PLANNING COMBINATIONS OF DAIRY CHORE METHODS AND EQUIPMENT WITH LINEAR PROGRAMMING

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PLANNING COMBINATIONS OF DAIRY CHORE

METHODS AND EQUIPMENT WITH

LINEAR PROGRAMMING

By

Andrew Jackson Lambert

ABSTRACT

Submitted to the Colleges of Agriculture and Engineering
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ABSTRACT

An analysis of the use of chore labor and equipment on dairy farms was made to determine if some type of coordinating procedure could be used in engineering the available components and known work methods into an efficiently operating system of performing dairy chores. The goal established was to formulate a guide which may be used in combining manual labor and chore labor-saving equipment to obtain the best combination and ultimately to maximize net revenue for an average dairy enterprise.

A number of methods exist for developing a systematic procedure to determine the best alternatives to use in performing dairy chores. A mathematical tool known as linear programming was selected as the method to use in this study. A dairy farm model based on area five of south central Michigan was formulated to analyze the use of labor, capital, feed, and other resources by the linear programming technique. Within the confines of the model selected, the problem was to determine a combination of chore labor, labor saving equipment, and arrangements to perform the necessary chores on the hypothetical dairy farm to maximize revenue.

The farm organization considered was static except for the number of dairy animals, chore routines, and related factors.

In formulating a model for linear programming of dairy chore activities, 22 equations defining restrictions or limiting resources were employed. The restrictions are labor, capital, feeds, housing, calves, manure, bedding, and the feeding of required feeds to proportionate numbers of replacements, dry cows, and milk cows. Eighty seven activities were employed to define alternatives in performing dairy chores, disposal coefficients required in the model, and product selling. Most presently used methods of performing chores on a dairy farm were considered as alternatives.

Two optimum solutions were obtained from the two different matrixes used. The initial matrix permitted the sale of hay, silage and prepared grain feed. The second matrix was the same as the first except that no sale of feed products off the farm was permitted. In the second matrix the value of feed products could be realized only through the sale of dairy products. The optimum solution to the initial matrix indicated that the hypothetical farmer should sell his feed and not try to maintain or milk a dairy herd. The solution to the second matrix satisfied the conditions outlined in the objective as related to the determination of an optimum combination of chore labor, equipment, and arrangements in the performance of dairy chores.

The optimum solution to the second matrix suggested a loose housing system of dairying. It was necessary to round certain numbers to get discrete units and to combine certain activities to get a feasible plan. The results indicate that this particular dairyman with limited labor and capital should use a loose housing arrangement to house, feed, and remove manure, but the stanchion barn should be retained for milking 35 cows. It appears that with this size herd there is not a sufficient increase in efficiency of a milking parlor arrangement to justify the high investment required for a milking parlor when there is a usable stanchion barn.

A field study was made to secure data to use in determining if subjective information on the use of chore labor-saving equipment could be applied to the linear programming technique. The dairyman's likes and dislikes relative to the use of chore equipment and arrangements can be written into the program if these opinions can be expressed in mathematical form. Although no effort was made to prove this in practice, data were collected and a point system designed to show how it might be done.

The use of linear programming as applied in this study should be examined further to seek possibilities for refinement and other applications. Possibilities for the use of linear programming appear great and with greater knowledge of its use many difficult problems can be solved. The engineer should aim still further effort at improvement of work routines, equipment, equipment placement, and arrangements from the system standpoint. Human factors should not be overlooked in making efforts to improve efficiency in doing chores on livestock farms.

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INTRODUCTION

The fact that earnings of farm labor remains low relative to labor earnings in other industries is an increasing problem in the farm industry. A partial solution to the problem might lie in the expansion of emphasis on labor-saving technology which would include handling livestock, feeds, livestock waste, and water. Studies have been made to overcome a serious lack of specific information concerning the effects of the use of mechanical farmstead equipment on labor efficiency. Other studies have approached the farm materials handling problem from the enterprise segment and industrial points of view. Most of the investigations to date offer valuable information on the problem of materials handling, but a need still exists for some type of coordinating effort to engineer the available components and known methods into an efficiently operating system.

An analysis of the use of chore labor and equipment on livestock farms seems to be a logical starting point for this investigation. A study made by the United States Department of Agriculture in 1955 showed that crop production per man hour increased by about 400 percent in the period from 1919 to 1955 (32) while livestock production per man hour only about doubled. Actually, labor incomes on most Michigan farms have declined recently and hired labor often fails to earn high enough returns to justify its use (7). In many instances farm family labor is working for considerably less than comparable labor in other industries. Labor incomes annually per man in south central Michigan (89 percent of farms had a dairy enterprise) varied from a low of $428.82 per year to a high of $2,492.35 per year for the four years 1955 through 1958 (2). Even with record breaking crop yields during 1958, farm labor did not receive income comparable to that received by industrial labor. A worker in industry could have earned about $1.25 per hour and worked only 40 hour weeks to have competed with his counterpart on the farm who often finds it necessary to work 60 or more hours per week. On the dairy farm many chores must be performed every day.

The economics of farming in Michigan indicates that the engineer should be concerned with arrangements, work routines, and equipment which will give the best combination of labor use and equipment in maximizing net return. An analysis of the use of chore labor and equipment on dairy farms seems most appropriate because: (1) some information is available on which to base system building; (2) dairy farms require relatively large amounts of chore labor or its equivalent in mechanization; (3) the dairy industry is important in the farm economy of Michigan; (4) systematic development of materials handling arrangements and reduction of chore labor on dairy farms has implications which extend to other farm enterprises; (5) studies leading to rearrangement and elimination of jobs, improved working conditions, and redesign of the work place and equipment are necessary for further labor-saving technological advances; and (6) an analysis of the performance of dairy chores leading to a systematic procedure for improvement seem desirable if the earning power of farm labor is to improve.

REVIEW OF LITERATURE

One of the earlier studies aimed directly at reducing chore labor on the dairy farm was conducted by Carter in 1942 (3). A detailed record was made of the time taken, the distance walked, and the routes traveled in doing the barn chores for a 22-cow dairy. A series of changes were made to make the work easier and to save time. These changes were of four general types: (1) rearrangement of the stable; (2) improvement of work routines; (3) provision of adequate and suitable equipment; and (4) convenient location of tools and supplies. Through motion and time study it was found that two hours and five minutes of time and two miles of travel could be saved daily on barn chores. Carter observed that this method of improving dairy chore routine can be applied anywhere.

Whenever manual work is performed, as in manufacturing or on dairy farms, there is always the problem of finding the most economical and satisfying way of doing the task. Five steps in a systematic approach to problem solving in industry have been described by Barnes (1958) (1) as purpose, analysis, challenge, application, and evaluation. This approach has been found very useful in the field of motion and time study. Operational analysis or operations research, as it is called by some authors, is a broader field which also includes motion and time study. It is a procedure used by industry and on at least one large commercial farm (6) to analyze all productive and non-productive elements of an operation with the thought of improvement. Niebel (1953) (22) thinks 25 percent of the operations performed by American industry can be eliminated through operations analysis.

In addition to those already mentioned, several agricultural researchers have approached farm material handling studies from the industrial point of view. Ronnfelt (1958) (26) made a study of industrial techniques for materials handling analysis and discussed the possibilities of applying these techniques to agriculture. Three important factors in farm materials handling were outlined as material, layout analysis, and equipment characteristics. A cost analysis of materials handling systems was advanced since computational procedure for figuring cost is well established. Ronnfelt concluded that the weak point in an analysis is the lack of standards and other information to use in the computations.

A technique following closely that of the methods analysist or industrial engineer was outlined by Ross (1957)

(27). His study was on human energy expenditure and he developed a method for analyzing a material handling system for all products on a grain-hog farm. A time, travel, and construction cost study of dairy cattle housing was made by Gummersheimer (1957) (8). The primary purpose of this study was to compare the system of loose housing for dairy cattle with a system of conventional housing with regard to: (1) construction cost; (2) labor time requirements; and (3) labor travel requirements. While the results of this study gave a mass of factual information on the operation of a specific dairy farm, it is the type of information recognized by Ronnfelt and others as a necessary prerequisite to any study of materials handling systems.

Kleis (1957) (14) set up a combination study and analysis to overcome a serious lack of specific information concerning the effects of the use of mechanical farmstead equipment on labor efficiency and, in turn, on overall production efficiency. A study was made of 320 Michigan livestock farms (270 dairy farms) to obtain information on the costs and effects on labor efficiency of various methods of performing materials handling operations. It was found that a high correlation exists between the degree of materials handling mechanization and over-all farm production efficiency.

The investigation made by Kleis was followed by that of McKenzie (1958) (18) who stated that coordinated equipment arrangements for complete mechanical handling were difficult to find. The general objective was to develop grain and feed storage and handling systems for livestock farms, a segment of the farm materials handling problem. The study was limited to consideration of grain feed handling systems from the in-take of the in-to-storage elevator to the common out-put of the out-of-storage conveyors. In addition to studying grain storage and handling systems for livestock farms, McKenzie proposed a number of arrangements and developed cost comparisons between different methods of handling grain.

While studies have recently been made, or are now being made, to develop methods of integrating buildings and equipment to reduce chore labor (an important phase of materials handling) a total workable solution to the problem has not been advanced. Seferovich (1958) (29) points out this by suggesting that some types of coordinating effort to engineer the available components into an efficiently operating system is sorely needed. In the same vein, Pinches (1958) (25) said there will be a need for successive and progressively more complete integrations of processing, materials handling, structures, sources of energy and power and means for their application, and for farm transportation.

In view of the studies already made and opinions on the direction of future research, it appeared that a review should be made of literature related to system planning. The term operations research has already been mentioned. Hall (1958) (9) reviewed this and some other approaches involving mathematics in his study of theoretical considerations in materials handling systems. The center of moments or center of gravity method was advanced as a possible way to locate storage units to enable the material to be handled at the least cost. Total system cost as determined for different volumes of flow was also advanced as a criteria for selecting a particular system. Another economic approach was that of justifying investment in materials handling equipment to save labor or time. Hall suggested that "a simple method is needed to relate various components into a materials handling system to determine the most economical arrangement." Mathematical programming techniques were offered as a possible solution to this need.

Two levels of activity are discussed by Sammet (1958) (28) in a planned approach to system studies. The first is defined as systems analysis which involves the definition, description and study of systems (their components and interrelationships), and the discovery of optimum relationships based on the performance goals and criteria selected. The second is defined as system design and development which involves research and development aimed at methods improvement at the level of individual operations and stages and the translation of the results of systems analysis into plans of action. The latter level of activity involving methods used in system design and development has been reviewed and is fairly well developed. On the other hand, methods of systems analysis as applied to agriculture are only recently receiving deserved attention.

The method of system analysis most often advanced in the literature is that of mathematical programming employing a mathematical technique known as linear programming (4). Mathematical programming is presented in a broader concept than linear programming and is one facet of the much broader field of operations research. Metzger (1957) (19) gave several definitions of mathematical programming. The one most fitting to this discussion is credited to Robert O. Ferguson and is quoted as follows: "---a method for picking a best choice when choices exist.---A formal method of calculating the best solution to a problem or situation where many solutions or management decisions are possible, depending on certain limiting conditions." Linear programming is an analytical method used to determine optimum plans from alternative combinations of variables interrelated in linear expressions. Metzger outlines the following necessary, though not necessarily sufficient, prerequisites which must exist in a problem to apply mathematical programming methods:

1. A number of choices or ways of taking action.
2. An efficiency (or cost) differential between the possible choices.
3. A set of restrictions or upper limits, i.e., that which cannot be exceeded.
4. A set of requirements or lower limits, i.e., that which must be accomplished.
5. An objective or policy statement, i.e., the goal to aim at; maximum profit, minimum costs, etc.
6. An interrelationship of the variables in significant expressions.
7. A common unit of measure.

Most materials handling problems have the foregoing prerequisites.

Agricultural economists have used a budgeting procedure similar to linear programming for many years. Recently, it was recognized that much more complicated problems could be solved with the linear programming technique if the production process could be broken down into a series of straight-line relationships. Heady (1952) (10) believes that farms are admirably adapted to this "process analysis" so long as linear steps are not confused with non-linear relationships. Even a curvilinear relationship can be considered by the technique where linear discontinuous segments on a curve can be approximated.

Turning to the practical possibilities of linear programming, farm magazines have recently predicted it will soon become one of the most important tools in choosing alternatives for farm enterprises. Doane (1959) (6) reports that linear programming can, to a considerable degree, substitute mathematics for bias or prejudice in determining the best operating plan for an individual farm.

PERFORMANCE GOALS AND CRITERIA

Any discussion of system planning leads immediately to a point of beginning which Sammet calls the selection of performance goals and criteria. A system could be planned to minimize chore labor or to maximize the use of mechanical chore equipment. The goal may be to maximize production on a dairy or livestock farm from a given set of resources conditioned by certain restraints inherent in the enterprise. In planning a system to perform farm chores, the goals to be attained could be to minimize distances traveled, energy used, or any other feasible criteria selected. A goal might be to try to employ the most profitable arrangement of given resources in a system of production. Since some maximum or minimum condition involving an economic end is most often desired, the goals of system planning are basically economic.

The goals of system planning as related to the use of chore labor and equipment on livestock farms then could be the arrangement of all factors involved in performing chores in such a way that a maximum net return given the resource limitations is extracted from the enterprise. Consequently, the maximization of output from a given set of resources leads to the maximization of net return. This is the normal end toward which most farm enterprises work, although factors such as worker satisfaction are important in any system design.

The two most important factors or resources to be considered in system planning as related to the performance of chores is labor and capital. Labor is versatile and can perform chores provided it is available. Capital is also versatile and can be invested in mechanical chore equipment and arrangements to perform chores provided it is available. Thus, it is the availability and use of these two resources within the framework of doing chores that most managers are concerned. This is true for other segments of the enterprise just as it is for that segment concerned with the performance of chores. However, when examining the use of chore labor and equipment, the manager is primarily concerned with efficiency in the sense that these two resources are so allocated that he is able to get the greatest net return from his enterprise. When labor and capital resources are limited, every effort is made to employ them so that maximum production is maintained, provided maximum production also contributes to the maximization of net revenues. Whether the farm operation is dairy, beef, hog, or poultry, it follows that if feed, medical service, and other factors are available, the farm should be organized in such a way as to allow limited labor and capital to perform necessary chores for a maximum number of animals or birds. When no change can be made in the use of limited labor and capital either by re-employment of one or the other to increase the total value of the product, then the chores are being performed at maximum efficiency.

PURPOSE

As cited in the introduction, the problem of system planning to reduce chore labor and/or to increase efficiency in the use of labor and capital to perform chores on dairy farms is sufficiently broad to limit the scope of this investigation to the dairy enterprise. The 845,000 dairy cows (13) over two years of age on Michigan farms in 1958 attest to possible usefulness of a limited study pertaining to the dairy enterprise. It is estimated that 85 million tons of materials are handled annually by Michigan farmers for these dairy cows, or approximately 100 tons per cow if the material is handled only four times (14).

Establishing Bounds for System Planning

The bounds of a system planning study need not be restricted since within the dairy operation several systems of harvesting, storing and feeding may be found. The entire haying operation from the cutter bar of the mower to feeding of the animals may be called a system. Several methods of handling hay from the field to the animal may be employed and to determine an optimum system of harvesting, storing and feeding hay on a given farm is a problem within itself. Whether the dairyman handles his hay as loose, chopped, baled or wafered will have an important bearing on how hay feeding chores are performed. Normally, field operations such as mowing, conditioning, raking, baling or chopping and hauling are not considered as part of the chore activities. Hence, more than chore activities are involved in considering a system of handling feed from the field to the animal.

Methods of harvesting which dictate the method of performance of chore activities can seriously limit possibilities of studying alternative chore arrangements. Fortunately systems of harvesting both baled and chopped hay have been developed which require approximately the same field labor and capital. In the case of chopped hay, the chopper picks the hay up from a windrow and delivers the chopped hay into a trailing wagon. The chopped hay is removed from the wagon and elevated into storage where it is dried. With baled hay, a hay baler picks the hay up from a windrow and ejects short bales into a trailing wagon. The baled hay is removed from the wagon and elevated into storage where it may or may not be dried. Mowing, conditioning, and raking are field operations which are essentially the same regardless of the system of hay making.

Many farms are equipped with both the hay baler and field chopper. Hence, if it can be shown that the use of one form of hay contributes more toward efficiency in the chore operation than another form, it would be simple for many farmers to tailor their field operations to the handling method indicated. This is the case provided there is no appreciable difference in these harvesting methods from the standpoint of labor and capital required, or convenience.

Field operations in harvesting forage for silage also vary depending on the harvesting practice used. Corn is chopped and grass may be chopped or unchopped for silage. Most farmers chop their ensilage which makes the methods of handling this feed resource less complicated when related to silage feeding chores. It must be pointed out that harvesting costs of ensilage for the upright silo and the horizontal silo are generally somewhat different. Different amounts of labor will be used in filling these silos. It is also generally believed that spoilage rates will be different, although research (33) shows that spoilage rates can be approximately the same where good management is used.

A premise of this investigation is that chore labor, chore labor saving equipment, and buildings and arrangements can be considered with the assumption that other factors within the dairy enterprise remain unchanged. It is believed that this approach can be justified since a large part of the chore labor on dairy farms falls within this segment of the enterprise. Chore labor is defined here as the labor involved in the removal of processed feeds, silage, and hay from storage to the feeding of the animal; the removal of all bedding from storage to the distribution of this bedding; the removal of all manure to the manure spreader or holding tank, but not the distribution of manure on land; and the entire milking operation including cleaning. Over 85 percent of the labor used in handling hay from the field (already loaded on vehicle) to the animal will be involved in chore labor as defined above. Over 85 percent of the labor used in harvesting, storing and feeding silage from an upright silo is involved. About 60 percent of the labor used in harvesting, storing and feeding silage from the horizontal silo falls within this definition.

From this discussion one recognizes the many factors which bear on a limited study such as this, making it practically impossible to give an absolute definition of bounds. It is believed, however, that with few exceptions field operations or systems involving these operations should not be considered in this study of chore activities on dairy farms.

Goal Established and Related Factors

The goal established in this study is to formulate a guide which may be used in combining the use of manual labor and chore labor-saving equipment to obtain the best combination and ultimately to maximize net revenue for the dairy enterprise to be considered. Said in another way, this study will attempt to outline the design of a materials handling system for doing the chores on a dairy farm based on known data and estimates by the author. Further, an effort will be made to locate or design systems which make efficient use of chore labor, i.e., from the standpoint of arrangement and ease in performing dairy chores. A practical procedure to use in making materials handling and labor-saving recommendations will be looked for.

The problem to be considered is similar to that posed to the process analysist in industry. Silage, hay, and processed feeds are raw materials which are stored at the farmstead. The cow is the machine which actually converts the raw materials into a product which is cooled, stored and later sold as whole milk. Some by-products are produced in the form of calves and manure. Stand-by machines must be maintained in the form of replacement stock and dry cows. Bedding might correspond to machine maintenance materials used by some industries and is required to maintain the herd. Labor, housing, equipment, and management are also required on the dairy farm in much the same way as in industry. The really big difference between industry and the segment of the dairy operation outlined above is that the dairy cow is less predictable than a machine. It will be necessary in this study to assume that the dairy cow does, in fact, behave as a machine and that diseases and other herd management problems beyond some minimum average have no bearing on the feeding, milking, and cleaning routine.

One other aspect of the problem at hand is bound up in subjective considerations of dairy farmers. Often no relationship exists between the easiest or most economical way to do a job and the way the job is actually done. Many farmers have no economic justification for investing in some piece of chore labor-saving equipment. On the other hand, some farmers do not invest in chore labor-saving equipment when clearly a greater return on their investment is possible by making the purchase. Another problem often confronted by the dairy farmer is inadequate labor supply and a consequence of this is investment in machinery which substitutes for labor. Perhaps the least important of the subjective factors affecting the dairy operation is investments made to impress neighbors or to maintain or improve prestige in the community. Subjective considerations of the dairyman are often more important to the success or failure of an operation than all other factors combined for it is within the realm of likes and dislikes that management decisions are made.

OBJECTIVE

Evaluation of previous research on materials handling and related subjects leads to the conclusion that this study should incorporate the following objective: To develop a systematic procedure in making layouts of chore labor-saving equipment on dairy farms and to develop a system of evaluating labor and chore equipment components to maximize efficiency from the standpoint of labor and capital use. This objective says that if labor is to be reduced and labor-saving equipment is to replace labor where capital is limited then some systematic procedure should be developed and followed in suggesting changes to be made. The question is what guide should engineers use in applying construction and mechanical principles which result in more efficient use of labor and capital on a dairy farm. Some specific questions might be asked. Should a dairyman build loose housing facilities or add a pipeline milker? What subjective considerations should the engineer recognize? Is there a way of evaluating subjective considerations? It is the purpose of the foregoing analysis to explore these and other questions related to engineering and economic aspects of performing dairy farm chores.

PROCEDURE

Collection of Data

The first obvious requirement in selecting chore performing alternatives on a dairy farm was the collection of data. It was necessary to outline much of the data now available relative to chore equipment and labor. This data included time and motion studies, equipment, capacity, cost, building plans and layouts. As indicated in the literature review and appendix, a comparatively large number of case studies exist on the subject (2,3,7,8,13,14,20,21). The existence of this resource material is one of the main reasons for selecting a study of dairy chore labor and arrangements. However, the fact that this resource material exists does not automatically make it applicable to any other than a given situation. Investigation of a number of time and motion studies on the performance of dairy chores indicates that either great variability exists among operators or the method of taking data varies considerably. In either case, it is extremely difficult to find consistent information which can be used with confidence. Morris (1955) (20, 21) used both the laboratory and field study approach to obtain time, motion, and effort data on the milking operation. The results of the field studies corresponded closely to the results of the laboratory study. Generally, this would indicate that averages can be accepted and applied with a fair degree of confidence.

One of the principle sources of data on labor used was the field study made by Kleis. In this study the handling methods and labor requirements were not broken down in the same way as in most other time and motion studies. Five classifications of methods were used in the Kleis study in the following way: (1) eliminated, (2) manual, (3) semi-mechanized, (4) mechanized, and (5) automatic. An operation was eliminated if it was not included in the farm program. A manual operation was performed without the aid of mechanical equipment and a semi-mechanized operation included both manual and machine handling. Where the operation was mechanized, manual effort was necessary but only for the operation of machinery. Automatic operations included neither manual handling nor a machine operator. In assembling data it was necessary to combine some of the operations from the Kleis study. Also, his study represents the only source of data in a few instances.

After investigating a number of possibilities for ways to develop a systematic procedure in determining the best alternatives to perform dairy chores, the linear programming technique seemed the most logical. It was recognized that most relationships to be considered were non-linear in the strictest sense. As an example, one cow might be milked in five minutes by a chore routine, but fifty cows can be milked in less than 250 minutes by the same chore routine. Up to a point, the more cows that are milked the less time it takes per cow. As the number of cows increase the time required to milk a cow decreases, but perhaps not at a constant rate. A curve to represent this activity may be something other than a straight line relationship. Several quadratics or equations of higher power representing curves become extremely difficult to handle even by experienced mathematicians and the more advanced computers. However, only a little accuracy might be sacrificed if the relationship was limited to that sector from possibly 25 to 35 cows or some other reasonable range.

Figure 1 shows the relationship of labor requirements for dairy cows to the size of herd based on the work of Fuller. Within the limits shown the relationships are nearly linear. If information shown by Day, Aune and Pond (1959) (5) in their study of the effects of herd size on

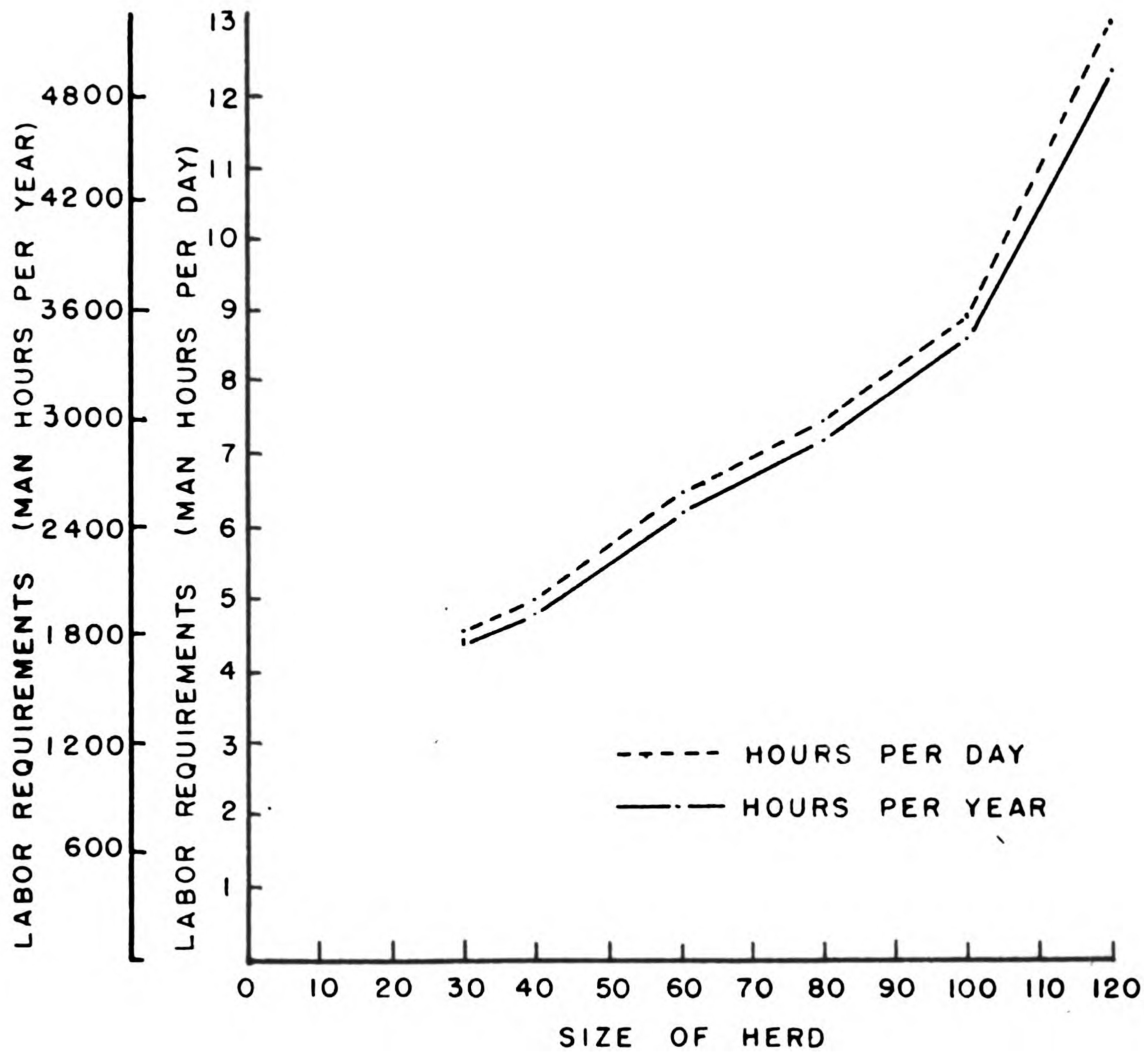

Figure 1 - Relation of Labor Requirements for Dairy Chores to Size of Herd (Curves developed from Appendix Table 2, Some Labor Efficient Dairy Farm Organizations, Ag. Econ. No. 690, Fuller, Earl I., Michigan State University, July 1957. Dairy chore labor includes the following items: prepare, milk, cleanup; care for maternity cows; feed calves grain and milk; feed silage and hay; bed total herd; yard scraping; and miscellaneous.)

dairy chore labor is plotted on a graph the same approximately linear relationship can be shown. Van Arsdall (1959) (34) shows approximate linearity within limits for some labor-cow and cost-cow relationships in his discussion of economic aspects of mechanization of feeding on dairy farms.

A Hypothetical Dairy Farm

In order to apply the linear programming technique, it is necessary to operate within the bounds of some existing problem or to formulate a model for analyzing the use of certain resources. One way would be to select a dairy farm which is typical of a large number of farms from the standpoint of size and the way chores are performed. This would require a detailed study of the farm to secure data and possibilities for change would have to be projected from existing conditions. The possibilities which might apply would be determined in large measure by realities which exist for the individual dairy operation being considered.

Another way to apply the programming technique is to set up a hypothetical dairy operation based on some average conditions and to try to make the problem match reality as nearly as possible. In this approach, the investigator has an advantage in not being limited by the restrictions imposed by any particular dairy farm operation. In working with averages, it appears that the results obtained would have broader application in the normative sense, i.e., stating what ought to be done given certain resources and restrictions.

A hypothetical dairy operation was used in this study based on average conditions in area five of south central Michigan (2). The basic farm organization is the average of 231 farms which kept records for the year 1958 and in some cases the price and yield figures used were ten year averages for the area. Eighty nine percent of the 231 farms had a dairy enterprise. In most cases, the data used refers to the dairy enterprise only. Eighty percent of the livestock income in the area was from dairy.

The average of the 231 farms in area five had 29.6 dairy cows per farm with an average of 9,715 pounds of milk sold per cow. The top third of the 231 farms with highest income had an average of 40.6 dairy cows per farm and sold an average of 9,950 pounds of milk per cow. A third of the 231 farms with lowest income had an average of 22.6 dairy cows per farm and sold an average of 9,174 pounds of milk per cow. It is interesting to note that Dairy Herd Improvement Records (13) for 1,084 herds in Michigan during 1958 show an average of 28.1 cows per herd and average production of 10,539 pounds of milk per cow. For purposes of a hypothetical dairy operation, a 30 cow dairy herd with an average of 10,000 pounds of milk sold per cow was selected.

An another important statistic from area five is man labor used per farm. The average farm was operated by an average of 1.7 men. For the hypothetical arrangement, it was necessary to estimate the number of man hours of labor available per year since no information was given on the number of hours the men worked. An estimated total of 5,920 man hours were used which is the equivalent of two men working 296 ten hour days per year. Using this figure, each worker would have off the equivalent of 52 Sundays and 17 other days during the year. The average owner-operator may work somewhat longer hours than this which will give a figure closer to the average of 1.7 men per farm as shown in the study.

It was estimated, as shown in Table 1, that 1,490.39 man hours were required to produce crops, pasture, and miscellaneous activities, and 4,430 man hours were available to perform dairy chores. The required man hours to produce and harvest crops was arrived at on the basis of an average of the number of acres of various crops produced in area five per farm and

Table 1 - Distribution of Labor on Crops and Dairy Chores[a]

Month	Man Hours of Labor										
	Corn for Grain 22A	Silage 37.1A	Alfalfa for hay 40A	Clover for hay 10.5A	Oats 23.2A	Wheat 23.2A	Tillable Pasture 29.5A	Other 25.3A	Total Used per Period	Total Used per Period	Avail. Dairy chores
Jan								1.07			
Feb.								1.01	14.85	1480.	1465.
March							11.65	1.12			
April	44.0	71.05	20.0	5.25	116.0	5.6		5.46			
May	88.0	144.2	160.0					9.89	509.45	986.6	477.2
June	44.0	79.87	80.0	5.25			11.8	2.17			
July	11.0	2.1	20.0	5.25	46.2	46.4	11.8	1.96	507.80	986.6	478.9
Aug.		3.78					34.0	2.13	59.91	493.3	434.42
Sept.		140.				104.4	34.0	2.34			
Oct.	33.0						14.75	23.3	351.79	986.6	634.87
Nov.	44.0							1.39			
Dec.								1.2	46.59	986.6	940.07
Total	264.0	441.0	280.0	15.75	162.6	156.4	118.0	53.03	1490.39	5919.7	4430.46

[a]Information adapted from Farm Management Reference Handbook, Vincent, W. H., Agricultural Economics Department, MSU; Monthly Distribution of Labor on Major Crops, Vary, K. A., Agricultural Economics Department, MSU; and Effects of Herd Sizes on Dairy Chore Labor, Day, L. M., H. J. Aune, and G. A. Pond, Minnesota Agri. Exp. Sta. Bul. 449.

the required hours of labor per month to produce these crops as reported by Vary, Vincent and others (35,36). Labor for harvesting is based on the belief that hay is most generally harvested in the baled form and silage is harvested in chopped form in this area.

Area five had an average of 211 tillable acres per farm. Only about 186 acres of this land was devoted to production of feed products which could presently be utilized in a dairy operation. The other 25 acres of tillable land could be converted, over a period of time, to crops used in the dairy enterprise since it was currently in the soil bank, idle, or used for other crops. From the 186 tillable acres, it was estimated, based on acres and average yields of various crops grown, that 458.2 tons of silage, 140.2 tons of hay, and 91.3 tons of grain were produced.

It was necessary to assume a hay and silage feeding program for the hypothetical farm arrangement since the length of feeding periods and average rations were not given in the data from area five. This farm was organized to give a 240 day silage feeding program for the dairy herd which extended from September 15 to May 15. The hay feeding program extended from August 15 to May 1. The roughage feeding program is important to this study since chores are reduced when animals go on pasture. In the roughage feeding program just outlined, 50 percent of the feed was hay and 50 percent was silage. Concentrates were fed to give 10,000 pounds of milk production per cow per year with this roughage feeding program. The concentrate feed was prepared from farm grown grains and mixed with 44 percent protein supplement purchased off the farm.

If the average dairyman in area five expects to change his chore routine, reduce chore labor, or otherwise improve his operation, he will probably need some investment capital. The average farm in this area had a book value of $37,316 not including the residence, machinery, feeds and crops, and livestock. It was assumed that the farmer could borrow or provide up to fifty percent of this amount, or $16,659. Interest at six percent on the $16,659 would reduce the amount available for investment the first year to about $15,660. This does not suggest that the average farmer in area five should make available all of his capital to purchase chore equipment and new arrangements. A decision to invest available capital should only be made after capital requirements for the total farm are considered. However, for purposes of a hypothetical farm in this study, the manager is permitted to consider investing all of his available capital in chore labor-saving equipment and new arrangements. After a study has been made to determine capital needs of any or all segments of the farm enterprise, the manager can decide on the allocation of limited funds. Determining the over-all use of limited resources is not an objective of this study.

Up to this point, the two most important resources involved in the performance of chores on a hypothetical dairy farm have been discussed. Certain other factors, especially the physical set-up, are related to the use of these capital and labor resources. Most of the detailed information on the physical set-up of the average farm in area five will be approximated. It will be necessary to make estimates of the physical arrangement where reliable data cannot be obtained.

The assumption is made that the farm is equipped with a thirty stall stanchion type dairy barn which is believed to be typical for the average size operator. Both the milk and dry cows are housed in this barn since only 25 cows are assumed to be giving milk at any one time during the year. With this type barn, hay is normally stored in the mow over the milking area for milk and dry cows. The hay is most often fed in the baled form, although it can be fed in either chopped or loose form from the mow of this barn.

The hypothetical farmer uses a two-unit milker and handles milk in cans although some local marketing outlets require a bulk cooling tank. Handling milk in cans and cooling milk in a bulk cooling tank can be consistent with the farm as organized since the chore routine is considered to be ended when the milk is delivered to the cooling medium. All of the milk produced on this farm is sold at $4.00 per hundredweight which is the ten year (1949-58) average price for whole milk produced in area five. Undoubtedly, many farmers use part of the milk produced for feeding calves and for home consumption, but these practices are not permitted for the average farm being studied.

On the typical farm being discussed, it is assumed that the replacement heifers can be raised on the farm. Normally, the replacements are cared for in different facilities than provided for milk and dry cows. Most farms have ample building space available which is suitable for raising replacement heifers. For the 30 cows in the milking herd, the assumption is that 9 replacement heifers are required and ample facilities for housing and storage of feed are available on the farm for these replacements.

A 290 ton concrete stave tower silo is assumed to be located adjacent to the present 30 cow stanchion barn. This silo will provide storage of silage for the present herd. It is also assumed that adequate facilities exist for the storage and processing of grain presently grown on the farm or that grain is sold and later purchased back as processed feed. In either event, the time or capital needed to process feed will not be considered in this study since the processing of feed on the average farm is not routine, i.e., done on a daily basis. The processing of feed can be a daily chore routine where automatic feed processing equipment is installed, but practically no daily labor is involved in the operation of a well engineered system. Even if feed is processed on the farm, it is done during slack labor periods, although labor for this purpose may become critical during the summer months. Thus, it seems most logical to start the chore routine with the processed feed in storage.

In the above discussion, it is assumed that all present facilities on the hypothetical farm are used as stated and debt free. Only annual operating expenses are attached to the continued use of these facilities, i.e., variable cost or costs such as electricity, equipment repair, etc. which vary with the number of cows in the herd. The dairy herd is also paid for and maintaining its present size does not call for any capital outlay. Any expansion in the size of the present herd will require an assumed investment of $225 per heifer ready to calve and enter the milking herd.

Products other than milk may be sold off the average farm in south central Michigan. Hay, silage, and grain can be sold or fed to other types of livestock not included as part of the dairy enterprise. The average ten year (1949-58) price for alfalfa hay in this area was $22.13. An estimated sale price of $7.05 per ton is placed on silage and $57.93 per ton was received for average grain sold off the farm. The ten year average price for corn in area five was $47.84 per ton and for wheat the price was $66.66 per ton. Heifer calves not needed for replacements is another product which may be sold at from 3 to 5 days old for an estimated $8 each. Young bull calves are also disposed of, usually within 3 days after they are born. Some dairymen report a sale price of $5 each and some say they give the bull calves away. For purposes of the hypothetical farm under consideration, bull calves will not be considered to have value. If the dairyman is fortunate enough to get something for his bull calves, the revenue might contribute toward veterinary expenses.

Up to this point, an effort has been made to show in general the existing dairy farm organization. It has been pointed out that labor is limited on this farm. Further, this labor is limited to months and time periods of one to three months depending on the time of year. These time periods are shown in Table 1. There are six labor restricting periods which are selected to allow for shifts of the timing of tasks within the periods, but no shift in tasks between periods are permitted. The amount of capital available to the farm is limited and may be used primarily for the purchase of labor saving chore equipment and rearrangement of structures. Any investment made in new facilities will have to be made from the limited capital available and the cost of the new facilities should include both the initial cost and the first years operating costs.[a] The reason for this is that new facilities must be installed and operated before income is realized from the investment. Funds must be available, first, to purchase the facility and, second, to operate the facility until it shows a return. Normally, one year is the period considered to be required to adjust from one facility to another, although, the time period varies depending on the type of equipment or new arrangement.

Within the setting just outlined, the problem now is to

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[a]As used here, the first years operating costs includes both fixed and variable cost. In this sense the fixed cost is a variable cost for planning purposes.

determine a combination of chore labor, labor-saving equipment and arrangements to perform the necessary chores on a hypothetical dairy farm to maximize profit as related to this segment of the enterprise. Field production costs and other factors unrelated to the performance of chores are not to be examined. In this study, gross return less all costs related to the performance of chores has been selected as the resource to be maximized. This is the criteria for determining the best combination of chore activities. Since factors unrelated to chore activities are not permitted to change, this should lead to a maximization of profits on the farm being discussed. It has been pointed out that the goal set-up could have been to minimize distances traveled, energy used, or tons of material handled. However, except for subjective considerations, whether a change in chore activities will increase returns or reduce costs is normally the yardstick by which the need for most chore labor reducing activities are measured. It appears difficult to engineer an optimum chore system without first determining what that system should be from an economic standpoint.

The Linear Programming Model

The general problem in linear programming can be stated formally and compactly in matrix form as:

Maximize: $f(X) = C'X$

subject to the programming restrictions:

$PX \leq S$

$X \geq 0$ Reference (11)

For $f(X) = C'X$, revenue,[a] as used in this study, is a linear function of the values assigned to the individual elements in X, as indicated in:

$$z_o = \sum_{j=1}^{n} c_j x_j = c_1 \ x_1 + - - - + c_n \ x_n$$

For purposes of this study, z_o denotes revenue. The c_j's are the gross revenue less costs related to the performance of chores for each activity or element in the revenue equation. The c_j's make up C'[b] or the single row matrix.

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[a]Revenue as used in the maximizing functional refers to gross return less all costs related to the performance of chores. This definition of revenue will continue to apply in the succeeding discussion.

[b]The C' in the function to be maximized is a transposed column vector, i.e., the C' represents an n column by an m (one) row matrix. The rows of matrix C are the columns of matrix C' and the column of matrix C are the rows of matrix C'. The matrix C represents a column vector or m row by single n column matrix.

Following the terminology used in matrix algera i refers to the number of the row in the matrix and j refers to the number of the column. The number of rows in the matrix is indicated by m and the number of columns by n.

From the above general statements on linear programming as used in this study, the revenue equation (as defined above) and the resource restrictions can be discussed in more detail. The revenue equation is $z_o = c_1x_1 + - - - + c_{87}x_{87}$ where z_o is the gross revenue less costs related to the performance of chores and c_1 through c_{87} are the coefficients to the x_i's. Each of these coefficients were arrived at by taking the gross revenue for each alternative way of performing a chore or activity and subtracting from this figure the annual cost of ownership and operation for that activity. The annual cost of ownership and operation of the resource defined by the activity is the sum of the annual depreciation, interest, insurance and taxes on the new investment only and the variable cost associated with the use of all facilities included in the activity. In a later discussion of activities which go to make up the model, the difference in activities as related to the revenue function will be pointed out.

<u>The restrictions</u>

The programming restrictions are generally stated in terms of the product of P, the matrix of input-output coefficients, and X, a column vector of levels of activities which are less than or equal to S, the column vector of resource supplies. Also, another restriction states that each activity level, x_i, contained in X must be equal to or greater than zero. By adding disposal or slack activities the former restriction $PX \leq S$ can be changed from an inequality to an equality. The latter restriction $X \geq 0$ is retained because of both economic and mathematical relevance.[a]

In formulating a model for linear programming of dairy chore activities, 22 equations defining restrictions were employed. These equations follow from the general restriction $PX \leq S$. Six equations restrict labor used to the supply available for each of six time periods. The general statement of this equation is that the total of all labor used in performing chores plus the amount of labor unused must be equal to the amount of labor available for a given time

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[a]For a more detailed discussion of matrix algebra, as used in linear programming, the reader should refer to Chapters 11 and 12 of "<u>Linear Programming Methods</u>" by Heady, Earl O. and Winfred Candler as cited in the reference.

period. One capital restriction limits the amount of capital used by all alternative activities plus the amount unused to the amount which is available for investment and operating expenses. A heifer calf restriction limits the number of heifer calves produced by milk cows to the number to be used in the replacement herd plus the number sold. In other words, the number of heifer calves produced (12 for every 25 milk cows) plus the number used in the replacement herd plus the number sold must equal zero.

Several restrictions maintain a predetermined ratio of the number of dry cows, and replacement heifers to milk cows which are fed silage, hay, and concentrate feeds. The proportionate number of milk cows, dry cows, and replacement heifers that must be maintained is based on the hypothetical farm arrangement. The first of these restrictions states that the number of replacement heifers fed silage plus the number of replacement heifers acquired ready to enter the milking herd must equal the number of replacements required annually for the milking herd. In all of these restrictions a negative sign will be associated with the coefficient of the activity which produces or increases the level of that restriction. A positive sign is associated with the coefficient of an activity which reduces the level of that restriction. The number of replacement heifers are fixed endogenously so that the number of replacement heifers increase or decrease as the number of milk cows increase or decrease.

Replacement heifers must also be fed hay and a restriction permits this to happen. The restriction states that the replacement heifers fed silage must equal the replacement heifers fed hay. Another restriction states that every replacement heifer fed hay must also be fed concentrates. In both of these restrictions a disposal activity enters but a high cost is attached to disposal use in the revenue equation. For all practical purposes the disposal activiities may be omitted in a discussion of restrictions like this. A restriction limits the number of dry cows to be fed silage based on the size of the milking herd. The restriction shows that the number of dry cows fed silage plus the number of dry cows disposed of plus 5 dry cows for every 25 in the milking herd must equal to zero. Following the scheme used for replacement heifers, two restrictions state that the number of dry cows fed silage plus the number fed hay must equal zero and the number fed hay plus the number fed concentrates must equal zero.

Only two restrictions relate to feeding of milk cows.

One restriction states that the number of cows milked plus the number disposed of plus the number fed silage must equal zero. Said in another way the number of cows fed silage must be milked or disposed of. All cows fed silage are expected to be milked, since milking is the only income producing choice in the revenue equation. A second restriction says that the same number of cows fed silage must also be fed hay, or the number of milk cows fed silage plus the number fed hay must equal to zero.

Milk cow space is restricted to 30 stalls in a stanchion barn as indicated in the discussion of the hypothetical farm. This restriction states that the algebraic sum of the number of spaces used by various milking arrangements plus the number not used must be equal to the number of spaces available. The silage, hay and concentrate restrictions are made up in the same general way. The sum of each type of feed fed to either milk cows, dry cows, or replacement heifers plus the amount of feed not used plus the amount sold must equal to the amount of each feed available.

A manure restriction is included to force the removal of all manure produced by milk cows, dry cows, and replacement heifers. The restriction states that the sum of all manure produced by milk cows, dry cows and replacement heifers must equal the amount removed by the manure removal activities. In the original make-up of this restriction, a disposal activity is included, but this is later nullified by the large cost attached to a disposal activity in the revenue equation.

The restriction on bedding should be discussed in detail since it was made up slightly different from other equations mentioned above. The original thought was that bedding must be maintained at a level at least equal to or greater than the amount required. Few farmers would quarrel with a situation where they have too much bedding, although there is no particular reason for having more bedding than required except that some farmers try to maximize manure production of which bedding is a part. The restrictions as set up states that the algebraic sum of the bedding used by milk cows, dry cows, and replacement heifers must be equal to or greater than zero. This restriction is not stated in a way to require that at least one bedding activity be included in the optimum solution. One way to encourage the use of bedding is to assume an initial stock of bedding to be available in the same way that feed was assumed to be available. If no initial stock of bedding is assumed to be available (as was the case here) the disposal activity needs to show bedding as having some revenue value in order for the supply of bedding to exceed requirements.

<u>The activities</u>

The restrictions described above state the conditions which any solution to the organization problem must satisfy. More important to this study are the activities since at the outset it was stated that combinations of chore activities to maximize efficiency from the standpoint of labor and capital use are of primary interest. In this study, gross return less the cost of performing chores has been selected as the resource to be maximized. The cost of doing chores does not include return to farm labor. The activities will be described briefly and a more detailed description can be found in the code to matrix columns located in the appendix.

Both groups and singular activities were selected to be considered by the linear programming technique. The group activities are: feeding silage, feeding hay, feeding concentrate, milking in combination with milk selling, manure removal, and bedding. Replacement heifer acquisition, heifer calf selling, silage selling, hay selling, and concentrate selling are additional singular activities considered. In the case of feeding silage, feeding hay, and feeding concentrates, the activities are sub-grouped according to the type of dairy animal being fed, i.e., milk cows, dry cows or replacement heifers.

The sub-group of activities considered under silage feeding to milk cows are eight in number and listed as P_{23} through P_{30}. Each activity represents a different way of feeding silage. Thus, one or a combination of silage feeding arrangements may be selected to feed silage to milk cows. The least amount of capital would be required to use the present concrete stave tower silo and hand feed the silage to the animals. In some of the activities, mechanical equipment was added to the silo which results in the use of more capital but less manual labor. New horizontal and vertical silos relocated for a loose housing system of dairying are also considered in these activities. To limit the size of the matrix, the bunker silo represents all horizontal silos in this study. The trench silo is not considered since construction cost and labor requirements for feeding are quite similar. Also, a promising new type of large diameter tower silo with center mechanical unloading is not included since the original matrix was set up before general information was available on its use.

The alternative ways of storage and feeding of silage to dry cows are the same as the silage feeding activities for milk cows. This group of activities is listed consecutively from P_{39} through P_{46} in the code to matrix columns. It may be assumed that milk cows and dry cows are fed together for purposes of this study although a fence or other barrier will sometimes separate the animals. The same type of storage and feeding equipment are normally used for both milk and dry cows. These groups of activities could have been combined if the same corresponding feeding coefficients had been used in every case. To summarize silage feeding activities for both milk and dry cows the following different ways of handling silage are considered: 1 - remove manually from present silo and feed in stanchion barn, 2 - remove with silo unloader from present silo and manually feed in stanchion barn, 3 - remove manually from present silo and feed with aid of monorail feed box in stanchion barn, 4 - self feed from new horizontal silo, 5 - automatically feed from new tower silo equipped with silo unloader and mechanical feeder, 6 - remove manually from relocated tower silo and manually feed, 7 - remove manually from relocated tower silo and mechanically feed, 8 - remove and feed from new horizontal silo with aid of tractor scoop and unloading wagon.

The methods of feeding silage to replacement heifers are more limited since these animals represent varying stages of growth and are often separated from mature animals. Four methods of feeding silage to replacements are represented in the group of activities from P_{58} through P_{61}. First, silage may be handled manually from the present tower silo to feeding racks in the heifer barn. This is probably the way most replacement heifers are now fed silage. Another activity reflects the possibility that silage can be mechanically unloaded from the present silo and manually fed to replacements in the heifer barn. If a change is made to a new type of milking arrangement, then the present stanchion barn becomes available for replacement stock. An activity permits manual feeding in the stanchion barn remodeled for replacements. Less labor is involved in feeding in this arrangement since the feed storage is closer to the animals, but some capital is needed to remodel the barn. The last of these activities permit manual feeding of silage to replacements in the remodeled stanchion barn with the aid of a mechanical silo unloader.

The next general group of activities is related to feeding of hay to milk cows, dry cows, and replacement heifers. Any one of the activities in a sub-group represent a way to completely feed hay to that class of animals being considered. The types of hay feeding activities range from the present method of feeding baled hay in a stanchion barn to the self-feeding of chopped hay from a self-feeding structure. Feeding arrangements equipped with artificial hay drying facilities are considered. Normally artificial hay drying is not considered a part of the chore routine. Two primary reasons for introducing hay drying into this study are (1) methods of handling chopped hay do not seem practical unless the hay is artificially dried and (2) factors on hay drying could be easily entered into some of the activities. In all cases where chopped hay is fed as an alternative, the activities include facilities for artificial drying. Artificially cured hay in terms of alfalfa number one equivalent is estimated to be 14.8 percent higher in value or worth $3.03 more per ton (based on 1957 price of alfalfa hay in south central Michigan) than field-cured hay with no rain damage (15). In the appropriate row under the activities including the use of artificially dried hay, both hay drying costs and increased value of hay are reflected in the revenue. More capital and in some cases more labor will be required in activities which includes artificial drying than in similar activities without drying.

The alternative ways of feeding hay to milk cows and dry cows are identical. The same general remarks made on the feeding of silage to dry cows and milk cows apply with regard to separation of animals and use of the same feeding facilities in feeding hay. The activities which represent the different ways of feeding hay to milk cows are listed from P_{31} through P_{38} in the cose to matrix columns. For dry cows these activities are listed from P_{47} through P_{54}. Both groups of activities are summarized as: 1 - manually feed baled hay from mow in present stanchion barn, 2 - semi-self feed artificially dried chopped hay at ground level from new pole type hay storage, 3 - manually feed artificially dried chopped hay from mow in present stanchion barn, 4 - manually feed baled hay at ground level in bunk along side of present remodeled barn, 5 - manually feed artificially dried chopped hay at ground level in new pole type barn, 6 - manually feed artificially dried chopped hay at ground level in bunk along side of present remodeled barn, 7 - semi-self feed hay at ground level in new pole type barn, and 8 - semi-self feed artificially dried baled hay at ground level in new pole type barn.

Only two activities, P_{62} and P_{63}, are considered in the sub-group for feeding hay to replacement heifers and both of these are manual methods. Essentially the two activities are the same except that baled hay is fed in the heifer barn and chopped hay fed in the remodeled stanchion barn. These two activities would be the same from the standpoint of labor required if either all baled or all chopped hay was used. A better set of possibilities could be offered by expanding the matrix to include the use of both forms of hay in both barn arrangements.

The third general group of activities is related to feeding of concentrates to dry cows and replacement heifers. It was necessary to place the activities representing the feeding of concentrates to milk cows with the milking activities. The reason for this is that most time and motion studies on milking activities combine time to feed concentrates with time to do some other element of the milking chores. Also, investment cost of concentrate feeding equipment is often quoted in the total cost of a milking system.

The three activities which represent methods of feeding concentrates to dry cows are listed as P_{55}, P_{56}, and P_{57}. These are 1 - manually feed in stanchion barn, 2 - automatic gravity feed in milking parlor, and 3 - mechanically feed in modified stanchion barn. Here it was assumed that dry cows can be fed concentrates with the same facilities used to feed milk cows. Some dairymen reduce the amount of concentrate given dry cows, but this does not greatly affect the chore routine as long as dry cows must be fed concentrates.

The only two alternative activities representing methods of feeding concentrates to replacement heifers are manually with bucket in heifer barn and manually with the aid of push cart in remodeled stanchion barn. These are listed in the code to matrix columns as P_{64} and P_{65}. It will be noted in this as well as in previous feeding activities for the raising of replacement heifers that possibilities are not as great for reducing manual labor as in milk cow and dry cow activities. If replacement heifers were produced in larger volume, considerations of greater use of mechanical equipment might be justified.

The milking and milk selling group of activities represent different arrangements to perform the milking chores and are listed in the code to matrix columns from P_{66} through P_{73}. The sale of milk and the cost to expand milking facilities are included in the appropriate rows under these activities. Milking activities given on a per cow basis include all regular chores where required in milking, cleaning equipment, feeding concentrates to milk cows, and other related jobs. Initially thirty cow spaces are available in the stanchion barn and the maximum permitted. Sixty cows are permitted to be handled in one stanchion barn arrangement which is mechanically equipped, and in all milking parlor arrangements. In reality some of these arrangements will handle even more cows. The coefficient in the revenue function specified for each alternative milking activity is the annual revenue from the sale of milk less the annual operating cost per cow.

The present milking arrangement is assumed to consist of a 30 cow stanchion barn equipped with a two-unit milker and the milk is handled and cooled in cans. An alternative arrangement is the same except a three-unit milker is used instead of a two-unit milker. A third milking activity represents a similar milking arrangement except that a four-unit milker is used instead of a three-unit milker and a 500 gallon bulk tank and pipeline system has been installed. It is considered possible to milk 60 cows with this arrangement by milking 30 cows at a time.

Five activities in the code to matrix columns are related to milking in milking parlor arrangements. In all of these arrangements, it is considered possible to milk at least 60 cows. From the standpoint of the amount of feed available on the farm, the maximum number of cows which can be fed are about 50 unless replacement heifers are purchased instead of raised. Therefore, enough capital ($75) on a per cow basis was included in the coefficients in the capital resource row under the milking activities to increase the herd by 20 cows. Figure 2 shows how this was done for the double four herringbone milking parlor.[a] The curves shown in Figure 2 would not be exactly the same for other milking parlors or where the stanchion barn is used as a parlor.

The milking parlor arrangements considered include the double-four-herringbone, three-U-side-opening, three-in-line side-opening, double-three-walk-through, and four-stall tandem elevated parlors. All of these arrangements are equipped with automatic concentrate feeders except the four-stall tandem elevated parlor. All five parlors are equipped with pipeline milkers and bulk tanks.

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[a]Figure 2 shows the relationship of actual investment in expansion of facilities and herd size to investment used in the linear programming (L.P.) model for the double-four herringbone milking parlor. The L. P. coefficient used in the capital resource row under the double-four herringbone milking parlor activity is a constant investment of $355.28 per cow or a total of the average building, equipment, and first years operating cost and the average investment in cows on a per cow basis. The curve representing the total actual average cost of building, equipment, first years operating cost and herd expansion is more nearly linear than the curve representing actual average investment in building, equipment, and first years operating cost alone.

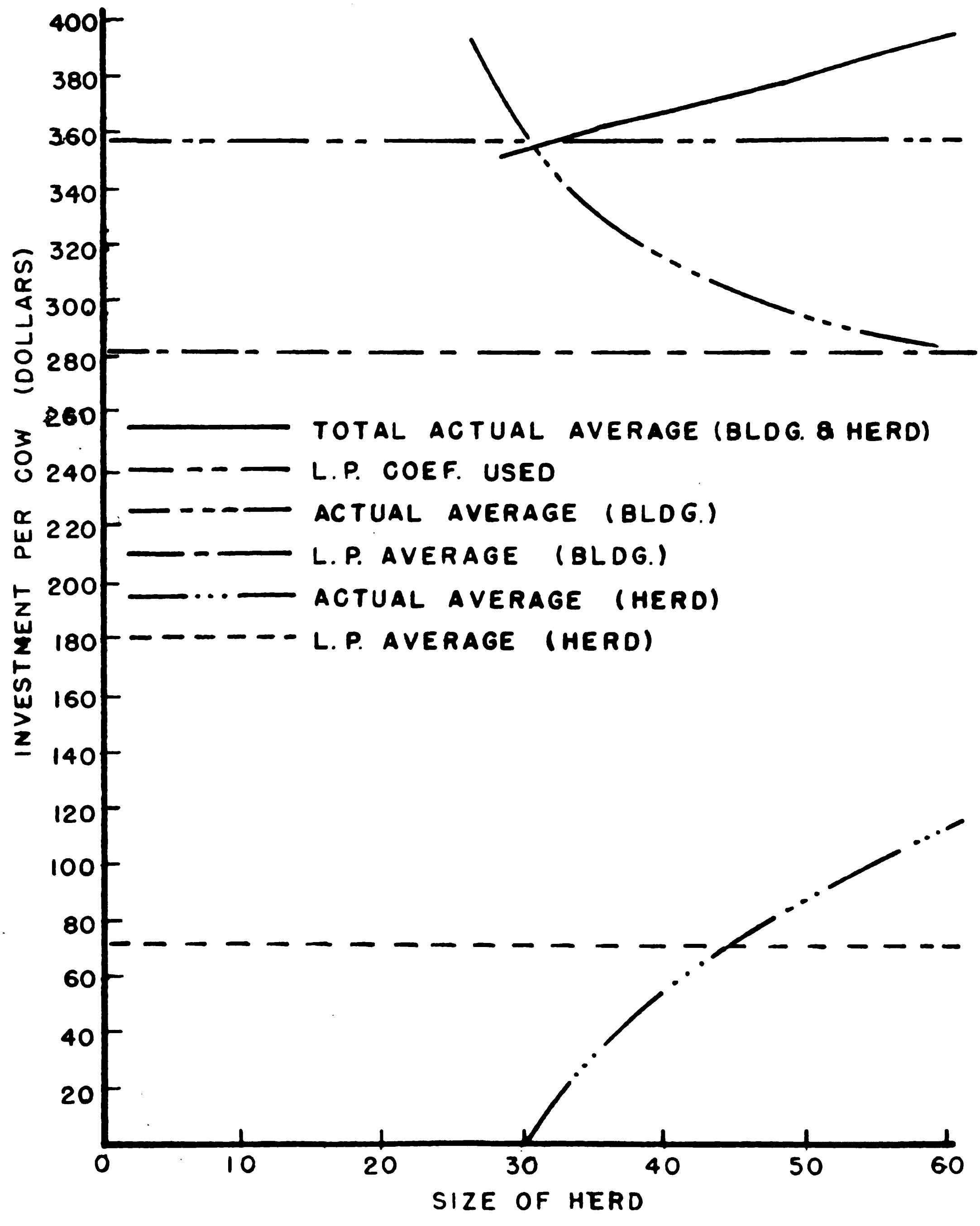

Figure 2 - Relationship of Actual Investment in Expansion of Facilities and Herd Size to Investment Used in L.P. Model (Double 4 herringbone parlor - based on addition of 20 cows to present 30 cow herd.)

In setting up the milking group of activities a number of factors had to be considered. First, the existing stanchion barn placed limitations on possibilities for expansion. The fact that existing livestock and milking facilities are debt free must be considered. Any expansion in the size of the dairy herd calls for capital outlay for both animals and facilities. The amount of feed available on the farm places limitations on the size of the herd. The new milking facilities considered have varying limitations when it comes to the number of cows that can be handled. These factors have to be considered if the activities as defined are to approach reality. On the other hand, each of the activities represent a milking arrangement which will provide for milking on a per cow basis up to the specified limit of the arrangement. Hence, the milking arrangements are not comparable in the strictest sense because one arrangement will provide for herd expansion whereas another does not. Therefore, it will be necessary to make some compromises in the statement of the activities or in analyzing the results.

In stating the activities an effort was made to be as realistic as possible. From the standpoint of results, care must be exercised in analyzing any optimum solution which calls for use of a milking arrangement for less than the number of cows the system will handle. Thus, if a milking arrangement is selected which will handle 60 cows and only 30 cows are called for in the optimum solution, an erroneous conclusion can be drawn since, in reality, no investment capital would be required for cows at this scale of operation. The cows are already available on the hypothetical farm as explained earlier. If the optimum solution calls for a shift from an arrangement which will handle 30 cows to one which will handle more than 30 cows with no increase in herd size, then some capital for investment will be included in the new arrangement. In analyzing this solution it would be necessary to subtract out this investment for cows and then add investment per cow for the new milking arrangement. The investment for the new milking arrangement was based on a larger size herd. In the end the investments will tend to cancel each other. In view of this, the activities will enter at a more realistic level than might be anticipated.

Another approach (17) which may be used relative to making provisions for expansion in the size of the dairy herd is to value the present cows at their purchase price and include this value in the amount of capital available. In this case, the assumption would be made that no cows are on the farm to begin with. Then for every cow milked one milk cow and the proportionate number of dry cows and replacement heifers would have to be acquired. This arrangement would satisfy capital investment conditions for expansion of the dairy herd, but varying capital investment in milking facilities would still have to be accounted for. Capital investment for various milking facilities can be prorated on a per cow basis for a smaller number of cows. With this method it would be necessary to make up several programs, but more realistic results could be obtained.

The last two groups of activities are manure removal and bedding. In an effort to limit the matrix array to a given size (23) the manure removal and bedding activities were each combined for milk cows, dry cows, and replacement heifers. Using this scheme, only those methods of bedding and removing manure could be considered which were applicable to all animals. Also, in figuring the amount of manure to be removed or bedding to be used, composite amounts had to be used since different amounts are handled for replacement heifers and mature dairy cows. The problem statement, and consequently the results, would more nearly approach reality if the activities were expanded to represent each class of livestock and related to the milking activities to guarantee the inclusion of one of the sub-group of manure or bedding activities in the same way as previously shown for other sub-groups.

The manure removal activities are represented by P_{74}, P_{75}, P_{76}, and P_{77} in the code to matrix columns. Stanchion barn cleaning may be done with or without the aid of a mechanical gutter cleaner as indicated in P_{74} and P_{76}. The methods of cleaning manure from a loose housing system is by tractor and scoop, and manure spreader. The only difference in P_{75} and P_{77} is the time period in which the loafing barn is cleaned.

Five alternative bedding activities are considered as represented by P_{78} through P_{82}. It was assumed that either straw or sawdust is available for bedding and either may be used in the stanchion barn. The alternative of either baled or chopped straw may be used for bedding in a loose housing system. All alternative methods of handling bedding are manual. The only difference is the form in which the bedding is handled and the distance involved. Chopped or baled straw can be stored in the loafing barn or baled straw can be stored in some other building. For the loose housing arrangements a bedding storage investment is included in these activities in the capital equation.

Several singular activities are included in the matrix array. One of these is activity P_{83} which permits replacement heifers about to begin their first lactation to be acquired rather than produced on the hypothetical farm. Activities have already been discussed which include recommended feeding and management practices for the production of replacement stock (12, 30) on the farm. The alternative of acquiring replacement heifers makes it possible to use investment capital to replace scarce labor and feed. Thus, it is possible to make available more of certain scarce resources to increase the size of the milking herd than would be the case if all replacements were produced on the farm. Activity P_{84} permits the sale of cull heifer calves or all heifer calves not needed when replacement heifers are not purchased.

Three other activities represent the sale of feeds produced on the farm. It is possible for the hypothetical dairy farmer to go out of the dairy business and only produce feed to sell. The sale of silage, P_{85}, is permitted at $7.05 per ton, good quality hay, P_{86}, can be sold for $22.13 per ton, and prepared grain feed, P_{87}, has a sale price of $57.93 per ton.

Subjective considerations

The use of linear programming as outlined does not include the consideration of subjective factors in dairy farm management. An exception could possibly be the statement on the amount of labor available which implies an assumption on how hard a man is willing to work. Early in the development of this study it was thought that subjective considerations would be included although no technique had been developed for the inclusion of farmer opinions. Later, after the matrix array became quite large for prospective use of available digital computers, the idea was abandoned. It was believed, and this belief still holds, that if numerical values can be attached to all chore activities or routines based on subjective considerations of a manager or an average of a number of managers, the optimum plan will be found which will be even more useful than that rendered by present objective data.

A questionnaire was developed with the goal of securing numerically rated subjective data. The farmer was asked to rate chore labor reducing equipment which may be used on a dairy farm. The farmer was permitted to rate the equipment only if he made use of the equipment. The rating was made according to how much he felt labor was reduced, what value he attached relative to its cost, how convenient the equipment was to him, what effect the equipment had on working conditions, the effect of the skill required to operate the equipment, the effect of the equipment on time required to do the chore, the mechanical reliability of the equipment, and the use of labor saved by the equipment. Generally, from three to seven degrees of opinion were permitted by the questionnaire on each of the points listed. For instance, if the piece of equipment in question was very valuable, the farmer said he would not do without it and the use of the equipment received a high rating; or, if the farmer thought the piece of equipment was not worth bothering with, the use of the equipment received a low rating. Information secured as numerical data can be put into equation form provided some maximum or minimum number of points are selected by the manager to indicate the level of convenience, working conditions, or other criteria he wants to operate at.

Formulation of the Model and Computations

The resource restrictions and the activities which make up the model have already been discussed. An abbreviated listing of all activities and resource restrictions with numerical coefficients are included in Table 2 which gives

Table 2 - Matrix for Initial Solution

Resource	UP_2	UP_3	UP_4	UP_5	UP_6	UP_7	UP_8	UP_9	UP_{10}	UP_{11}	UP_{12}	UP_{13}	UP_{14}	UP_{15}	UP_{16}	UP_{17}	UP_{18}	UP_{19}	UP_{20}	UP_{21}	UP_{22}	UP_{23}
	Disposal Activities (slack vectors)																					
Max. Revenue								-M	-M	-M		-M	-M		-M		-M					
P_2	1.0																					
P_3		1.0																				
P_4			1.0																			
P_5				1.0																		
P_6					1.0																	
P_7						1.0																
P_8							1.0															
P_9								1.0														
P_{10}									1.0													
P_{11}										1.0												
P_{12}											1.0											
P_{13}												1.0										
P_{14}													1.0									
P_{15}														1.0								
P_{16}															1.0							
P_{17}																1.0						
P_{18}																	1.0					
P_{19}																		1.0				
P_{20}																			1.0			
P_{21}																				1.0		
P_{22}																					1.0	
P_{23}																						1.0

Table 2 - (Continued)

Resource	Activities and Processes Unit	Amount	P_{23}	P_{24}	P_{25}
c_j			-3.40	-2.32	-8.46
P_2	Man hours	1465.0	4.07	0.81	0.26
P_3	Man hours	477.2	2.04	0.41	0.14
P_4	Man hours	478.9			
P_5	Man hours	434.4			
P_6	Man hours	634.9	2.04	0.41	0.14
P_7	Man hours	940.0	2.72	0.54	0.18
P_8	Replacement heifers fed silage	0			
P_9	Replacement heifers fed hay	0			
P_{10}	Replacement heifers fed concentrate	0			
P_{11}	Heifer calves	0			
P_{12}	Dry cows fed silage	0			
P_{13}	Dry cows fed hay	0			
P_{14}	Dry cows fed concentrate	0			
P_{15}	Milk cows fed silage	0	-1.0	-1.0	-1.0
P_{16}	Milk cows fed hay	0	1.0	1.0	1.0
P_{17}	Unit milk cow space	60.0			
P_{18}	Tons manure	0	-16.05	-16.05	-16.05
P_{19}	Tons bedding	0	-1.09	-1.09	-1.09
P_{20}	Tons silage	458.2	7.2	7.2	7.2
P_{21}	Tons hay	140.2			
P_{22}	Tons concentrate	91.3			
P_{23}	Dollars capital	15660.00	2.04	29.52	122.41

Table 2 - (Continued)

	Real Activities						
Resource	P_{26}	P_{27}	P_{28}	P_{29}	P_{30}	P_{31}	P_{32}
c_j	-9.24	-3.88	-3.05	-5.34	-8.09	-9.19	-7.00
P_2	2.54	3.46	4.07	1.66	1.54	1.14	0.042
P_3	1.27	1.73	2.04	0.83	0.77	0.45	0.014
P_4							
P_5						0.19	0.007
P_6	1.27	1.73	2.04	0.83	0.77	0.76	0.028
P_7	1.69	2.3	2.72	1.11	1.03	0.77	0.029
P_8							
P_9							
P_{10}							
P_{11}							
P_{12}							
P_{13}							
P_{14}							
P_{15}	-1.0	-1.0	-1.0	-1.0	-1.0		
P_{16}	1.0	1.0	1.0	1.0	1.0	-1.0	-1.0
P_{17}							
P_{18}	-16.05	-16.05	-16.05	-16.05	-16.05		
P_{19}	-1.09	-1.09	-1.09	-1.09	-1.09		
P_{20}	7.2	7.2	7.2	7.2	7.2		
P_{21}						2.4	2.4
P_{22}							
P_{23}	43.19	9.39	72.74	97.96	51.78	3.45	177.26

Table 2 - (Continued)

Resource	Real Activities P_{33}	P_{34}	P_{35}	P_{36}	P_{37}	P_{38}	P_{39}	P_{40}
c_j	-14.66	-7.75	-6.58	-9.24	-4.34	-4.34	-3.40	-8.46
P_2	0.65	1.34	0.52	0.35	1.05	0.84	4.07	1.27
P_3	0.22	0.45	0.17	0.12	0.35	0.28	2.04	0.64
P_4								
P_5	0.11	0.24	0.09	0.06	0.17	0.14		
P_6	0.43	0.87	0.35	0.22	0.70	0.55	2.04	0.63
P_7	0.43	0.89	0.35	0.23	0.70	0.56	2.72	0.85
P_8								
P_9								
P_{10}								
P_{11}								
P_{12}							-1.0	-1.0
P_{13}							1.0	1.0
P_{14}								
P_{15}								
P_{16}	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0		
P_{17}								
P_{18}							-15.96	-15.96
P_{19}							-1.1	-1.1
P_{20}							7.2	7.2
P_{21}	2.4	2.4	2.4	2.4	2.4	2.4		
P_{22}								
P_{23}	12.04	46.81	170.39	55.40	133.90	133.90	2.04	122.41

Table 2 - (Continued)

Resource	Real Activities P_{41}	P_{42}	P_{43}	P_{44}	P_{45}	P_{46}	P_{47}	P_{48}
c_j	-2.32	-9.91	-3.88	-3.05	-5.34	-8.09	-9.19	-7.00
P_2	2.03	2.54	3.46	4.07	2.03	1.27	1.14	0.042
P_3	1.02	1.27	1.73	2.04	1.02	0.64	0.57	0.021
P_4							0.38	0.014
P_5							0.28	0.01
P_6	1.02	1.27	1.73	2.04	1.02	0.63	0.76	0.028
P_7	1.36	1.69	2.3	2.72	1.36	0.85	0.77	0.029
P_8								
P_9								
P_{10}								
P_{11}								
P_{12}	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0		
P_{13}	1.0	1.0	1.0	1.0	1.0	1.0	-1.0	-1.0
P_{14}							1.0	1.0
P_{15}								
P_{16}								
P_{17}								
P_{18}	-15.96	-15.96	-15.96	-15.96	-15.96	-15.96		
P_{19}	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1		
P_{20}	7.2	7.2	7.2	7.2	7.2	7.2		
P_{21}							2.4	2.4
P_{22}								
P_{23}	29.52	43.51	9.39	72.74	97.96	51.78	3.45	177.26

Table 2 - (Continued)

Resource				Real Activities				
	P_{49}	P_{50}	P_{51}	P_{52}	P_{53}	P_{54}	P_{55}	P_{56}
c_j	-14.66	-7.75	-6.58	-9.24	-4.34	-4.34	-2.01	-5.21
P_2	0.65	1.34	0.52	0.35	1.05	0.84	7.056	2.86
P_3	0.33	0.69	0.26	0.18	0.53	0.42	4.70	1.91
P_4	0.22	0.45	0.17	0.12	0.35	0.28	4.70	1.91
P_5	0.165	0.36	0.09	0.105	0.255	0.21	2.35	0.95
P_6	0.43	0.87	0.35	0.23	0.70	0.56	4.70	1.91
P_7	0.43	0.89	0.35	0.23	0.70	0.56	4.70	1.91
P_8								
P_9								
P_{10}								
P_{11}								
P_{12}								
P_{13}	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0		
P_{14}	1.0	1.0	1.0	1.0	1.0	1.0	-1.0	-1.0
P_{15}								
P_{16}								
P_{17}								
P_{18}								
P_{19}								
P_{20}								
P_{21}	2.4	2.4	2.4	2.4	2.4	2.4		
P_{22}							1.28	1.28
P_{23}	12.04	46.81	170.39	55.40	133.90	133.90	11.50	30.21

Table 2 - (Continued)

	Real Activities							
Resource	P_{57}	P_{58}	P_{59}	P_{60}	P_{61}	P_{62}	P_{63}	P_{64}
c_j	-4.75	-2.08	-5.05	-8.95	-5.98	-4.58	-9.62	-2.08
P_2	4.08	2.28	1.569	1.362	2.079	0.4803	0.4525	0.2094
P_3	2.72	1.14	0.784	0.681	1.039	0.4246	0.2794	0.1396
P_4	2.72					0.1558	0.1450	0.1396
P_5	1.36					0.0779	0.0725	0.0698
P_6	2.72	1.14	0.784	0.681	1.039	0.2971	0.2602	0.1396
P_7	2.72	1.52	1.046	0.908	1.386	0.3202	0.2986	0.1396
P_8		-1.0	-1.0	-1.0	-1.0			
P_9		1.0	1.0	1.0	1.0	-1.0	-1.0	
P_{10}						1.0	1.0	-1.0
P_{11}		1.0	1.0	1.0	1.0			
P_{12}								
P_{13}								
P_{14}	-1.0							
P_{15}								
P_{16}								
P_{17}								
P_{18}		-9.90	-9.90	-9.90	-9.90			
P_{19}		-1.455	-1.455	-1.455	-1.455			
P_{20}		3.67	3.67	3.67	3.67			
P_{21}						1.21	1.21	
P_{22}	1.28							2.01
P_{23}	23.61	1.25	22.17	44.74	23.82	1.72	25.54	0.78

Table 2 - (Continued)

	Real Activities							
Resource	P_{65}	P_{66}	P_{67}	P_{68}	P_{69}	P_{70}	P_{71}	P_{72}
c_j	-5.04	238.05	218.30	208.15	238.61	212.79	209.00	209.98
P_2	0.1212	10.92	8.91	6.83	8.38	8.63	9.75	7.78
P_3	0.0808	6.95	5.92	4.55	5.41	5.75	6.50	5.18
P_4	0.0808	6.33	5.82	4.54	5.24	5.75	6.50	5.18
P_5	0.0404	3.35	2.91	2.27	2.77	2.88	3.25	2.59
P_6	0.0808	6.79	5.92	4.54	5.57	5.75	6.50	5.18
P_7	0.0808	7.14	5.94	4.55	5.47	5.75	6.50	5.18
P_8		0.36	0.36	0.36	0.36	0.36	0.36	0.36
P_9								
P_{10}	-1.0							
P_{11}		-0.48	-0.48	-0.48	-0.48	-0.48	-0.48	-0.48
P_{12}		0.2	0.2	0.2	0.2	0.2	0.2	0.2
P_{13}								
P_{14}								
P_{15}		1.0	1.0	1.0	1.0	1.0	1.0	1.0
P_{16}								
P_{17}		2.0	1.0	1.0	2.0	1.0	1.0	1.0
P_{18}								
P_{19}								
P_{20}								
P_{21}								
P_{22}	2.01	1.28	1.28	1.28	1.28	1.28	1.28	1.28
P_{23}	23.82	16.50	238.04	355.28	20.83	344.99	347.69	339.57

Table 2 - (Continued)

Resource	Real Activities P_{73}	P_{74}	P_{75}	P_{76}	P_{77}	P_{78}	P_{79}	P_{80}
c_j	212.87	-0.40	-25.65	-6.98	-25.65	-11.40	-12.77	-11.40
P_2	8.64	6.46	2.49	5.73	24.25	2.04	1.15	0.867
P_3	5.85	4.34	23.37	3.84	1.62	1.29	0.70	0.528
P_4	6.10	4.38	1.48	3.90	1.48	1.08	0.51	0.376
P_5	3.05	2.19	9.58	1.95	9.58	0.54	0.25	0.188
P_6	5.85	4.34	1.62	3.84	1.62	1.29	0.70	0.528
P_7	5.76	4.32	1.66	3.82	1.66	1.36	0.76	0.528
P_8	0.36							
P_9								
P_{10}								
P_{11}	-0.48							
P_{12}	0.2							
P_{13}								
P_{14}								
P_{15}	1.0							
P_{16}								
P_{17}	1.0							
P_{18}		14.65*	14.65*	14.65*	14.65*			
P_{19}						1.18	1.18	1.18
P_{20}								
P_{21}								
P_{22}	1.28							
P_{23}	316.56	0.15	126.85	40.87	126.85	0.33	141.11	0.33

*Corrected

Table 2 - (Continued)

	Real Activities						
Resource	P_{81}	P_{82}	P_{83}	P_{84}	P_{85}	P_{86}	P_{87}
c_j	-12.96	-12.77	-225.00	8.00	7.05	22.13	57.93
P_2	0.516	1.146	0.10				
P_3	0.313	0.700					
P_4	0.220	0.508					
P_5	0.110	0.254	0.10				
P_6	0.313	0.700					
P_7	0.344	0.764	0.10				
P_8			-1.0				
P_9							
P_{10}							
P_{11}				1.0			
P_{12}							
P_{13}							
P_{14}							
P_{15}							
P_{16}							
P_{17}							
P_{18}							
P_{19}	1.18	1.18					
P_{20}					1.0		
P_{21}						1.0	
P_{22}							1.0
P_{23}	142.14	141.11					

the initial matrix. A second matrix was also used which is the same as the initial matrix except that activities representing the sale of grain, hay, and silage were omitted from the initial matrix.

After the initial matrix was formulated, it was necessary to test the model to detect any irregularities in its make-up. Testing the model was also important from the standpoint of time required for a digital computer to find an optimum solution. The larger the model, the more expensive it is to process; hence, a prototype of the model served to determine if the model was structurally sound. For a test of the model, the I.B.M. 650 at Virginia Polytechnic Institute was used. This computer is limited in capacity to a matrix which does not exceed 26 rows and 52 columns including slack or artificial vectors. It was necessary to scale down the initial matrix to 24 rows (same as original) and 52 columns by eliminating some of the activities in each sub-group of activities. The prototype thus produced was processed through the I.B.M. 650 digital computer on three separate occasions and revised between runs before an acceptable tableau was produced. The revisions were made to guarantee equations which maintain equality and are linearly independent.

The model was processed twice by the Tennessee Valley Authority Computing Center at Chattanooga, Tennessee on their I.B.M. 704 digital computer. The information contained in the model was placed on cards by keypuching at V.P.I. Computing Center and mailed to the T.V.A. Computing Center for processing. The matrix was coded, based on instructions identified as Fortran Linear Programming No. 480-CE FLP.

RESULTS

The results of this study are discussed under two main headings. The first is the optimum solutions found through the application of linear programming. The second is results of a field study to obtain both subjective and objective data. No effort was made to tie the subjective data to other factors considered in the application of linear programming. The relationship of the two will be discussed in a general way.

Optimum Solutions

The first optimum solution found by the digital computer at the T.V.A. Computing Center is shown in Table 3. The problem statement was such that labor was fixed on the hypothetical farm. Labor was fixed in the sense that it had no value off the farm and no provision was made for hiring additional labor on the farm except through investment in labor-saving devices. The initial matrix permitted the sale of hay, silage, and prepared grain feed off the farm through activities P_{86}, P_{87}, and P_{88}. The optimum solution shows that it would be to this hypothetical farmers advantage to sell his feed and not maintain or milk

Table 3 - Optimum Solution I

With Labor Fixed on Farm

Activity Number	Real Activity or Chore Routine	Unit	Size
		Milk Cows	
P_{69}	Milking and milk salvage from present 30 cow stanchion barn with 3 unit milker in cans	each	0
P_{37}	Hay feeding to dry cows manually from present 290 ton concrete stave tower silo in stanchion barn	each	0
P_{58}	Silage feeding to replacement heifers in heifer barn from present 290 ton concrete stave silo - unload mechanically and manually feed	each	0
P_{62}	Hay feeding to replacement heifers manually from storage in present heifer barn	each	0
P_{84}	Sell heifer calves	each	0
P_{64}	Concentrate feeding to replacement heifers manually in present heifer barn	each	0
P_{53}	Hay semi-self feeding to dry cows in long form at ground level in new pole barn	each	0
P_{74}	Manure removal from present 30 cow stanchion barn manually	cows each	0
P_{24}	Self feeding silage to milk cows from new 400 ton horizontal bunker silo	each	0
P_{86}	Sell hay	ton	140.199

Table 3 - Optimum Solution I (Continued)

(With Labor Fixed on Farm)

Activity Number	Real Activity or Chore Routine	Unit	Size
P_{85}	Sell silage	ton	458.199
P_{87}	Sell concentrate feed	ton	91.299
P_{41}	Silage self feeding to dry cows from new 400 ton horizontal bunker silo	each	0

Table 3 - Optimum Solution I (Continued)

Matrix Row	Resource	Unit	Amount Available	Amount Used	Amount Unused	MVP Dollars
P_2	Labor: Jan.-Feb.-March	Man hrs.	1465.00		1465.00	
P_3	April-May	Man hrs.	477.20		477.20	
P_4	June-July	Man hrs.	478.89		478.89	
P_5	August	Man hrs	434.39		434.39	
P_6	Sept.-Oct.	Man hrs.	634.89		634.89	
P_7	Nov.-Dec.	Man hrs.	940.00		940.00	
P_8	Silage for replacement heifers	each				177.654
P_9	Hay for replacement heifers	each				149.876
P_{10}	Concentrate replacement heifers	each				118.519
P_{11}	Heifer calf	each				7.990
P_{12}	Silage for dry cow	each				0
P_{13}	Hay for dry cow	each				46.826-
P_{14}	Concentrate for dry cow	each				104.278-
P_{15}	Silage for milk cow	each				104.343
P_{16}	Hay for milk cow	each				57.451
P_{17}	Milk cow space	unit	60		60	
P_{18}	Manure	ton				0.036-
P_{19}	Bedding	ton				6.207
P_{20}	Silage	ton	458.20	458.20		7.049
P_{21}	Hay	ton	140.20	140.20		22.129
P_{22}	Concentrate feed	ton	91.30	91.30		57.929
P_{23}	Capital	Dollar	15660.00		15660.00	

Optimum Revenue $11,621.94

Table 3 - Optimum Solution I (Continued)

Real Activities or Chore Routines	Opportunity Cost-Dollars	Real Activities or Chore Routines	Opportunity Cost-Dollars
P_{23}	1.079	P_{55}	180.438
P_{24}		P_{56}	183.638
P_{25}	6.139	P_{57}	183.178
P_{26}	6.919	P_{58}	
P_{27}	1.559	P_{59}	2.470
P_{28}	0.730	P_{60}	6.369
P_{29}	3.019	P_{61}	3.399
P_{30}	5.769	P_{62}	
P_{31}	4.849	P_{63}	5.039
P_{32}	2.660	P_{64}	
P_{33}	10.319	P_{65}	2.960
P_{34}	3.410	P_{66}	0.559
P_{35}	2.240	P_{67}	20.309
P_{36}	4.899	P_{68}	30.460
P_{37}		P_{69}	0.000
P_{38}		P_{70}	25.819
P_{39}	1.079	P_{71}	29.609
P_{40}	6.139	P_{72}	28.630
P_{41}		P_{73}	25.740
P_{42}	7.589	P_{74}	0.000
P_{43}	1.559	P_{75}	25.250
P_{44}	0.730	P_{76}	6.579
P_{45}	3.019	P_{77}	25.250
P_{46}	5.769	P_{78}	18.724
P_{47}	4.849	P_{79}	20.094
P_{48}	2.660	P_{80}	18.724
P_{49}	10.319	P_{81}	20.284
P_{50}	3.410	P_{82}	20.094
P_{51}	2.240	P_{83}	47.345
P_{52}	4.899	P_{84}	
P_{53}		P_{85}	
P_{54}		P_{86}	
		P_{87}	

a dairy herd. The prices per ton for hay, silage, and prepared grain feed are $22.13, $7.05, and $57.93 respectively. Thus, milk should sell at something greater than $4 per hundredweight to make it profitable for this hypothetical farmer to stay in the dairy business.

The optimum revenue (not deducting the cost of producing hay, silage, and prepared grain feed) is $11,621.94 for this farm without a dairy enterprise. In addition, the farmer has some unused labor and capital for which he might find a more profitable alternative. Table 3 shows the marginal value products (MVP) and the opportunity costs of the activities. The marginal value products for disposal activities indicates the amount which would be added to revenue by a one-unit increase in the availability of each resource indicated by the activity or column. The opportunity costs for real activities indicates the amount of revenue which would be sacrificed by increasing the level of the particular activity by one-unit.

While the solution to the initial matrix is a perfectly feasible one, it is not the type of solution which fulfills the objectives of this study. An original goal was to find the combination of feeding activities which make the most profitable use of labor and capital investment in labor-saving equipment and arrangements. To accomplish this goal it was necessary to eliminate the alternatives of selling feed products produced on this typical dairy farm by not allowing any salvage value for feeds. Thus, activities P_{85}, P_{86}, and P_{87} were eliminated from the initial matrix and a new matrix gave optimum solution II which is shown in Table 4. Again, labor was fixed on the farm with no salvage value and this time feed was fixed on the farm with no salvage value.

An examination of optimum solution II reveals that a combination of chore labor, equipment, and arrangements have been selected for maintaining a dairy on the farm under consideration. The number of cows to milk is set at 34.664 or rounded to 35 cows. In this case it is believed that rounding does not introduce any appreciable error in the results. In a more extensive study (37) involving several possible ways of organizing a farm the effects of rounding the results of linear programming showed that net returns to fixed factors were changed by from 0.05 to 0.8 percent when comparing the computer solution with the rounded solution.

The optimum solution calls for 6.932 or 7 dry cows, 12.479 or 12 replacement heifers, 4.159 or 4 heifer calves to be sold, and no replacement heifers to be purchased.

Table 4 - Optimum Solution II

Labor Fixed on Farm - (No Salvage Value)
Feed Fixed on Farm - (No Salvage Value)

Activity Number	Real Activity or Chore Routine	Unit	Size
P_{74}	Manure removal from present 30 cow stanchion barn manually	cows each	35.834*
P_{69}	Milking and milk salvage from present 30 cow stanchion barn with 3-unit milker in cans	milk cows	25.335
P_{32}	Hay feeding to milk cows at ground level in new pole type hay storage barn in chopped form. Hay artificially dried and semi-self fed	each	26.519
P_{59}	Silage feeding to replacement heifers in heifer barn from present 290 ton concrete stave tower silo unloaded mechanically and manually fed	each	12.479
P_{68}	Milking and milk salvage from double-4 herringbone system	milk cows each	9.329
P_{84}	Sell heifer calves	each	4.159
P_{64}	Concentrate feeding to replacement heifers manually in present heifer barn	each	12.479
P_{41}	Self-feeding silage to dry cows from new 400 ton horizontal silo	each	6.932
P_{48}	Hay feeding to dry cows at ground level in new pole barn in chopped form. Hay artificially dried and semi-self fed	each	6.932

Table 4 - Optimum Solution II (Continued)

Labor Fixed on Farm - (No Salvage Value)
Feed Fixed on Farm - (No Salvage Value)

Activity Number	Real Activity or Chore Routine	Unit	Size
P_{38}	Hay feeding to milk cows at ground level in new pole barn in baled form. Hay artificially dried in storage and semi-self fed	each	8.145
P_{24}	Self feeding silage to milk cows from new 400 ton horizontal bunker silo	each	34.664
P_{77}	Manure removal from loose housing system. Loafing barn cleaned in March and August	cows	18.241*
P_{62}	Hay feeding to replacement heifers manually from storage in present heifer barn	each	12.479
P_{56}	Concentrate feeding to dry cows in milking parlor with aid of automatic gravity feeders	each	6.932

*Error resulted from use of inaccurate composite amounts of manure for animals - corrected by simple budgeting procedure.

Some of the activities which enter the plan are slightly inconsistent. For instance, 25.335 or 25 cows are to be milked in the present 30 cow stanchion barn with a three-unit milker instead of the original two-unit milker. The plan also calls for 9.329 or 9 cows to be milked in a double four herringbone system. Clearly the farmer should use all of one system or all of the other since milking factors per cow on a 30 cow basis is not the same as milking factors per cow on a one cow basis. Perhaps the reason an entire herringbone milking system was not selected is the restrictions on capital available. On the other hand the reason an entire stanchion system was not used may have been the restrictions on labor available.

It will be noted that in general the optimum plan calls for a loose housing system of dairying. Chopped hay should be fed to 26.519 or 27 milk cows at ground level in a new pole type hay storage barn where it can be semi-self fed. This activity included the artificial curing of hay in storage since no provision was made for handling field cured chopped hay. Chopped hay should be fed to 6.932 or 7 dry cows in exactly the same way. The plan calls for the feeding of the remaining 8.145 or 8 milk cows at ground level in a new pole type hay storage where the hay can be semi-self fed.

The difference is that the hay should be fed in baled form rather than chopped. More labor was required for feeding baled hay than chopped hay, and more capital was required to feed chopped hay than baled hay. In the computations, when capital became scarce for the use of chopped hay, the next best alternative was the use of baled hay. The use of field cured hay was permitted as an only change in one activity, but the plan still called for the use of artificially cured baled or chopped hay. The optimum solution indicates that all replacement heifers should be fed baled hay manually from storage in the present heifer barn. The reason this could have occured is that chopped hay was not given as an alternative in a comparable storage arrangement, although it was an alternative in a storage arrangement which required much more capital.

The optimum solution includes the self-feeding of 34.664 or 35 milk cows and 6.932 or 7 dry cows from a new 400 ton horizontal bunker silo. The 12.479 or 12 replacement heifers are to be fed silage from the present concrete stave silo. This activity includes the use of the silo unloader but not a mechanical bunk feeder. Again the silo unloader cannot be paid for at the rate indicated in the input data when its use is limited to only 12 replacement heifers. In the light of new information more recently published (16) it is believed that capital, labor, and related inputs should be revised which in turn might suggest a new plan.

Concentrate feeding is included in the milking activity for milk cows. The optimum plan calls for concentrate feeding to all 6.932 or 7 dry cows in a milking parlor which is equipped with automatic gravity feeders. The 12.479 or 12 replacement heifers should be manually fed concentrates in the present replacement heifer barn according to the plan.

Two different methods of manure removal come into the plan; manual removal of manure from a stanchion barn for approximately 36 cows and manure removal by tractor and scraper from a loose housing system with loafing barn cleaned in March and August for approximately 18 cows. The cows referred to here are composite cows which are based on the average of manure from milk cows, dry cows, and replacement heifers. It was pointed out in the procedure that these results would be more meaningful if the activities had been expanded to represent each class of livestock. The same statement applies to the bedding activities. One or more bedding activities did not come into the final plan although Table 5 shows the correct amount of bedding in tons was used. Thus, it appears that a bedding activity should be forced

Table 5 - Optimum Solution II, Resource Restrictions and Related Factors

Matrix Row	Resource	Unit	Amount Available	Amount Used	Amount Unused	MVP Dollars
P_2	Labor: Jan.-Feb.-March	Man hrs	1465.00	1261.14	203.86	
P_3	April-May	Man hrs	477.20	477.20		10.808
P_4	June-July	Man hrs	478.89	434.203	44.697	
P_5	August	Man hrs	434.39	434.39		0.452
P_6	Sept.-Oct.	Man hrs	634.89	482.189	152.711	
P_7	Nov.-Dec.	Man hrs	940.00	490.302	449.698	
P_8	Silage for replacement heifers	each				77.546
P_9	Hay for replacement heifers	each				12.840
P_{10}	Concentrate replacement hefiers	each				3.625
P_{11}	Heifer calf	each				8.000
P_{12}	Silage for dry cow	each				117.753
P_{13}	Hay for dry cow	each				34.833
P_{14}	Concentrate for dry cow	each				26.476
P_{15}	Silage for milk cow	each				84.997
P_{16}	Hay for milk cow	each				8.279
P_{17}	Milk cow space	unit	60.00	60.00		23.061
P_{18}	Manure	ton				4.347-
P_{19}	Bedding	ton		63.568		
P_{20}	Silage	ton	458.20	345.304	112.896	
P_{21}	Hay	ton	140.20	114.935	25.265	
P_{22}	Concentrate	ton	91.29	78.329	12.971	
P_{23}	Capital	Dollar	15660.00	15660.00		0.063

Optimum Revenue: $6.837.66

into the plan by reformulating the model. This is done by introducing a coefficient representing a high reduction in revenue in the bedding disposal activity to guarantee that bedding is maintained at the desired level.

Table 5 gives the various resource restrictions, the amounts of resources available, used and unused, and the marginal value of an additional unit of a product or restriction. It will be seen that labor for the April-May period and the August period are in scarce supply. The farmer could afford to pay \$10.80 for an additional hour of labor or its equivalent in the April-May period and \$.45 for an additional hour in August. Surplus labor is available during other time periods of the year and most especially during the winter months. Milk cow space was completely used in the optimum solution; however, other combinations would give more space for milk cows. An additional milking space is valued at the rate of \$23.06 per stall. All feeds were in greater supply than needed for the herd size specified. Capital was a limiting factor in the organization of this hypothetical farm. Additional investment capital would increase gross revenue (less the cost of performing chores) at the rate of 6.3 cents per dollar invested. The gross revenue less costs of performing chores is \$6,837.66 for the dairy farm as organized in the manner discussed above under optimum solution II.

Table 5 shows that the marginal value products of different feeds is different for each of the different classes of livestock fed. The return from feeding the milk cows, dry cows, and replacement heifers is different in each of the feeding activities in the revenue function. These activities are interrelated in such a way that a definite value of each feed product cannot be shown for each class of animal.

It may be of some value to know what an additional unit of an activity or chore will cost. These costs are in terms of the amount of revenue that would be sacrificed if they were forced into the solution at a one unit level. Table 6 lists all the real activities or chore routines and the cost of an additional unit of that activity or routine. In the group of activities designed for feeding silage to milk cows, the new tower silo equipped with a silo unloader and an automatic bunk feeder has the lowest opportunity cost. It would cost less to purchase an additional unit of this activity than any other alternative with the exception of the activity which enters the optimum plan. The least opportunity costs attached to non-optimum activities for

Table 6 - Optimum Solution II
Real Activities and Opportunity Cost

Real Activities or Chore Routines	Opportunity Cost-Dollars	Real Activities or Chore Routines	Opportunity Cost-Dollars
P_{23}	18.523	P_{56}	.000-
P_{24}		P_{57}	8.438
P_{25}	3.811	P_{58}	1.245
P_{26}	16.302	P_{59}	
P_{27}	15.699	P_{60}	2.930
P_{28}	18.622	P_{61}	3.696
P_{29}	7.994	P_{62}	
P_{30}	9.802	P_{63}	3.619
P_{31}	5.881	P_{64}	
P_{32}		P_{65}	2.457
P_{33}	8.884	P_{66}	17.440
P_{34}	4.739	P_{67}	4.203
P_{35}	1.260	P_{68}	
P_{36}	2.635	P_{69}	
P_{37}	0.770	P_{70}	8.541
P_{38}		P_{71}	20.622
P_{39}	11.930	P_{72}	5.024
P_{40}	2.622	P_{73}	9.438
P_{41}		P_{74}	
P_{42}	10.380	P_{75}	235.088
P_{43}	9.106	P_{76}	1.325
P_{44}	12.029	P_{77}	
P_{45}	3.454	P_{78}	25.589
P_{46}	1.804	P_{79}	21.345
P_{47}	7.142	P_{80}	17.194
P_{48}		P_{81}	17.295
P_{49}	10.021	P_{82}	21.346
P_{50}	7.311	P_{83}	147.498
P_{51}	2.155	P_{84}	
P_{52}	3.227		
P_{53}	2.677		
P_{54}	1.467		
P_{55}	27.471		

feeding hay to milk cows is: first, semi-self feeding of loose (not artificially dried) hay in a pole barn, and second, hand feeding chopped, artificially dried hay in a pole barn. The self feeding of silage from a bunker silo came in as the lowest opportunity cost activity for feeding silage to dry cows which is the same activity in the optimum plan for feeding silage to milk cows. The activity with the lowest opportunity cost for feeding hay to dry cows is the same as the optimum activity for feeding hay to milk cows. This activity involves the semi-self feeding of artificially dried baled hay in a pole barn.

It is interesting to note that the opportunity cost of feeding concentrates to dry cows with an automatic system in a modified stanchion barn is a third less than manually feeding with the aid of a push cart. Only two alternatives are allowed in feeding concentrates to replacements, thus the opportunity cost alternative can be compared only with the optimum activity.

Turning to the milking activities, it will be noted that zero costs (which is as it should be for an activity appearing in the optimum solution) were attached to the present stanchion system with three unit milker and the herringbone system which came into the optimum plan. The milking arrangement with the lowest opportunity cost was another activity representing the present stanchion barn equipped with four unit pipeline milker and bulk tank. The opportunity cost of the double-three walk through parlor was about 82 cents more per cow than the stanchion barn equipped with the bulk tank and the pipeline milker. All alternative milking parlor arrangements were equipped with bulk tanks and pipeline milkers. The three-in-line side opening milking parlor had the highest opportunity cost.

The manure removal activity with the lowest opportunity cost was the present stanchion barn equipped with a mechanical gutter cleaner. Its marginal cost of $1.32 per cow was indeed low when the highest opportunity cost of $235.08 was attached to a loose housing system where manure was removed in April and August, two critical labor periods. This would indicate that the time of year when manure is removed from a loose housing barn is extremely important in allocating labor.

The opportunity cost of two systems of bedding cows is about the same. Either the use of straw in a stanchion barn or chopped straw stored over the loafing area in a pole type barn costs about the same per composite animal in terms of revenue sacrificed. The opportunity cost of bedding with baled straw transported to the loafing barn is the same as bedding with sawdust or shavings in the present stanchion barn, although both are higher than the previous two activities.

Revenue would be decreased by $147.49 if a decision was made to purchase an additional replacement heifer rather than produce it as the optimum plan calls for. Thus, on first observation, it appears by the large cost attached that replacement heifers will continue to be produced on the farm. Had the program permitted the disposal of feed for replacement heifers at the same value as indicated in the initial matrix, the optimum solution might have been quite different. In the plan used, feed is fixed on the farm and for all practical purposes is free to replacement heifers. However, a replacement heifer, purchased ready to calve, has been fed off the farm with someone else's feed. It is estimated that the cost for feed to feed an average replacement heifer is $169.07. Thus, if the feeds could be sold for this amount, it appears that it might be more profitable to buy replacement heifers than to raise them. However, this was not an alternative and the opportunity did exist for reallocating the feed from replacement heifers to the milking herd.

The optimum plan indicated in the discussion above is not entirely feasible for some of the reasons mentioned. A few adjustments are necessary to make the optimum plan a practical plan. The first of these adjustments is the necessity for rounding to get whole animals. This was done in Table 7 and, as already pointed out, is not expected to make more than one percent change in the results. The next obvious need for adjustment is in the milking activities. Since the optimum plan calls for more than 25 cows to be milked in a stanchion barn and more than 9 cows to be milked in a herringbone milking parlor, it is necessary to have all 35 cows milked in one system or the other. If a 30 cow stanchion barn is selected, the capacity of the barn is exceeded when this system is retained. If, however, cows are milked in a stanchion barn and other chores are performed in a loose housing system, more than 30 cows could be milked in the stanchion barn. Hence, the optimum plan indicates the desirability of a loose housing system and, within the realm of practicability, all 35 cows can be milked in the stanchion barn. This is not only practical, but it is also what many dairymen with limited capital and a desire to improve their operation are doing.

To examine several factors related to the milking arrangement, some calculations were made using both computer

Table 7 - Optimum Solution II, Computer Solution and Rounded Solution

Activity	Unit	Computer Solution Size	Rounded Solution Size
Manure removal from present 30 cow stanchion barn and associated buildings manually	cows each	35.834[a]	36
Milking and milk salvage from present 30 cow stanchion barn with 3-unit milker	milk cows each	25.335	25
			35
Milking and milk salvage from double herringbone sys.	each	9.329	9
Hay feeding to milk cows at ground level in new pole type hay storage barn in chopped form. Hay artificially dried and semi-self fed	each	26.519	27
			35
Hay feeding to milk cows at ground level in new pole barn in baled form. Hay artificially dried in storage and semi-self fed	each	8.145	8
Self feeding silage to milk cows from new 400 ton horizontal bunker silo	each	34.664	35
Self feeding silage to dry cows from new 400 ton horizontal bunker silo	dry cows each	6.932	7
Hay feeding to dry cows at ground level in new pole barn in chopped form. Hay artificially dried and semi-self fed	each	6.932	7

Table 7 - (Continued

Activity	Unit	Computer Solution Size	Rounded Solution Size
Concentrate feeding to dry cows in milking parlor with aid of automatic gravity feeders	each	6.932	7
Silage feeding to replacement heifers in heifer barn from present 290 ton concrete stave silo unloaded mechanically and fed manually	replacement heifers each	12.479	12
Hay feeding to replacement heifers manually from storage in present heifer barn	each	12.479	12
Concentrate feeding to replacement heifers manually in present heifer barn	each	12.479	12
Manure removal from loose housing system. Loafing barn cleaned in March and August	cows each	18.241[a]	18
Sell heifer calves	each	4.159	4

[a]Results from error in figuring the composite amount of manure for milk cows, dry cows, and replacement heifers. Corrected by simple budgeting procedure.

and rounded milk cow numbers. If it were possible to use both the stanchion and herringbone parlor arrangements as suggested in the optimum solution, the expected revenue would be $7,987.01 as shown in Table 8.

This is the revenue expected from milking 34.664 cows which is the computer combination for the two systems. The revenue expected from 35 cows milked in a stanchion system would be $8.351.35 provided this could be done. The revenue expected from 35 cows milked in a herringbone parlor system would be $7,285.25. The stanchion system requires more labor than available and the herringbone parlor system requires more capital than available. With the use of the stanchion barn primarily for milking, the labor needed to clean the stanchion barn has been overestimated. Hence, labor for the stanchion barn may not be quite as restricted as might be anticipated. With the stanchion system of milking, revenue can be increased $364.34 subject to the possibility and cost involved in hiring additional labor during the time periods of April and May, which is the most critical, and also the time period of August or if the farmer can work longer hours.

Capital was one of the limiting factors in expanding to the herringbone parlor system. The capital required for

Table 8 - Comparison of Optimum Solution II and Rounded Solutions for Milking Activities

Number Milk Cows	Activity	Revenue	Requirement[a]	Labor Requirement April-May	Labor Requirement August
25.335	Milking in stanchion barn	$6045.18	$ 603.10	137.06 hrs	70.17 hrs
35	Milking in stanchion barn	8351.35	2979.05	189.35	96.95
9.329	Milking in herringbone parlor	1941.83	4713.75	42.44	21.17
35	Milking in herringbone parlor	7285.25	12059.80	159.25	79.45
34.664	Computer combination Stanchion and parlor	7987.01	5316.85	179.31	91.34

The following statements can be made with reference to the optimum solution when all factors remain unchanged except those stated:

1 - With the milking of 35 cows in a stanchion barn, revenue is increased $364.34 subject to hiring additional labor during April, May and August.

2 - With the milking of 35 cows in a stanchion barn $2,337.80 less capital is needed subject to working longer hours or to hiring labor in April, May and August.

3 - With the milking of 35 cows in a stanchion barn it will be necessary to hire 10.04 additional man hours of labor in April and May or work this much longer.

4 - With the milking of 35 cows in a stanchion barn it will be necessary to hire 5.61 man hours of labor in August or work this much longer.

5 - If labor can be employed in critical periods, the farmer can afford to pay up to $23.28 per man hour for the extra labor needed to milk in the stanchion barn. This figure was calculated by dividing $364.34 by 15.65 man hours.

[a]Includes required expansion investment for all over 30 cows in herd at $225.00 per cow. Capital investment per cow for milking activity based on 30 cows for stanchion barn and 60 cows for herringbone milking parlor.

the milking activities in the optimum plan was $5,316.85 for 34.664 cows. The capital requirement for 35 cows in the present stanchion system was $2,979.05 and the capital requirement for 35 cows in the herringbone milking parlor was $12,059.80. The herringbone parlor for the 35 cows will actually handle at least twice as many cows. Hence, if capital and other scarce resources were available to expand to 60-75 milk cows, the system might be justified. With a stanchion milking system and 35 milk cows, $2,337.80 less capital is needed for milking facilities and herd expansion. Again the use of the stanchion system is subject to the availability of additional labor during April, May and August.

Since more labor is required in April, May and August than is available for 35 cows in a combination stanchion loose housing system, the labor requirements were enumerated as shown in Table 8. The milking activities in the optimum solution calls for 179.31 man hours in the April-May time period. Thirty five cows milked in a herringbone parlor system would require 159.25 man hours. The same cows milked in a stanchion system would require 189.35 man hours, i.e., the parlor system required 30 man hours less than the stanchion system. Using the stanchion loose housing arrangement, it would be necessary to make available 10.04 man hours of additional labor for the April-May time period. Also, with this arrangement, the additional labor needed in August would be 5.61 man hours for 35 cows. Thus, it appears that the farmer can afford to pay up to $23.28 ($364.34 ÷ 15.65 man hours) per man hour for the additional labor needed to milk 35 cows in a stanchion system if other factors remain unchanged. Based on Solution II the farmer could afford to pay at a rate of $0.45 per hour in August, and up to $10.81 per hour in April and May for the labor needed. A similar analysis to that made for the milking activities can be made where the optimum plan calls for more than one activity to perform a chore. However, the optimum plan does not call for more than two activities to perform a chore in any case. A compromise will have to be made on the form of hay to be fed to both milk cows and dry cows. Of the 42 dairy animals the optimum plan suggested that 34 be fed artificially dried chopped hay in a new pole barn arrangement. Eight were to be fed artificially dried baled hay in a new pole barn arrangement. Thus, it would be desirable to feed all milk and dry cows chopped hay and the resulting effect on capital and labor requirements would be insignificant.

The conflict which exists in the manure removal activities is not as great as it might appear on first observation. It was not anticipated that the stanchion barn would be used for milking only; therefore, the milking activities related to the stanchion barn do not include manure removal in cleaning the barn as is the case with milking parlors. Most of the manure in the suggested arrangement will have to be removed from a loose housing arrangement. Some manure would still have to be removed from the stanchion barn where the cows are milked and some from the housing for replacement heifers. Manure removed from the loose housing arrangement should be for more than the 18 cows the plan suggested but not for as many as 42 milk and dry cows. It is not believed that an adjustment in the method of removing manure to accomodate the cows in the loose housing arrangement will greatly alter the plan. It has already been pointed out that any adjustment in either the bedding or manure removal activities should be done through a restatement of the problem to more accurately account for the various methods of bedding and manure removal for different classes of dairy animals.

The optimum plan calls for self-feeding of silage to 35 milk cows and 7 dry cows from a new bunker silo. It also calls for silage feeding to 12 replacements from the present concrete stave silo equipped with a mechanical silo unloader. Capital investment in a mechanical silo unloader was based on its use by 30 animals. Hence, not enough capital has been allocated to make it possible to have a silo unloader under the optimum plan. If the replacement herd was increased to 2 1/2 times its present size, the use of the mechanical unloader might be used on the basis of the least number of cows it could serve. Another possibility is that the farmer might find a good used silo unloader for which he could afford to pay $560 rather than the new price of $1,400. Often discrete units such as silo unloaders and other mechanical equipment can be used in applications for limited capacity when the unit can be secured for proportionally less capital.

The optimum plan calls for concentrate feeding to seven dry cows in a milking parlor system with the aid of automatic gravity feeders. This was possible if the herringbone milking system had been retained as shown in the optimum solution, but if all cows are milked in the stanchion barn as suggested above, the dry cows should probably be fed concentrates in the stanchion barn. This again calls for a slight reduction in capital investment and an increase in labor.

In summing up the discussion on optimum solution II, two entirely different milking systems were selected and the selection of certain other activities tended to follow this plan. Important chore activities such as the feeding of silage and hay to milk and dry cows were entirely related to the loose housing system. The optimum plan showed 71.6 percent of all milk cows should be milked in the present stanchion barn and 100 percent should be fed hay and silage in a new loose housing arrangement. A clearly stated method of bedding was not evident since some factors which should be considered were not written into the problem in the composite animal scheme. The plan for handling replacement heifers was consistent with possibilities as presented except that a discrete unit in the form of a silo unloader was called for in the silage feeding activity with an insufficient number of animals to support it.

Field Study

The results of a field study showing objective and subjective data are included in Tables 9 through 13. The purpose of this field study was to determine if subjective information on the use of chore labor saving equipment could be used in finding an optimum solution through the linear programming technique. The subjective data was collected

Table 9 - Summary of Data Collected on First Page of Questionnaire

Farm No.	Total Acres	Opr's age	Family labor man-mos.	Hired labor man-mos.	Dairy cows	Young dairy stock	Beef cows	Feeders per year	Concentrate feed is[a] A	B	C	D
1	300		30	1	30	20			x			
2	170	31	13.5	2	34	18						x
3	120	45	12	4			50	30	x			
4	170	25	12		33	40			x			
5	116	45					80				x[b]	
6	225	27	20		35	25			x			
7	500	33	12	12	60	60						x
8	400	36	12	24	75	65	10				x	
9		34	12	30	70	80						x
10	470	71	36	12	50	70	2					
11	300	27	24	1	40	50					x	
12	260	56	24		80	40					x	
13	195	43	18	1	30	22			x			
14	500	50		12				300	x			
15	137	40	24	12	32	25			x			
16	490	38	13	12	37	30			x			
17	340	38		24	45	35					x	
18	360	31	24	18	38	42					x	
19	360	42	24	6	95	75	8				x	
20	160		12	2	28	20			x			
21	877	35		13	75	25					x	
22	200	43	12	6	40	9					x	
23	230	38	24	1	28	28						x
24	365	45	13	3	30	35					x	
25	122	32	18	0.24	36	21						x

Table 9 - (Continued)

Farm No.	Total Acres	Opr's age	Family labor man-mos.	Hired labor man-mos.	Dairy cows	Young dairy stock	Beef cows	Feeders per year	Concentrate feed is[a] A	B	C	D
26	210	41	14		30	25					x	
27		40	15	18	70	30			x			
28	300	30	12	2	37	12				x		
29	275	35	12	8	48	15			x			
30	80	45	19	20	20	20				x		
31	148	39	18		25	32						
32	200	64	30		50	50			x			
33	430	54	6	18				200	x			
34	163	26	12	2	35	17						
35	400	28	12			80					x	
36	340	34	12	15				180	x			
37	380	51	22	3	50	50			x			
38	378	28	18	6	57	31	28		x			
39	515	55	12	18	40	60			x			
40	390	55		15	40	60					x	
41	363	38	24	13				500		x		
42	142	42	18	20	15						x	
43	410	18	92	75		18					x	
44	142	57	12	1.5				125	x			
45	700	33	24	24	170	50					x	
46	331	65	24	4	38	40					x	
47	435	32	18	12				500				
48	190	37	24		40	31					x	
49	350		18	1.5	33	29						x
50	450	27	24		82	63			x			

Table 9 - (Continued)

Farm No.	Total acres	Opr's age	Family labor man-mos.	Hired labor man-mos.	Dairy cows	Young dairy stock	Beef cows	Feeders per year	Concentrate feed is[a] A	B	C	D
51	240		24		41	21					x	
52	225	38	12	3	30	18					x	
53	460	37	13	15	55	45			x			
54	220		18		23	22			x			
55	310	51	6	1.5			25	135		x		
56	530	32	16	24	100	100			x			
57	400		12	36	109	40			x			
58	432		6	30	75	70					x	
59	320	35	18	12	70	60			x			
60	300	50	18	15	30	25					x	
61	309	40	24	3				250	x			
62	300	40	18	18	23	20					x	
63	200	35	12	1	35	35			x			
64	165	37	18		70	30					x	
65	345	49	24	0.24	50	25						x
66	124	34	12	1	29	30						
67	1000	37	30	6	36	25	85	118	x			
68	400	47	18	son	30	40					x	
69	196	34	30		105	30				x		
70	178	45	18						x			
71	133	32	12	6	36	26					x	
72	222	44	25	2.7	30	30					x	
73	240	48	21		25	25					x	
74	400	30	21	3	47	0					x	
75	360	43	24	6	54	50						

Table 9 - (Continued)

Farm No.	Total acres	Opr's age	Family labor man-mos.	Hired labor man-mos.	Dairy cows	Young dairy stock	Beef cows	Feeders per year	Concentrate feed is[a] A	B	C	D
76	410	28	12	12	92	63					x	
77	487	49	16	6				80				
78	1000		10	24	275	200				x		
79	250	47	24		44	35						x
Total	25245	2841	1319.5	714.78	3490	2595			26	6	30	8
Average	327.8	40.0	17.8	11.7	52.8	40.5						

[a]Concentrate feed is:

A - Ground and mixed on farm
B - Purchased ready to feed
C - Custom prepared off farm
D - Custom prepared on farm

[b]Mix on farm

Table 9 - (Continued)

Type of Dairy Milking Facility by Farm Number

1	Stanchion
2	Stanchion - 34 stalls
3	
4	Stanchion - 28 stalls
5	
6	Double-5 herringbone
7	Walk through parlor
8	Stanchion - loose housing, 4 stalls
9	Six stall walk through parlor
10	Double 3 walk through parlor and 22 stall stanchion
11	Three stall U-parlor
12	Double 6 herringbone
13	Three-in-line side opening parlor
14	
15	Stanchion - 32 stall
16	Stanchion - 37 stall
17	Stanchion - 36 stall
18	Stanchion - 30 stall
19	Side opening U-parlor
20	Four stall walk through parlor
21	Stanchion - 55 stall
22	Double 4 walk through parlor
23	Stanchion - 28 stall
24	Stanchion - 31 stall
25	Double 2 walk through parlor
26	Stanchion - 32 stall
27	Double 3 walk through parlor
28	Double 3 walk through parlor
29	Stanchion
30	Double 2 walk through parlor
31	Double 2 walk through parlor
32	Double 3 walk through parlor
33	
34	Three-in-line side opening parlor
35	
36	
37	Double 3 walk through parlor
38	Stanchion - 42 stall
39	Stanchion - 40 stall
40	Stanchion - 44 stall

Table 9 - (Continued)

Type of Dairy Milking Facility by Farm Number

41	
42	Stanchion
43	Double 4 walk through parlor
44	
45	Double 6 herringbone parlor
46	Stanchion - 41 stall
47	
48	Four stall U-parlor
49	Four stall U-parlor
50	Four stall U-parlor
51	Stanchion - 32 stall
52	Stanchion - 30 stall
53	Double 2 parlor
54	Stanchion - 28 stall
55	
56	Stanchion - 80 stall
57	Double 6 herringbone
58	Stanchion - 40 stall
59	Double 6 herringbone
60	Stanchion - 21 stall
61	
62	Stanchion - 21 stall
63	Three-in-line side opening parlor
64	Three stall U-parlor
65	Three-in-line side opening parlor
66	Stanchion - 22 stall
67	Six stall U-parlor
68	Three-in-line side opening parlor
69	Double 4 side opening parlor
70	Five stall U-parlor
71	Double 4 walk through parlor
72	Stanchion - 37 stall
73	Three-in-line side opening parlor
74	Four-in-line side opening parlor
75	Three-in-line side opening parlor
76	Double 3 side opening parlor
77	
78	Double 5 walk through parlor
79	Four stall U-parlor

but not applied to the programming procedure for reasons already cited. Some of the objective data seemed to apply to the problem and was used as input data.

One hundred questionnaires, similar to the one shown in the appendix were prepared and distributed approximately five each among 20 farm service advisors of a Michigan electric power supplier. These personnel assisted farmers in filling out and returning 79 of the 100 questionnaires. Instructions to the farm service advisors were to locate preferably dairy farmers who used one or more items of chore labor-saving equipment listed in the questionnaire and to ask them to cooperate in completing the questionnaire. These are the only criteria given and the advisors selected all farms surveyed.

In addition to the questionnaire, a step was taken to try to determine the arrangement of an efficiently operated dairy farm from the standpoint of the use of labor-saving chore equipment. Specialists from the Agricultural Engineering and Dairy Departments of Michigan State University and two farm service advisors of a local power supplier were asked to select the farms fitting this description within a 100 mile radius of Lansing, Michigan. Five of these farms were visited and two sketches showing typical equipment and arrangements are shown in the appendix.

In some respects the questionnaire was similar to one used early in 1957 and by coincidence, twenty of the same farmers were surveyed. The first page of the questionnaire asked for general information on acreage, operator's age, family labor, hired labor, dairy and beef stocks, method of concentrate preparation, and type of milking facility. The 79 farms contained an average of 327.8 acres. The average operator was 40 years of age, and an average of 17.8 man months of labor was employed on the farm. An average of 11.7 man months of labor was hired per farm. The average number of dairy cows and young dairy stock on farms with dairy animals was 52.8 cows and 40.5 heifers respectively. Eighty seven and three tenths percent of all farms surveyed had a dairy enterprise. Of the farms answering the question on feed preparation, 37.1 percent or 26 farms ground and mixed feed on the farm; only 8.5 percent or 6 purchased feed already prepared; 42.8 percent or 30 had feed custom prepared off the farm; and 11.4 percent or 8 had feed custom prepared on the farm by a mobile grinding, mixing, and blending unit. Of the respondents indicating a type of milking facility, 26 used the stanchion barn and 41 used some type of milking parlor.

The averages in size of farms, number of dairy animals, and amount of labor used are considerably higher for these farms than for the averages of area five in south central Michigan. It is also suspected that the average amount of chore labor saving equipment and number of milking parlors are greater. Thus, the information secured from the questionnaires will represent the opinions of larger and perhaps more successful than average dairy farmers.

The questionnaire also asked about the initial plus installation cost and the operation cost of the listed chore labor reducing equipment. This information was helpful in the preparation of input data for the linear programming problem already discussed. The average number of units of various pieces of equipment and average installation cost are reported in Table 10. Also, the average annual operation cost for reported units are shown in this table.

Table 10, summary of results of the questionnaires on use of chore equipment, also lists the factors on which an opinion was asked. The first item of equipment listed was the mechanical barn cleaner. Thirteen out of 26 or one-half of the replies indicated that the barn cleaner reduced labor to a push button and observe operation. About one-fourth of the respondents thought the cleaner reduced labor to about

Table 10 - Summary of Results of Questionnaire on Use of Chore Equipment

Subjective Consideration or other factors	Chore Equipment or Routine[a] A	B	C	D	E
Number of units reported	27	32	4	17	13
Average installation cost	$1572	$388.66	$506	$337	$298.84
Number of units reported	19	17			
Average operation cost per year	$7.71	$ 27.54			
Reduction of labor: No. of replies	26	45	6	20	18
7-completely eliminates labor				2	2
6-reduces labor to pushbutton only	5			1	2
5-reduces labor to pushbutton and observe	13			2	3
4-reduces labor to about ¼ of original	6	25	5	8	8
3-reduces labor to about ½ of original		7	1	3	3
2-reduces labor to about ¾ of original	2	13		1	
1-no reduction in labor				3	
Value: No. of replies	27	47	5	20	18
5-wouldn't do without	21	37	3	11	12
4-worth more than total cost	5	5	1	7	2
3-worth about the same as total cost	1	4	1	1	4
2-worth less than total cost		1			
1-not worth bothering with				1	
Convenience: No. of replies	26	47	6	20	18
5-very convenient	21	26	4	10	14
4-convenient	5	20	2	9	4
3-does not make any difference					
2-slightly inconvenient		1			
1-very inconvenient				1	

Table 10 - (Continued)

Subjective Consideration or Other Factors	Chore Equipment or Routine[a] A	B	C	D	E
Working Conditions: No. of replies	25	47	6	20	18
3-improves working conditions	25	44	6	17	18
2-no change in working conditions		3		3	
1-makes working conditions worse					
Skill required: No. of replies	24	47	6	20	17
5-able to hire worker for less wages	5	1		2	2
4-little less skill required (same worker)		4		1	3
3-no change in skill required	4	3	1	10	7
2-little more skill required (same worker)	13	31	5	6	2
1-more skill caused increase in wages	2	7		1	2
1a-unable to hire extra skill required		1			1
Time to do chores: No. of replies	26	45	6	20	18
6-eliminated		1		3	2
5-reduced to push button only	10				3
4-reduced to about ¼ of original	10	29	5	7	8
3-reduced to about ½ of original	2	9	1	4	3
2-reduced to about ¾ of original	4	6		4	2
1-no reduction				2	
1a-causes increase in time for other chores					
Mechanical reliability of equipment:					
No. of replies	26	47	6	19	18
3-dependable	13	30	3	18	17
2-occasional break-down	8	15	3		1
1-frequent break-down	5	2		1	

Table 10 - (Continued)

Subjective Consideration or Other Factors	Chore Equipment or Routine[a] A	B	C	D	E
Use of labor saved by mechanization:					
No. of replies	64	87	20	38	31
Enabled me to stay in dairy business	9	13	3	7	4
Labor used for productive work on other jobs	16	22	5	9	11
More time to devote to management	9	10	1	3	2
Expand size of farming operation	16	28	6	16	13
More leisure time	6	6	1	1	
Devote more time to improving knowledge and skills	4	4	2	1	1
Devote more time to community service	4	4	2	1	
Amount of indicated equipment on farms	27	47	6	20	18
Total possible points	1026	1786	228	760	684
Total points given by respondents	730	1190	154	527	511
Average possible points	38	38	38	38	38
Average points per unit given by respondents	27.037	25.319	25.666	26.35	28.388

Table 10 - (Continued)

Subjective Consideration or Other Factors	Chore Equipment or Routine[a] F	G	H	I	Total
Number of units reported	34	49	43	67	286
Average installation cost	$661.39	$1322	$1954.72	$401.30	
Number of units reported				24	
Average operation cost per year				$ 3.27	
Reduction of labor: No. of replies	35	45	44	54	293
7-completely eliminates labor			3	1	
6-reduces labor to pushbutton only	10	18	7	1	
5-reduces labor to pushbutton and observe	16	15	2	10	
4-reduces labor to about ¼ of original	5	9	7	28	
3-reduces labor to about ½ of original	2		13	7	
2-reduces labor to about ¾ of original	1	1	10	5	
1-no reduction in labor	1	2	2	2	
Value: No. of replies	36	45	44	54	296
5-wouldn't do without	27	35	32	39	
4-worth more than total cost	6	5	6	11	
3-worth about the same as total cost	2	3	6	4	
2-worth less than total cost	1	1			
1-not worth bothering with		1			
Convenience: No. of replies	35	44	43	54	293
5-very convenient	28	29	37	35	
4-convenient	6	13	4	18	
3-does not make any difference	1	1	1	1	
2-slightly inconvenient		1			
1-very inconvenient		1			

Table 10 - (Continued)

Subjective Consideration or Other Factors	Chore Equipment or Routine[a] F	G	H	I	Total
Working Conditions: No. of replies	36	44	44	53	293
3-improves working conditions	32	42	39	51	
2-no change in working conditions	3	2	5	2	
1-makes working conditions worse	1				
Skill required: No. of replies	35	42	44	51	286
5-able to hire worker for less wages	3	3	1	7	
4-little less skill required (same worker)	5	2	1	3	
3-no change in skill required	8	7	4	8	
2-little more skill required (same worker)	16	25	28	32	
1-more skill caused increase in wages	3	5	8	1	
1a-unable to hire extra skill required			2		
Time to do chores: No. of replies	36	43	44	52	290
6-eliminated	1		3	1	
5-reduced to push button only	15	22	4	7	
4-reduced to about ¼ of original	16	15	9	23	
3-reduced to about ½ of original	1	3	8	14	
2-reduced to about ¾ of original	2	3	12	6	
1-no reduction	1		7		
1a-causes increase in time for other chores			1		
Mechanical reliability of equipment:					
No. of replies	32	43	43	54	288
3-dependable	21	24	37	38	
2-occasional break-down	10	12	6	14	
1-frequent break-down	1	7		2	

Table 10 - (Continued)

Subjective Consideration or Other Factors	Chore Equipment or Routine[a] F	G	H	I	Total
Use of labor saved by mechanization:					
No. of replies	69	91	93	101	594
Enabled me to stay in dairy business	7	12	17	13	85
Labor used for productive work on other jobs	19	22	15	26	145
More time to devote to management	7	10	12	13	67
Expand size of farming operation	21	31	30	31	192
More leisure time	7	7	7	9	44
Devote more time to improving knowledge and skills	4	3	5	6	30
Devote more time to community service	4	6	7	3	31
Amount of indicated equipment on farms	36	45	44	54	297
Total possible points	1368	1710	1672	2052	
Average possible points	38	38	38	38	
Average points per unit given by respondents	28.25	27.4	25.5	26.611	

[a]Code to chore equipment or routine

A - Manure removal with mechanical barn cleaner
B - Manure removal with tractor scoop
C - Mechanical distribution of bedding by manure spreader or wagon unloader
D - Self feeder (hay bunks or silage feeding gates)
E - Mechanical concentrate feeder
F - Mechanical bunk feeder
G - Silo unloader
H - Pipeline milker
I - Wagon unloader

one-fourth of that employed by the original manual method. Twenty one of 27 thought they would not do without the barn cleaner and 21 of 26 replies thought its use was very convenient. All replies said the barn cleaner improved working conditions. Over half of the replies (13 of 24) thought a little more skill was required of the same worker to use the mechanical barn cleaner. The respondents were not quite as sure about the time required to do the manure removal chore; however, the question was included to see how nearly the answer would correspond with the answer to the related question on reduction of labor. In the case of reduction of chore labor, 19 of 26 replies were in two of the same categories as mentioned under reduction of labor although division within the two categories was markedly different. To one-half of those using the mechanical barn cleaner, this equipment was considered convenient, i.e., not over one break-down per year.

The replies for other chore equipment are listed in Table 10 and shown under (2) manure removal with tractor scoop, (3) mechanical distribution of bedding by manure spreader or wagon unloader, (4) self feeders (hay bunks and silage feeding gates), (5) mechanical bunk feeder, (7) silo unloader, (8) pipe-line milker, and (9) wagon unloader. A numerical value was given each reply permitted in the questionnaire as indicated in Table 10. The highest value was assigned to the choice of replies which indicated the most desirable labor-saving or other features. Adding the highest possible points for all factors considered gave the total possible points available to each piece of equipment. As an example, the total possible points available for the mechanical barn cleaner was 1026 (27 barn cleaners x 38 possible points per barn cleaner) for all farms surveyed. Actually, 27 units of this equipment were on the farms surveyed and all respondents gave the barn cleaner a total of 730 points out of the possible 1026. The possible points per respondent for the mechanical barn cleaner were 38 and the average points given per respondent for this piece of equipment were 27.037.

By using this method, some degrees of desirability for certain pieces of chore equipment are shown in Table 10. The highest ratings were received by the mechanical concentrate feeder and the mechanical bunk feeder. Third and fourth place went to the silo unloader and mechanical barn cleaner respectively. The reason why the above equipment was given a higher rating may be that it is electrically driven and can be controlled automatically.

A question was asked with reference to the use of labor saved by increased mechanization. Point values were not assigned to possible replies to this question and the replies do not reflect in the point system discussed above. The replies may be helpful, however, in determining some of the reasons for mechanization. The respondents were asked to check all applicable statements. Labor saved by mechanization was used to expand the size of the farming operation in the largest number (192 of 594) of replies. The next most popular use of labor saved was for more productive work on other jobs. The order of the other replies is as follows: 3rd, enabled the respondent to stay in the dairy business; 4th, more time to devote to management; 5th, more leisure time; 6th, devote more time to community service; 7th, devote more time to improving knowledge and skills (attending short courses, field days, etc.). It is important to note that respondents said they devoted the least amount of time saved by mechanization to the improvement of knowledge and skills. An implication of this is that learning may be one of the most difficult of the choices permitted.

Since a similar and larger survey was made in Michigan in 1957, it was thought that a comparison of replies might be helpful in showing trends on the farms surveyed. After investigation of the original data, it was found that 20 farms from the 1957 survey were the same farms as surveyed in 1959. The information received from the respondents on these farms was tabulated and compared in Tables 11 and 12.

Average acres for the 20 farms increased from 282 in 1957 to 296.1 in 1959, a period of approximately 2.5 years. The man months per year of family labor decreased from 16.9 to 16.6, but the man months per year of hired labor increased from 6.46 in 1957 to 7.04 in 1959. The average number of dairy cows increased from 31.7 to 35.5 and the average number of young dairy cattle increased from 27.8 to 31.0.

Table 12 shows a comparison of equipment cost and the amount used on the 20 farms for 1957 and 1959. In 1957 four silo unloaders were reported on these farms, but in 1959, thirteen silo unloaders were reported, an increase of nine. This would be considered a rather rapid adoption of labor saving equipment. Nine mechanical barn cleaners were in use on these farms in 1957 and ten in 1959. Practically no change in the number of mechanical barn cleaners may be attributed to the greater use of the loose housing system of dairying. The number of mechanical feeders on these 20 farms increased from six in 1957 to thirteen in 1959. The number of tractor manure loaders or tractor scoops remained

Table 11 - Comparison of Data From Selected Farms

Farm No.	Acres		Operator's age		Family labor man-mos/year		Hired labor man mos/year	
	1957*	1959	1957*	1959	1957*	1959	1957*	1959
5	96	116	42	45	12			
6	275	225	23	27	22	20		
13	225	195	39	43	18	18		1
20	150	160	45		12	12	1.5	2
24	370	365	42	45	24	13	1	3
26	350	210	39	41	14	14		
28	320	300	32	30	12	12	2	2
33	380	430	49	54	11	6	5	18
34	163	163	24	26	12	12		2
40	390	390	52	55	24			15
42	160	142	38	42	15	18		20
44	160	142		57	12	12	12	1.5
46	320	331	60	65	24	24	6	4
49	350	350	42		24	18	3	1.5
51	265	240	69		12	24	12	
58	365	432	45		18	6	12	30
61	160	309	36	40	12	24	3	3
63	200	200	34	35	12	12	1	1
67	750	1000	37	37	24	30	6	6
72	192	222	41	44	24	25	6	2.7
Average	282.0	296.1	41.5	42.8	16.9	16.6	6.46	7.04

Table 11 - (Continued)

Farm No.	Dairy cows		Young cattle		Beef cattle		Feeder per/year	
	1957*	1959	1957*	1959	1957*	1959	1957*	1959
5							75	80
6	20	35	30	25				
13	21	30	15	22				
20	28	28	18	20				
24	30	30	25	35				
26	30	30	25	25				
28	39	37	35	12				
33							100	200
34	25	35	20	17				
40	40	40	40	60				
42	22	15	8					
44							50	125
46	38	38	40	40				
49	41	33	28	29				
51	34	41	27	21				
58	50	75	50	70				
61							275	250
63	30	35	30	35				
67	30	36	20	25	60	118	70	85
72	30	30	35	30				
Average	31.7	35.5	27.8	31.0	60	118	114	148

*Field data from 320 farms - R. W. Kleis and D. E. Wiant, M.S.U., 1957.

**No explanation for variation in operator's age--- Enumerators may have guessed operator's age in some cases.

Table 12 - Comparison of Cost and Equipment in Use on Selected Farms for 1957 and 1959

Silo Unloader						
	1957*			1959		
Farm No.	No. units	Cost new $ each	Maintenance $ each/year	No. units	Cost new $ each	Maintenance $ each/year
5				1	1100	7.50
6						
13				1	1000	12.00
20	1	1000	12.00	1	1000	
24				1	1125	3.00
26				1	1200	5.40
28						
33				1	1300	50.00
34				1	1325	
40						
42						
44				1	1600	40.00
46						
49						
51						
58	2	1000	21.00	3	1167	12.00
61	1	1500	25.00	1	2000	11.00
63						
67				1	1100	15.00
72						

Table 12 - (Continued)

Barn Cleaner						
	1957*			1959		
Farm No.	No. units	Cost new $ each	Maintenance $ each/year	No. units	Cost new $ each	Maintenance $ each/year
5						
6						
13						
20	1	1000	25.00			
24				1	1000	4.00
26	1	1300	60.00	1	2000	7.20
28						
33						
34						
40				1	1600	
42	1	1000	4.00	1	1000	
44						
46	1	1500	10.00	1	2500	7.00
49						
51	1	2500	30.00	1	2500	25.00
58	3	878	22.00	3	867	
61						
63						
67	1	1600	12.00	1	2000	3.64
72						

Table 12 - (Continued)

Mechanical Feeder						
	1957*			1959		
Farm No.	No. units	Cost new $ each	Maintenance $ each/year	No. units	Cost new $ each	Maintenance $ each/year
5				1	1100	1.50
6				1	150	0
13				1	500	10.00
20				1	800	
24						
26						
28				1	300	0
33				1	1200	45.00
34				1	250	
40						
42						
44				1	700	30.00
46						
49	1	1000	10.00		2200	6.00
51						
58	2	900		2	900	
61	1	2000	5.00	1	1500	11.00
63						
67	2	350	25.00	2	300	15.00
72						

Table 12 - (Continued)

Tractor Manure Loader or Tractor Scoop						
	1957*			1959		
Farm No.	No. units	Cost new $ each	Maintenance $ each/year	No. units	Cost new $ each	Maintenance $ each/year
5		425	5.00	1	400	5.00
6				1	150	
13			4.00	1	380	60.00
20	1	300				
24	1	375	2.00			
26						
28				1	150	
33				1	1500	25.00
34	1	300	25.00	1	300	25.00
40	1	350	5.00			
42						
44	1	300	15.00	1	800	15.00
46	1	600	15.00			
49	1	300	5.00	1	600	10.00
51	1	360				
58	1	345				
61	2	350	5.00	2	350	
63	1	250	3.00	1	450	70.00
67	1	450		1	400	80.00
72						

*Field data from 320 farms - R. W. Kleis and D. E. Wiant, M.S.U., 1957.

about the same, although it appears that a number of units in use in 1957 were not reported in 1959. This equipment had been fairly well adopted by these farms when the survey was made in 1957.

A comparison was made of respondent replies on use of time saved as a result of the use of chore labor saving equipment. Table 13 gives a comparison and some other factors which were checked in the two different surveys. Of the 16 respondents who said they used labor saved to expand production in 1957, 12 said the same thing in 1959. Of the four who did not check expanded production in 1959, three checked labor used for productive work on other jobs, one checked more time for community service, one checked more leisure time, and one failed to check anything.

The adaptation of the subjective information tabulated from the questionnaires to the technique of linear programming seems possible. If MP stands for some minimum number of points a total system must possess and PA stands for the points that a chore activity should possess as determined by a large group of respondents, then $\sum PA \geq MP$. If a slack or disposal activity is added, the expression becomes $\sum PA = MP + DA$ or $\sum PA - DA = MP$. This equation must be adapted to the general form $PX \leq S$. Again it has been

Table 13 - Comparison of Respondents Replies on Use of Time From Labor Saved by Chore Equipment

Farm No.	Expanded production		More leisure time		More time community service		Labor used productive work	
	1957*	1959	1957*	1959	1957*	1959	1957*	1959
5	x	x						
6	x	x		x		x		x
13	x	x			x			x
20	x				x			x
24	x	x						
26	x					x		x
28	x	x						x
33		x	x		x			
34		x	x	x				
40	x				x			x
42	x	x	x		x		x	
44	x			x	x		x	
46	x	x		x	x	x		x
49	x	x						x
51	x			x			x	x
58	x	x					x	x
61	x	x					x	
63	x	x					x	
67		x					x	x
72	x	x				x	x	x

Table 13 - (Continued)

Farm No.	Reduction of labor supply	Care and maintenance machinery	Enabled me to stay in dairy bus.	More time to devote to mgmt.	Devote time improving knowledge & skills
	1957*	1957*	1959	1959	1959
5					
6	x	x	x	x	x
13		x	x	x	
20					
24	x		x		
26	x		x	x	
28	x	x	x	x	
33					
34	x		x	x	x
40	x				
42	x				
44				x	
46	x		x	x	x
49			x		
51	x				
58	x				
61			x		
63			x		
67	x		x		x
72	x		x		x

*Field data from 320 farms - R. W. Kleis and D. E. Wiant, M.S.U., 1957.

assumed that subjective considerations which apply per unit of chore activity for one unit applies, proportionally, for many units. This is the expression of linearity inherent in the technique.

CONCLUSIONS

Linear programming is a systematic procedure which can be applied to system development of chore routines and equipment to maximize efficiency on dairy farms. Linear expressions carefully selected and used within predetermined limits are sufficiently accurate to give information which will aid the engineer in system planning. Mathematical expressions of higher power than linear equations would more accurately represent conditions as they exist; however, a large number of these expressions would be extremely difficult to handle even with more advanced electronic computers. Refinement in the use of the present linear programming technique seems to be the most logical approach for agricultural engineers interested in system problem solving.

Reliable input data is presently not available in the quantities needed to make detailed studies of system planning. Research has been accelerated in the recent past and more input data is rapidly becoming available, but often this data is not recorded or reported in the detail necessary for a study such as this. One of the serious defects in this study was the lack of input data which could be used with confidence. Often the data from similar studies was recorded in such a way that no correlation could be established.

Considering the many possibilities for error in the input data, the results of the application of the linear programming technique coincide closely with what appears to happen in reality. The results suggest that the dairyman with limited labor and capital should go to a loose housing arrangement for housing, feeding, and manure removal, but retain the stanchion barn for milking. In other words, the labor efficiency of a parlor system is not sufficient in this case where there is a usable stanchion barn to justify the high investment required.

The results of this study do not necessary apply to any farm organization other than the one given. Extreme precaution should be observed in projecting results of this study beyond herd sizes of over 45 to 50 cows. For instance, researchers (16) report that the tower silo equipped with mechanical unloader and bunk feeder is more economical for larger herds which consume approximately 800 tons of silage per year. Even this study indicates that the herringbone milking parlor should be used if a greater supply of capital was available. For the larger herds of 60 or more cows the herringbone seems practical.

The system suggested for the performance of chores is based on a herd size of 42 cows and 12 replacement heifers. Thirty five milk and seven dry cows make up the 42 cow herd. The system for milk and dry cows consists of the present 30 cow stanchion barn for milking and concentrate feeding purposes only, a new 400 ton bunker type self feeding silo, a loafing barn where bedding is stored and manually distributed, a concrete loafing area where manure is removed by tractor and scoop and a new pole barn for curing, storing and semi-self feeding chopped hay. The replacement heifers are raised on the farm in the present heifer barn. To give a feasible system of feeding heifers, the silage is stored in the present 290 ton silo and manually fed, hay is fed manually from storage in the present heifer barn and concentrate is fed manually in the present heifer barn. The methods of performing dairy chores do not completely parallel the computer solution and are suggested only to offer what appears to be a practical solution.

It has been observed that better managers with limited resources progressively organize their chore activities in the manner outlined above. This is true for a number of Virginia dairymen who the author has had an opportunity to observe. Hence, it can be concluded that the technique as applied did indicate a direction to go in the short run selection of dairy chore equipment and arrangements. However, decisions involving large amounts of capital should be made based on long time goals and planning. The ultimate size of the dairy herd planned is an important factor in the planning of any system.

The problem of discrete units is a bothersome one to the programmer and complications exist in all the directions considered. If an attempt is made to prepare the problem to eliminate indivisible activities, the problem statement becomes unwieldy, or if large units are used, the results may not reflect the degree of precision wanted. If the units are sufficiently small, rounding seems to be the best way to handle this problem. The changes in results caused by rounding can be small as has already been pointed out. While an optimum solution is desired, a near optimum solution would be of considerable value to a large number of dairymen whose operations closely parallel the specific average situation outlined in this study.

The dairyman's likes and dislikes relative to the use of chore equipment and arrangements can be written into the program if these opinions can be expressed in mathematical form. Although no effort was made to prove this in practice, data were collected and a point system designed to show how it might be done.

This study points to the need for agricultural engineers to continue to examine methods of performing chores from the standpoint of reducing labor, reducing costs, and improving working conditions. Often facts can be obtained for consideration by managers when the entire operation is studied in detail and alternative systems are presented for performing chores. Work methods on farms will have to be considerably revised to approach the efficiency of some operations in other industries. The agricultural engineer and economist have a joint opportunity to make farms even more efficient by the use of system planning techniques and sound engineering practices in the construction of housing and equipment.

SUGGESTIONS FOR FUTURE RESEARCH

The job of collecting data in the volume needed is a tremendous one. For a study such as this, large amounts of input data which are current and fits the situation at hand, are most important. Results from a system planning study are only as accurate as the input data used. It appears it will take the efforts of a large number of investigators to secure the volumes of data needed for mathematical programming. Therefore, the collection of data should be an organized effort with a common understanding of the form in which it will be recorded. This is perhaps the greatest need preliminary to effective research in the area of system planning.

The use of linear programming as applied in this study should be studied further to seek possibilities for refinement and other applications. Possibilities for the use of linear programming appear great and with greater knowledge of its use many difficult problems can be solved. Engineers who are familiar with linear programming techniques will find it less difficult to grasp non-linear programming or other mathematical programming techniques when and if computers become readily available to handle more complicated mathematical relationships. There is definitely a need for better methods of handling discrete units in the make-up of the matrix.

The basic structure of the model used in this study appears to be satisfactory for the purpose it was designed. Improvement should be made in the bedding restriction and herd expansion might be handled in a better way than it was handled in the capital restriction. These points have already been discussed. Restrictions were used in the model to control the ratio of dry cows and replacement heifers to milk cows and to maintain feeding activities for the different classes of livestock. Restrictions could also be used to maintain the use of one form of hay (baled or chopped) for the entire herd just as feeding of different feeds has been maintained. The possibility of using various activities to define methods of bedding or manure removal for various classes of livestock and tying these together with appropriate restrictions has already been mentioned.

Future research should be aimed at determining the practicability of the use of chore equipment in lieu of labor on larger dairy farms than considered in this study.

Also, some accurate method should be designed to tie investment cost and other input data on a per cow basis to the number of cows in the herd as shown by any optimum solution. Restrictions which maintain a predetermined ratio of input factors to cow factors might increase capital or labor per cow as the number of cows goes down or up. These are possible areas which might be explored in any further study of linear programming as applied to chore routines.

The engineer should aim still further effort at improvement of work routines, equipment, equipment placement, and arrangements from the system standpoint. Human factors should not be overlooked in making efforts to improve efficiency in doing chores on livestock farms.

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APPENDIX

A - Code to Matrix Columns

UP - 1 = Amount of gross revenue less cost of performing chores

UP - 2 = Labor I (January, February and March)

UP - 3 = Labor II (April and May)

UP - 4 = Labor III (June and July)

UP - 5 = Labor IV (August)

UP - 6 = Labor V (September and October

UP - 7 = Labor VI (November and December)

UP - 8 = Silage for replacement heifers

UP - 9 = Hay for replacement heifers

UP -10 = Concentrate feed for replacement heifers

UP -11 = Heifer calf

UP -12 = Silage for dry cows

UP -13 = Hay for dry cows

UP -14 = Concentrate for dry cows

UP -15 = Silage for milk cows

UP -16 = Hay for milk cows

UP -17 = Milk cow space

UP -18 = Manure expressed in tons

UP -19 = Bedding expressed in tons

Code to Matrix Columns (Continued)

UP -20 = Silage expressed in tons

UP -21 = Hay expressed in tons

UP -22 = Concentrate expressed in tons

UP -23 = Investment capital

P - 23 = Silage feeding to milk cows manually from present 290 ton concrete stave tower silo in stanchion barn (cart and fork)

P - 24 = Self feeding silage to milk cows from new 400 ton horizontal bunker silo

P - 25 = Silage feeding to milk cows from new 400 ton concrete stave tower silo equipped with silo unloader and mechanical bunk feeder

P - 26 = Silage feeding to milk cows from present 290 ton concrete stave tower silo equipped with silo unloader and manually feed in stanchion barn

P - 27 = Silage feeding to milk cows from present 290 ton concrete stave tower silo manually unloading and feeding with aid of monorail feed box in stanchion barn

P - 28 = Silage feeding to milk cows manually from new 400 ton concrete stave tower silo relocated for loose housing system (allows for expanding size of herd)

P - 29 = Silage feeding to milk cows from new 400 ton concrete stave tower silo manually unloading and equipped with mechanical bunk feeder

P - 30 = Silage feeding to milk cows from new 400 ton horizontal bunker silo feeding in bunks with aid of tractor scoop and unloading wagon

P - 31 = Hay feeding to milk cows manually from present mow in baled form in stanchion barn

Code to Matrix Columns (Continued)

P - 32 = Hay feeding to milk cows at ground level in new pole hay storage barn in chopped form - hay artificially dried and semi-self fed

P - 33 = Hay feeding to milk cows manually in baled form at ground level in bunk along side of present barn

P - 34 = Hay feeding to milk cows manually in chopped form from present mow and hay artificially dried in storage

P - 35 = Hay feeding to milk cows manually in chopped form at ground level in new pole barn and hay artificially dried in storage

P - 36 = Hay feeding to milk cows manually in chopped form at ground level in bunk along side of present barn and hay artificially dried in storage

P - 37 = Hay feeding to milk cows at ground level in new pole barn in long form (semi-self feed)

P - 38 = Hay feeding to milk cows at ground level in new pole barn in baled form. Hay artificially dried in storage and semi-self fed

P - 39 = Silage feeding to dry cows manually from present 290 ton concrete stave tower silo in stanchion barn (cart and fork)

P - 40 = Silage feeding to dry cows from new 400 ton concrete stave tower silo equipped with silo unloader and mechanical bunk feeder

P - 41 = Silage self feeding to dry cows from new 400 ton horizontal bunker silo

P - 42 = Silage feeding to dry cows from present 290 ton concrete stave tower silo equipped with silo unloader and manually feed in stanchion barn

P - 43 = Silage feeding to dry cows from present 290 ton concrete stave tower silo manually unloading and feeding with aid of monorail feed box in stanchion barn

Code to Matrix Columns (Continued)

P - 44 = Silage feeding to dry cows manually from new 400 ton concrete stave tower silo relocated for loose housing system (allows for expanding size of herd)

P - 45 = Silage feeding to dry cows from new 400 ton concrete stave tower silo manually unloading and equipped with mechanical bunk feeder

P - 46 = Silage feeding to dry cows from new 400 ton horizontal bunker silo feeding in bunks with aid of tractor scoop and unloading wagons.

P - 47 = Hay feeding to dry cows manually from present mow in baled form in stanchion barn

P - 48 = Hay feeding to dry cows at ground level in new pole barn in chopped form. Hay artificially dried and semi-self fed.

P - 49 = Hay feeding to dry cows manually in baled form at ground level in bunk along side of present barn

P - 50 = Hay feeding to dry cows manually in chopped form from present mow and hay artificially dried in storage

P - 51 = Hay feeding to dry cows manually in chopped form at ground level in new pole barn and hay artificially dried in storage

P - 52 = Hay feeding to dry cows manually in chopped form at ground level in bunk along side of present barn and hay artificially dried in storage

P - 53 = Hay semi-self feeding to dry cows in long form at ground level in new pole barn

P - 54 = Hay feeding to dry cows in baled form at ground level in new pole barn. Hay artificially dried in storage and semi-self fed

P - 55 = Concentrate feeding to dry cows in stanchion barn with aid of hand tools

Code to Matrix Columns (Continued)

P - 56 = Concentrate feeding to dry cows in milking parlor with aid of automatic gravity feeders

P - 57 = Concentrate feeding to dry cows in modified stanchion barn with aid of mechanical feeders

P - 58 = Silage feeding to replacement heifers manually in heifer barn from present 290 ton concrete stave tower silo

P - 59 = Silage feeding to replacement heifers in heifer barn from present 290 ton concrete stave tower silo--unload mechanically and manually feed

P - 60 = Silage feeding to replacement heifers manually in remodeled stanchion barn from present silo

P - 61 = Silage feeding to replacement heifers in remodeled stanchion barn from present silo unloaded mechanically and manually feed

P - 62 = Hay feeding of baled hay to replacement heifers manually from storage in present heifer barn

P - 63 = Hay feeding of chopped hay to replacement heifers manually in remodeled stanchion barn from present hay mow

P - 64 = Concentrate feeding to replacement heifers manually in present heifer barn

P - 65 = Concentrate feeding to replacement heifers in remodeled stanchion barn by semi-mechanization

P - 66 = Milking and milk selling from present 30 cow stanchion barn with two-unit milker and in cans

P - 67 = Milking and milk selling from present 30 cow stanchion barn with three unit, pipeline, bulk tank system

P - 68 = Milking and milk selling from double four herringbone system

Code to Matrix Columns (Continued)

P - 69 = Milking and milk selling from present 30 cow stanchion barn and four unit milker in cans

P - 70 = Milking and milk selling from three U side opening milking parlor system

P - 71 = Milking and milk selling from 3 in line side opening milking parlor system

P - 72 = Milking and milk selling from double 3 walk through milking parlor system

P - 73 = Milking and milk selling from 4 stall tandem elevated milking parlor system

P - 74 = Manure removal from present 30 cow stanchion barn manually

P - 75 = Manure removal from loose housing system. Loafing barn cleaned in April and August

P - 76 = Manure removal from present 30 cow stanchion barn with aid of mechanical gutter cleaner

P - 77 = Manure removal from loose housing system. Loafing barn cleaned in March and August

P - 78 = Bedding cows in present 30 cow stanchion barn manually with saw dust

P - 79 = Bedding cows in loose housing system manually with baled straw stored over loafing area

P - 80 = Bedding cows in present 30 cow stanchion barn manually with straw (Minnesota data)

P - 81 = Bedding cows in loose housing system manually with chopped straw stored over loafing area

P - 82 = Bedding cows in loose housing system manually with baled straw transported from storage

P - 83 = Replacement heifers acquired ready to calve

Code to Matrix Columns (Continued)

P - 84 = Sell heifer calves

P - 85 = Sell silage

P - 86 = Sell hay

P - 87 = Sell prepared concentrate feed

B - Time and Effort to Milk Cows in Laboratory Study a/

Layout	Element	Regular buckets	Regular pipe-line
Single level, with work area (simulated stanchion)	Preparing the cow	.33 minutes	.31 minutes
	Applying the unit	.35 minutes	.23 minutes
	Removing the unit	.17 minutes	.11 minutes
	Travel to and from cow	.30 minutes	.26 minutes
	Total time	1.85 minutes	1.61 minutes
	Effort b/	193.1 percent	152.2 percent
Cow standing 36 inches above work area (simulated parlor)	Preparing the cow	.32 minutes	.35 minutes
	Applying the unit	.33 minutes	.23 minutes
	Removing the unit	.15 minutes	.11 minutes
	Travel to and from cow	.30 minutes	.30 minutes
	Total time	1.80 minutes	1.69 minutes
	Effort	98.5 percent	93.3 percent

a/ Time and effort to milk cows, W. H. M. Morris and L. L. Boyd, Agricultural Engineering, August, 1955. Table 2 - Corrected treatment means from results of laboratory study with explanations added.

b/ Effort rating was the ratio of the rate of oxygen consumption during the cycle to that of the same operator standing still, expressed as percentage.

C - Effect of Man - Machine Balance on Milking a/

Number of men	Number of units	Number of cows milked per man hour			Parlor		
		Stanchion barn	3 types of parlors	All studies	Man min. per cow	Cows milked per man hour	Cows milked per hour
1	1			12.2	3.52	17	17
2	2	7.0	7.6	8.1	5.79	10.2	20.4
2	3	12.5		13.6	5.17	11.6	23.2
1	2	10.8	13.2 & 15.6	14.0	3.43	18	18
2	4			13.6	3.69	16.2	32.4
1	3	18.9	18.3	19.5	2.24	26.8	26.8

a/ Adapted from Tables 1 and 7, Efficiency of the milking operation, W. H. M. Morris and L. L. Boyd, Agricultural Engineering 36:9, pages 595-598, September, 1955.

D - Disposition of Time in 40 Cow Stanchion Barn 1/
(Average of 28 cows milked)

Description of chores	Minutes per cow per day			Hours per cow per year	Percent of total time
	Summer	Winter	Annual		
Preparation to milk	.68	.71	.69	4.2	2.2
Milking 2/	6.41	7.72	7.65	46.5	23.9
Cleaning equipment	1.53	1.50	1.52	9.2	4.8
Feeding cows 3/	2.89	3.53	3.21	19.5	10.0
Releasing and tying cows	1.11	1.07	1.05	6.4	3.3
Bedding cows 4/	1.97	1.76	1.87	11.4	5.8
Cleaning barn 5/	4.80	6.61	5.71	34.7	17.8

1/ Data adapted from "A time, travel, and construction cost study", Marvin A. Gummersheimer, a thesis for the degree of M. S., Pennsylvania State University, 1957.

2/ Barn equipped with bulk tank and two unit milker.

3/ Silo equipped with mechanical unloader.

4/ Sawdust used for bedding.

5/ Barn equipped with shuttle type gutter cleaners.

E - Disposition of Time in 40 Cow (face-out) Stanchion Barn 1/
(Average of 32 cows milked)

Description of chores	Minutes per cow per day			Hours per cow per year	Percent of total time
	Summer	Winter	Annual		
Preparation to milk	.74	.70	.72	4.4	2.9
Milking 2/	3.61	3.89	3.75	22.8	14.8
Cleaning equipment	1.46	1.34	1.40	8.5	5.5
Feeding cows 3/	1.69	2.73	2.21	13.4	8.7
Releasing and tying cows	.69	.67	.68	4.1	2.7
Bedding cows 4/	1.08	1.36	1.22	7.4	4.8
Cleaning barn 5/	3.91	3.82	3.87	23.5	15.3

1/ Data adapted from "A time, travel, and construction cost study", Marvin A. Gummersheimer, a thesis for the degree of M. S., Pennsylvania State University, 1957.

2/ Barn equipped with two unit milker, two extra pails, bulk tank.

3/ Chopped hay and silage feed from cart - silos equipped with mechanical unloaders

4/ Sawdust used for bedding

5/ Barn equipped with chain type gutter cleaner

F - Disposition of Time in 4-Stall Milking Parlor
(Two row tandem) and Loose Housing Barn 1/
(32 cows milked)

Description of chores	Minutes per cow per day			Hours per cow per year	Percent of total time
	Summer	Winter	Annual		
Preparation to milk	.99	.74	.87	5.29	3.4
Milking 2/	3.24	3.08	3.16	19.22	12.2
Cleaning equipment	1.88	1.91	1.90	11.56	7.3
Feeding cows 3/	1.24	1.74	1.49	9.06	5.8
Bedding cows	.28	.38	.33	2.01	1.3
Cleaning barn 4/	5.02	6.04	5.53	33.64	21.2
Cleaning milk parlor	.88	1.06	.97	5.9	3.7

1/ Data adapted from "A time, travel and construction cost study", Marvin A Gummersheimer, a thesis for the degree of M. S., Pennsylvania State University, 1957.

2/ Parlor contained a two unit pipeline milker and bulk tank

3/ Concentrates were hand fed - lot equipped with mechanical silo unloader and bunk feeder.

4/ A tractor powered scraper used to scrape manure for lot into gutter cleaner.

G - Sample Questionnaire

OPERATOR'S NAME________________________

ADDRESS________________________________

ADVISOR'S NAME_________________________

OWNER OPERATED_________________________TENANT________________

TOTAL ACREAGE_______________OPERATOR'S AGE__________________
(both owned and rented)

LABOR - Man month/yr____________(Family)______________(hired)
(Consider children over 12 and under 16 as half-man for time they work - include custom work as hired labor)

Type of farm - dairy__________(cows)___________(young stock)
beef___________(cows)___________(feeders/year)

Feed is (ground and mixed on farm by operator) (purchased ready to feed) (custom prepared off farm)

If this is a dairy farm, what type of milking arrangement do you use?

____

Stanchion type_________ Number of stalls____________

Loose housing type_______

Herringbone
Double 4_____________
Double 5_____________
Double 6_____________
Double 8_____________

Walk-through

Double 3_____________
Double 4_____________

U-parlor
3-stall______________
4-stall______________

Side opening

Three in line________
Four in line_________
Double 3_____________
Double 4_____________

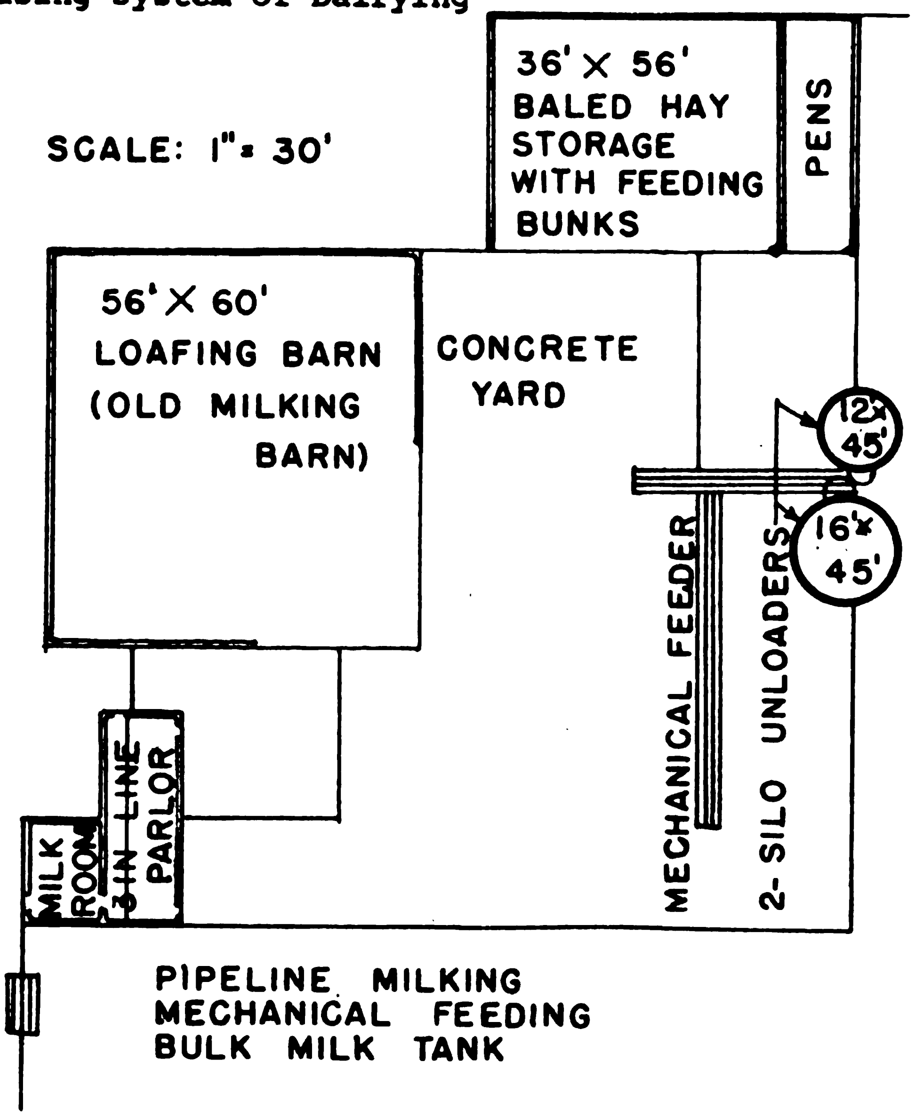
	A[a]	B	C	D	E	F	G	H
COST:								
Initial plus installation cost___								
Operation cost___								
REDUCTION OF LABOR:								
7 Completely eliminates labor___								
6 Reduces labor to push button only___								
5 Reduces labor to push button and observe operation___								
4 Reduces labor to about 1/4 of original___								
3 Reduces labor to about 1/2 of original___								
2 Reduces labor to about 3/4 of original___								
1 No reduction in labor___								
Remarks:___								
VALUE:								
5 Wouldn't do without___								
4 Worth more than total cost*___								
3 Worth about the same as total cost___								
2 Worth less than total cost___								
1 Not worth bothering with___								
*Total Cost = Fixed cost + Variable cost								
Remarks:___								
CONVENIENCE:								
5 Very convenient___								
4 Convenient___								
3 Does not make any difference___								
2 Slightly inconvenient___								
1 Very inconvenient___								
Remarks:___								

	A[a]	B	C	D	E	F	G	H
WORKING CONDITIONS:								
3 Improves working conditions (less odor, cleaner clothes, less lifting, etc.)								
2 No change in working conditions								
1 Makes working conditions worse								
Remarks:								
SKILL REQUIRED:								
5 Able to hire worker for less wages								
4 Little less skill required (same worker)								
3 No change in skill required								
2 Little more skill required (same worker)								
1 Little more skill caused increase in wages of worker or the hiring of a more experienced worker								
1a Unable to hire extra skill required								
Remarks:								
TIME TO DO CHORE:								
6 Eliminated								
5 Reduced to push button only								
4 Reduced to about 1/4 of original								
3 Reduced to about 1/2 of original								
2 Reduced to about 3/4 of original								
1 No reduction								
1a Causes increase in time to do other operations								
Remarks:								

	A[a]	B	C	D	E	F	G	H
MECHANICAL RELIABILITY OF EQUIPMENT:								
3 Dependable (not over one break-down per year)__________								
2 Occasional break-down (not over 3 times per year)________								
1 Frequent break-down (once every 4 months or oftener)______								
Remarks:________________________								
USE OF LABOR SAVED BY MECHANIZATION: (check all applicable statements) Enabled me to stay in the dairy business________________								
Labor used for productive work on other jobs______________								
More time to devote to management________________________								
Expand size of farming operation_								
More leisure time______________								
Devote time to improving knowledge and skills (attending short course, field days, etc.__________________________								
Devote more time to community service________________________								
General Remarks:________________________								

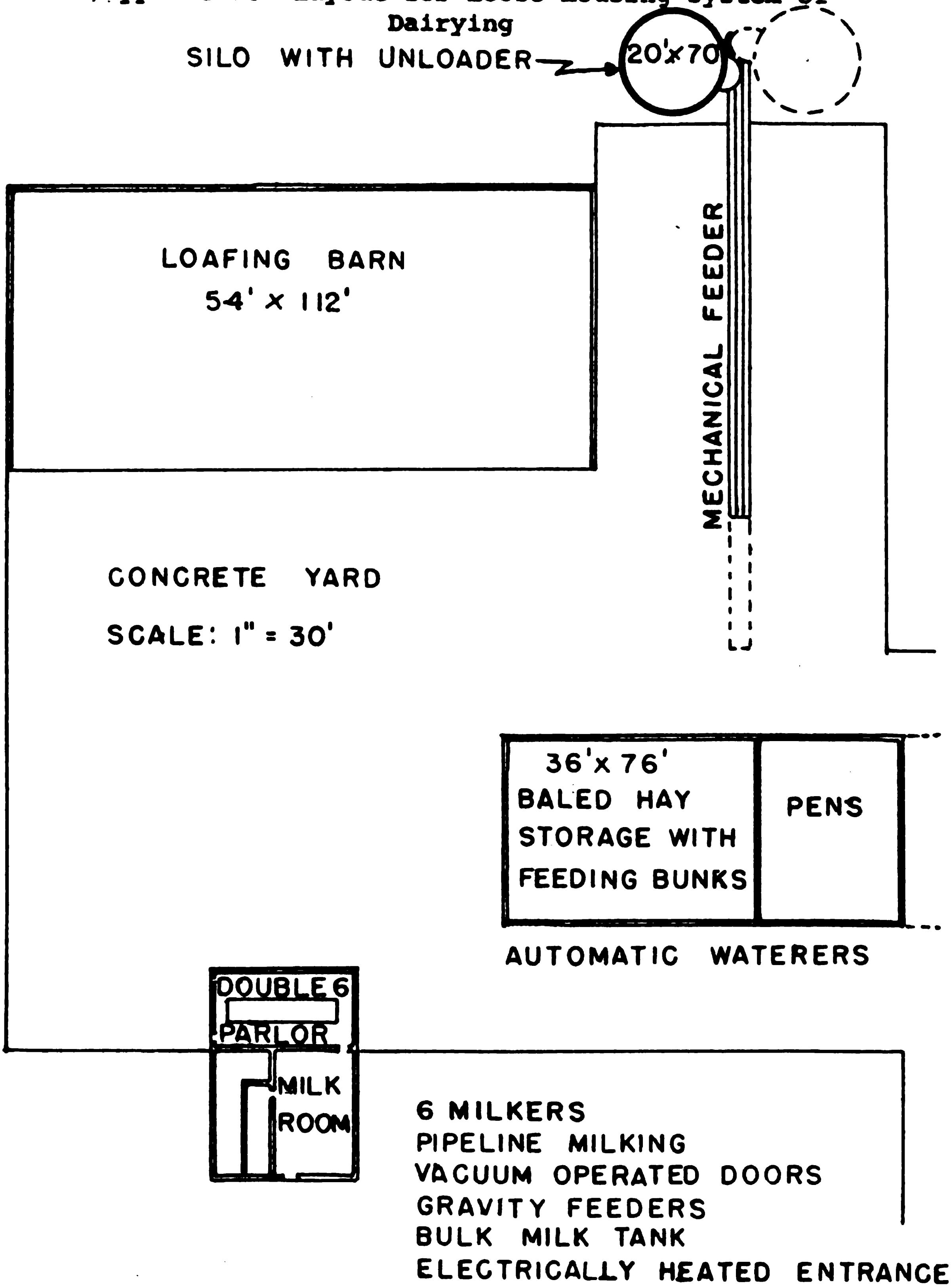
[a] A - Wagon unloader
B - Pipeline milker
C - Silo unloader
D - Mechanical bunk feeder (silage, hay, concentrate or combination)
E - Mechanical concentrate feeder
F - Self-feeder (specify)
G - Mechanical distribution of bedding (how?)
H - Manure removal (tractor, scoop, barn cleaner) specify

H - Typical Layout for Converting From Stanchion to Loose Housing System of Dairying



50 COW LOOSE HOUSING SYSTEM
(A CHANGE FROM STANCHION TO LOOSE HOUSING SYSTEM OF DAIRYING.)

I -. Typical New Layout for Loose Housing System of Dairying



LOOSE HOUSING FOR 150 COWS