MATERIALS HANDLING ON THE FARMSTEAD
AN ANALYTICAL APPROACH

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by

CARL AXEL RONNFELT

AN ABSTRACT

Submitted to the Michigan State University of
Agriculture and Applied Science in partial
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ABSTRACT

Materials handling on the farmstead is becoming of increased relative importance because of the larger specialized units in today's farming and due to the comparatively high mechanization in other phases of farm work.

In industry, materials handling studies organized in the field of industrial or management engineering have been carried on for a long time. The handling problems on the farmstead being somewhat different from those in industry, can not to any great extent be solved with techniques now used in industry; flow diagrams and flow process charts are examples of industrial techniques that could be used.

Industrial materials handling analysis is worked mainly as a traffic problem, main factors in the analysis being:

1. Unit loads of packaged or baled material
2. Speed of travel
3. Distances traveled
4. Scheduling and routing for handling equipment
5. Distribution of storages with respect to the locations where material is used

Main interest in farmstead materials handling can be concentrated around the following possibilities:

1. Changing materials characteristics e.g. fluidize
2. Eliminate handling through self-feeding or other arrangements in the layout
3. Equipment that is designed not only for transport but also for transfer of material, facilitating mechanization or automation of complete systems.

With the interest centered around the three factors material, layout and equipment, it is still difficult to determine the influence of each one of these factors on the materials handling. Weight, volume, distance, etc. which are used as units in industry give generally no good over-all measure for a materials handling problem. Time in man-hours and cost are the only meaningful measurements to determine the influence of the different factors in the solution of a materials handling problem.

The main requirement for a cost comparison are good time standards for methods where man labor is involved. Such standards are not available as yet, and development of such data is an urgent need for careful selection of methods. Standard data should be developed from methods studies and improvements and not represent averages from a number of farms.

Once in possession of time standards the rest of the cost computations are comparatively simple. Selection of appropriate interest rate and service life for equipment and buildings is important for a good result. The interest rate has to be determined with respect to return on money in alternative uses. Service life estimates must consider wear and deterioration as well as obsolescence. Limitations in service life due to wear can be predicted from wear tests within reasonable limits. Data sheets are developed that can be used for the computational procedure. Obsolescence usually being more difficult to predict, is of great importance for structures and some equipment with a long physical life. Considerations should be given to the cost of inferiority in a present system when other alternatives are accepted or rejected. A continuous follow-up on methods development would give information for better predictions of present and future inferiority, and facilitate appropriate replacements. Acceptance of new techniques at appropriate time is going to be a most important decision for a prosperous agriculture in the future.

Money being scarce, the allocation of resources between alternatives is important. Return on money in other alternative uses in mechanization on the farm or for other production factors has to be considered. The efficiency due to scale of operation should be considered, and tends to furthermore encourage the development of larger units.

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CHAPTER I

INTRODUCTION

In periods of rapid development farmers and manufacturers are sometimes ahead of research in adapting new methods. Some farmers buy and some manufacturers sell equipment and buildings that cannot be justified from cost or other viewpoints. Yet some farmers hesitate too long before they adopt new methods. Both types of farmers encounter losses or reduced income that to some extent could be avoided with careful planning.

There is a tremendous development going on right now in the area of farm materials handling. New equipment and buildings have been presented to the farmers and several different solutions have developed for mechanization of nearly all jobs that are connected with materials handling on the farmstead. Still more hand labor is used in work around the farmstead than in field work and it often appears to be some disproportion between the often highly mechanized fieldwork and the sometimes primitive methods used in caring for the livestock.

Obviously there is often too little planning behind today's decisions in farm mechanization, often because of lack of basic information. The area of farm materials handling as being an unorganized field is one of the most difficult phases as far as decision making on farm mechanization is concerned.

One approach to the problem is to see what has been done in the area of materials handling in industry, where handling has been a recognized problem for a long time, and has been carefully studied.

This thesis will be an attempt to go through industrial techniques for materials handling analysis and to discuss and determine the possibilities of these techniques being applied in agriculture. Special consideration will be given the problem of materials handling on the farmstead for the livestock enterprises.

CHAPTER II

REVIEW OF LITERATURE

A broad survey of industrial management techniques and their possible application in agriculture was made in 1951 (54). Mostly discussed with the "Farm Work Simplification" movement as a basis, it was concluded that the field of farm management had developed only part of the broad field that management in industry has. The case study technique used in industry was opposed to the comparative study that has been mostly adopted in farm management. Case study is the study of a single method or operation to improve it, while comparative study begins with many existing methods and from them makes a selection of the best elements and synthesizes them into an improved method. The development of farm management in a framework of economics and production sciences was given as a reason for the differences from industrial management, that has relied heavily upon engineering in its development. Time and motion study techniques, production planning and control, methods studies, plant layout and materials handling are main points in industrial management, while farm management has been limited mostly to the question of combination of enterprises.

Four major categories of problems in industrial management are:

1. Planning what to produce
2. Techniques in planning and controlling operations
3. Techniques in improving operation methods
4. Techniques in attainment of personnel cooperation

Characteristics in farming hindering the application of scientific management was pointed out to be the few repetitive tasks, the size of the business, the scale of operation, the diversity in production and the lack of concentration in production.

The same hinderances to the application of scientific management in agriculture were mentioned in another work (47) published in 1952, and primarily dealing with methods studies, which are defined as organized applications of common sense to find easier and better methods of doing work. The difference between the case study and the comparative approach mostly used in agricultural studies was noted and the limitations of the latter method were indicated. An advantage pointed out was the wide variety of methods for performing the same job that is observed in comparative studies. This wide variety gives a good base for the selection of the best parts of alternative methods before synthesizing these best parts into an improved method. Therblig-analysis and other types of analysis used in industry and tools and equipment were described. Different types of charts adopted by industry were shown.

An application of industrial analysis methods on a hog operation (40) used mainly flow process chart analysis to evaluate different alternatives from the standpoint of time (man-hours), energy and capital requirements. Consideration was given to all handling on the farm, even that located in the field. The complete charting became so elaborate and the computational procedure so time consuming that the method can be used only in very few cases on the individual farm.

An analysis of the materials handling procedure on 320 livestock farms in Michigan (29) gave indications on the magnitude of different handling problems and the labor saved through different degrees of mechanization The relationship between capital investment and labor consumed on the investigated farms was found to be $RLR = 141 - 0.0107\ I$. RLR is relative labor requirement compared to a certain standard which for milk cows is 0.6 man-months per year. I is capital investment in materials handling equipment in dollars. RLR decreased by 1.07 per cent for every hundred dollars investment.

CHAPTER III

MANAGEMENT ENGINEERING IN INDUSTRY

"An engineer is a person who can do for one dollar what any fool could do for two dollars".(12) This is an old definition for an engineer and even if we could expect an engineer to do better than that, the sentence is used here to emphasize the importance of economic considerations in an engineer's job. "All engineering is cost engineering" (12) is another statement expressing the same idea.

Undoubtedly practical engineering is largely a matter of cost. Though now a great many engineers go into scientific work or get specialized jobs with a big concern, for many of them economic decisions are a great part of their work. From the design engineer, who for every single part has to make a decision as to material, process, finish and so on, to the one who has advanced to a leading position in management - they are all concerned with economic problems.

The more factors we get involved in that are to be considered, the more difficult it is to take everything into account and make a decision based only on pure facts. We get to a point where there is a whole system to consider rather than single details. Integration of the parts of a system to a well balanced whole is as much or even more of a challenge to the engineer than the design of every small detail. Development of a machine always means integration of elements to a unit. Integration of different machines to a plant is mostly included in the function called management.

In industry, where enterprises of considerable size started developing long ago, the field of management and the engineer's role in that field has been recognized since industrialization first started. "The Engineer as an Economist" is a paper presented by Henry R. Town in 1886, which pointed out the important role the engineers were going to play in management and economic decisions. In 1911 Frederick W. Taylor presented the first edition of his "Principles of Scientific Management", which is the first real attempt to present decision-making and management as based on scientific laws and relationships. Though most unpopular and sometimes referred to as "a diabolic scheme for the reduction of the human being to the condition of a mere machine", (49) Taylor's ideas could not be hindered. Industrial Engineering was given as a name to the discip-line founded by Taylor, because most people concerned with related problems were engineers. The term Management consultant is sometimes used instead of industrial engineer to indicate that people in this field were not necessarily engineers.

Today, industrial engineering, which is the term commonly used, is a very broad field including the following functions (34):

Methods:

- Methods engineering
- Operations analysis
- Motions study
- Materials handling
- Production planning
- Safety
- Standardization

Work Measurements:

- Time study
- Predetermined elemental time standards
- Clerical procedures

Wage Payment:

- Wage incentives
- Profit sharing
- Job evaluation
- Merit rating
- Wage and salary administration

Controls:

- Production control
- Inventory control
- Quality control
- Cost control
- Budgetary control
- Management control

Plant facilities and design:

Plant layout
Equipment procurement and replacement
Product design
Tool and gage design

Others:

Industrial relations
Suggestion systems
Management research
Preparation of operating and maintenance manuals

This list being the result of a survey made in industry shows how versatile industrial engineering has grown and how it ties in in all phases of industry today, even if only a few companies are of a magnitude that all these different functions are developed. Recent development, mainly during the last fifteen years, has shown that the area of management now has available other and more powerful tools that might make management a science as exact as engineering and economics.

Operations research is the name for this new development in the area of management. The tools that are used are taken from the areas of mathematics, statistics and probability theory, econometrics and electrical engineering, just to mention some of them. Techniques as linear programming, marginal analysis, the calculus of variations, and information theory are now used to solve management problems (8, 13, 44). And though the methods have been shown most useful where applications have been made, most areas of management are still not touched by these new possibilities. Problems possible to solve are sometimes referred to as "well-structured" and have to satisfy the following criteria (44):

1. It can be described in terms of numerical variables, scalar and vector quantities.
2. The goals to be attained can be specified in terms of a well-defined objective function, for example the maximization of profit or the minimization of cost.
3. There exist computational routines (algorithms) that permit the solution to be found and stated in actual numerical terms.

"Ill-structured" problems, on the other hand, are those where essential variables are not numerical but symbolic or verbal. The goal is vague and nonquantitative or computational algorithms are not available.

Most problems in management still belong to the "ill-structured" type; common sense and judgement are still bound to play a predominating role in management. But this role is going to decrease more and more as we get more powerful tools for measuring and computation.

With the subsistence type of farming giving way for a commercialized type of food production, more and more of these techniques adopted by industry will find a place also in planning of the farm enterprise and the farm operations. Though the problems in farming, mostly because of the structure and nature of the farm industry, are somewhat different from other industries, methods similar to those used in industry are needed for analysis and integration of the farm operation.

Management engineering sometimes used (7, 37) to define the application of engineering training and facilities to problems of organization instead of design will be used in this thesis to define activities in farm planning and organization of the same nature as the functions of industrial engineering. Until now most interest for the field of management engineering in agriculture has been shown by the agricultural economists, a natural consequence since farm management is a part of agricultural economics. With the advent of mechanized agriculture the integration and balancing of a farm-industry takes much knowledge of an engineering nature. Management engineering in agriculture today necessarily involves both agricultural engineering and agricultural economics and calls for a high degree of team work that will be most stimulating for both parties. In industry the management science as a combination of engineering and economic knowledge is well established.

CHAPTER IV

MATERIALS HANDLING ON THE FARMSTEAD

Materials handling is old as a job but new as a science. From the primitive stage when everything had to be moved or carried by hand to the invention of the wheel and the use of animals for transportation, man has strived towards simplification of materials handling. Though being a function of management engineering itself, solution of materials handling problems requires the application of most of the other functions of management engineering too.

The broadness of its scope is illustrated by the following definition of materials handling (5):

> "Materials handling is the picking up and putting down, moving of materials or products in any plane or combination of planes, by any means, which includes storage and all movements except processing operations or end use of the material."

Adding nothing to the value of the products, materials handling cost in industry often amounts to 20 to 50 per cent of the production cost (5). In farming, a livestock enterprise with 20 dairy cows includes handling around 500 tons of material per year, much of it being handled several times (29). In the following table are shown amounts of materials handled per cow per year, one group of figures referring to findings in a survey made in Massachusetts on dairy farms (19) and the other group of figures referring to dry lot feeding in high producing herds in Michigan, including young stock.

TABLE 1

AMOUNTS HANDLED PER COW, TONS PER YEAR

	Grazing partly (Massachusetts)	Drylot Feeding*
Silage	6	10
Manure	6	10
Milk	4	5
Grain	1.5	2
Hay	1	3
Bedding	0.5	1
Total	19	31

* Personal communication, L. M. Brown, July 1958.

On a dairy farm 80 per cent of the total time is spent on work at the farmstead (29), most of which can be classified as materials handling.

The amounts of materials moved by farmers every year are considerable. The tonnage of one years production gives an idea of the magnitude of the problem, disregarding the frequency of handling and the distances involved.

TABLE 2

TOTAL TONNAGE PER YEAR OF AGRICULTURAL PRODUCTS IN THE U.S.A. (41,50,51,52) MILLION TONS PER YEAR (Round Numbers)

Wheat, average 1945-54	43.5
Corn for grain 1955-56	83.5
Oats, average 1945-54	21.3
Barley, average 1945-54	6.7
All hay, including grass silage converted to dry weight, average 1945-54	103.6
Silage made from grass or hay crops, green weight, 1954	6.6
Corn silage, 1955-56	53.8
Milk, 1956	123.6
Manure, total production based on number of animals 1957	1,317.0
Fertilizer and lime, 1954	41.5
Oilseed cake & meal and animal protein, 1953	18.5

Tonnages involved in some American industries give a good background for comparison to get an idea of the magnitude of the problem.

TABLE 3

TOTAL TONNAGE PRODUCED BY SOME INDUSTRIES IN THE U.S.A. (52) MILLION TONS PER YEAR (Round Numbers)

Petroleum, crude, 1956	400.0
Coal, 1955	490.8
Iron ore, 1954	88.0

In the recent developments towards a mechanized agriculture most of the progress has been in the area of field machinery, while work around the farmstead has proven not as easily adaptable to mechanization. The following indexes of output per man-hour give an indication of the lag in the mechanization of the livestock enterprises (50).

TABLE 4

INDEX OF OUTPUT PER MAN-HOUR* IN FARM ENTERPRISES FOR 1956 (1947-49 = 100)

Meat animals	108
Milk cows	122
Poultry	140
Feed grains	171
Hay and forage	129
Food grains	148

*Index of farm output (production available for human use) divided by index of man-hour requirements.

At present the areas of greatest possibilities in farm mechanization are to be found in the livestock enterprises, the jobs being mainly handling of feed, manure, and products from the animals. As far as hay and forage are concerned, even the field part of the work is not yet highly mechanized.

The handling of materials on the farmstead often consists of repetitive tasks performed every day during the year, and even small savings in time amount to a considerable number of hours per year. Considering the tonnage involved and the energy spent on materials handling, eliminations, simplification and mechanization in this area would considerably lighten and relieve drudgery from farm work.

The labor requirements for different handling operations as found on 320 livestock farms in Michigan (29) are shown in Appendix 1. Weighted averages for farms handling the material are given, and in addition the averages for the group of farms with the least labor requirement for a certain operation. The table gives some idea of the present stage of materials handling on the investigated farms, and also indicates which possibilities for saving labor, that have been used on these particular farms. The figures are particularly interesting if seen in relation to the amount that has to be handled every year. Using the amounts involved per year per cow as given in Table 1 for drylot feeding, Table 5 shows the time of handling involved per year for a milkcow including young stock. Figures are shown using the time-averages from tables in Appendix 1.

TABLE 5

TIME IN HOURS PER YEAR FOR HANDLING DIFFERENT MATERIALS FOR A MILK COW INCLUDING YOUNG STOCK

	Hours per year	
	Averages for the best methods, all farms handling the material	Averages for the best group of farms using the best method
Silage	8.9*	2.4**
Manure	6.2	0.0
Grain***	5.0	1.3
Hay	5.2****	2.2****
Bedding	2.6****	2.1****
Total	27.9	8.0

* Horizontal silo
** Vertical silo
*** Including grinding and mixing
**** Chopped

The table shows materials handling on the farmstead, from the time a material is unloaded until a material is loaded for transport from the farmstead. The averages for all farms show that silage is taking a great deal of the total handling time, bedding being the least time consuming item. On the best farms with the best methods it is interesting to note how the order and the relative importance of different materials have changed. Silage still being the most time consuming item, has a considerably reduced time requirement. Note that the horizontal silo gave the least time requirement on all farms, but that the vertical silo required the least time amongst the best farms. Hay is second and bedding third. Bedding handling does not show much improvement from the average group.

CHAPTER V

FUNCTIONAL ANALYSIS OF MATERIALS HANDLING SYSTEMS

Before going into the discussion of the analysis, some definitions are given on terms that will be used in accordance with their use in industry (38).

<u>Handling</u> is one transport (repeated) between two points, plus the transfer before and after the transport;

<u>Transport</u> is one move of one load (repeated) over a distance more than 5 feet;

<u>Transfer</u> is a transport over a distance less than 5 feet, such as piling, tiering, loading, unloading, de-tiering, and unloading;

<u>(Unit) load</u> is a unit of parts or package handled intact, or a single part or package. In either case, units must not vary by more than plus or minus 50 per cent from the average unit in weight and dimension;

<u>Frequency</u> is number of moves per day (or year).

Mathematical Model

From an engineering standpoint it is most desirable to consider the basic physical characteristics of the materials handling problem if a successful analysis is to be carried through. A materials handling function of the following type expressing the magnitude of a materials handling operation is theoretically conceivable.

$$y = f(x_1,\ x_2,\ x_3,\ \ldots\ldots,x_m \mid x_{m+1},\ldots\ldots,x_n)$$

Some of the variables could be held fixed while others were varied.

$x_1 \ldots\ldots\ldots x_n$ would be

amount of material to move

volume weight of material

other material properties (shape, form, etc.)

distances involved

other "layout-properties"

speed

unit load

mechanical energy

human energy

.

.

.

etc.

Units and measurements for several parameters are not yet available, the magnitude of the materials handling problem could possibly be expressed in man-hours, but that is a poor technical unit and considerable difficulty will be met to make the equation work unitwise.

Furthermore the influence on the materials handling problem by the different parameters is impossible to state or it varies widely. The value of the constants for each factor cannot be determined correctly due to the variation between situations and the interaction between the factors. In many parts the problem, like the ones mentioned earlier, is "ill structured".

Check Lists and Other Techniques Used in Industry

Because it is not possible to give the problem a strictly mathematical solution, several attempts have been made to express solutions verbally. Many check lists both for agricultural and industrial use (32, 38, 46) have been published. Some of these are very elaborate, others simple, and in spite of the lack of exactness it is helpful to check through one of them when planning a materials handling problem. No one list is perfect and the one published here is a collection of some principles which might be of considerable value to have clearly in mind when planning a farm operation:

1. Eliminate handling
2. Avoid rehandling
3. Condense the material
4. Handle in bulk and strive for continous flow

5. Use largest possible unit loads

6. Minimize distances

7. Use gravity when possible

8. If possible, adopt buildings to the handling system

9. Mechanize whenever economically justified

10. Strive for versatility in buildings and equipment

Scheduling and routing are of great importance for a successful solution of industrial materials handling, but of less importance on the farm, where most of the handling operations are not of a continuous nature.

Important Factors in Farm Materials Handling

The interest in farm materials handling can be concentrated around these three factors:

Material

Layout

Equipment

These three, together with management, make the method. Any progress or improvement in the area of materials handling will be found in these factors. Management is the integrator of the physical factors in a system.

Though the only successful approach is the "systems approach" where all factors are considered together it is of interest to consider each one of these factors for analytical purpose. In that way weak points in an existing system and ideas for further development and improvements can be found. For that reason each of the factors will be handled in a separate section of this chapter. Though human energy is of great importance, and deserving of consideration in solving materials handling problems, it will not be considered in this thesis. Although intangible by nature, human energy has become the object of extensive research, and data are now available which facilitate limited computations in human energy expenditures. Energy requirements for some work on the farm as taken from an unpublished report of the Purdue Farm Cardiac Project (40) are listed in Appendix 2.

Materials Characteristics

A standard unit expressing the properties of the material that determine the magnitude of the handling problem is desirable for several reasons. Some of these reasons for a standard unit are:

1. Makes possible a comparison with other

handling methods and results in a meaningful comparison.

2. Provides a common measure of efficiency for different materials and handling methods.

3. Enables predictions in case new methods or changes in materials are planned.

4. Furnishes an overall measurement for identification of a certain handling problem as far as materials involved are concerned.

Considering materials handled on the farmstead, there is no uniformity in properties. Liquid and solid type materials, bulk and packaged materials, and materials with a wide range of bulk densities are involved.

TABLE 6

BULK DENSITIES FOR MATERIALS HANDLED ON THE FARMSTEAD (18)

	Lbs/cuft
Ear corn, husked	28.0
Corn, shelled	44.8
Barley	40.0
Oats	25.6
Wheat	48.0
Hay, pelleted, large size * pellets made from long hay	20-30

TABLE 6 (Continued)

	Lbs/cuft
Hay, loose baled	10.0
Hay, ordinary baled	12-15
Hay, chopped	8-10
Hay, long loose in storage	4- 5
Silage	30-40
Milk	67.4**

* Personal communication, J. L. Butler, July, 1958.

** Farrall, A. W. Dairy Engineering, John Wiley & Sons, New York 1953.

Number. Usable as a unit for packaged material, cans, bales etc. but without specification it is arbitrary and does not provide a good standard measure.

Weight. The most common way to express the amount and from a practical standpoint the best is weight because amounts in storage and rations mostly are expressed as a weight. As a unit for materials handling though, weight has its limitations when materials with varying bulk densities are involved, as is the case in farm handling. In many cases the volume determines the amount of time and effort and the cost, rather than weight.

Volume. An investigation of packaging cost (23) showed that when packaging cost for each of 40 items was plotted against gross weight and against cube, points representing cost per pound and cost per cuft respectively were so widely scattered that no curve could be drawn. No useable relationship exists between packaging cost and weight or cube.

Weight and Volume. If the materials in the previously mentioned investigation were divided into classes according to density (lbs/cuft) the points for each density group could be joined and formulas for packaging cost computed. Figures computed according to these formulas were used as standards to check the efficiency of different handling operations. Looking at the table for bulk densities it can be seen that the materials on the farm in very few cases could be grouped together according to this classification, each being a class of its own. Volume divided by specific weight is suggested as work unit by some industrial firms (35). Another unit that the shipping freights are based on, is the unit load that one adult man can comfortably lift and carry, which is supposed to be 50 pounds or 1 cuft (53). In determining sea freight charges the weight is divided by 50 to get the "computed cube" and the "actual cube" is measured. Which ever is largest, "actual" or "computed" cube determines the charge. A similar work unit applied to materials on the farm would be simple and have the advantage that it takes into consideration the both basic properties in material, i.e. weight and cube. Without a careful study of several handling operations in farm work, it is not possible to evaluate its use for analytical purposes.

<u>Time Standards.</u> The time used for handling a material can to some extent be used to characterize the material. But time is not specifically intrinsic with the material, but depends to a great extent on layout, equipment, etc. Furthermore in mechanized or automatic handling, the time factor has decreased in importance. For some basic, preferably manual operations, it might be used. If time standards could be made available for a great number of basic operations in materials handling, it would be of considerable value. Some examples of basic time units worked out for industry, considering both volume and weight characteristics are given in Appendix 3.

<u>Other Material Properties</u>. A unit for material properties should be a true index of the useful work performed to handle the material (53). As such it can

not be limited to the basic properties weight and volume, but should also include several other properties as fluidity, viscosity, size of particles and tendency to stick together. Many of these properties are beyond what we can get a measurement for. Hay is an excellent example of a material that can appear in several different forms, and in which several properties are changed in going from one form to another. Feeding silage only to milk cows involves around three times as much weight as feeding hay only as roughage. Still a silage feeding program is considered easier by most farmers because of easier handling and possibilities for mechanization. Water, being the largest tonnage involved in farming, generally offers the least problem because of its fluid characteristics. These few examples indicate the great importance of other materials properties than weight and volume, the possibility to fluidize being a most desirable characteristic.

Layout Analysis

The layout - the arrangement of work places, storage and routes - is most important for the materials handling function. A functional layout should provide the best possible facilities for the production process as a whole and would affect the following functions:

1. Distances involved
2. Number of rehandlings
3. Flow of material
4. Mechanical equipment needed
5. Possibilities to mechanize
6. Human energy input
7. Versatility in production

To get an overall expression for how good a layout is, is difficult or impossible if everything should be considered. Without a measurement it is hard to make an appraisal of how good a present or planned layout is and to make comparisons between them. Design of a layout lacks computational procedures to solve the problem.

Though the whole layout cannot be solved as a mathematical problem, some techniques and computational methods are available, which are helpful in solution of part of the problem.

Flow Diagram. A flow diagram is simply a floor plan with lines representing the flow of material. It can be used on a single work place, within a building or for the whole farmstead layout. As a first inspection of a layout it is a good way to illustrate long distances, backtracking, crisscrossing, and bottlenecks in the layout if the process to study is not too complicated. Many things become obvious on a flow diagram, which are hard to see otherwise, and it is wise to work the relocations on a flow diagram, to see how it affects the total flow, before the changes are realized. The method with drawn flow diagrams can be refined and made more illustrative if templates or three-dimensional models are used. Drawn to scale, usually ¼ inch = 1 foot (1), the flow diagram can be used to determine the distance moved in a certain layout. Strings used instead of drawn lines are good aids to make the planning more flexible, and works better for complicated processes. The distance moved is conveniently represented by the total length of the string.

Appendix 4 shows an example of a flow diagram.

<u>Flow Process Chart</u>. A layout planning chart is a flow process chart that is especially applied to study of a layout. A flow process chart is a record of all activities, and classifies and summarizes the various kinds of activities during a series of operations. Time is taken and distances measured (1). A suggested flow process chart or layout planning chart is shown in

Appendix 5.

It is not possible to evaluate and measure a layout only, because method, equipment, etc. also show up in the suggested chart.

Adding the columns for livestock, processes movements and storage gives an indication of the complication of the process and how it compares with others. Especially the number of movements ($\sum O$) is a figure to watch, when evaluating the layout. This figure gives the number of rehandlings the material has to go through before the process is completed. The less the number of rehandlings in relation to the number of processes on livestock stations, the better is the layout. A rehandling factor, expressing the number of rehandlings for a certain system, could well be used as one comparison in evaluating different layouts.

Distance and Weight. Distance multiplied by weight sometimes used as a measurement for the handling (26) is a means to put certain weights on every distance. It is a way to tell how important every distance is considering the amount of material that has to be handled over the distance. This type of expression has the advantage that it makes every distance more meaningful, but there are other limitations to it. In a certain system the amount of handling, weight and distance can be minimized if the layout is placed in a coordinate system and the distances minimized according to conventional formulas used in mathematics for the distance between two points in a coordinate system. Accepting this way of computing means accepting that moving 1 pound over 1000 feet is the same as moving 1000 pounds over 1 foot. Such a unit cannot be physically justified and neither cost nor time can be expected to vary according to this unit. From a cost and time standpoint, the shorter the distance the greater the influence of weight and the less the influence of distance. When materials are moved a long distance or if the transfer is automatic, the handling cost can be considered as somewhat proportional to distance. Still the influence of weight and distance respectively is not possible to determine in a general way. A hypothetical graph for time of handling material (could be hay or grain) is shown in Figure 1. The comparatively small influence of transport time in a small area as a farmstead is seen from the graph. Assumptions made when drawing the graph are:

Loading and unloading takes 0.6 man-hours per ton

Speed of travel is 200 feet per minute

Unit load is 200 pounds

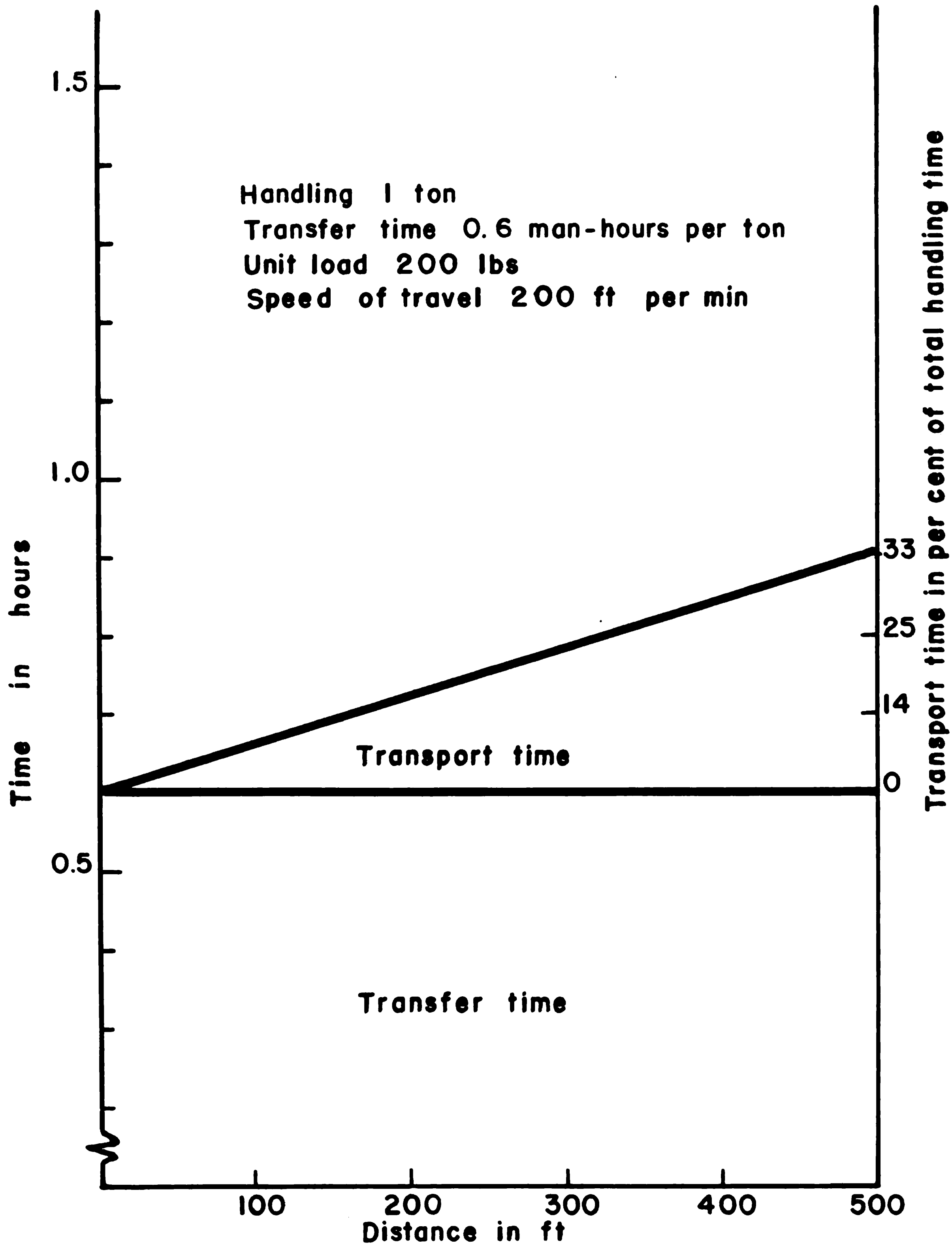


Figure 1 Time for Handling Material over Different Distances

This graph is a very simple example of a common handling procedure but indicates that the distances involved have to be judged carefully and that too much should not be sacrificed to minimize distances. In case of automatic or mechanized handling the importance of distance might be still less because the time is generally of less importance if man-hours are not involved. The cost of equipment, though, is affected by distance. In some cases, where the distance extends beyond the range of certain equipment, its influence on cost could be very high.

The importance of distance may not be over emphasized as a factor in designing and evaluating a layout. Still, for the whole layout, if every move is counted, the distance involved gives some indication of how good a layout is.

Cross Charts. In most cases for the farmstead, where the layout is comparatively simple, a flow-diagram and a flow process chart is sufficient for examination of a layout. The flow diagram is an aim to visualize the layout and the flow process chart a means to break down the process into its component parts and to express amounts, distances, and time involved. The cross charts sometimes applied in industrial use (30,31) seem to have little place in analysis of the farmstead layout.

A refinement of the cross chart is the linear programming technique applied on transportation problems (15, 20). Being most useful in problems involving assignment (which truck to carry which load), scheduling, (determine routes for trucks) and shipping, (which stores to supply which consumers), its application in problems encountered in farm materials handling is difficult to find. But the technique of linear programming is promising and there might be found some applications to transportation problems on farms.

Other Factors in the Layout. Size of doors, width of aisles, ceiling height, obstructions as poles or partitions, etc. are other factors, that together sometimes affect the efficiency of a layout more than distance and location.

Equipment Characteristics

Power Requirements. The third factor affecting the materials handling is machinery and equipment. As far as it is economically justifiable it is desirable to substitute man power with machinery. Man is a poor power producer and expensive. Figures published by the Electric Industrial Truck Association show that 1 horsepower-hour produced by man costs around $10 while it costs only $0.04 if developed by electric motor (32). This comparison is inaccurate because in one case (man power) the total cost is shown while in the other (electricity) only the power cost, but it gives an indication of how expensive horsepower is when produced by man. Though the efficiency sometimes is low, in materials handling equipment, they still can compete very favorably with man power as far as power cost is concerned, the power cost in many cases being negligible. Different materials handling equipment still show a wide range if their power requirements are figured as KWh per ton.

TABLE 7

POWER REQUIREMENTS FOR DIFFERENT MATERIALS HANDLING EQUIPMENT

Equipment	KWh/Ton	Conditions	Ref.
Bucket elevator	0.06	Material with bulk density 50 lbs/cuft Capacity 25 - 60 tons/hr Vertical transport, 30-50 ft	27
Screw conveyor	0.05-0.25	Wheat 13-31 tons/hr Inclination 10 - 90^{o}	36
Pneumatic conveyor	0.7-0.9	Grain 2 tons/hr Horizontal or vertical transport	30

TABLE 7 (Continued)

Equipment	KWh/Ton	Conditions	Ref.
Forage blower	1.3	Alfalfa-timothy silage, ½ in lengths 36 tons/hr	39
Silo unloader	4.3	Grass silage 0.27-1.5 tons/hr Surface unloading	2

The range for common materials handling equipment seems to be within 1 kwh per ton. This is certainly enough to encourage research and development, but on the other hand is not a big enough difference to weigh too heavily in the choice between different handling equipment on the farmstead. The amount handled by the same machine or equipment is seldom more than 500 tons, which means 500 kwh or about $10 per year in power cost. The limiting factor for mechanization is the high capital investment required, the main question being how much equipment can be afforded. This question will be discussed in the next chapter.

Unit Load. In case of manual handling or handling by truck or cart, the question of unit load is important. Being a function of material and equipment, unit load will be discussed here. Going back to the example used earlier,

the importance of greatest possible unit load can be illustrated by the graph, Figure 2. From the graph it can be seen how important the unit load is, especially over great distances, but also how relatively small part of the handling time the transport time is. The two extreme cases of this graph would be:

1. Automatic loading and unloading, no transfer time and the time (man-hrs) would be equal to travel time and vary with distance;

2. Automatic transport (elevator, screw conveyor) but manual transfer of material. Time (man-hrs) equal to transfer time and does not vary with distance.

Case 1 is not common in farm materials handling, more so Case 2 and it appears that most of the handling operations in modern farming are going to be a combination of 1 and 2 with no transfer time and automatic transport.

Degree of Mechanization. Though the highest possible mechanization is not always economical, a measurement for the degree of mechanization is desirable. A measurement that is physically correct is not achievable without complicated measuring devices. One that possibly might give some indication of how highly mechanized a handling system is, and also serve for the purpose of

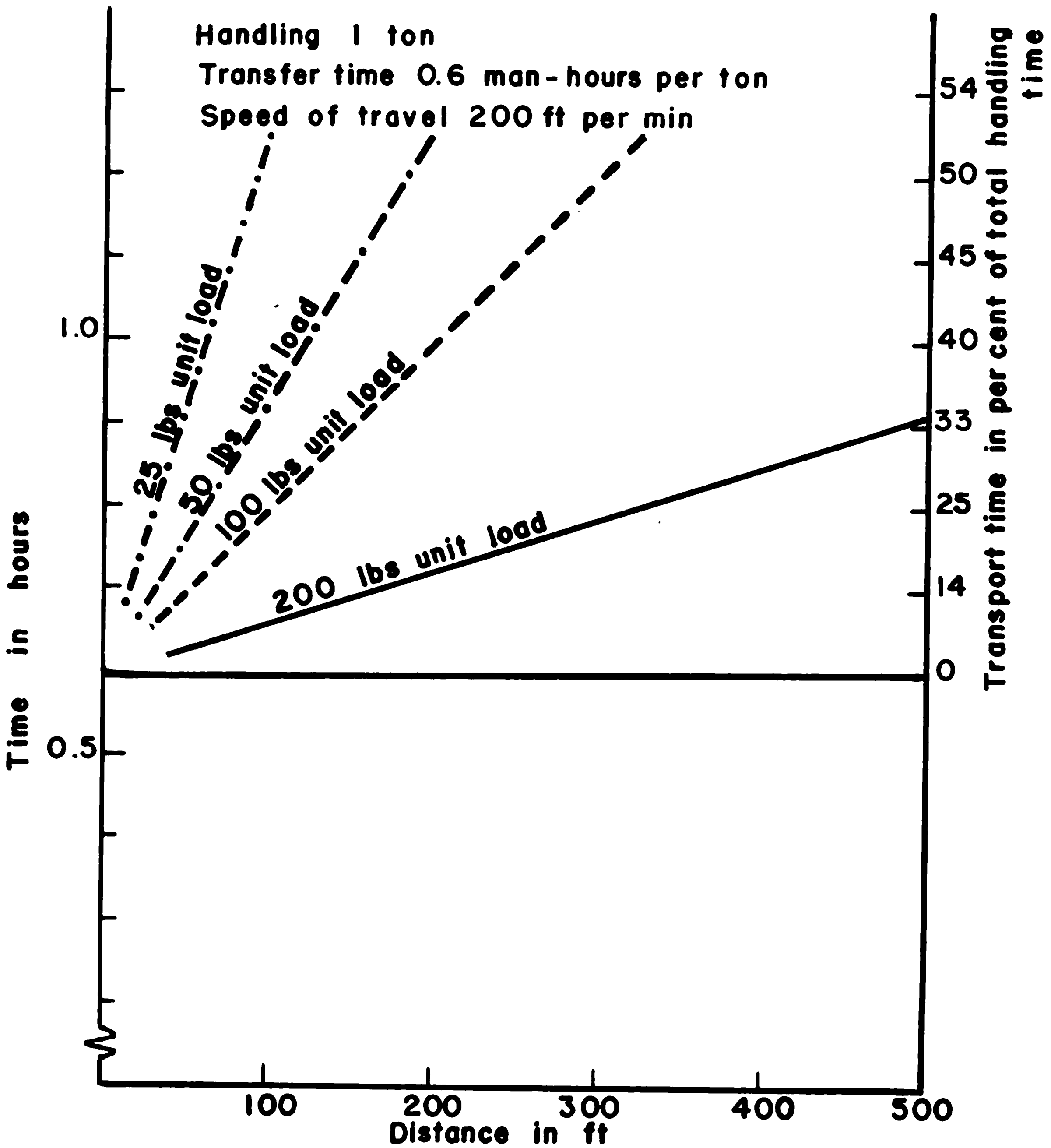


Figure 2 Time for Handling Material over Different Distances and with Varying Unit Load

comparison between systems is outlined here. The following abbreviations are used:

A (lbs or tons) = Amount of material handled. Weight counted for every rehandling.

A_m (lbs or tons) = Amount of material handled mechanically. Weight counted for every rehandling.

I_m = Index of mechanization for handling.

$$I_m = \frac{A_m}{A}$$

Consider the following example to illustrate the use of this formula. In a grain handling system the handling sequence on the farmstead is as follows:

		Manual	Mech.	Total
1.	5000 lbs of grain unloaded by auger		5000	5000
2.	2000 lbs of the grain bagged	2000		2000
3.	Bags loaded on truck	2000		2000
4.	3000 lbs shoveled into conveyor	3000		3000
5.	3000 lbs conveyed		3000	3000
6.	Ground on hammermill and blown to hopper		3000	3000
7.	Emptied from hopper to feed cart (gravity)		3000	3000
8.	Feed cart pushed to feeding area	3000		3000
9.	Fed from feed cart	3000		3000
	Total	13000	14000	27000

$$I_m = \frac{14000}{27000} = 0.52 = 52\%$$

This index might be criticized as not regarding distances involved but in connection to the previous discussion of the relative importance of distance, it is considered to be a usable measure for the degree of mechanization on the farmstead. It is not to any extent a measure of how good a handling system is from an economic standpoint, just an indication of how mechanized the handling procedure is.

Another attempt to classify the degree of mechanization, and at the same time list the equipment, is given in Appendix 6. This list is based on the following definitions:

Manual. Handling activities in which no power equipment is used. Basic tools (forks, baskets, carts) could be used as long as it is not powered.

Semi-mechanized. Powered equipments are used. Still a considerable amount of man power and man time is involved. Equipment that has to be fed and/or where distribution has to be made by hand.

Mechanized. Man power is practically eliminated in the handling, but man time is still required for supervision or to operate the machine.

Automatic. Both man power and man time eliminated. The only effort by man is to push buttons or release handles to start or shut off the process, or that could be made automatically too. Though no power is involved, self-feeding of animals and feed by gravity had been included in this category because the arrangement or investment in buildings or storage is considered to be comparable to investment in machinery.

CHAPTER VI

COST ANALYSIS OF MATERIALS HANDLING SYSTEMS

Cost Computations

After the attempt to approach the pure physical properties of the materials handling problem on the farmstead, the following statements might be justified:

1. The physical properties of the materials handling problem are not well defined, and the only feasible measurement to express efficiency and to compare systems seems to be cost.
2. The influence of the different factors in materials handling (material, layout and equipment) are difficult to isolate. Thinking must rather be in terms of systems than in terms of the different components in the system, when making studies of materials handling.

Cost like time is in many respects a poor measurement, but it is practical and most meaningful. Today most materials handling jobs can be mechanized with available machinery and through arrangements in layout. The only limitation for complete mechanization is cost.

The Nature of Cost. Since farms are getting larger and with steadily increasing mechanization, the investments in a modern farm are considerable. As capital cost is one of the major items in cost estimates, careful consideration has to be given to the mathematical model used for computations. Even knowing that the data used in the computations have some possible errors involved, there is no excuse for using a less accurate computational method.

Since the concept of cost varies greatly, clear definitions are needed for the cost concept. The breakdown of costs that will be recommended for materials handling cost estimates, whether concerning machinery and equipment or buildings, follows:

Fixed costs or overhead

- Depreciation
- Interest
- Taxes, insurance
- Repair and maintenance

Variable cost or operating cost

- Power, fuel, etc.
- Labor

Consideration of each one of these cost elements will be given.

<u>Depreciation</u>. According to generally accepted business principles depreciation is based on recovery cost rather than being a provision for replacement (21). For accounting purposes several different methods of figuring depreciation are available (48) which there is little reason to use for cost estimation. Charged as part of the yearly cost it is most logical to distribute the depreciation cost evenly over the numbers of years that the asset is assumed to be in use, especially in cases where the service rendered by the asset most likely is going to be the same over the span of its life. Its value in the open market is of little meaning as long as it is not sold or traded and should not affect cost calculations. Straight line depreciation with cost evenly distributed over the years is

$$D = \frac{P - L}{n} \quad \text{(I)}$$

where:

D = depreciation per year

P = first cost of asset

L = estimated salvage value

n = estimated life of asset, years

Salvage value, L, is in many cases negligible, being so small that an error in estimation or omission would not affect the result too much except for assets with a short life. The major errors are caused by errors in "n", the service life, which must be estimated considering not only physical but also economical life of machinery and buildings. Not knowing about future developments in technology, this is a most difficult figure to arrive at. According to present day expectation 10 - 15 years seems to be reasonable assumptions for service life of materials handling equipment (29). The variations are wide due to the hours of use and the kind of service. In cases where estimated life of equipment is available in terms of hours, this figure usually gives a better background for estimations. In cases where obsolesence is the major cause of depreciation, judgement and best possible predictions must be used. Buildings (here including all kinds of storage, grainaries and silos) used to be estimated to a service life of 40 - 50 years or more, which has proven too long, at least for the economic life of the kind of structure for which it was used. Careful estimates for todays modern structures runs around 20 - 30 years which certainly in many cases is less than their technical life. With todays modern farm structures, being clear span buildings without partitions, stanchions or other fixed installments, it might even be considered if not more than 25 years could be reasonable, as the versatility in the structures seem to leave some guarantee for usefulness even with changes occuring in farming. Milking parlors and some other structures where technological changes can be expected have to be estimated carefully and more than 15 - 20 years life is probably optimistic. Though depreciation partly is a function of hours of use, it is generally considered as being a fixed cost.

Interest. On invested money, interest should be figured according to the interest on the money in alternate use. Less than current interest paid in banks is never justifiable to use, because the bank always is an alternative and is available. The scarcer the money the higher is the interest in alternative uses and the less the challenge from projects with long life and/or high investment. Less than 5 per cent and more than 15 per cent interest is not feasible in our present situation, around 10 per cent being a frequently used average in industry (43). Interest in machinery cost computations is usually figured on the average investment according to the following formula (4):

$$I = \left|\frac{P + L}{2}\right| i \qquad \text{(II)}$$

where

I = Interest per year

P = first cost of the asset

L = estimated salvage value

i = the rate of interest (decimal)

A more exact method is to figure the interest on unrecovered balance. Interest for the first year being $(P - L)i + Li$ and for the n-th year $\left(\frac{P - L}{n}\right) i + Li$. Usually, when this method is used, an average is taken between the first and the last (n-th) year which results in average interest on unrecovered balance. (48).

$$I = (P - L) \left[\left(\frac{n + 1}{n}\right) \frac{i}{2}\right] + Li \qquad \text{(III)}$$

The formula neglecting salvage value reduces to:

$$I = \frac{P\,i}{2} \left(\frac{n + 1}{n}\right) \qquad \text{(IV)}$$

Capital Recovery Factor. Added together annual depreciation and interest gives the total yearly capital cost. The factor with which to multiply the present value of an investment to arrive at the yearly cost, (R), is called capital recovery factor (CRF).

Yearly cost can be computed according to the following methods:

1. Capital recovery at 0% and interest on the average investment

$$R = \frac{P - L}{n} + \left(\frac{P + L}{2}\right) i \qquad \text{(V)}$$

2. Straight line depreciation and average interest on unrecovered balance

$$R = (P - L)\left[\frac{1}{n} + \left(\frac{n+1}{n}\right)\frac{i}{2}\right] + Li \qquad \text{(VI)}$$

3. Using compound interest formula (capital recovery factor from table)

$$R = (P - L)\left[\frac{i \quad (1 + i)^n}{(1 + i)^n - 1}\right] + Li \qquad \text{(VII)}$$

The different methods for computing yearly cost are illustrated by the following example solved in three different ways. Consider an investment of $25,000 with 8% interest and depreciation in 20 years, no salvage value.

1. $R = \frac{25000}{20} + \left(\frac{25000 + 0}{2}\right) 0.08 = 2250$

2. $R = 25000 \left[\frac{1}{20} + \left(\frac{20 + 1}{20}\right)\frac{0.08}{2}\right] - 0 \times 0.1 =$ 2300

3. $R = 25000 \times 0.10185 = 2546$

$2546 per year for 20 years will exactly pay back $25,000 with 8 per cent interest and is the actual cost of capital recovery.

For assets with long life and when the interest rate is high, the error in using methods 1 and 2 is considerable. In case of such assets (i.e. buildings) method 3 is recommended. For assets with short life method 1 could be used at least for a rough estimate because of its simplicity. Note that for short life assets (less than 10 years) the methods used for computing CRF is of little importance compared to the importance of correct estimate of years of life. Appendix 7 has a table for comparison of the error in using different methods for figuring capital recovery.

Good judgement is essential in determining both years of life and depreciation rate. As will be shown later, the sometimes appearing policy to estimate a short life and keep interest high "to be safe" can be very harmful too with respect to replacements. Such a policy preserves the present stage of technology longer than is really justified.

Tax and Insurance. Charges for taxes and insurance varies widely between different states and locations. If exact rates are not known, 1 per cent of original cost for property tax and 0.25 per cent of original cost for insurance is suggested (31).

Repair and Maintenance. Repair and maintenance falls between fixed and variable costs. To some extent and for some items (structures) it is mostly a fixed cost while in other cases it depends more on hours of use. An evenly distributed repair cost taken as a percentage of the first cost is commonly used but does not give a true picture of the actual timing. Major overhauls might occur every 5th or 10th year or more seldom for structures, the rest of the repairs and maintenance occurring at a rate of diminishing increase. Because of our imperfect knowledge of the future it is hardly possible to arrive at a cost distribution that is anywhere close to the exact, and this is why the method predominantly used is to take a certain percentage of the first cost. Several authors have published suggestions for annual repair cost in per cent of first cost, some based on estimates, others on surveys made on farms. Unfortunately few of them include materials handling equipment or related structures. Published data for materials handling equipment (29) show approximately the following yearly average cost for repair and maintenance.

TABLE 8

ANNUAL REPAIR COST IN PER CENT OF FIRST COST
FOR MATERIALS HANDLING EQUIPMENT

Equipment	Per cent of first cost
Chain or belt elevator	1.5
Blowers	2.0

TABLE 8 (continued)

Equipment	Per cent of first cost
Auger elevators, barn cleaners, mechanical feeders, tractor loaders, feed mixers	3.0
Self unloading wagons, hay hoists	5.0

For storage structures (16) used for grain, the following yearly maintenance was found on Indiana farms.

TABLE 9

AVERAGE ANNUAL MAINTENANCE COST FOR GRAIN STORAGE STRUCTURES

Structure	Per cent of first cost
Bins in cribs and other buildings	0.30
Sheet metal bins	0.20
Prefabricated wooden bins	0.40

For structures a figure around 1.5 per cent is commonly used (6), but some modern structures can be considered to be practically free from all requirements of future maintenance.

Though it can be criticized that annual repair and maintenance, as well as taxes and insurance, are figured as a percentage of the first cost, the method will be used here for the sake of convenience. It will also be shown that the error introduced that way is not of any great importance for the final result.

A handy expression to work with is arrived at if the percentages for capital recovery, taxes and insurance, and repair and maintenance expressed as decimals are added together. The sum is an "Overhead Cost Factor" In Figure 3 a screw conveyor is taken as an example, and the factor is shown for different estimated lengths of life and for different interest rates. Figure 4 shows a similar graph for a structural asset. The graphs show clearly how small a part of the "Overhead Cost Factor" is made up of repairs, maintenance, taxes and insurance, which fact might justify using the approximate method of figuring these costs as a percentage of the first cost. If interest is figured on average investment neglecting compound interest, or if the service life is not estimated correctly, the deviation is several times greater than the deviation due to any possible error in estimates of taxes, insurance, repair and maintenance figured as a percentage of first cost, at least for high interest rates and long lives.

<u>Power Cost</u>. Power cost can usually be figured

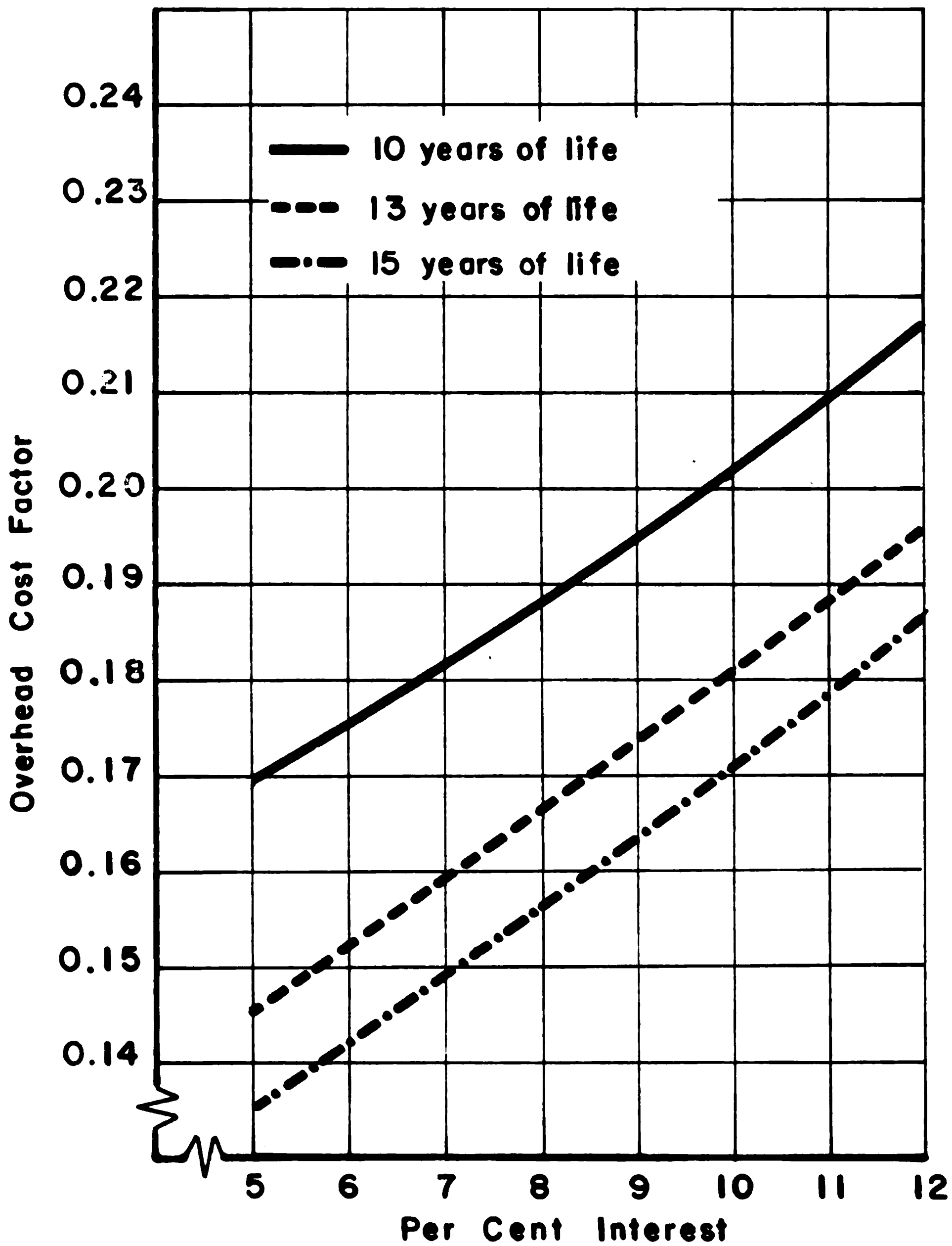


Figure 3 Overhead Cost Factor for Screw Conveyor at Different Interest Rates and Expected Years of Life

Taxes & Insurance Factor = 0. 0125

Repair & Maintenance Factor = 0. 0270

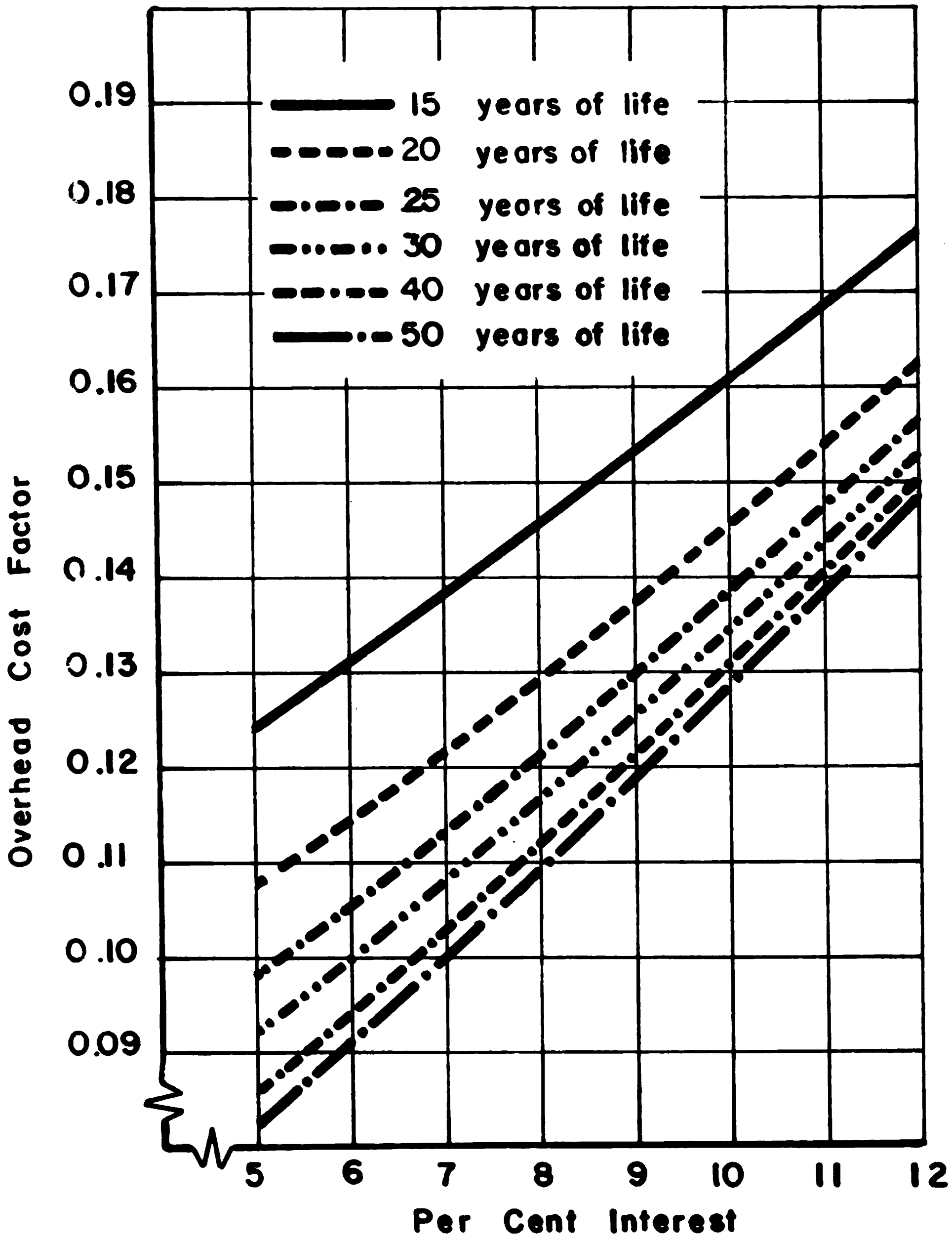


Figure 4 Overhead Cost Factor for Structural Asset at Different Interest Rates and Expected Years of Life

Taxes & Insurance Factor = 0. 0125
Repair & Maintenance Factor = 0. 0150

from actual figures for the source of power used. If an electric motor is mounted on the equipment, fixed costs for the motor are usually included in the fixed cost for the implement, electric energy being the only power cost. When electric motors are used for several purposes, the fixed cost for the motor has to be charged to the different uses. If divided between materials handling equipment and some other use, a certain amount per year (in proportion to use) has to be charged to the handling operation and added to its fixed cost. The cost of electric energy is added to the variable cost. Note that electric motors often have considerably longer life than the handling equipment. In cases where farm tractors are used as power source the average fixed cost per hour plus fuel costs are charged to materials handling.

When electric motor or tractor power are available and can be used for materials handling equipment, only marginal or added cost for the extra use should be used for comparison with other power sources. The marginal cost is the extra cost caused by the extended use and is principally equal to fuel or electricity cost. The power cost for materials handling equipment is mostly too small to be of any great significance in cost comparisons.

Labor Cost. The cost for manual labor is a major part of the variable cost for many materials handling operations, but it is very difficult to determine without extensive studies. For a planned system many of the steps are not even possible to study and judgement must be made from similar prodecures in other jobs. The difficulties in estimation of labor cost result from the following:

1. The time elements are not known
2. The value of the saved labor is usually not known

Development of time standards for different elements of handling would be most helpful in computations. A standard time is desirable representing the best a good man can do using best known techniques for a certain system rather than an average from a number of farms including bad as well as good operators. A standard should tell the time an operation should take rather than recording the time it actually takes. It should be something to check one's own operation and alternative operations against, not just a statistical presentation of the average situation on a number of farms at present. It is believed, that intense methods studies on only a few farms, including methods improvement along with the study, would be the proper procedure in developing standards.

Broad surveys including a great number of farms, however interesting and useful for other purposes, are usually a poor basis for development of time standards.

In comparing systems, cost should be figured on standard times to give a correct comparison. With standard times available it would be found in some cases that methods improvement is what is really needed rather than new equipment and buildings.

Knowing the efficiency in a present system through comparing actual time with standard time gives a good indication of what efficiency could be expected in a prospective system when methods improvements can not be carried through (in cases where human or other factors can not be changed).

Lacking these standards, today's situation is that there is usually no basis for a correct comparison. The best that can be done is to take the few data available and apply common sense and judgement on them. Other measurements attempted to apply in the first part of this thesis generally fail to express what is desirable to know about a system. Time, in spite of its limitations as an exact measurement, seems to be the only way to measure a materials handling system.

The other difficulty, to evaluate the labor that is saved, can not be solved by some standards. To put the hourly wage rate on an hour saved is not always correct and to find the "opportunity cost" is rather difficult. It is generally desirable, though, to figure savings and expenditures from the standpoint of the business, which talks for the use of the hourly wage rate in estimating the value of saved labor.

Data Sheets. For the appraisal of a present system and in comparison between alternative systems and with standards, many data must be gathered. Suggested sheets for gathering these data are included in Appendix 8.

Equipment Selection Charts. An extensive individual analysis is in many cases not possible in farming like in industry for planning a materials handling system. The high cost for the usually small operations is prohibitive. As an aid in extension or consulting work out in the field, an equipment selection chart can be worked out. Handling characteristics for different equipment is listed in this chart and suitability for different working ranges can be indicated. A basis for this chart, besides technical specifications for the equipment, is a break-even analysis. A break-even point is a common point for two or more variable situations (17). If functions have one variable in common, a break-even point exists. The functions under consideration could be

$$C_1 = f_1 (x)$$

$$C_2 = f_2 (x)$$

where C_1 and C_2 = annual cost or
total cost or
cost per day or
cost per piece

and x = extent of operation per year or
expected life or
expected period of operation

Working under the assumption of a straight line cost curve with a base of fixed cost and a tapered part of variable cost, graphs representing the cost for two different machines for a certain job could be represented as in Figure 5.

The equations for the two lines could be written:

$$y_1 = A_1 x_1 + B_1$$

$$y_2 = A_2 x_2 + B_2$$

where y_1 , y_2 = cost per year

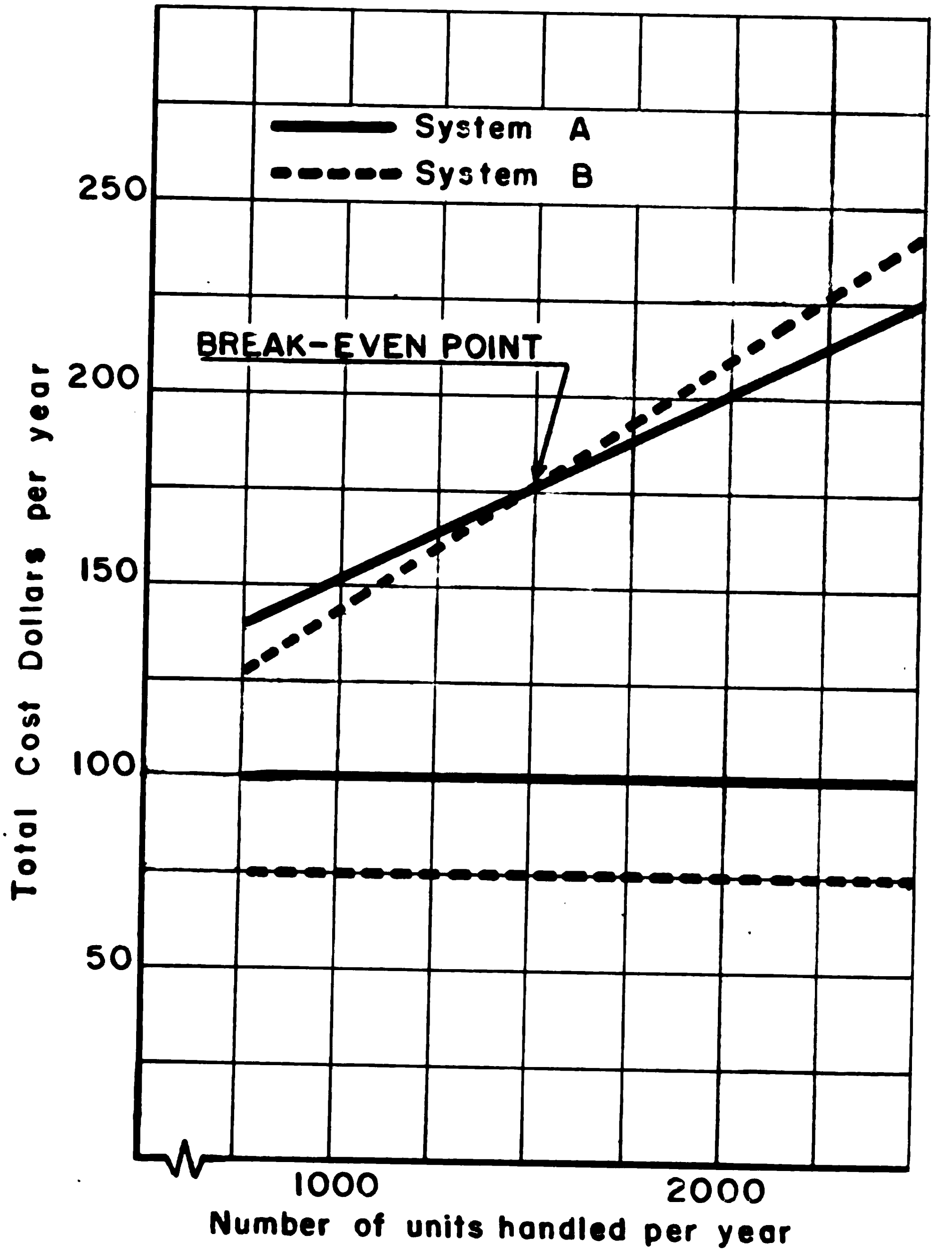


Figure 5 Break-Even Chart

x_1 , x_2 = number of units

A_1 , A_2 = variable cost per unit (= slope of the cost curve)

B_1 , B_2 = fixed cost (total)

The point of intersection, break-even point, can be read from the graph or arrived at through solving the two equations for $y_1 = y_2$, $x_1 = x_2$

$$A_1x + B_1 = A_2x + B_2$$

$$x = \frac{B_2 - B_1}{A_1 - A_2}$$

The break-even chart could be used for a single machine as well as for a system with several components, where fixed and variable costs for the component parts can be added to a "system cost curve".

The characteristics of a machine, if marked in the machinery selection chart, Appendix 9, can then be matched against desired characteristics, and conclusions about the suitability of different equipment can be arrived at.

The machinery selection chart is not an exact method to use. Its value depends wholly on how careful and thorough the analysis that has proceeded the making of the chart. Carefully made and used with judgement it can be a very good help to avoid overlooking things in equipment selection and to roughly point out which equipment to select.

The characteristics desired are numerous but vary widely between different handling operations, like do the intervals for the characteristics. No attempt has been made to work out a general standard for an equipment selection chart. The one shown in Appendix 9 just gives an idea of the form and procedure of making such charts.

Scale of Operation. Until now the discussion, with one exception, has been limited to either total cost or average cost, all the time assuming that there were a given amount that has to be handled. Notice must here be given to the fact that a considerable amount of efficiency is due to the scale of operation. If the total cost curves drawn in Figure 5 are converted to unit cost curves, the diminishing unit cost is readily shown in Figure 6. With the model used here, the unit cost is diminishing all the time, while a more true picture would show that the unit cost reaches a minimum and then will start increasing again. This increase for materials handling

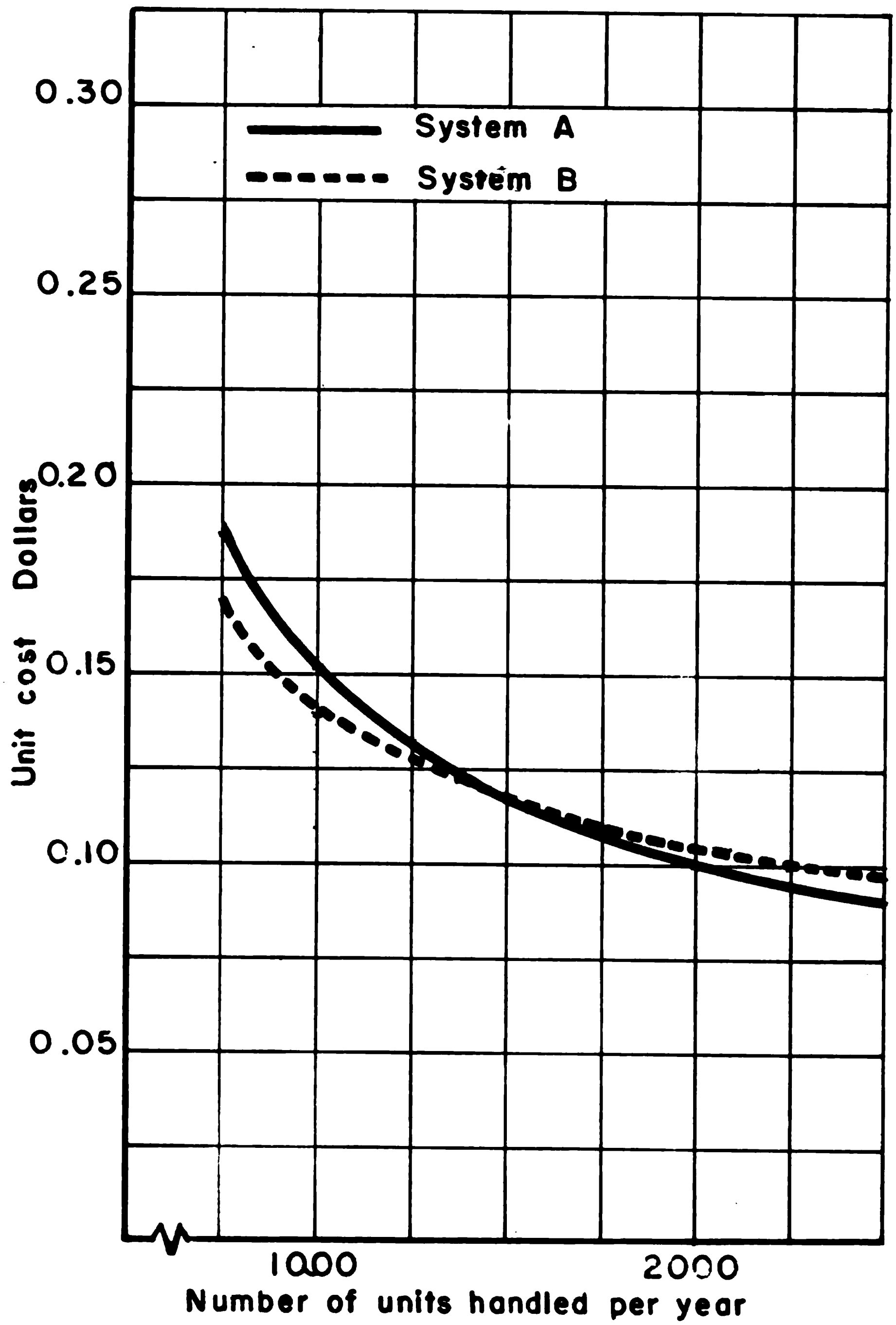


Figure 6 Unit Cost Curves

equipment can not be expected to occur until the limit for the capacity is reached. The capacity limit for some equipment (silo blowers, screw conveyors for self unloading wagons) is very important, while for some others (bunkfeeders, barn cleaners) it has less significance. The importance of the decreased unit cost (efficiency due to scale) is so great, that in the future in many cases the production has to be matched to the system rather than the opposite, to approach the minimum point on the cost curve, which practically means that production will be carried on close to the capacity limit. This is somewhat different from the approach in industry, but is exactly what is going on in milk production today, where many dairy herds are expanded beyond the point where most of the feed can be produced on the farm. The man and the equipment is the framework to which the production has to be fitted, and production extends to the limit of the system.

Marginal Cost Analysis. For a refined and exact analysis in modern production economic analysis, marginal cost is used instead of average cost to determine accurately the scale of operation and the least costly combination of inputs. Under conditions of scarce resources to be allocated between different production factors an accurate allocation can be arrived at considering incremental and second order conditions of the output function (second order conditions or the first derivative of a production function gives the marginal or incremental cost) (9, 22). Production is carried on until marginal cost is equal to marginal output, which under certain conditions and for a limited time might mean operation above minimum average cost as profitable. These clearly defined concepts which are computable with exact mathematical expressions, are somewhat difficult to apply on the cost analysis of the materials handling problem for these reasons (16):

1. A clearly defined common denominator for the outputs is not available.
2. The choice is between methods rather than between quantities of input.
3. Inputs are discontinuous scattered points that are not numerous enough to form a continuous curve.

Unable to apply conventional marginal analysis correctly, the way to compare alternatives is to consider total cost and total return. From this basis a mechanization preference list can be made up for ranking different alternatives in mechanization which could be used also for comparison with other potential alternatives for use of money (Appendix 10).

Other Methods for Cost Comparison. The previous discussion has been based on the unit cost or annual cost for cost comparisons. Several other methods are used in industry, the ones mostly referred to listed below (25):

1. Equivalent uniform annual cost
2. Present worth method
3. Capitalized cost
4. Rate of return on investment
5. Time required for investment to pay for itself (pay off period)

Methods 2 - 5 as not presented before will be briefly described here.

Present Worth Method. By this method money-time series are converted to one single payment. The present worth is an expression for how much has to be placed in a bank today to pay for all future costs for a given number of years. The period of time used for comparison must be the least common multiple of years for the alternatives to be compared.

Capitalized Cost. The difference between present worth and capitalized cost is that the latter is considering perpetual service instead of a given period of time.

The following relationships between methods 1 - 3 should be realized:

$$\text{Present worth} \times \left[\frac{i\,(1 + i)^n}{(1 + i)^n - 1}\right] = \text{Equivalent annual cost}$$

Equivalent annual cost / i = capitalized cost.

<u>Return on Investment and Pay Off Period</u>. In cases where service life or interest will be compared for different alternatives or to find break-even points for service life or interest rate, the capital recovery factor in the computations could be the unknown and solved for. From an interest table, with service life given, an interest rate can be found and if an interest rate is assumed service life can be determined. It is for the purpose of illustration helpful to compare alternatives in terms of return on investment or pay off period. A variation in service life and interest rate, factors where a great deal of possible error is involved, gives a good concept of the importance of probable errors.

Of these different methods, some of which are given much consideration in engineering economy (10, 28) methods 4 and 5 have some possibilities to give a good illustration of an equipment investment, while 2 and 3 probably are more confusing than helpful.

Replacement Theory

With a careful study of available systems and techniques as outlined before, the least costly method of handling a certain amount can be determined. The present situation is, that there are lots of labor-consuming systems in use in farming, obsolete but still with many years of service life left. One of the most difficult decisions to make from a management standpoint is to give up an old system, that is not worn out, and adopt new methods. In materials handling, where the question is not only to give up some pieces of equipment but often also old buildings and other items with high capital investment, obsolete methods have a tendency to be preserved longer than they should. It is obvious today, that a great many old systems could be replaced with a considerable economic advantage. A method is needed to tell when the point for replacement is reached and also to express the loss of not replacing.

MAPI (Machinery & Allied Products Institute) has carried on considerable research in the area of replacement theory (33, 43, 46) and the method they developed has been used with a great deal of success in industry. Its main principles and its possible applications in the area of replacement on the farm will be discussed.

Some special terms commonly used in the discussion of a replacement problem are developed by MAPI:

Defender is the system or equipment used at the present

Challenger is a proposed equipment or system

Time-adjusted annual average is a uniform annual equivalent amount, not an arithmetic average. It is based on selected interest rate and service life.

Adverse minimum is the lowest time-adjusted annual average of operating inferiority and capital cost obtainable from the equipment in question

Operating inferiority is the amount (expressed in dollars) by which a facility is operationally inferior to its best alternative. Operating inferiority is due to deterioration and obsolescence.

Annual inferiority gradient is the yearly amount (expressed in dollars per year) of operating inferiority which the challenger accumulates.

The longer the depreciation time is for an asset, the less its capital cost, and the longer it will stand the challenge from renewal. To make a fair comparison, the operating inferiority should be charged against the equipment also, besides the capital cost. The cost curve for equipment over a number of years looks like the graph in Figure 7.

From the graph it is seen that the adverse minimum is at 16 to 17 years of life, which would be the number of years to keep the asset for minimum cost. As the graph is drawn, operating inferiority is supposed to increase at a constant rate and this assumption for an estimate of the future seems reasonable for many types of machinery and equipment (46).

In comparing alternatives, the one with the lowest time-adjusted average or adverse minimum is the cheapest. When a new alternative occurs, with a lower adverse minimum than that of the system in use, replacement should take place. This is because the comparison is made between a succession of either the defender and the challenger or of the challenger only. The difference between the two successions will occur before the challenger is installed. With a higher adverse minimum a challenger will be more expensive to keep. If the challenger has a higher adverse minimum than the defender replacement should not take place.

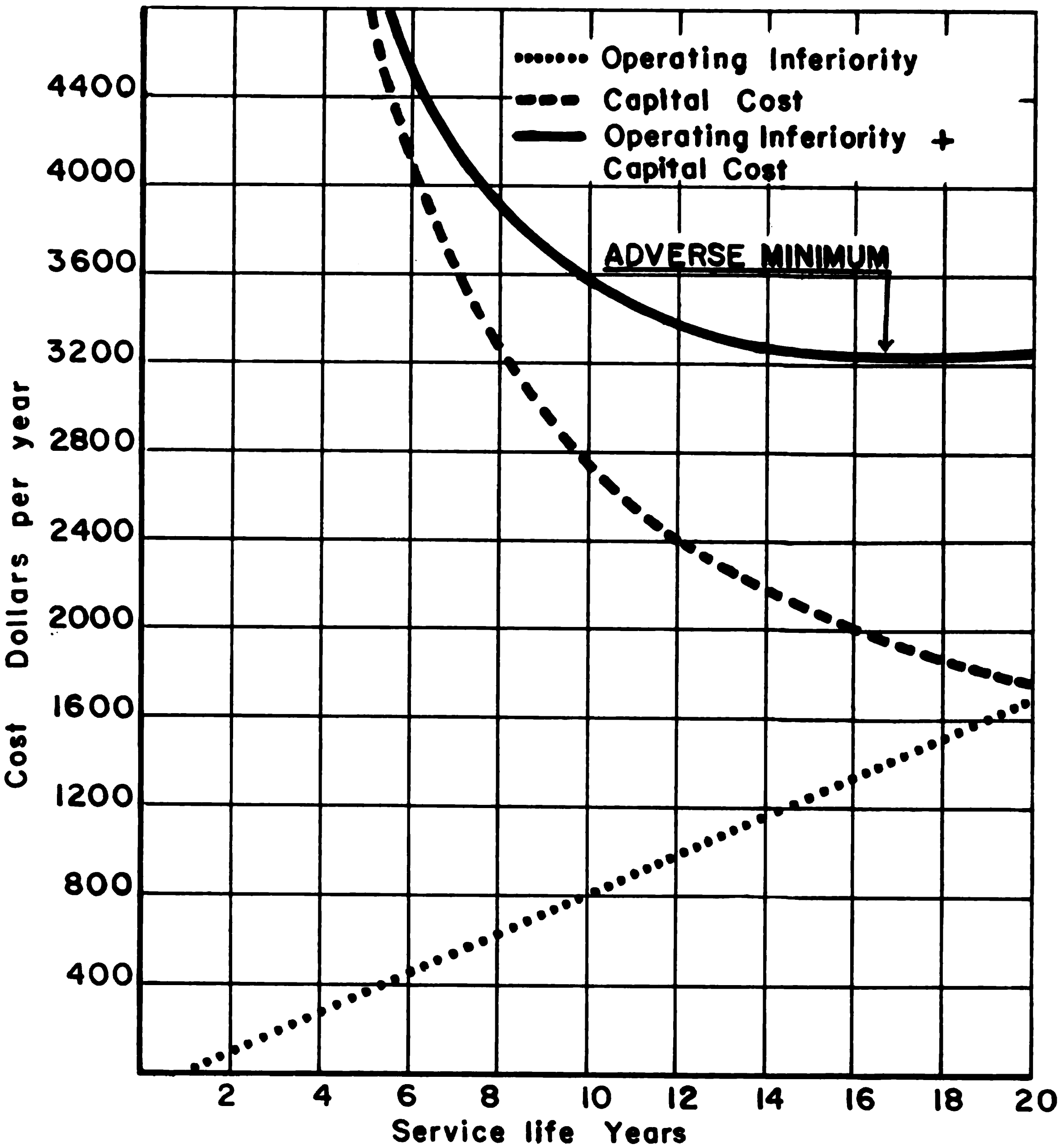


Figure 7 Cost Curve for Determining Adverse Minimum
The curves are drawn from data shown in Appendix 12

The adverse minimum for a challenger can be computed after assumptions about the annual inferiority gradient have been made. Operating inferiority has to be converted to present worth and then transferred to time-adjusted annual averages through multiplication by capital-recovery factor. This factor multiplied by initial cost gives the time-adjusted annual average of capital cost. Appendix 12 shows how these computations can be made for the adverse minimum of a challenger. Future capital additions and expected salvage value can be included in the computations. Similar computations for determination of the defenders adverse minimum are possible.

The advantages with the system outlined here are:

1. The future and the present will be considered, not the past.

2. Comparisons will be made using the best present alternative as standard.

3. Future operating inferiority for the challenger will be taken into account.

4. The cost of not replacing is available from the computations.

The method shown above to arrive at the adverse minimum is too complicated to be practical. A short-cut method has been developed that considerably shortens the computations and still for most purposes has proven accurate enough (46).

This short-cut method is developed with the following three assumptions:

1. Future challengers will have the same adverse minimum as the present one.

2. The present challenger will accumulate operating inferiority at a constant rate over its service life.

3. For a defender the time-adjusted average of capital cost and operating inferiority for next year is less than for any other year in the future. That is to assume that the defender at the time for the challenge is at, or to the right of the adverse minimum of the cost curve, Figure 7.

The first assumption does not mean that there could not in the future be challengers with an adverse minimum lower than the present one; it only indicates that the comparison is made with an infinite succession of challengers with the present challenger's adverse minimum.

The second assumption is as realistic as any other assumption for the future, and is a necessity to simplify the computations. The great difficulty is in determining the annual inferiority gradient, but the most unrealistic assumption is not to consider the gradient.

The third assumption is also acceptable. At a point where replacement is considered, the asset is mostly at a part of the curve where the cost is increasing, i.e. to the right of the adverse minimum where the increase in operating inferiority is predominately over the savings in capital cost for future service. This is an assumption that certainly applies on most materials handling systems, at least when old buildings are included.

Formulaes for deriving a challenger's adverse minimum have been developed. One is considering salvage value while another is neglecting it. It has been proven, though, that in cases where the salvage value is not effective within the first five years of service or if it is less than 10 per cent of the acquisition cost, it is negligible (46). As the defender's and the challenger's adverse minimum are the background for the comparison, the procedure for their computation will be given here.

Defender's Adverse Minimum. Accepting the assumption that next year is the defender's adverse

minimum, simplifies the computations considerably. The operating inferiority is arrived at simply through comparison of next year's operating costs for defender and challenger, the difference being the operating inferiority for the defender (or the challenger). Even expansion made possible through change to the challenger are taken into account. This consideration is most important because a simplified materials handling system on a farmstead is usually followed by an expansion.

The capital cost for the next year is the decrease in salvage value during the year and interest on the salvage value at the beginning of the year.

In some cases a defender requires capital addition to be usable for future service and considering the period of the expected life for the capital addition. The defender's adverse average is computed as following:

Adverse average = next year's inferiority +

$$+ \frac{g(n-1)}{2} + \frac{c-s}{n} + \frac{i(c+s)}{2}$$

where:

n = period of additional service

c = the present investment (the sum of capital addition and present salvage value)

s = salvage value at the end of the period

g = inferiority gradient during the period

In a case with capital addition it must be remembered that if a defender is worth keeping at all, it usually has to be kept over the full period of additional service to distribute the cost of capital addition. Its adverse minimum would otherwise be much higher and it could probably not compete with the challenger.

Challenger's Adverse Minimum. Salvage value, mostly not effective within 5 years and mostly less than 10 per cent of the initial cost, can for most cases in farmstead mechanization be neglected. The no salvage value formula for the challenger's adverse minimum is (Derivation of the formula is shown in Appendix 11):

$$\text{Challenger's adverse minimum} = \sqrt{2\,cg} + \frac{ic - g}{2}$$

where:

c = acquisition cost

g = annual inferiority gradient

i = interest rate

It should be observed that because the formula is derived from a differentiation with respect to the number of years, it solves for the adverse minimum without knowing the expected service life.

Capital additions to the challenger, when being significant, can be taken into consideration, and will give a higher adverse minimum. If capital additions do not occur within the first five years, they must be of considerable size to affect the result to any extent (46). According to this, in this study it would not be necessary to consider capital additions.

How the described technique can be used in making decisions about replacement will be shown by the following example:

A present dairy set up for 50 cows takes 2 men full time. A complete new set up which makes one man capable of handling 60 cows is planned and would cost $20,000. Power cost for the new set up is $100 per year higher than the old system. Net income above feed cost for every extra cow is $200 per year. Assume annual inferiority gradient for the system is $200 per year. Can the new set up be justified and if so, how much would be lost in keeping the old system for one more year?

Solution:

a. compute defender's adverse minimum

Next year's operating advantage in dollars

	Challenger	Defender
Labor	3000	

	Challenger	Defender
Net from 10 cows	2000	
Power cost	___	100
	5000	100

Net challenger's advantage or defender's

inferiority = \$4900

No salvage value can be expected for the old buildings, thus there is no capital cost for keeping the old buildings.

Defender's adverse minimum = \$4900

b. compute challenger's adverse minimum

Using formula $\sqrt{2\ cg} + \dfrac{ic - q}{2}$ gives

$$\sqrt{2 \times 20{,}000 \times 200} + \frac{0.06 \times 20{,}000 - 200}{2} = 3330$$

Challenger's adverse minimum = \$3330.

The solutions show that it is advantageous to adopt the new system under the assumptions made and that not adopting the system would lessen the possible income with 4900 - 3330 = \$1570 for the next year. The exact solution for the challengers adverse minimum is shown in Appendix 12.

Operating Inferiority Gradient. The most difficult of all estimates is the inferiority gradient. Translation into service life is sometimes helpful to realize its meaning. In the case where no salvage value is considered, the service life corresponding to a certain inferiority gradient is obtained if the inferiority gradient is divided into the adverse minimum computed from the no salvage value formula. This is true because no addition is made for decreased salvage value for the last year, and operating inferiority is equal to adverse minimum, as in the example used here. The inferiority accumulated during a period of time divided by the number of years, consequently gives the annual gradient. In the example, the adverse minimum 3330 divided by the gradient 200 per year gives a corresponding service life of 16.6 years, or the same as found in the exact computation in Appendix 12. This shows perhaps more clearly that the assumption of $200 per year as inferiority gradient is reasonable.

The order should be to compute corresponding service life from inferiority gradient. The replacement is often due to the inferiority to present systems, rather than deterioration and wear.

An estimate of inferiority gradient from historic data is the best that can be done. If the development in an area (example, silage making; feed handling) or for a certain machine or equipment is followed closely from year to year, and the best system or machine available at the present is measured (man hours per ton, man hours per cow) a picture of the inferiority gradient in the past is arrived at. From this, the future can be predicted, of course with probability involved, as always when dealing with the future. The technique would be the same and the justification as good for such computations as for determinations of trends, which are accepted and have been shown very useful in business and economics.

<u>Accuracy of the Short Cut Formula</u>. From the computations in Appendix 12 it is seen that the exact adverse minimum is 3220 against 3330 computed by the short cut formula, which means a deviation of around 3 per cent. It has been proven (46) that the deviation within the area of normal interest rates and for gradient cost ratio of 1 per cent or more, the deviation is less than 3 per cent, which, in many cases, is accurate enough to save the elaborate computations shown in Appendix 12.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

Today's commercialized farming is becoming more and more in common with industry as far as organization and management are concerned. The area of farm materials handling is becoming an important problem in farming, but is still an unorganized field. Industrial techniques and their possible application in analysis of materials handling on the farmstead are discussed in this thesis.

An analytical approach is made from a functional as well as from a cost stand point. Analysis of the physical properties of the materials handling problem are centered around the influence of material, layout, and machinery. A physical unit to express the magnitude of a handling problem is discussed.

Weight, volume, and other properties of material are tried as appropriate units, considering the specific characteristics of materials handled on the farm.

In evaluation of layouts, distance is the main property that is measurable, its significance in materials handling on the farmstead is evaluated.

Equipment and machinery are discussed from the standpoint of power requirement. The influence of unit load and distance on the performance of handling equipment is shown. A possible index to express the degree of mechanization is developed and an implementation chart classified according to degree of mechanization is made up.

The cost analysis goes into the different components in handling cost and their relative importance in solving handling problems. Different techniques in cost computations and their influence on the results are compared. Data sheets for a detailed cost analysis are developed and an implement selection chart based on break-even analysis. A replacement theory and its possibilities and applications in the area of farm materials handling system is described.

Conclusions

Industrial materials handling analysis is usually worked as a traffic problem based on the following factors:

1. Unit loads of packaged or baled material
2. Speed of travel
3. Distances traveled

4. Scheduling and routing for handling equipment

5. Distribution of storages with respect to the places where material is used.

Materials handling on the farmstead is not a problem of exactly the same nature as in industrial enterprises because:

1. Most of the material can be changed to fluidized form

2. Possibilities to eliminate handling are often present through self-feeding or other arrangements in the layout

3. Fixed equipment as conveyors, pneumatic systems, pipelines, are used to a great extent for the handling rather than fork trucks and tractors.

For these reasons the analysis has been concentrated around the three factors: material, layout, and equipment.

In materials the possibility to fluidize is of more importance than weight and volume, water being an example of a material with ideal handling characteristics.

Layout planning is more a problem of proper arrangement to minimize the number of handlings and facilitate self-feeding or automatic feeding rather than a problem of minimizing distances. Versatility and structure characteristics, though difficult to measure, are very important factors. Flow diagrams and flow process charts are helpful in layout analysis.

Equipment used generally has small power requirements which in connection with the few hours of use per year makes the influence of power cost small. Transport time is often relatively small or negligible, transfer time in many cases being more important. An index of mechanization is developed for the purpose of comparison between systems.

In general the physical properties of materials handling systems are difficult to measure. Some characteristics can be expressed in physical measures, but the only overall measure that works throughout a whole system is cost.

The method used for computation of capital cost becomes important when items with great differences in expected life are compared as is often the case for some equipment and structures on the farmstead. An appropriate capital recovery factor is recommended to use for such items. Added together with a factor for repairs, maintenance, taxes and insurance, an overhead cost factor is arrived at which is convenient to use. The suggested data sheets can be used to work out costs for single machines as well as for a complete system.

Appropriate replacement is essential to eventually eliminate obsolete methods. The method given is a more correct approach to replacement than is usually used, because it compares systems in use with the best method available rather than an imperfect present stage. It also considers future inferiority for the system, that is best at the present. The inferiority gradient is difficult to specify at the present, but a continuous follow up on methods development would give a good background for estimates.

The computational procedure for figuring cost is well established, the weak point in an analysis being the lack of standards and other information to use in the computations.

In analysis for choice between systems the future is always a factor in one or several alternatives. Probability must necessarily be involved, and the future must be predicted from our knowledge at the present. Planning and analysis will never be simply a slide-rule job that anyone could do. The analytical frame work that is used is a very important tool, but the results can not be expected to be more accurate than the data used in the calculations. With a careful choice of computational methods and careful selection of data, we still can get much further than with snap decisions or "hunching".

CHAPTER VIII

RECOMMENDATIONS FOR FURTHER STUDIES

To facilitate adequate planning of materials handling systems, systematic and continuous studies of methods are recommended to provide:

1. Reliable time standards for comparison of methods and systems
2. A continuous follow-up on methods developments to give the inferiority gradient for replacement studies
3. A basis for determination of how different characteristics in materials, layout, and equipment affect the handling time and cost

None of these suggested studies are one-man research projects, but rather they should be pursued as cooperative projects at several universities and experiment stations, after standard methods have been established.

Future work to simplify materials handling is most likely to be successful in the areas of:

1. Materials characteristics, e.g. fluidize materials

2. Layout planning to estimate handling, increase versatility and provide possibilities for changes with changing technology

3. Equipment design for complete systems considering the transfer from one operations stage in the handling to another.

APPENDIX

APPENDIX 1

LABOR REQUIREMENTS, MAN HOURS PER TON, FOR DIFFERENT HANDLING OPERATIONS ON THE FARMSTEAD (10)

	Weighted Averages for Farms Handling the Material			Averages for Group of Farms with Least Handling Time		
	Baled	Chopped	Long-Loose	Bales	Chopped	Long-Loose
1. Handling hay						
Unloading	0.23	0.20	0.78	0.21	0.17	0.45
Distribution in storage	0.27	0.15	0.56	0.10	0.00	0.56
Removal from storage	0.41	0.55	0.71	0.17	0.55	0.71
Moving from storage	0.35	0.38	0.41	0.27	0.00	0.41
Feeding	0.51	0.46	0.53	0.00	0.00	0.53
Total	1.77	1.74	2.99	0.75	0.72	2.66
2. Handling bedding						
Unloading	0.28	0.26	0.37	0.23	0.19	0.25
Distribution in storage	0.27	0.28	0.17	0.24	0.21	0.00
Removal from storage	0.46	0.61	0.91	0.46	0.46	0.91
Moving from storage	0.54	0.49	0.58	0.53	0.33	0.58
Distribution in stable	1.40	0.92	1.50	1.40	0.92	1.50
Total	2.95	2.56	3.53	2.86	2.11	3.24

APPENDIX 1 (continued)

	Weighted Averages for Farms Handing the Material		Averages for Group of Farms with Least Handling Time	
	Vertical Silo	Horizontal Silo	Vertical Silo	Horizontal Silo
3. Handling silage				
Unloading	0.13	0.14	0.13	0.10
Distribution in silo	0.11	0.10	0.11	0.00
Removal from silo	0.51	0.33	0.00	0.31
Moving from silo	0.47	0.21	0.00	0.11
Feeding	0.54	0.11	0.00	0.00
Total	1.76	0.89	0.24	0.52
4. Handling manure (dairy)				
Removal from stable	0.31		0.00	
Transport to pile	0.25		0.00	
Loading into spreader	0.06		0.00	
Total	0.62		0.00	
5. Handling small grain				
Unloading	0.27		0.19	
Distritution in storage	0.08		0.00	

APPENDIX 1 (continued)

	Weighted Averages for Farms Handling the Material	Averages for Group of Farms with Least Handling Time
Removal from storage	0.50	0.00
Total	0.85	0.19
6. Grinding and handling ground feed		
Grinding and blending	0.77	0.65
Moving to feeding area	0.49	0.00
Feeding	1.25	0.00
Total	2.51	0.65
7. Handling concentrates		
Unloading	0.34	0.20
Distribution	0.16	0.00
Removal from storage	0.67	0.00
Total	1.17	0.20

APPENDIX 2

ENERGY REQUIREMENTS FOR WORK ON THE FARM

Walking, wearing boots, 3 mph on level		Cal. per min.
	pavement	5.2
	grassland	5.5
	plowed land	7.0
Carrying a load of 50 lbs at 2.5 mph on level pavement		
on the shoulder		8.7
on the hip		9.5
in both arms across the abdomen		8.4
Walking upstairs, 100 steps per min		15.0
Pushing a feed cart on level firm ground		
pushing force 25 lbs		8.7
pushing force 30 lbs		10.3
Pushing force 35 lbs		11.7

Shoveling grain, shovel and load weigh 20 lbs

Cycles per min	15	10
Throwing material horizontally		
3 feet	7.5	5.5
6 feet	10.2	7.2
10 feet	14.4	10.0
Throwing material vertically		
3 feet	12.9	9.0

APPENDIX 2 (continued)

	Cycles per min	15	10
Throwing material vertically			
Throwing	7 feet	16.2	11.2
Farm work with a tractor driving along road or track			2.7
using front end loader			5.5

Energy requirements can be estimated by adding to these figures values for basal metabolism, body posture or activity and activity of the limbs.

		Cal pr minute
Basal metabolism		1.2
Posture		
sitting		0.3
standing		0.6
walking		2.0-3.0
climbing, per foot of rise		0.24
Activity of limbs	Range	
Hand work, light	0.2-1.2	0.4
heavy		0.9
one arm, light	0.7-2.5	1.0
heavy		1.8
two arms, light	1.0-3.5	1.5
heavy		2.5

APPENDIX 2 (continued)

Activity of limbs

body and limbs,	light	3.5
	moderate	5.0
	heavy	7.0
	very heavy	9.0

APPENDIX 3

MANUAL HANDLING TIME CHART (26)

(time in TMU, 1 TMU = 0.00001 man-hrs)

Weight Class	Plane I Transfer			Plane II Transfer			Plane III Transfer		
Volume, cuft	-2,0	2.1-6.0	6.0-10.0	-2.0	2.1-6.0	6.1-10.0	-2.0	2.1-6.0	6.1-10.0
A. Light, 25 lbs.	172	196	280	242	265	350	260	280	365
B. Medium, 25-50 lbs.	210	230	314	280	300	380	300	320	400
C. Heavy, 50-75 lbs.	270	295	350	340	365	420	360	380	440

Note: When distance of transfer exceeds 4 ft add 17.0 TMU for each additional pace required in each direction.

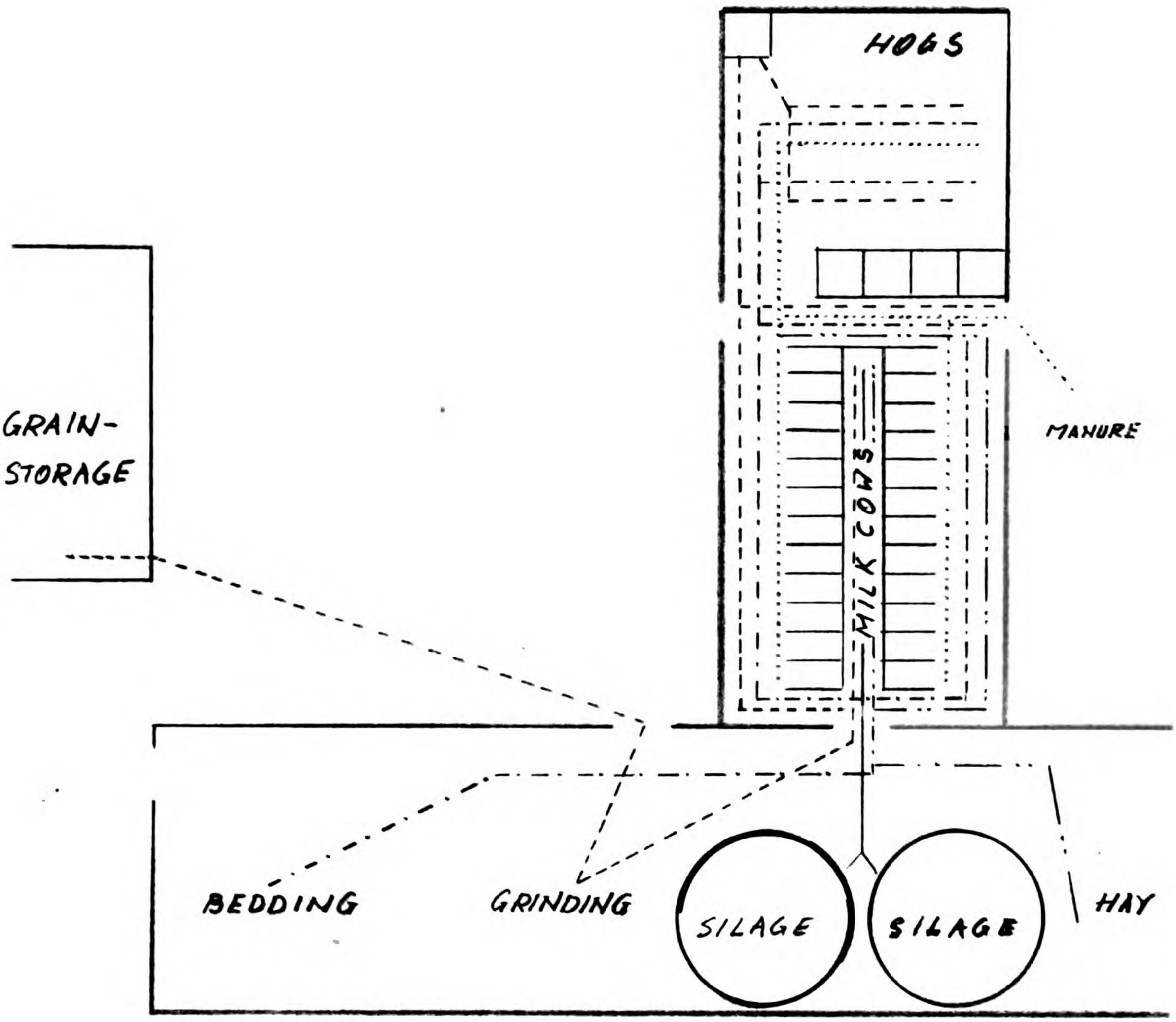
Plane I Transfer: Transfer on one level such as from floor, shoulder to shoulder or waist to waist. No body bend required

Plane II Transfer: Transfer from one level to another such as from waist to floor, or floor to waist.

Plane III Transfer: Transfer from floor to shoulder level, or shoulder to floor level. Same as Plane II with sidestep and move added.

APPENDIX 4

FLOW DIAGRAM



APPENDIX 5

FLOW PROCESS CHART

Product:- - - - - - - **Description:- - - - - - -**

Work Place or Building - - -- - - - - - -

Amount Moved per Year - - - - - lbs.

L	P	M	S	METHOD OR/AND EQUIPMENT *	MOVEMENT		UNIT LOAD Lbs.	DIST. MOVED PER UNIT LOAD			MAN HRS. PER UNIT LOAD		
□	◇	○	△		From	To		Loaded	Empty	Total	Trans.	Trans.	Tot.

* Symbols as suggested by F. H. Buelow

□ **Livestock**

◇ **Process**

○ **Movement**

△ **Storage**

APPENDIX 6

CLASSIFICATION OF MECHANIZATION AND IMPLEMENTATION LIST FOR HANDLING OPERATIONS

1. Hay handling, long hay

Operation	Manual	Semi-mechanized	Mechanized	Automatic
Unloading	By hand		Hoist	
Transport into storage and distribution	By hand	Conveyor Blower	Hoist	
Removal from storage	By hand			Self-feeding
Moving to feeding area	By hand	Conveyor Blower		Self-feeding
Feeding	By hand	Conveyor Blower		Self-feeding

2. Hay handling, baled hay

Operation	Manual	Semi-mechanized	Mechanized	Automatic
Unloading	By hand		Hoist	
Transport into and distribution in storage	By hand	Conveyor	Hoist	

APPENDIX 6 (continued)

Operation	Manual	Semi-mechanized	Mechanized	Automatic
Removal from storage	By hand	Conveyor		Self-feeding
Moving to feeding area	By hand	Conveyor		Self-feeding
Feeding	By hand	Conveyor		Self-feeding
3. Hay handling, chopped hay				
Unloading	By hand		Hoist	
Transport into storage and distribution	By hand	Conveyor	Hoist	
Removal from storage	By hand	Conveyor		Self-feeding
Moving to feeding area	By hand	Conveyor		Self-feeding
Feeding	By hand	Conveyor		Self-feeding
4. Silage handling, vertical silo				
Unloading	By hand	Mech. unloaded wagon	Mech. unloaded wagon	

APPENDIX 6 (continued)

Operation	Manual	Semi-mechanized	Mechanized	Automatic
Transport into storage and distribution	By hand	Conveyor Blower	Conveyor Blower	
Removal from storage	By hand		Silo unloader	
Moving to feeding area	By hand		Feedwagon	Bunkfeeder
Feeding	By hand		Feedwagon	Bunkfeeder
5. Silage handling, horizontal silo				
Unloading	By hand		Mech. unloaded wagon	
Moving into storage and distribution		Conveyor	Mech. unloaded wagon	
		Blower	Conveyor, Blower	
Removal from storage	By hand		Front end loader on tractor, Conveyor	Self-feeder

APPENDIX 6 (continued)

Operation	Manual	Semi-mechanized	Mechanized	Automatic
Moving to feeding area	By hand		Front end loader on tractors, conveyor	Self-feeding
Feeding	By hand		Front end loader on tractor, conveyor	Self-feeding
6. Grain handling				
Unloading	By hand	Conveyor	Mech. unloaded wagon	Mech. unloaded wagon
Moving into storage and distribution	By hand		Conveyor	Conveyor
Removal from storage	By hand	Conveyor	Conveyor	Conveyor
Transport to feeding or grinding	By hand	Wagon	Wagon	Conveyor
Feeding	By hand		Conveyor	Conveyor

APPENDIX 6 (continued)

Operation	Manual	Semi-mechanized	Mechanized	Automatic
7. Ground feed handling				
Grinding and/or blending			Burr or stone mill	Hammer mill
Moving to feeding area	By hand	Wagon	Conveyor	Hammer mill
Feeding	By hand	Wagon	Conveyor	Conveyor

APPENDIX 7

DEVIATIONS IN CAPITAL RECOVERY FACTORS COMPUTED IN DIFFERENT WAYS

(Method 1 - 3 refers to the description in the text, (p.51)

Estim. life years	Method 1		Method 2		Method 3
4% Int.	CRF	Dev.	CRF	Dev.	CRF
5	0.2200	-2	0.2240	-0.3	0.22463
10	0.1200	-2.5	0.1220	-1	0.12329
15	0.0860	-4	0.0880	-2	0.08994
20	0.0700	-5	0.0710	-4	0.07358
50	0.0400	-14	0.0404	-13	0.04655
8% Int.					
5	0.2400	-4	0.2480	-1	0.25046
10	0.1400	-6	0.1440	-3	0.14903
15	0.1060	-9	0.1093	-7	0.11683
20	0.0900	-11	0.0920	-10	0.10185
50	0.0600	-27	0.0680	-17	0.08174
12% Int.					
5	0.2600	-6	0.2720	-2	0.27741
10	0.1600	-10	0.1660	-6	0.17698
15	0.1260	-14	0.1306	-11	0.14682
20	0.1100	-18	0.1130	-16	0.13388
50	0.0800	-34	0.0812	-33	0.12042

APPENDIX 8

DATA SHEET I

Method: Present
Proposed

MATERIALS HANDLING ANALYSIS FORM

ANIMAL		MATERIAL			HANDLING			
KIND	NO	NAME AND DESCRIPTION	MAX. STORAGE CAPACITY	AMT. HANDLED PER YEAR	FROM	TO	DISTANCE IN FEET	UNIT LOAD

APPENDIX 8 (continued)

DATA SHEET I

METHOD AND COST							
EQUIPMENT	LABOR (Man Hrs /Ton)				NO OF MEN	LABOR COST PER TON	LABOR COST PER YEAR
	TRANSFER	TRANSPORT	OTHER	TOTAL			

APPENDIX 8

DATA SHEET II

EQUIPMENT	FIRST COST	USE PER YEAR		EXPECTED LIFE YEARS	CAPITAL RECOVERY FACTOR	TAX & INSURANCE FACTOR
		HRS.	TONS			

APPENDIX 8 (continued)

DATA SHEET II

REPAIR & MAINTENANCE FACTOR	ANNUAL OVERHEAD FACTOR	ANNUAL OVER-HEAD COST $	POWER COST $	LABOR COST $	TOTAL COST PER YEAR $	TOTAL COST PER TON $

APPENDIX 9

EQUIPMENT SELECTION CHART

<table>
<tr><th rowspan="3">EQUIPMENT AND METHOD</th><th rowspan="3">MATERIAL</th><th colspan="7"></th><th colspan="24">TRANSPORTATION CHARACTERISTICS</th></tr>
<tr><th colspan="7" rowspan="2">CAPACITY TONS/HR</th><th colspan="13">TRANSPORT DISTANCE FT.</th><th colspan="11" rowspan="2">AMOUNT TRANSPORTED PER YEAR</th></tr>
<tr><th colspan="7">HORIZONTAL</th><th colspan="6">VERTICAL</th></tr>
<tr><td></td><td></td><td></td><td>.5-1</td><td>1-3</td><td></td><td></td><td>3-5</td><td>5-10</td><td>0-5</td><td>5-10</td><td>10-15</td><td>15-20</td><td>20-25</td><td>25-50</td><td>50-100</td><td>0-5</td><td>5-10</td><td>10-20</td><td>20-40</td><td>40-80</td><td>80-</td><td>-10</td><td>10-20</td><td>20-30</td><td>30-40</td><td>40-50</td><td>50-60</td><td>60-70</td><td>70-80</td><td>80-90</td><td>90-100</td><td></td></tr>
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</table>

APPENDIX 10

MECHANIZATION PREFERENCE CHART

OPERATION OR MACHINE	ADDED COST $ PER YEAR A	DECREASED COST $ PER YEAR B	RETURN ON ADDED MECHANIZATION B/A $/$

APPENDIX 11

DERIVATION OF "NO SALVAGE VALUE FORMULA" FOR CHALLENGER'S ADVERSE MINIMUM

Life average of operating inferiority and capital cost can be computed from the formula

$$\frac{g(n-1)}{2} + \frac{c-s}{n} + \frac{i(c+s)}{2}^{*}$$

where

g = annual inferiority gradient

c = acquisition cost

s = terminal salvage value

n = number of years in service

i = rate of interest in decimals

If salvage value can be neglected the formula reduces to

$$\frac{g(n-1)}{2} + \frac{c}{n} + \frac{ic}{2}$$

Which expression if differentiated with respect to "n" can be minimized, the minimum value being the adverse minimum

$$\frac{du}{dn} = \frac{g}{2} + \frac{c}{n^2} = 0 \qquad n = \sqrt{\frac{2c}{g}}$$

If this value for "n" is used in the original formula

$$\frac{g(\sqrt{\frac{2c}{g}} - 1)}{2} + \frac{c\sqrt{\frac{2c}{g}}}{\frac{2c}{g}} + \frac{ic}{2}$$

which can be reduced to

$$\sqrt{2\ \ cg} - \frac{ic - q}{2}$$

* More exact $\frac{c - s}{2}\left(\frac{n + 1}{n}\right) + s$

APPENDIX 12

EXACT COMPUTATIONS FOR ARRIVING AT CHALLENGER'S ADVERSE MINIMUM

Year	Oper. Infer.	Present Worth Factor	Present Worth	Accum Oper. Infer.	Capital Recovery Factor	Time Adjusted Annual Average		
						Oper. Infer.	Cap. Cost	Total
1	0	0.9434	0	0	1.060	0	21200	21200
2	200	0.8900	178	178	0.545	97	10900	10997
3	400	0.8396	336	514	0.374	192	7480	7672
4	600	0.7921	476	990	0.289	286	5780	6066
5	800	0.7473	598	1588	0.237	377	4740	5117
6	1000	0.7050	705	2293	0.203	465	4070	4535
7	1200	0.6651	796	3089	0.179	554	3580	4134
8	1400	0.6274	877	3966	0.161	639	3220	3859
9	1600	0.5919	950	4916	0.147	723	2940	3663
10	1800	0.5584	1000	5916	0.136	805	2720	3525
11	2000	0.5268	1050	6966	0.127	882	2540	3422

APPENDIX 12 (Continued)

Year	Oper. Infer.	Present Worth Factor	Present Worth	Accum. Oper. Infer.	Capital Recovery Factor	Time Adjusted Annual Average		
						Oper. Infer.	Cap. Cost	Total
12	2200	0.4970	1095	8061	0.119	960	2380	3340
13	2400	0.4688	1125	9186	0.113	1035	2270	3305
14	2600	0.4423	1150	10336	0.108	1115	2170	3285
15	2800	0.4173	1165	11501	0.103	1190	2070	3260
16	3000	0.3936	1180	12681	0.099	1260	1980	3240
17	3200	0.3714	1190	13871	0.095	1320	1900	3220 *
18	3400	0.3503	1192	15063	0.092	1385	1840	3225
19	3600	0.3305	1190	16253	0.090	1462	1800	3262
20	3800	0.3118	1185	17438	0.087	1520	1740	3260

* Minimum annual time adjusted average = adverse minimum

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