of different tractors of comparable size varies under test from 10 to 20 per cent of the average (69). If this information was used in making tractor purchases, an expected saving of, say, 5 per cent might be assumed. In terms of average expenditure on fuel on Canadian farms, this represents a possible saving of $30 per farm each year.

Similarly, it is known that repair costs may generally be described as a probabilistic function for a population of machines.

Again it can be shown that two machines, operated under almost identical conditions, can have wide differences in their repair cost patterns (83). If, by selecting the more reliable machine, or by replacing a machine more expeditiously, a further saving of 5 per cent of repair costs could be made, then the average saving per farm would be another $25 per year.

In addition, large savings may be made by selecting the best-sized equipment for the job. Studies have shown that cost reductions of 10 to 20 per cent are possible (31). Not all farmers will need or be able to improve their investment decisions, but perhaps one in three might (see Appendix B). If these made a 10 per cent saving, this would be equivalent to about 3 per cent over all farms. On an average annual investment of about $1,500 per farm, this would give a further saving of about $45 per farm each year.

Together, these savings total $100 per farm each year. On the basis of 300,000 commercial farms in Canada, this represents a national saving of $30 million per year. This is approximately equal to the research budget of the Canada Department of Agriculture. However, if *one-tenth* of these savings could be made -- that is, saving $3 on fuel, $2.50 on service parts, and $4.50 on capital costs -- this would still add up to a gain of $10 per farm or some $3 million each year for Canada as a whole, without considering gains in productivity or benefits other than cost effects. In terms of the average farm business, the expenditure of $10 per year, in order to know more about the determinants of half its total costs, would not seem excessive in the light of the possible gains.

A third approach to the problem of assessing reasonable expenditure on a program of evaluation is by considering acceptable "search" costs. Large industries might frequently spend 3 to 5 per cent of total investment in a project assessing that project. In some cases the proportion spent might be considerably more than 5 per cent. If the Government of Canada was to expend *1 per cent* of total investment in evaluating the national outlay on farm machinery each year, it would be providing some $5 million annually (on the basis of annual sales of all farm machinery in recent years of some $500 million per year).

A fourth estimate of needed expenditure might be made in terms of the costs likely to be incurred in running an evaluation program. The Saskatchewan Agricultural Machinery Administration spent about

$200,000 per year, but was much too small an operation to evaluate all machinery on the market (2). To undertake a program on the same scale for the whole of Canada, the budget would need to be at least five times as large, without allowing for any different or additional projects.

Various rules of thumb are used in projected research costs. In general, the cost of keeping a scientist fully effective seems likely to be between three and four times his salary. This suggests an average cost per head of, say, $40,000 - $50,000 a year. This includes the operating costs of salaries for technical and secretarial assistance, and all other costs, including capital costs. Thus it should be possible to employ 20 scientists with about an equal number of technical staff for about $1 million a year. Once established, a team of this size could evaluate a large proportion of the major decision alternatives relating to farm purchase and use of machinery in Canada, though research activity may justify more extended program.

Even allowing an equal amount for capital costs, or for other activities such as research grants, the total budget of an institute set up to evaluate farm machinery might cost less than one-half of 1 per cent of the total annual expenditure on farm machinery in Canada. This amount is more than covered by expected savings based on even the most conservative estimates, and without even considering the possible indirect gains that might ensue from better designs or assistance to manufacturers in reducing their costs or improving their products.

All this is not to say that such gains will be achieved spectacularly in a short space of time. In fact, the presumption that they can be obtained at all assumes that many problems can be overcome. These include not only the conceptual and procedural problems outlined above, but also those concerned with getting the information used by farmers. This implies the need for an active policy of extension, and this may involve some reorientation of advisers as well as farmers. For this reason, the benefits from a program of evaluation may not be apparent for some time. On the other hand, benefits from this very applied scientific work should manifest themselves in a shorter time than those from many types of biological research.

Although it would seem desirable to have a rapid development of such a program in order to have some effect across as broad a front as possible, it is also of some importance that this program should not prejudice existing research work. If expansion were to occur very rapidly, so that the staff required were pulled out of universities and other places, the opportunity cost could exceed the gains. This would be particularly true if existing teaching programs relating to farm mechanization were to be adversely affected. The need to accommodate these considerations suggests that considerable administrative problems will be encountered in such a scheme.

Nevertheless, the possible benefits from such a scheme, and the trends that seem likely to enhance them, are such that a major program of farm machinery evaluation for Canada warrants serious consideration. The need for an information system to facilitate improved farm management has been recognized in setting up the "Canfarm" farm recording and analysis program. It must be recognized, also, that *ex post* analysis of farm records will not provide all of the data necessary for the guidance of future farm decisions. In particular, it will not be adequate to permit analysis of those aspects of farm production that are changing most rapidly. No aspect is changing more rapidly than farm machinery technology.

REFERENCES

1. Agricultural Machinery Administration. *Test Reports.* Numbers 161-2461, Department of Agriculture, Regina, Saskatchewan, 1960-63.

2. Agricultural Machinery Administration. *Annual Report.* Department of Agriculture, Regina, Saskatchewan, 1965.

3. American Society of Agricultural Engineers (ASAE). *Standards, Recommendations and Data.* Agricultural Engineers' Yearbook, 1967.

4. American Society of Agricultural Engineers. *Agricultural Tractor Test Code.* Machinery Test Standard: ASAE S209.2.1964.

5. American Society of Agricultural Engineers. *Conference Proceedings: Computers and Farm Machinery Management.* Chicago, Ill., December 1968.

6. Antipin, V. G. "Determination of Throughput of Combine-Harvesters", *Mekh. Elektrif. sots. sel. Khoz.* National Institute of Agricultural Engineering (NIAE) translation, No. 1, 1963.

7. Archer, Ralph C. *Feedback on Gratis Reports as a Tool for Improving Reliability.* American Society of Agricultural Engineers, Paper No. 63-617, 1963.

8. Archer, Ralph C. "Reliability Engineering: Its Application to Farm Equipment", *Agricultural Engineering.* Vol. 44, No. 11, October 1963.

9. Baillie, W. F., and Vasey, G. H. "Eight Medium Tractors Compared", *Farm Mechanization and Buildings.* No. 222, February 1968.

10. Baillie, W. F., and Vasey, G. H. "The Rating and Testing of Stock Model Goods in Accordance with Standard Test Codes", *Journal of Institution of Agricultural Engineers.* Australia, April - May 1968.

11. Barber, C. L. *Notes on European Trip.* Royal Commission on Farm Machinery, Ottawa, Working Paper, 1967.

12. Beem, Eugene R. "Consumer-Financed Testing and Rating Agencies", *Journal of Marketing*. January 1952.

13. Bilkey, Warren J. "Government and the Consumer Interest", *American Economic Review*. Vol. 47, No. 2, May 1957.

14. Brown, W. T., and Vasey, G. H. *Wheat Harvester Survey*. Wheat Industry Research Council, Australia, 1967.

15. Callen, P. W. *Selection of a Data Acquisition System as a Research Tool*. Society of Automotive Engineers, No. 670706, May 1967.

16. Canadian Standards Association. *Sampling Procedures*. CSA Special Publication Z 90, Ottawa, Canada, 1967.

17. Candler, W. "The Rate of Interest and the Second Hand Market for Farm Machinery", *Journal of Agricultural Economics*. Vol. 15, No. 3, June 1963.

18. Coales, J. F. "An Outline of Systems Engineering", *Journal of the Institution of Agricultural Engineers*. Vol. 24, No. 1, Spring 1969.

19. Cochran, William G. *Sampling Techniques*. Second Edition, New York: Wiley, 1954.

20. Crampin, D. J., and Dalton, G. E. "Replacement Models for Agricultural Machinery", *Farm Economist*. Vol. 11, No. 8, 1968.

21. Culbertson, A. T. "Air Force Turns Heat on Reliability", *Journal of Society of Automotive Engineers*. Vol. 73, No. 3, March 1965.

22. Dewisbarry, A. F. *The Laboratory Program Behind Massey-Ferguson's New Tractors*. American Society of Agricultural Engineers, ASAE Paper No. 65-662, 1965.

23. Dixon, J. "Uncertainty and Information in Agriculture", *Farm Economist*. Vol. 11, No. 4, 1967.

24. Domier, K. W. *Pumpability and Viscosity Tests of Crankcase Oils*. Canadian Society of Agricultural Engineering, ASAE Paper No. 66-011, June 1966.

25. Domier, K. W., and Friesen, O. H. *Performance Parameters of Tractors Equipped with Singles, Duals and Four Wheel Drive*. Canadian Society of Agricultural Engineering, June 1968.

26. Domier, K. W., and Persson, S. P. E. *Performance of Hay Conditioners*. Department of Agricultural Engineering, University of Manitoba, Winnipeg, Manitoba, April 1963 (mimeographed).

27. Domier, K. W., and Persson, S. P. E. *Performance Characteristics of Tractor Tires on Agricultural Soils*. American Society of Agricultural Engineers, and Canadian Society of Agricultural Engineering, ASAE Paper No. 67-139, June 1967.

28. Donaldson, G. F. "Allowing for Weather Risk in Assessing Harvest Machinery Capacity", *American Journal of Agricultural Economics*. Vol. 50, No. 1, February 1968.

29. Donaldson, G. F. "Factors Influencing Decisions on Farm Mechanisation", (a series of five items), *Farm Mechanisation*. Vol. 19, Nos. 217-221, September 1967 - January 1968.

30. Donaldson, G. F., and McInerney, J. P. "Combine Capacity and Harvest Uncertainty", *Farm Economist*. Vol. 11, No. 4, 1967.

30a. Donaldson, G. F. *Farm Machinery Safety: Physical Welfare Effects of the Man-Machine Interaction on Farms*. Royal Commission on Farm Machinery, Ottawa: Queen's Printer, Study No. 1, 1968.

31. Donaldson, G. F. *Farm Machinery Capacity: An Economic Assessment of Farm Machinery Capacity in Field Operations*. Royal Commission on Farm Machinery, Ottawa: Queen's Printer, 1970 (to be published).

32. Dunford, W. J., and Rickard, R. C. "The Timing of Farm Machinery Replacement", *Journal of Agricultural Economics*. Vol. XIV, No. 3, 1961.

33. Elfes, L. E. "Reliability Testing", *Tillage for Greater Crop Production*. Conference Proceedings, ASAE PROC-168, December 1967.

34. Ellis, B. *Basic Concepts of Measurement*. Cambridge: Cambridge University Press, 1968.

35. Emery, F. E. (Editor). *Systems Thinking*. Harmondsworth Middlesex: Penguin Books Limited, 1969.

36. FIEI and ASAE, *Standards - A Vital Tool in Engineered Agriculture*. Proceedings, Conference of the Farm and Industrial Equipment Institute and the American Society of Agricultural Engineers, Chicago, Ill., December 1965.

37. Fife, L. S. "Economic Considerations in Farm Equipment Management", *IBM Agricultural Symposium*. New York: Endicott, February 1962.

38. Fink, Harry, Jr. *Improving Design Quality with Computers - Harvesting Equipment*. Society of Automotive Engineers, No. 670721, September 1967.

39. Friesen, O. H., and Domier K. W. *1967 Traction Tests*. Manitoba Department of Agriculture and the Agricultural Engineering Department of the University of Manitoba, Manitoba: Queen's Printer, 1967.

40. Frisby, James Curtis, and Bockhop, C. W. *Influence of Weather and Economics on Corn Harvesting Machinery Systems*. ASAE Paper No. MC-66-306, March 1966.

41. Fussell, G. E. *Farming Technique from Prehistoric to Modern Times*. Oxford: Pergamon Press, 1965.

42. Grant, J. K. "Independent Machinery Testing Is not Necessary", *Massey-Ferguson (Australia) Review.* November - December 1966.

43. Harrison, H. P. *Functional and Durability Performance of Farm Machinery.* Brief presented to the Royal Commission on Farm Machinery, Ottawa, March 1967.

44. Heady, Earl O., and Krenz, R. D. *Farm Size and Cost Relationships in Relation to Recent Machine Technology.* Agricultural and Home Economics Experiment Station, Iowa State University, Bulletin 504, May 1962.

45. Hunt, Donnell R. "Efficient Field Machinery Selection", *Agricultural Engineering.* Vol. 44, No. 2, February 1963.

46. Hunt, D. R. "A Systems Approach to Farm Machinery Selection", *Journal of Institution of Agricultural Engineers.* Vol. 24, No. 1, Spring 1969.

47. Innen, Loren, and Heady, Earl O. *Cost Functions in Relation to Farm Size and Machinery Technology in Southern Iowa.* Agricultural and Home Economics Experiment Station, Iowa State University, Bulletin 527, May 1964.

48. Jeffers, J. P. W., and Staley, L. M. *Minimum Cost Forage Machinery Selection Related to Rainfall Probabilities.* ASAE Paper No. 67-148, June 1967.

49. Johnson, G. L. (Editor). *A Study of Managerial Processes of Mid-western Farmers.* Ames: Iowa State University Press, 1961.

50. Jones, J. A. *Dollars and Sense in Machinery Buying.* Alberta Department of Agriculture, Publication No. 825-7, 1968.

51. Kloth, W. "The Problem of Durability in Agricultural Engineering ", *Technikinder Landwirtschaft.* National Institute of Agricultural Engineering (NIAE) translation, Vol. 23, No. 10, 1942.

52. Lee, J. H. A., and Karkanis, E. A. "Effect of Ground Speed and Type of Fertilizer on Metering Accuracy", *Transactions of the ASAE.* Vol. 8, No. 4, 1965.

53. Lewis, H. A., and Symes, O. L. *Selection of Farm Power.* University of Saskatchewan, Extension Bulletin No. 148, 1963.

54. Link, David A. *A Method of Predicting the Capabilities of a System of Farm Field Machinery Operating under Realistic Weather and Crop Conditions.* VIth International Congress of Agricultural Engineering, (Lausanne, Switzerland), Vol. III, September 1964.

55. Link, David A., and Bockhop, C. W. "Mathematical Approach to Farm Machine Scheduling", *Transactions of the ASAE.* Vol. 7, No. 1, 1964.

56. MacHardy, F. V. "Programming for Minimum-Cost Machinery Combinations", *Canadian Agricultural Engineering.* Vol. 8, No. 1, January 1966.

57. MacHardy, F. V. *Economics of Farm Machinery Utilization.* Brief presented to the Royal Commission on Farm Machinery, Ottawa, March 1967.

58. Manby, T. C. D. *Official Tests of Agricultural Tractors.* National Institute of Agricultural Engineering (United Kingdom), reprinted from Annual Report, 1957-58.

59. Manby, T. C. D. *Interpretation of Tractor Test Reports by the User.* FAO, Rome, Informal Working Bulletin, No. 19, 1960.

60. Manby, T. C. D. "The Measurement of Tractor Performance", *Proceedings Institute of Mechanical Engineers.* (Automobile Division), No. 4, 1961-62.

61. Marley, J. S., and Bockhop, C. W. *Field Work Completion Probabilities for Row Crop Production.* ASAE Paper No. 66-671, December 1966.

62. Mitchell, J. K., and Beer, C. E. "Effect of Land Slope and Terrace Systems on Machine Efficiencies", *Transactions of the ASAE.* Vol. 8, No. 2, 1965.

63. Moberg, A. H. *Tractor Safety Cabs, Test Methods and Experience Gained During Ordinary Farm Work in Sweden.* National Swedish Testing Institute for Agricultural Machinery, Uppsala 7, Sweden, 1965.

64. Morris, W. H. M., and Groenewald, J. A. *The Utilization of Data from Work Study for Decision Making in Farm Management.* XIV CIOSTA/IRL Congress, Geneva, 1968.

65. McDonough, A. M. *Information Economics and Management Systems.* New York: McGraw Hill, 1963, particularly Chapters 1-6.

66. National Institute of Agricultural Engineering (NIAE). *Test Reports.* British Society for Research in Agricultural Engineering, Silsoe, Bedfordshire, England, Nos. 304 to 353, 1962-63.

67. National Swedish Testing Institute for Agricultural Machinery. *Swedish Test Reports.* Statens Maskin-Provninger, Uppsala 7, Sweden.

68. Neal, A. E., and Cooper, G. F. *An Approach to Laboratory Testing of Harvest Equipment.* ASAE, Paper No. 67-147, June 1967.

69. Nebraska State. *Nebraska Test Reports.* University of Nebraska Agricultural Experiment Station, Lincoln, Nebraska, U.S.A., Nos. 379 to 980, 1960-65.

70. Nyborg, E. O. "A Test Procedure for Determining Combine Capacity", *Canadian Agricultural Engineering.* Vol. 6, No. 1, January 1964.

71. O'Callaghan, J. R. "The Systems Approach to Engineering Design", *Journal of Institution of Agricultural Engineers*. Vol. 24, No. 1, Spring 1969.

72. Organisation for Economic Co-operation and Development. *Economic Aspects of Mechanization in Agriculture*. Paris, France, March 1966.

73. Organisation for Economic Co-operation and Development. *Draft OECD Standard Procedure for the Testing of Combine Harvesters*. Paris, France, February 8, 1967.

74. Organisation for Economic Co-operation and Development. *OECD Standard Code for the Official Testing of Agricultural Tractors*. No. 79, January 1966.

75. Organisation for Economic Co-operation and Development. *Summary of Tractor Tests Carried Out Under the OECD Tractor Code*. Autumn 1966.

76. Organisation for Economic Co-operation and Development. *Standard Testing Procedure for Fertilizer Distributors*. Paris, France, March 1967.

77. Organisation for Economic Co-operation and Development. *OECD Standard Code for the Official Testing of Small Engines Used in Commercial Horticulture*. Paris, France, April 1967.

78. Parish, Ross. "A Consumers' Report on 'Choice'", *The Bulletin*. Sydney, Australia, 1963.

79. Peck, J. A. *Farm Machinery in Perspective*. Saskatoon: Modern Press, 1965.

80. Pfundstein, K. L. "Optimizing Farm Tractor Design and Use - An Approach", *Transactions of the ASAE*. Vol. 3, No. 2, 1960.

81. Phillips, J. "A Revised Approach to Marketing", *Review of Marketing and Agricultural Economics*. Vol. 36, No. 1, March 1968.

82. Preston, T. A. *Outline of a Farm Work Study Unit*. Brief presented to the Royal Commission on Farm Machinery, Ottawa, March 1967.

83. Puzey, George A., and Hunt, Donnell. *Field Machine Repair Cost Patterns*. American Society of Agricultural Engineers, ASAE Paper No. 66-673, December 1966.

84. Redmond, G. N., and Webster, F. M. *Chrysler's 5 and 50 Warranty Program*. Automotive Engineering Congress, Detroit, Michigan, SAE No. 660059, January 1966.

85. Reece, F. N., and Larson, G. H. "Performance of Fifty Farm Tractors", *Transactions of the ASAE*. Vol. 9, No. 1, 1966.

86. Reethof, Gerhard, and Weber, G. W. *Probabilistic Design Tools Promise Higher Levels of Initial Reliability*. Jet Engine Dept. General Electric Co., Society of Automotive Engineers, Paper No. 650210, 1965.

87. Rich, Barrett G.; Smith, O. A.; and Korte, Lee. *Experience with a Formal Reliability Program.* Construction and Industrial Machinery Meeting, Milwaukee, Wisconsin, SAE No. 670731, September 1967.

88. Riggs, J. L. *Economic Decision Models for Engineers and Managers.* New York: McGraw-Hill, 1968.

89. Rutledge, P., and MacHardy, F. V. *The Influence of the Weather on Field Tractability in Alberta.* Canadian Society of Agricultural Engineering, June 1968.

90. Sargent, Hugh W. *Consumer-Product Rating Publications and Buying Behaviour.* Urbana: University of Illinois, 1959.

91. Sayler, R. L. *Corn Harvesting Equipment - Information Dissemination to Dealers and Farmers.* American Society of Agricultural Engineers, ASAE Paper No. 65-565, 1965.

92. Seferovich, G. H. "1970 - How Much Horsepower? - How Many Tractors?", *Implement and Tractor.* April 1967.

93. Segall, Alexander. *A Survey of the Attitudes and Behaviour of Prairie Farmers in Regard to the Purchasing of Farm Machinery.* Royal Commission on Farm Machinery, Ottawa, 1969.

94. Slavkovic, B. "Selection of Working Speed for Combine-Harvesting", *Poljoprivredna Tehnika.* National Institute of Agricultural Engineering (NIAE) Translation, Vol. 2, No. 2, 1962.

95. Southwell, P. H. *An Analysis of Tractor Purchase Costs and Efficiencies.* American Society of Agricultural Engineers, and Canadian Society of Agricultural Engineering, ASAE Paper No. 67-124.

96. Sowell, R. S., and Link, D. A. *Dynamic Programming Formulation of the Machinery Replacement Problem with Application to the Replacement of Cotton Pickers.* American Society of Agricultural Engineers, ASAE Paper No. 67-616, December 1967.

97. Stigler, G. J. "The Economics of Information", *Journal of Political Economy.* Vol. 69, No. 3, June 1961.

98. Sulek, J. J., and Lane, D. E. *Predicting Varying Power Fuel Economy of Tractors from the Maximum Power Fuel Economy.* American Society of Agricultural Engineers, ASAE Paper No. 67-601, December 1967.

99. Thompson, F. A., and Stein, W. D. *The Titan Reliability Program.* Air Transport and Space Meeting, Society of Automotive Engineers, SAE No. 856 B, April 1964.

100. Thompson, J. L. *Agricultural Machinery Costs.* Canada Department of Agriculture, Publication 1291, 1966.

101. United Grain Growers. "Summary of Farm Machinery Testing Questionnaire", *The Grain Grower.* United Grain Growers, Limited, Winnipeg, Manitoba, October 1967.

102. United Nations, FAO: *List of Legislation Enacted by Some Countries Concerning Agricultural Tractors and Machinery.* Informal working paper prepared by the Land and Water Use Branch, Agriculture Division, in Co-operation with the Legislative Service, Rome, 1957.

103. Van Gerpen, H. W. "Using Digital Computers in Farm Equipment Design", *Agricultural Engineering.* Vol. 49, No. 7, July 1968.

104. Weiss, E. B. "Marketers Fiddle While Consumers Burn", *Harvard Business Review.* Vol. 46, No. 4, July 1968.

105. Whelsley, T. D. *A Mobile Digital Data Acquisition System - An Essential Link to Computer Processing of Test Results.* SAE Paper No. 68-0610, September 1968.

106. Wolfe, Robert R.; Liljedahl, J. B.; and Peart, R. M. *Method for Accelerated Reliability Testing of Complex Systems.* American Society of Agricultural Engineers, ASAE Paper No. 65-144, June 1965.

107. Zimmerman, Mark. "Dual-path R & D to Invent a New Machine", *Implement & Tractor.* Vol. 83, No. 5, February 1968.

108. Zimmerman, Mark. "Toward 'Service Proof' Machinery", *Implement & Tractor.* Vol. 83, No. 1, January 1968.

APPENDIX A

PUBLIC ATTITUDES AND REACTIONS CONCERNING FARM MACHINERY EVALUATION

The opinions and feelings of various individuals and groups in the agricultural community may provide an indication of the level of concern about this issue, and may be regarded as an important consideration in assessing policy alternatives. The Commission was able to take three different soundings of those attitudes: (1) through the public hearings held across Canada, (2) in a survey study made of machinery purchasing on the Prairies (93), and (3) by the action of a commercial organization that sent a detailed questionnaire to its members and presented the results to the Commission (101). The major findings are summarized below.

Hearings Evidence -- The majority of farmers and farmer organizations giving evidence before the Commission favourably endorsed the idea of "testing". There were no contrary views expressed, though there were several qualifications -- particularly to the effect that test information was available too late, and that the data were too general and required local interpretation. The cost of $2 per farm (based on the AMA budget) was acceptable to everyone asked. The data provided by manufacturers were considered inadequate, and there was a suggestion that manufacturers should pay for independent evaluation for the farmer's benefit.

All of the provincial government agricultural representatives considered "testing" desirable, though they disagreed on how it should be organized. The three Prairie Provinces would like to see a program established like that of the AMA in Saskatchewan. Alberta suggested that it be financed on a joint federal-provincial basis, while Manitoba sought a scheme based on an extension of university programs. British Columbia urged that more work be done on specialist machines. Only those from the Maritime Provinces were unenthusiastic about a "testing" program, but they endorsed the idea of a modified program which they considered would be less expensive than durability and reliability "testing". The Ontario group emphasized the need for "local" information and objected that most test data were available too late.

University staff from various centres supported the idea of machinery evaluation. Professor H. P. Harrison, former director of the AMA, favoured an independent organization, and emphasized the shortage of capacity information available. Professor Harrison also asserted that manufacturers often do not do adequate testing, and that their field testing is often restricted to a few particular production areas. He suggested, too, that durability testing in field conditions was the cheapest way to undertake a series of tests of operating characteristics. Other staff of the University of Alberta suggested the setting up of a farm work study institute to provide farmers with machinery performance data and an analysis that would facilitate better selection and use of farm machinery. Professor Jean-Marie Fortin advocated a "testing" program for Québec in conjunction with Laval University. Professor O. L. Symes, University of Saskatchewan, suggested that "testing" should be part of a wider program of research and development.

Most manufacturers expressed the belief that their products were very adequately "tested" and that all the information the farmer could use was made available through brochures and dealers' handbooks. They emphasized the amount of "testing" done on prototype and production models. It was stated that a period of three to five years was often involved in development, prototype testing in laboratory and field, and production-line testing under varying conditions in different locations.

It was pointed out that farm machinery is not a mass production good and that since production runs are not large, the amount of "testing" that can be done is limited. It was also suggested that it was unfeasible to evaluate machines under all possible conditions. The companies noted that machines were designed to be sufficiently versatile to suit a wide range of conditions, but that evaluation under all these conditions would add too much to the price of a machine.

In general, manufacturers were not in favour of independent "testing" schemes. They observed that the results were available too late to do the farmer much good, since many machines were sold and in use before the information was available. Faults discovered by testing agencies were said to be usually corrected before the problem was reported in test findings. There was also doubt expressed as to the usefulness of technical data to farmers, as it was contended that company reputation, dealer relations and neighbours' experiences were much more important in farmers' decision-making. It was also noted that "on-farm" trials were often used in evaluating a new product, and that modifications often flowed from these. To this extent, independent testing was considered to be duplicating.

Replying to questions, several manufacturers agreed that their test data could be released, but they noted that it would probably be meaningless to farmers or their advisers. There were problems in predicting machine performance because, it was claimed, standards were lacking. All manufacturers who were asked agreed that they could make evaluations under certain conditions and publish the results. It was again stated that the farmer did not seek detailed technical or economic information. However, after a prolonged exchange, Mr. John Staiger, President, Massey-Ferguson Industries, Inc., assented that if sufficient concern was expressed, the industry could and would make its data available -- and furthermore that "the first several competitors to make this kind of information available would have a competitive edge".

Survey Study -- In the survey study carried out for the Commission it was possible to explore the attitudes of a group of farmers in more detail. In general the farm operators interviewed strongly disapproved of the type of testing done by machinery companies -- 73 per cent displayed a negative attitude. Many farmers stated that sufficient testing was not done by the manufacturer before machinery was sold to the farmer, and that the farmer was "still the major tester" of new machinery.

On the other hand, 62 per cent of the sample felt that available sources of information about new farm machinery were adequate. Another 34 per cent, however, expressed dissatisfaction with existing sources and suggested that alternative measures were necessary. Thirty-five per cent of this group simply stated that "more" or "more honest" information was required. A further 38 per cent specifically stated that additional information based on evaluation of farm machinery by an independent agency (or more specifically a government agency) should be made available to farmers.

This same study provides considerable evidence of the imprecise rules of thumb that farmers use in making their farm machinery decisions. For instance, 45 per cent did not appear to have any specific method of determining the amount of capital to be invested in new farm machinery. Of the rest, 18 per cent said that the major consideration was "amount of income", and another 19 per cent said it was the "need" for a new machine. There was no evidence to suggest that if more relevant information was available, farmers would not make use of it.

Farmer Questionnaire -- This mail-in survey schedule was sent to local board members of United Grain Growers Limited, in Manitoba, Saskatchewan and Alberta. In answer to direct questions, 88 per cent of the 761 respondents indicated that they would like to have farm machinery sold on the Prairies, tested on the Prairies. Some 70 per cent indicated that manufacturers should be "forced" to test all machines sold.

The reasons behind the high proportion reacting this way were that (i) "performance and durability" were much poorer than expected, and (ii) the information obtained from the dealer is considered suspect. Almost 25 per cent of the respondents found more than half of their purchases were not satisfactory in terms of performance and durability. Only 5 per cent were satisfied with all machinery they bought. Similarly, 63 per cent felt they did not have enough information; 30 per cent felt they had been misled with false information; and only 6 per cent were satisfied with the information they could obtain prior to purchase of a machine.

In reply to other questions, 42 per cent indicated that they would like all machinery evaluated, but given a limited choice, some 40 per cent opted for tractors and another 40 per cent for harvesting equipment. (These are the largest items of expenditure and the machines most involved in time-restricted operations.)

When asked who should set up an evaluation organization, 78 per cent suggested either provincial, federal or some joint government responsibility. When offered a variety of ways in which such an organization could be financed, 36 per cent chose combinations in which the farmer would be required to pay towards the service provided.

In comparing the replies to the *survey* and the *questionnaire*, the reactions seem somewhat different. This could be a reflection of the fact that a more passive question will get a less positive answer. However, it might also arise because the survey sample was taken from "all farmers" while the questionnaire sample is from "local board members". Since the latter are more likely to be group leaders, theirs may be a more informed opinion or perhaps more positive opinion than that of the farm population as a whole.

APPENDIX B

LEVEL OF MACHINE UTILIZATION IN HARVESTING ON THE PRAIRIES

In order to make some assessment of the difficulty confronting a farmer in the purchase of adequate machinery, an analysis was made of the level of use of different-sized combines in certain areas of Saskatchewan. To do this, data were obtained from farm surveys completed in recent years by the Economics Division, Prairie Regional Office of the Canada Department of Agriculture. The combine models held on farms were identified and assigned to one of three categories -- small, medium or large -- on the basis of their static physical characteristics. The acreage of cereals harvested using the combine was noted for the year of the survey.

The average (mean) acreage covered by each class of combine is shown in Table B.1. The acreage distributions were approximately normal, and so were subjected to tests of significance. There was found to be no significant difference (at the 95 per cent confidence level) between the acreages covered by the small and medium classes of combine, though there was between small and large, and medium and large. The lack of difference between the small and medium groups suggests either imprecise classification of the machines in the two categories, or that farmers, for some reason, tend to physically extend small combines more than medium ones.

TABLE B.1

COMBINE CLASSES AND ACRES COVERED

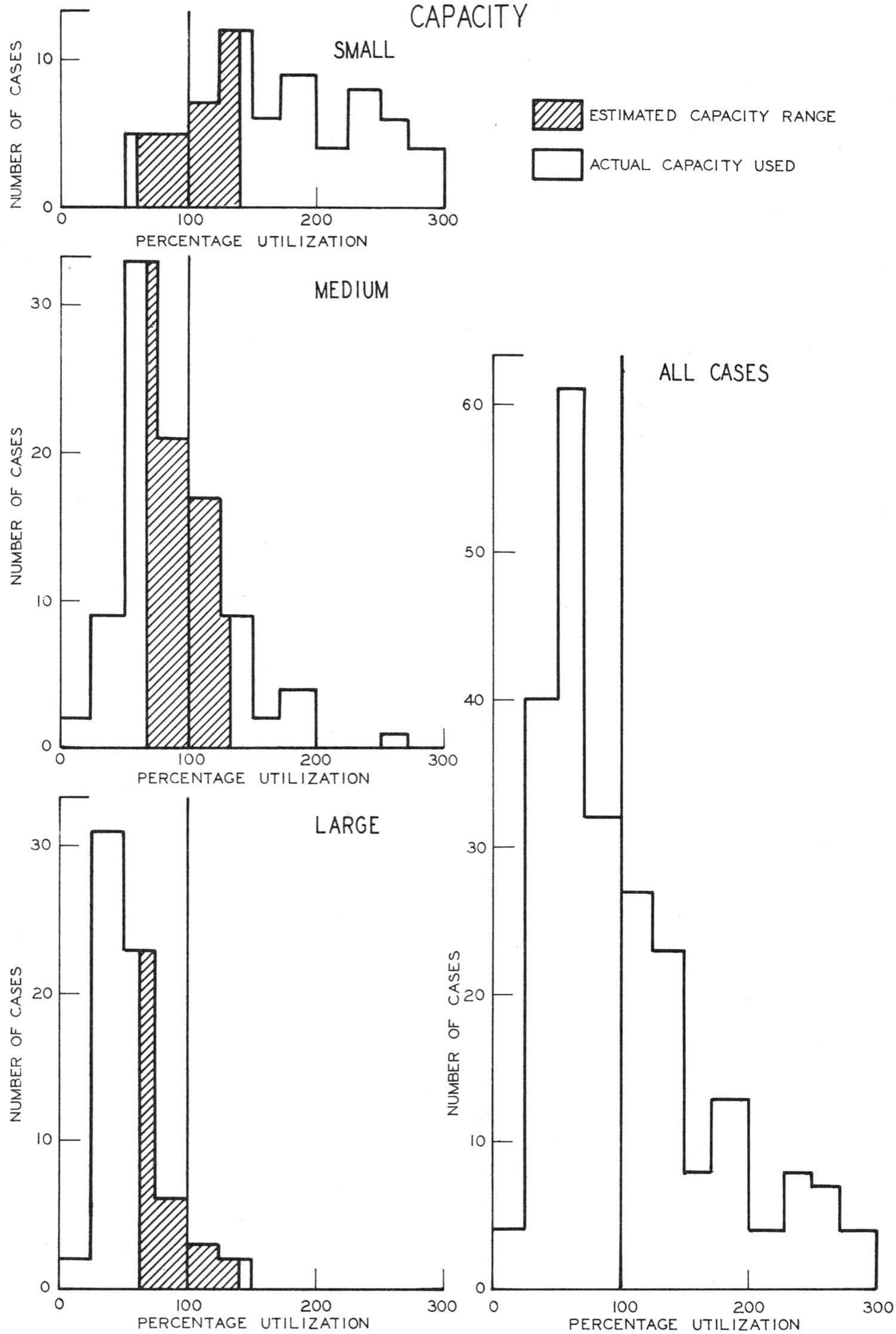
Combine Size	Small	Medium	Large
Number sampled	66	98	64
Mean acres	452	465	890
Standard deviation	197.8	210.6	226.6
Coefficient of variation	43.7	45.3	38.4

To make a further assessment of the accuracy of farmers' decisions, the acreage covered in each case was compared with estimated capacity ranges. These were ascertained from a separate study in which simulation models were used to assess the minimum-cost capacity ranges for a series of combines when operated on the Prairies (31). Using the mid-point of the range as an arbitrary optimum capacity, the percentage utilization was calculated. The results are presented in Figure B.1. These suggest that many farmers with small and large combines would have reduced their operating costs by having a medium-sized machine. Even if the estimated capacity ranges are not accepted, the very wide range of used capacity alone suggests that some error has been made in selection.

Of course, no such startling conclusion can be presented without several caveats and qualifications. Since the "capacity used" figure refers to the acreage harvested in one year only, it is possible that a wrong indication has been obtained and that the level of use in previous or subsequent years would justify the purchase decision. Since the age of the machines was not ascertained, it is possible that some farms with apparent excess capacity were using older, larger machines to harvest a smaller acreage -- as would seem appropriate. There is also the possibility that the combines held on farms were used for custom work on other farms. A check on the survey data revealed that of 68 cases showing excess combine capacity, seven were in fact used on outside custom work in the year of the survey. Alternatively, of 47 cases with inadequate capacity, six hired additional custom services in the year studied.

FIGURE B-1

PERCENTAGE UTILIZATION OF ESTIMATED COMBINE CAPACITY



In assessing the practical implications of the presented results, the financial situation and the risk aversion of the farmer may also be important. The smaller farmer may have less access to funds for investment. Because of his economic circumstances, he may use an older combine; and in the total population of combines on farms the older ones are also smaller. In terms of risk aversion, the larger farmer may be more interested in trying to guarantee a particular level of income than to minimize cost. It can be shown, too, that the degree of risk involved increases with the size of business. It can also be shown that additional capacity is often risk-reducing even when cost-increasing.

The over-all results suggest, however, that there is scope for farmers to make more accurate decisions if the information were available to permit it.

APPENDIX C

MEASUREMENTS REQUIRED FOR FARMERS' MACHINERY DECISIONS

The aim of the farmer can generally be interpreted as the maximizing or minimizing of an objective function relating to the whole farm. It follows that any farm machinery investment decision, if it is to be consistent with such an aim, must take into account all the interdependencies such a decision has with the rest of the farm plan.

How far such interdependencies are taken into account depends on the sophistication of the planning tool used. However, the point has already been made that the more accurate and realistic the planning models become, the greater is the detail and quantity of data required.

Figure C.1 outlines many of the variables thought to be relevant in deciding farm machinery investment policy. All are theoretically relevant, though in practice some may be of little significance. The sophistication of the analytical method will depend upon how significant some of the factors are judged to be, and on the costs of data retrieved and of running the model in the computer.

The farmer, to make a comprehensive decision, should have the values of the various variables listed for all possible machine alternatives, including those of the present machine if there is one. In this way the decision as to whether to replace, and if so with what, may be made.

FIGURE C-1: VARIABLES RELEVANT IN FARM MACHINERY MANAGEMENT DECISIONS

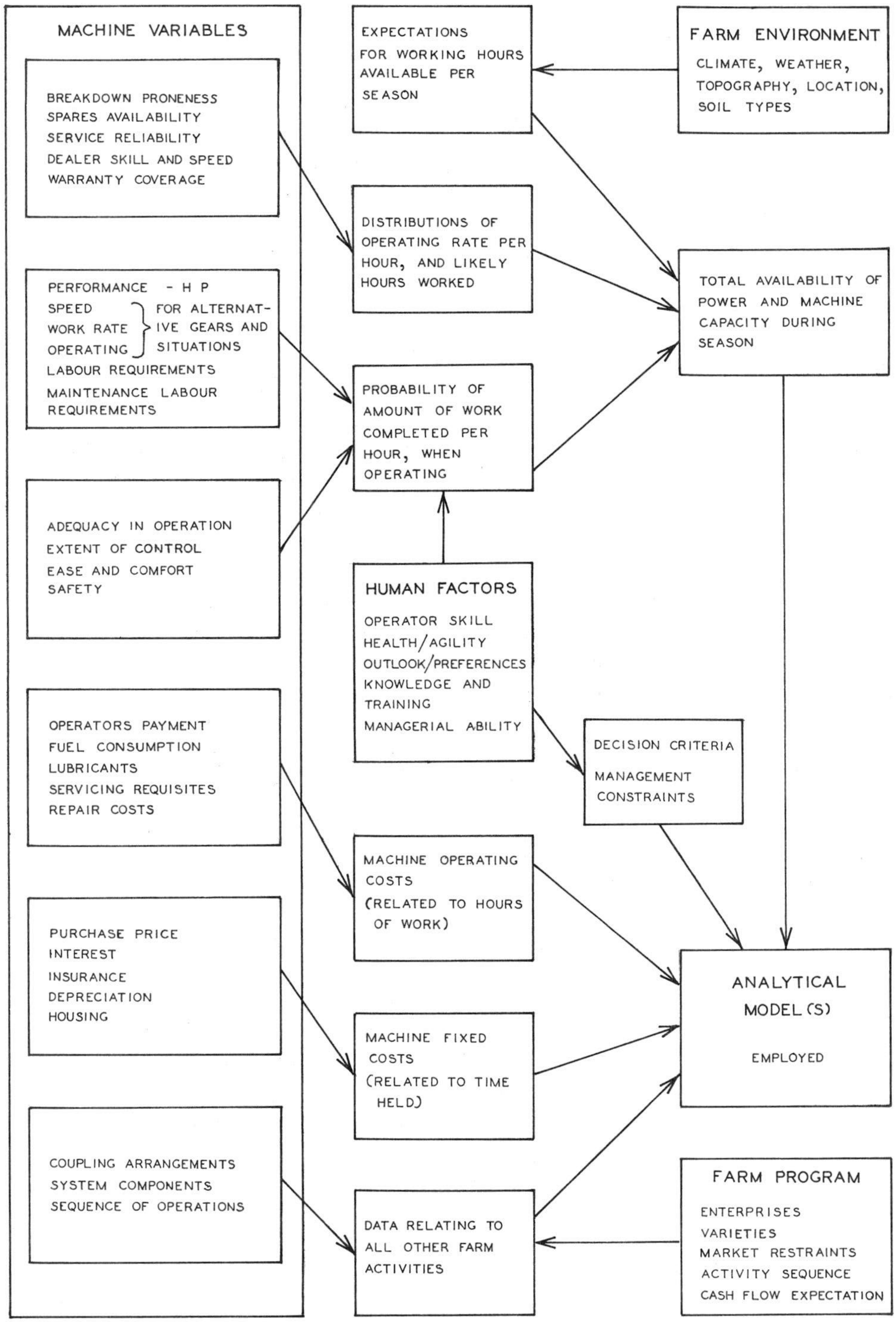


TABLE C.1

MACHINERY MANAGEMENT DECISIONS

Decision	Relevant Variables
1. Type of machine	a) use requirement (type of operation) - machine or no machine - replacement b) flexibility (multipurpose) c) versatility (effectiveness within a crop) d) auxiliary systems (existing equipment)
2. Machine make	a) machine performance b) dealer standing (interpersonal relationship) (dealer reputation) c) dealer service d) personal preference (match other machinery) e) dealer proximity and availability f) size of company (long, short, short short-line)
3. Machine model	a) capacity (over- or undersized) b) price - value per unit - alternative capital use c) ease of operation d) ease of service - time required - frequency, etc. e) operating cost function f) reliability and durability
4. Replacement time	a) operating costs b) reliability c) improvements in design d) changes in farm production setup e) spares and service availability

Note: Many of the criteria will be used for more than one decision. Also there is substantial interaction between the decisions. One decision may affect the others.

TABLE C.2

DECISION ANALYSIS TOOLS AND THEIR REQUIREMENTS

Analytical Method	Decision Involved	Variables Considered	Measurements
Budgeting	Mechanize Purchase Replacement Capacity Capital use	Total cost Average cost Marginal cost Operating costs Overhead costs	Machine cost curves vs. capacity Repair costs, fuel, oil and grease costs, depreciation, housing, insurance
Break-even analysis	Machine replacement Capital use To mechanize To purchase	Operating costs Planning time	Repair costs, fuel, oil and grease costs, depreciation, housing, insurance
Production functions	Capacity Cost alternative	Rates of work Price Operating costs	Acres, speed, efficiency, yield, usable HP, farmer's price
Replacement models	Replacement time	Operating costs Interest charges Purchase price Trade price	Repair costs, fuel and lubricants, market values, depreciation, extent of wear and tear
Network analysis	Capacity, operating system Cost alternative Capital use	Performance rating Rates of work Price Operating costs	Acres, speed, efficiency, yield, usable HP, farmer's price
Simulation models	Capacity Cost alternative Optimum usage Capital use	Performance rating Rates of work Price Operating costs	Acres, speed, yield, efficiency, usable HP, farmer's price
Linear programming	Capacity Cost alternative Optimum usage Capital use	Performance rating Rates of work Price Operating costs	Acres, speed, yield, efficiency, usable HP, farmer's price
Dynamic programming	Capacity Cost alternative Capital use Replacement	Price Operating costs Planning restraints	Acres, speed, yield, efficiency, usable HP, farmer's price, repair costs, fuel, oil and grease costs, depreciation, housing, insurance

Figure C.1 is a static flow chart. Obviously, expectations as to the future values of these variables may be relevant as well. Dynamic planning tools are available to tackle such possibilities, and in this way, for instance, replacement policy and estimates of obsolescence may be explicitly taken into account.

Break-even analysis, budgeting, and linear programming belong to the same genre of planning model. They are all concerned with the effect of discrete changes in the levels of variables, and emphasize the distinction between fixed and variable costs. Relationships are usually assumed to be linear. Programming methods become more useful as the scope of investment and farm plan alternatives become large. Budgeting and break-even analysis are likely to use a fairly arbitrarily determined single-valued estimate for machine variables, and thus the accuracy from these source boxes does not need to be so great.

Cost-curve analysis represents the marginal approach to decision-taking by deriving curves for average total cost over acres. This method makes most use of data on machine operating and fixed costs, and does not assume linear relationships. In general, the *range* of data required is greater, though the previous tools discussed can be extended to approach marginal analysis.

Simulation and Monte Carlo programming are probably the most comprehensive tools and make use of data from all source boxes. In particular, uncertainty generated through the Environment box may be simulated if the distribution of the disturbing variables can be estimated. Likewise, that of machine breakdown for any period may be assessed and allowed to enter the model.

It can be seen that the decision data required differ from much of the engineering data presently published, in that measurements are required of *operating* characteristics. In addition, several of the variables may not be precisely measured or even specified on any scale, and probability distributions are needed for many variables.

PUBLICATIONS OF THE ROYAL COMMISSION ON FARM MACHINERY

Reports

Special Report on Prices of Tractors and Combines in Canada and Other Countries
(Z1-1966/4-1-1, $2.50)

Available in French:

Rapport Spécial sur les Prix des Tracteurs et des Moissonneuses-Batteuses au Canada et dans d'Autres Pays
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Studies

1. Farm Machinery Safety: Physical Welfare Effects of the Man-Machine Interaction on Farms
   - Graham F. Donaldson
   (Z1-1966/4, $1.00)

   Available in French:

   La Sécurité Agricole: Répercussions sur la Santé de l'Interaction de l'Homme et de la Machine dans les Exploitations Agricoles
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   - N.B. MacDonald, W.F. Barnicke, F.W. Judge, K.E. Hansen
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3. Productivity in the Farm Machinery Industry: A Comparative Analysis between Canada and the United States
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4. Farmers' Attitudes to Farm Machinery Purchases: A Survey Conducted in the Prairie Provinces, in Mid-1967
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5. The Prairie Farm Machinery Co-operative: "The Canadian Co-operative Implements Limited"
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Mimeographed Studies Prepared for the Canadian Agriculture Congress - Ottawa, 1969

Farm Tractor Prices in Canada Compared with Those in England and Other Countries

Les Prix des Tracteurs Agricoles au Canada en Comparaison avec Ceux d'Angleterre et des Autres Pays

Farm Machinery Costs and Productivity

Coût et Productivité des Machines Agricoles

Technological Changes in Farm Machinery and Canadian Agriculture

Les Transformations Techniques dans le Domaine de l'Outillage Agricole et Leur Portée sur l'Agriculture Canadienne

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Note: These studies can be obtained from the Royal Commission on Farm Machinery, Ottawa.