A COMPUTER APPLICATION TO RUMINANT FEED FORMULATION UNDER ISRAELI CONDITIONS

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A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

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TABLE OF CONTENTS

INTRODUCTION

Linear Programming, as a method of calculating least-cost formulas with the aid of computers, is widely used today in the feed industry. As the knowledge of the mathematical applications of L. P. increases, and as new models of fast computers allow more complex calculations at reasonable time and cost, more possibilities are being added to the practical use of computers in feed formulation and feed production processes. The degree to which feed companies are applying these methods depend on their size, conditions, know-how, and special characteristics of the production in every feed mill.

Even though historically the first least-cost formula reported was for dairy cattle (Hutton, 1), more emphasis has been given to the use of this technique in poultry formulation. The fact that feed supplied to the avian specie must be nutritionally complete, and that the proper relation of nutrients (amino acids, etc) is more critical than in the case of ruminants, made the use of Linear Programming of special value to poultry feeds. Nevertheless, the number of reports on the use of computers to formulate dairy and cattle rations has been increasing in the last years (2, 3, 4, 5, 6) and economical and nutritional benefits are being obtained.

The feed industry in Israel has followed patterns of development similar to other countries. The use of computers in feed formulation has been of special importance for poultry rations, but the technique has been used less for ruminant feeds.

The objective of this work was to analyze the formulation of ruminant concentrates of a feed mill in Israel during a two year period, and to try to draw conclusions on the best method of formulation and utilization of several ingredients which are available in limited quantities.

The conclusions of this type of study can have direct application, and also give indications on size and number of storage bins for a new mill to be constructed for the production of only ruminant feeds.

REVIEW OF LITERATURE

Linear Programming and Feed Formulation:

Linear Programming deals essentially with the problem of allocation of limited resources among competing activities in an optimal manner (7). It has been defined as "a mathematical procedure for obtaining a value weighted solution to a set of simultaneous equations and/or inequations" (Hutton, 1).

The first successful application of L. P. is credited to the mathematician George B. Dantzig in 1947 (8, 9) working for the U. S. Department of the Air Force. But the first published report of the so called "Simplex" method, developed by Dantzig, dates only from 1951 (10), as mentioned by Dorfman et al. (9).

Feed formulation has been intimately related to the development of Linear Programming. The "diet problem" has been a classical example of the application of the Simplex method, and in 1951 F. V. Waugh, agricultural economist for the U. S. Department of Agriculture published an article on "The minimum cost dairy feed" (11), as discussed by Hutton (12).

The practical application of this procedure dates however from the late fifties, when the use of computers made possible the solution of large sets of equations without laborious hand calculations.

The mathematical fundamentals of Linear Programming are explained in basic texts on the subject (8, 9), as well as in many other books on disciplines where this method has been used.

Considerable work was published by Hutton and coworkers from The Pennsylvania State University regarding the specific application to feed formulation (13, 14, 15). Hutton, King and Boucher (16) reported a detailed method of derivation for a least-cost broiler formula, and Hutton explained the technique and possibilities of the application to the feed industry in a series of articles published in 1958 (1). The calculation of one of the first formulas, which included 24 ingredients and 22 restrictions, took 40 minutes using the computer available at that time (Pennstac) at a cost of $50.

Since those days, Least-cost Formulation using computers has become a common technique, and numerous works have been written on the subject.

Dent and Casey (17) have presented the mathematical and nutritional principles involved in the use of this technique in a book on "Linear Programming and Animal Nutrition".

From the standpoint of the nutritionist, L.P. is a calculation technique, and the results obtained with it depend entirely on: (a) the validity of the data supplied (nutrient content of the ingredients), (b) the proper definition of the nutrient characteristics desired for each formula, and (c) correct criteria of selection of ingredients and restrictions based on levels of use (maximum or minimum). This last point takes care of properties which can not be expressed as yet in terms of numerical values (presence of Unidentified Growth Factors, palatability, lateral effects, etc.).

Computer formulation of least-cost formulas has been discussed under different aspects by Bishop (18), Maddy et al. (19), Scott et al. (20), Stafford and Snyder (21), Schrader (22), and others. The following criteria are considered in the calculation of single formulas:

1. Least cost combinations of feedstuffs to meet specific nutrient requirements.

2. Acceptance or rejection of ingredients based on their cost, nutritional value or cost ranging.

3. Relationships between requirements for a specific nutrient and the cost of the feed formula.

4. Computer report generation of least cost information.

Several criticisms have been made to the nondiscriminatory use of computers in feed formulation. Titus (23) and Church (24) summarize some of the most common objections:

1. The fact that there are variations in the composition of ingredients.

2. Imperfect knowledge of nutritional requirements.

3. The properties of different ingredients are not always linearly additive.

4. Calculations should probably be based on available or digestible nutrients not on total content.

5. Some feedstuffs present associative effects and may have different values according to the combination of ingredients.

6. Lack of numerical data on taste, palatability, and preference by livestock for a certain texture.

Some of these criticisms are not relevant to Linear Programming or to computers but apply equally to any type of feed formulation. It is clear that the nutritionist must control the output given by the computer, keeping in mind that results are generated by a machine that will perform according to the quality of the instructions, which are man-designed.

The original L. P. calculations, and still the most commonly found are based on a minimum cost for a certain weight of feed. Different variations are also possible, according to Hutton (25, 12), Maddy et al. (19), Dudley and Parks (26) and Taylor (27):

(a). Formulation on the basis of energy, over a certain range. This involved formulation on a least-cost nutrient density and can represent a better criteria in the case of integrated operations. There are programs where all the nutrient requirements can be adjusted to the energy level.

(b). Non-linear profit optimization. Formulations for the most economical level of nutrition based on rate of growth, price of the final products, etc.

(c). Compensation for moisture content in ruminant formulation. The requirements are stated in a dry-matter basis and the computer adjusts the results to an "as fed" basis.

(d). Comparison of formulas. Some additions to the program can check the conditions prevailing at the moment of formulation and produce an output only when the difference exceeds a previously determined level.

In addition to these variations to the standard feed formulation, several new techniques have been developed and reported.

Swanson and Woodruff (28) suggested a sequential approach to the feed mix problem to find ways to reduce the number of formulations and the computing time. If a feed mill needs to reformulate all its formulas due to changes in prices, a proper order of formulation can store information from the first formula solution and reach the next solutions with less iterations.

The use of parametric Linear Programming (29, 27) offers other possibilities of evaluation of ingredient costs, diet requirements, etc. By analyzing one or sometimes several factors at different levels, the information obtained becomes more complete than in single formulations.

Simultaneous calculation was discussed by Bishop several years ago (30, 31). This allowed formulation of several feeds for a feed mill in order to optimally allocate ingredients which might be limited, or could include production restrictions. The method described in more detail in a publication of I. B. M. on Linear Programming in feed manufacturing (32) includes the reservation that the size of the matrix may become excessive and thus computational costs prohibitive. Taylor (27) referred to the method as a concrete possibility.

A more general approach to the problem of feed formulation was that from Purdue University (33, 34, 35) which considered formulation as an integral part of the total operation in a feed mill. Labor utilization, production constraints, pricing policy as well as formulation was to be considered simultaneously. To overcome the problem of size of the matrix, which reached a number of 2,100 rows for a 70 formula program, Snyder and Guthrie (34) suggested the use of a "compacted matrix technique" which reduced this number to 200 - 300 rows. The compacted matrix consisted of computer generated least-cost formulas stored in the system.

The fields of application of Linear Programming and computers to feed formulation, or in general to feed and animal production are extensive and development of new techniques should be seen in the near future.

A common statement found in the literature covering Linear Programming and formulation refers to differences in cost that can be obtained by the use of this technique. Figures of $1.50 up to $5.00 per ton are found commonly in articles of a popular type as well as in scientific reports. These figures should be considered with caution since they depend on how good (or how bad) the formulation work was done before the use of this technique, and should consider the computational costs not only for one time but as a system. Beyond doubt, Linear Programming results in true least-cost formulas and the larger the number of possibilities allowed to the computer, the higher the probability of reducing the cost of the formula.

Nutritional Requirements:

Any system of feed or ration formulation must be based on reliable requirement data for different types of livestock. The application of total requirements for ruminants is not straightforward since the feed supplied by the concentrate represents only part of the daily ration. Nevertheless, the feeding practice used in a certain area as well as the available forage during all seasons of the year must be known in order to formulate suitable concentrates to fit the different rations.

Crampton and Harris (36) refer to the definition of feeding standards as "a table which records what is believed to be the daily need of a specific animal for one or more of the recognized nutrients". It should be added that feeding standards must include a set of values for individual feedstuffs (Moe and Flatt, 37).

There are different systems and recommendations for dairy cows and other ruminants. These systems differ according to the criteria selected for measuring energy requirements, to the method of experimental determination of these requirements, and to the method of feedstuffs evaluation.

Maynard and Loosli (38) describe the historical development of feeding standards. Some methods introduced during the first or second decade of this century are still in use. In Europe, methods based on Estimated Net Energy became the most accepted (Kellner, Hansson). A similar system developed by Armsby in the United States was less successful in gaining acceptance by dairymen and nutritionists, who gave preference to the evaluation of feedstuffs based on Total Digestible Nutrients. Henry and Morrison in 1915 adapted different works and information into feeding standards based on TDN.

Animal nutritionists agree today that the evaluation of feedstuffs based on TDN or other measures of digestibility suffers from several drawbacks and do not reflect the true utilization of nutrients by the animal, for maintenance and production purposes. The change to more accurate systems using Net Energy takes time and will require more tabulated values for the different ingredients than those available today.

The most reliable source of feeding standards are the publications of the United States National Research Council (N. R. C.) (39, 40) which are periodically revised taking in consideration new findings. It must be realized that levels of milk production which are obtained today differ drastically from those of years ago; Reid et al. (41) and Coppock and Tyrrell (42) discuss the nature of the change in requirements for lactating cows.

The British standards, published by the Agricultural Research Council in London (43) are used in many countries and are based on estimates of Metabolizable Energy requirements.

The trend in development of feeding standards according to Moore (44) is to use Net Energy as the most meaningful criteria. Beef cattle formulations are moving in this direction, based primarily on the work of Lofgreen and Garrett (45).

The use of Net Energy for maintenance and production in the case of dairy cows has been suggested by Moe and Flatt (37). Considerable work has been done at the U. S. D. A. Energy Metabolism Laboratory at Beltsville, Maryland, and it should be expected that when enough information and experience are accumulated, this system should be the most reliable. Regression equations allow the conversion of values from one system to another within certain limits (McCullough, 46).

In Israel, Net Energy for cattle nutrition has been introduced and Metabolizable Energy has been applied to the lactating cow. The most commonly used system, however by dairymen in Israel, is the Scandinavian system (Hansson) which expresses the energy values in terms of barley units (feed units). In comparison to Kellner's method of starch units based on the potential of a feedstuff to produce fat, the Scandinavian system is based on the potential for producing milk. Hansson applied a coefficient of 1.43 to the Digestible Protein value of the feedstuffs since protein was more efficient for the production of milk than for the production of fat. The unity measure of the system was 1 kg barley and comparative values of other feedstuffs were determined using lactating cows (Bondi, 47).

The feeding standards being used in Israel do not differ drastically from those of Morrison (48) or the N. R. C. (39, 40). Protein values for maintenance and for milk production are expressed in terms of Digestible Protein. Regarding energy, the standard allowance has been 0.4 to 0.5 feed units per kg of FCM (fat corrected milk) depending on the level of production (Lev, 49).

Composition of Feedstuffs:

An important factor in feed formulation using Linear Programming or any other technique is the reliability of composition values for the ingredients. The Weende method of Proximate Analysis of feeds is still the most used in spite of its limitations (36).

Values which can not be easily determined in a Chemical Laboratory (Digestible Protein, Energy values) must be obtained from tables. It is a well known fact that tables cover a wide range of a value for a specific ingredient. The most used tables in Israel are those of Bondi and Neumark (50) who summarized their own determinations and works from other countries. These tables are not complete or up to date and must be complemented with other sources of information of this type. Morrison's tables (48), The Joint United States-Canadian Tables of Feed Composition (51), or its revision which appears in the Crampton and Harris book (36), Lofgreen and Garrett values for Net Energy (52), Feed Industry Red Book (53), etc. are only examples of reference sources in order to build a chart of values which appear to be suitable for locally used ingredients.

Variations in the composition of ingredients.

Tables give averages or values expected to be found. Ingredients of the same type however vary in composition due to different factors (Deyoe, 54). Chung and Pfost (55) suggested three possibilities for overcoming this ingredients variation: (a) blending of lots of the ingredient before using them, (b) assaying of the lots before unloading and segregation into two or more bins for every ingredient according to composition, and (c) use of different types of ingredients to compensate for the variations. Nott and Combs (56) proposed a deduction from the mean values assayed. They suggested subtracting one half of one standard deviation (or the addition of this amount in the case of moisture, ash, etc.) as a way of insuring guaranteed levels in the final mix.

Formulation with Linear Programming should consider this point and introduce corrections in the matrix values when necessary.

It has been mentioned that the Proximate Analysis does not define nutritional value properly. Figures reported for "Crude fiber" or "Nitrogen free extract" can have a completely different chemical meaning and feeding value in two ingredients. Van Soest (57, 58) has made valuable contributions in the effort of chemical evaluation of feedstuffs in a more meaningful way from the nutrition standpoint. We can expect more specific definitions of properties and relative ratings of quality for different sources of fiber for ruminants. This point is especially important when the computer is used for formulation: a maximum quantification of properties can give better nutritional results.

Nutritional Restrictions of Ingredients:

Quite often it is desirable to give an upper limit of use for one or more ingredients based on nutritional considerations; this can be related to palatability, texture, and deleterious effects of certain ingredients when they exceed certain levels. Also, certain ingredients might be needed in a mix under any conditions of price.

In early reports on computer formulated diets, Potter et al. (59) mentioned the case of a broiler ration formulated without ingredient restrictions which gave a least-cost formula containing 50.4% hominy feed, 19.2% corn gluten meal and 9.7% meat scrap. Such formulation could be typical if no control was applied. Excessive use of restrictions on the other hand may increase the cost of the formula. In the mentioned case, the defined solution had a cost of $69.63 per ton versus $62.72 for the unrestricted.

Church et al. (60) indicated some ingredient restrictions in rations for beef cattle: alfalfa meal, not less than 5% and not more than 15%; beet pulp, minimum 10%; molasses, minimum 5%, maximum 10%.

In the Nebraska publication on Computer Feed Formulation Data (61) every specification for rations includes a list of minimum and/or maximum levels for certain ingredients, taking into consideration palatability, dustiness, bulkiness, etc.

The need for these restrictions are obvious, but justification of the levels adopted are often not fully explained in the literature.

Application of Linear Programming to Ruminant Rations:

Practical formulations for dairy and cattle rations have been reported recently. Bath (2, 3) explained the economical advantages of the procedure. Howard et al. (5) reported the results of a comparative trial using: (a) a least-cost constant formula, computed once with cost figures of a previous year; (b) a least-cost variable formula, recalculated every two weeks according to the market prices, and (c) a control conventionally calculated. No significant differences were obtained in consumption, milk production or milk fat between the three treatments, in spite of the abrupt changes in composition of the diet. The formulated rations were "complete rations" in all cases.

Bath et al. (4) reported four trials involving 251 cows where a conventional commercial concentrate was compared to an iso-nutrient least-cost formula. Only minor differences occurred in one trial and a reduction in cost occurred in all the computer calculated formulas.

Dean et al. (6) studied the application of Linear Programming to the dairy cattle industry in order to maximize income above feed cost. The program selected simultaneously components of the concentrate mix, the components of the roughage portion of the ration, roughage - concentrate ratio, levels of feeding and quantities of milk production which maximized profits. If different nutritional relationships can be specified in a mathematical way and follow linear functions, this type of program provides another example of the possibilities offered by application of Linear Programming.

MATERIALS AND METHODS

The conditions prevailing in Israel of restricted soil and water impose a feeding system based heavily on concentrates. The breed almost universally found for dairy cows is the Friesian-Israeli which normally serves also for meat purposes. The type of ration used and genetical development of the breed allow an average production of 7,000 liters of milk per cow per year.

Formulas and Specifications:

1. Description of the operation.

The AMBAR Feed Mill in Israel has an annual production of about 100,000 tons (metric). Around 35% of this output has been ruminant feed and includes essentially four types of formulas:

(a) Dairy cow concentrate with 16% crude protein (abbreviated Dairy 16).

(b) Dairy cow concentrate with 14% crude protein (Dairy 14).

(c) Beef cattle concentrate (Cattle).

(d) Growing heifer concentrate (Heifers).

A calf starter formula also produced was excluded from this study since it represented only a minor item in the production. Only standard formulas were considered.

All these feeds are produced in the form of pellets: 12 mm diameter in the case of dairy and cattle concentrates and 6 mm diameter for the heifer concentrates. Small amounts of dairy feed are supplied as mash, and this represents a slight change in composition, but for the purpose of this work all feeds were considered pelleted.

In actual operation some diets are interchangeable and are used individually or in combination to fulfill the requirements of dairy cows at different stages of lactation. The available forage also influences formula use. In other words, a Cattle feed might be used for dairy cows with a low production level if the roughage supplied enough protein, or a Dairy 14 feed could be the concentrate used for beef cattle with a poor quality roughage addition.

Production data for these four types of formulas during a two year period (1968-1969) are included in Appendix I.

2. Nutritional requirements.

The specifications used for the formulation of the four concentrates are shown in Table I.

TABLE I. NUTRITIONAL SPECIFICATIONS, RUMINANT FORMULAS

	Dairy 16	Dairy 14	Cattle	Heifers
Crude protein, min. %	16.0	14.0	12.0	15.5
Digestible prot., min. %	13.0	11.5	9.0	13.0
Crude fiber, min. %	7.0	7.0	8.0	6.0
Calcium, min. %	0.75	0.75	0.70	0.75
Calcium, max. %	0.80	0.80	0.75	0.80
Phosphorus, min. %	0.60	0.60	0.60	0.65
Phosphorus, max. %	0.65	0.70	0.65	0.70
Energy (feed units/100 kg)	89.0	88.0	85.0	94.0

The purpose of some requirements used in formulation are as follows:

(a) Both Crude protein and Digestible protein were requested. Digestible protein meets feeding standards but total protein value is used for control and tag guarantee.

(b) Minimum values of Crude fiber were used due to the nature of ruminant feeding in Israel. The use of high levels of concentrate is the reason for this specification. No maximum values were specified since the energy level and the cost of fiber control these factors.

(c) Feed units were selected as the measure of energy. The value of Metabolizable Energy for dairy cows and Net Energy for cattle formulas were calculated but no minimum was specified.

The composition of the ingredients used for the ruminant formulas is shown in Table II.

Comments on the data in the table of ingredients.

(a) Costs are indicated in Israeli pounds (I.L.) per ton. The conversion to American currency is: $ 1.0 = 3.50 I.L. The cost used for computations is the net cost plus transportation cost, but no storage or processing costs were included.

(b) The values for Metabolizable Energy are referred to when used for dairy cows. The values of Net Energy are applied to cattle and heifers.

(c) Hansson's values of feed units were oriented to milk production and give a high energy value for protein rich ingredients like soybean meal or cottonseed meal. In practice, the same units are used for cattle feeding.

(d) Wheat straw was not an ingredient during the time covered by this study; it was included in the list of ingredients to evaluate the economic possibilities. The cost listed was modified after calculation of the Dairy 16 formulas; later information with more realistic cost estimates gave a value of 130.00 I.L. per ton of this product.

(e) Some ingredient costs were based on prices at the feed mill, so no transportation cost was listed.

(f) A value for Vitamin A was considered for alfalfa meal (50,000 I.U.A./kg), but a similar value was not given to corn or other ingredients.

TABLE II. INGREDIENTS FOR RUMINANT FEEDS

	Crude Prot.	Dig. Prot.	Fat	Fiber	Ca	P
	%	%	%	%	%	%
Corn	8.8	7.4	4.0	2.5	0.02	0.27
Sorghum	9.0	7.0	3.0	3.0	0.02	0.30
Barley	10.0	8.0	1.8	6.5	0.05	0.35
Wheat	12.5	9.5	1.5	2.8	0.05	0.41
Soybean meal	45.0	42.0	1.0	6.5	0.25	0.65
Cottonseed meal	42.0	33.7	1.5	11.0	0.15	1.10
Wheat bran	15.0	12.0	4.0	11.0	0.10	1.20
Rice bran	13.0	10.0	18.0	7.0	0.10	1.30
Alfalfa meal	20.0	15.0	3.0	22.0	1.30	0.25
Citrus pulp	6.0	3.1	1.5	14.5	3.00	0.12
Cottonseed hulls	4.0	0.0	1.4	35.0	0.14	0.09
Wheat straw	4.0	0.0	1.5	35.0	0.15	0.07
Molasses	7.0	3.0			0.78	0.08
Limestone					39.00	
Dicalcium phosphate					28.00	18.00
Salt-Bentonite						
Bentonite						
Vitamin premix	16.5	14.1	3.6	7.0		

TABLE II. CONTINUATION

	Feed Units /kg	ME Mcal /kg	NEm Mcal /kg	NE_g Mcal /kg	Cost I.L.	Trans. Cost I.L.
Corn	1.070	2.928	2.03	1.32	250.0	3.20
Sorghum	0.960	2.893	1.93	1.27	230.0	3.20
Barley	1.000	2.892	1.93	1.27	255.0	3.20
Wheat	1.025	2.786	2.00	1.30	230.0	3.20
Soybean meal	1.250	2.640	1.72	1.15	387.0	3.20
Cottonseed meal	0.955	2.315	1.40	0.90	337.0	3.20
Wheat bran	0.835	2.242	1.52	1.01	185.0	7.80
Rice bran	0.950	2.206	1.65	1.10	210.0	7.80
Alfalfa meal	0.665	2.025	1.23	0.70	273.0	-
Citrus pulp	0.912	2.710	1.78	1.19	200.0	-
Cottonseed hulls	0.350	1.537	0.93	0.20	125.0	7.80
Wheat straw	0.250	1.555	0.91	0.14	100.0	-
Molasses	0.625	2.478	1.43	0.90	150.0	7.50
Limestone					20.0	6.00
Dicalcium phosphate					420.0	6.60
Salt-Bentonite					87.0	6.00
Bentonite					97.0	6.00
Vitamin premix	0.980	2.548	1.74	1.14	470.0	-

(g) The first set of formulas was calculated with different cost values for the binder, salt and premix, but this difference has only a side effect on formulation. In other calculations these ingredients were grouped as "fixed ingredients" without taking in consideration the slight nutrient contribution of the premix carrier. The cost of alfalfa meal was changed to 261.00 I.L. per ton in these cases, to compensate for the Vitamin A value.

(h) Costs for ingredients are a rather constant factor under Israeli conditions. Prices are regulated by the Ministry of Agriculture and minor changes in the world market are absorbed. For this study prices were considered unchanged during the 24 month period.

(i) Normally one price applies to each ingredient even if it comes from different sources. Wheat bran was considered as an example of one ingredient which might be available as a special supply item (up to 15% of the total available supply of this ingredient) at a premium price (210.0 I.L. per ton).

3. Nutritional and technological restrictions for the ingredients.

Barley was included in all formulas at a minimum level of 10%.

Alfalfa meal was included at a 5 - 6% minimum level.

Molasses was restricted to a 3% maximum level.

Sorghum grain was limited to 15% in the cattle formulas.

4. Availability restrictions.

The problem of availability of ingredients is the main factor in periodic changes in formulation under Israeli conditions. This is related especially to local by-products from other industries. Here the amount is a function of the capacity of consumption or production by the country. Some of these by-products are produced only during certain months of the year.

Grains are imported, mostly from the United States, and can be ordered through Government offices according to need. The situation of availability for the listed ingredients can be briefly summarized as follows:

Corn - unrestricted

Sorghum - unrestricted

Barley - unrestricted

Wheat - relatively small amounts are used by the feed industry. It may come from local crops unsuitable for milling purposes or from the U. S. market.

Soybean meal - unrestricted. Israel imports soybeans for the extraction of oil and adequate quantities of soybean meal are produced.

Cottonseed meal - a local by-product. The production of cotton has increased during recent years, so additional quantities of cottonseed meal are found in the market. It might be in shortage during certain months of the year since processing normally occurs close to the ginning season.

Wheat bran - available in limited amounts. The supply of this product is subject to erratic factors.

Rice bran - small amounts are available with a rather stable monthly supply.

Alfalfa meal - produced during 9 or 10 months of the year. Winter months may show a decrease in availability according to climatic conditions. Storage becomes a critical problem during summer months.

Citrus pulp - variable amounts of pulp are dried during the citrus season (December to March), depending on many climatic and marketing factors. The product must be stored if intended for use during the rest of the year.

Cottonseed hulls - availability depends on cottonseed meal.

Molasses - produced during spring months, must be properly stored for the rest of the year.

Minerals - unrestricted.

Wheat: not used at more than 10% for dairy feeds, nor more than 15% for cattle. Not used in heifer formulas.

Wheat bran: not more than 30% in dairy formulas, nor more than 20% in cattle and heifer concentrates.

Rice bran: used only for cattle formulas at levels up to 6-8%.

Citrus pulp: used up to 5-6% in all formulas, except for heifers.

A table with the amounts of restricted ingredients which were used during 1968 and 1969 is given in Appendix II.

The availability of ingredients has been expressed in some formulation restrictions based on subjective judgment evaluations.

5. Poultry formulas.

In order to evaluate the possibility of the technique of simultaneous formulation for a feed operation, three poultry formulas having a large volume of production in AMBAR were added to the ruminants program. The selected formulas were: (a) broiler grower, (b) broiler finisher, and (c) heavy breeder formula. The specifications for these formulas, the ingredient composition and the ingredient restrictions are shown in Tables III, IV and V.

Experience indicates there is no need to give all constraints to the computer, but only the most critical nutritional requirements are needed. In the Multiformula model it is especially important to try to reduce the size of the matrix.

Crude fiber was excluded as a restriction. Available Phosphorus was used in broiler rations and Total Phosphorus in the breeders ration. Methionine-Cystine as a restriction was enough to control the Methionine level. All the tabulated requirements were supplied by calculation from the formulas obtained.

TABLE III. SPECIFICATIONS FOR POULTRY FORMULAS

	Broiler Grower	Broiler Finisher	Heavy Breeder
Protein, min. %	18.3	16.2	15.2
Fiber, max. %	3.5	3.5	4.7
Calcium, min. %	0.8	0.8	2.8
Calcium, max. %	0.9	0.9	2.9
Total Phosphorus, min. %	0.64	0.60	0.66
Available Phosphorus, min. %	0.42	0.40	0.39
Methionine, min. %	0.40	0.33	0.30
Methionine-Cystine, min. %	0.70	0.60	0.52
Lysine, min. %	0.99	0.82	0.70
Met. Energy, min. Mcal/kg	2.84	2.86	2.55

TABLE IV. INGREDIENTS FOR POULTRY FORMULAS

	Prot.	Fat	Fiber	Ca	Total P	Avail. P
	%	%	%	%	%	%
Corn	8.8	4.0	2.5	0.02	0.27	0.10
Sorghum	9.0	2.5	2.5	0.02	0.30	0.10
Wheat	12.5	1.5	2.8	0.05	0.41	0.13
Fish meal	63.0	5.0		4.50	2.80	2.80
Soybean meal	45.0	1.0	6.5	0.25	0.65	0.20
Cottonseed meal	42.0	1.5	11.0	0.15	1.10	0.35
Wheat bran	15.0	4.0	11.0	0.10	1.20	0.40
Rice bran	13.0	18.0	7.0	0.10	1.30	0.43
Alfalfa meal	20.0	3.0	22.0	1.30	0.30	0.10
Molasses	7.0			0.74	0.08	0.03
Limestone				39.00		
Dicalcium phosphate				28.00	18.00	18.00
Methionine	58.7					
Fixed Ingredients B.G.						
Fixed Ingredients B.F.						
Fixed Ingredients H.B.						

TABLE IV. CONTINUATION

	Meth. %	Meth. Cyst. %	Lys. %	PE Mcal/ kg	ME Mcal/ kg	Cost I.L.
Corn	0.19	0.35	0.25	2.508	3.410	253.20
Sorghum	0.14	0.29	0.22	2.420	3.256	233.20
Wheat	0.19	0.39	0.35	2.310	3.100	233.20
Fish meal	2.00	2.80	5.00	1.892	2.552	576.80
Soybean meal	0.66	1.32	2.90	1.672	2.244	390.20
Cottonseed meal	0.55	1.28	1.50	1.320	1.870	340.20
Wheat bran	0.15	0.35	0.55	1.078	1.144	192.80
Rice bran	0.22	0.31	0.54	1.870	2.860	217.80
Alfalfa meal	0.30	0.70	0.90	0.803	1.408	261.00
Molasses				1.540	1.980	157.50
Limestone						26.00
Dicalcium phosphate						426.60
Methionine	100.00	100.00				4000.00
Fixed Ingredients B.G.						401.76
Fixed Ingredients B.F.						363.79
Fixed Ingredients H.B.						601.20

The list of ingredients include some feedstuffs not used commonly for poultry rations (rice bran, wheat, cottonseed meal) to check the potential possibility of use.

The fixed ingredients include Vitamin and Mineral premixes, Salt, and a binder. No nutrient value was given to the carrier in the premix.

The maximum levels for fish meal given in Table V stem from availability limitations.

TABLE V. INGREDIENT RESTRICTIONS FOR POULTRY FORMULAS

	Broiler Grower	Broiler Finisher	Heavy Breeder
Corn, min. %	20.0	20.0	5.0
Fish meal, min. %	1.0	1.0	1.0
Fish meal, max. %	3.0	1.0	3.0
Wheat bran, max. %	-	-	15.0
Alfalfa meal, min. %	1.0	1.5	2.0
Molasses, max. %	2.0	2.0	2.0
Fixed ingredients, %	4.5	3.9	2.0

Computer Programs:

1. Individual formulas

The formulas were calculated using the 360-50 I.B.M. computer at the Kansas State University Computing Center.

The program for L.P. is standard and its use is explained in the publication: Mathematical Programming System/360, (360A - CO - 14X), Linear Programming - User's Manual (62).

The different sections of the program for the individual formulas were:

Rows. The rows included cost and weight and the characteristics indicated in the Table of Ingredients, including different expressions of energy content. Vitamin A was included in part of the formulations.

Columns. All the ingredients used in a specific formulation. In comparative formulas, all the ingredients listed were included, giving a high cost value (M) to those which normally would not have been considered for a specific formula. The unit used to relate nutrient content of the ingredients was 1 kg.

Right Hand Side. This section included a value 100 for Weight. Minimum levels were used for Crude protein, Digestible protein, Crude fiber, Feed units and Phosphorus. A maximum level was used for Calcium. Small requirement values were given for Fat, Metabolizable energy and Net energy to obtain a calculated value without interfering with the solution.

Spread. The maximum and minimum values for Calcium and Phosphorus were controlled by this section.

Bounds. The control of maximum, minimum and fixed levels of ingredients was accomplished using this section.

2. Simultaneous formulation.

The same L. P. program was used to solve this problem. In this case all requirements for the individual formulas are introduced in one matrix, with the maximum amounts of limiting ingredients to be used. By using the proper statement of the equations to be solved, an optimal total solution was obtained.

Details of this application of Linear Programming can be found in the I.B.M. publication: Linear Programming - Feed Manufacturing (32), where a scheme of equations and a matrix tableau are described.

The different sections for this particular program can be summarized as follows:

Rows. Besides the cost, several submatrices are built in the model and include: ingredient supply, ingredient use, formulation control and production requirements.

The first set of rows is formed by the ingredients to be used. This may include different sources of the same ingredient supplied at different prices. The second group of rows indicates ingredient transfer, one row for every ingredient to be used.

The formulation control indicates the properties of the ingredients of interest for formulating the set of equations (Weight, Protein, Fiber, etc.). Every formula to be calculated constitutes a submatrix similar to the model for individual formulas.

The production requirement control lists the formulas to be calculated.

Columns. The first group of columns is related to the total supply of ingredients. Every ingredient source will show a coefficient 1 to the corresponding unknown in the "supply" and in the "transfer" sections of the rows.

For every formula to be computed, the ingredients must be defined according to the corresponding rows. In addition to these values, a coefficient of -1 should be given to the transfer row for the same ingredient. Thus, the total amount of a certain ingredient to be used will be partitioned between the different formulas where this ingredient is used.

Following the columns which give the composition of the ingredients, the requirement for each formula should be defined. Negative values are used here to keep the right hand side of the equation equal to Zero. Every summarizing formula was linked to the production control row.

Right hand side. Tons were used as the unit to quantify the requirements. The supply figures for the ingredients can be greater or less than some value, if one is to force the use of some material or to limit its use according to availability. Ingredients which can be used at any level must have a right hand side value large enough to avoid infeasible solutions. The transfer RHS values are equal to Zero since they represent the total amount used of a certain ingredient minus the amount it used in the individual formula.

In the formulation control rows, equations were established which had a value of Zero. The possibility of being less or greater than this value can also be considered according to the specifications.

Production requirement rows had a RHS value for the desired quantity to be produced of each formula.

Spread and Bounds. These sections had the same use as in individual formulations. The numerical values assigned to restricted properties or ingredients can not be expressed as percentages, but were indicated in tons, according to the specified production.

3. Nutrient content calculations.

The solution of the multiple formulation was obtained in terms of amounts of ingredients for the total weight requested. This will easily give the percentage composition of each formula, but gives no information on the nutrient content.

A simple FORTRAN program was written to do this calculation. The ingredient composition was read in as a table. The formulas to be analyzed are then read, and the contribution of every ingredient in terms of nutrients was calculated and added sequentially to give the total composition. This computation can also be easily done with a desk calculator.

Outline of the Procedure:

I. Individual least-cost formulas:

(a). Development of formulas under gradual restrictions;

(b). Evaluation of the relative dollar-value of ingredients.

II. Analysis of ruminant formulas for two specific months:

(a). Actual changes in formulation;

(b). Average monthly formulation;

(c). Evaluation of ingredients.

III. Simultaneous formulation:

(a). Solution;

(b). Economic comparison between systems.

IV. Ruminant-Poultry formulations:

(a). Individual poultry formulas;

(b). Simultaneous formulation;

(c). Comparison of systems, ingredient distribution, economic effect.

RESULTS AND DISCUSSION

I. Individual Least-Cost Formulas:

Normal formulations usually start with a number of predetermined constraints, according to nutritional, technological or availability restrictions on ingredients, as stated in the Materials and Methods section.

In order to learn the effect of each restriction, a set of formulas was calculated for one of the ruminant rations (Dairy concentrate, with 16% protein). Details of the relative dollar-value of the ingredients (opportunity prices) will be discussed only in the final formula, since its validity for one ingredient counts only for specific relationships with the other components of the formula.

Dairy 16 formula. The results of the computations are reported in Table VI, with the following explanation on the restrictions applied to each formulation:

1. No ingredient restrictions.
2. Molasses limited to 3%. As explained, this was a technical restriction under present conditions of operation.
3. Wheat limited to 10%. (Availability).
4. Citrus pulp, not more than 6%. (Availability).
5. Wheat straw excluded from the diet. (Technology).
6. Wheat bran, regular supply, restricted to 25%. (Availability).
7. Rice bran excluded from the diet. (Availability, nutrition).
8. Barley required at 10% as a minimum level. (Nutrition).
9. Alfalfa meal, not less than 6%. (Nutrition).
10. Wheat bran, special supply, limited to 5% (Availability).

Underlined values in the tables indicate some type of restriction.

TABLE VI. DAIRY 16 FORMULATIONS

	1	2	3	4	5
Corn	-	-	-	18.5	-
Sorghum	-	-	3.1	-	22.5
Barley	-	-	-	-	-
Wheat	27.2	40.7	10.0	10.0	10.0
Soybean meal	13.0	11.9	15.1	14.7	14.4
Cottonseed meal	-	-	-	-	-
Wheat bran	36.3	33.3	39.2	37.6	36.4
Wheat bran, special sup.	-	-	-	-	-
Rice bran	-	-	-	-	-
Alfalfa meal	-	-	-	-	-
Citrus pulp	9.2	1.1	23.0	6.0	6.0
Cottonseed hulls	-	-	-	-	1.5
Wheat straw	-	3.4	1.7	4.0	
Molasses	8.4	3.0	3.0	3.0	3.0
Limestone	1.0	1.7	-	1.3	1.3
Dicalcium phosphate	-	-	-	-	-
Premix, Salt, Binder	4.9	4.9	4.9	4.9	4.9
Cost (I.L.)	230.28	230.46	231.59	235.11	235.38
Crude protein, %	16.0	16.0	16.0	16.0	16.0
Digestible protein, %	13.1	13.1	13.1	13.4	13.4
Crude fiber, %	7.0	7.0	9.7	8.1	7.3
Calcium, %	0.80	0.80	0.80	0.80	0.80
Phosphorus, %	0.65	0.65	0.65	0.65	0.65
Feed units/100 kg	89.0	89.0	89.0	89.0	89.0
Met. Energy Mcal/100 kg	239.6	237.5	239.2	237.3	240.9

TABLE VI. CONTINUATION

	6	7	8	9	10
Corn	-	-	-	9.6	-
Sorghum	19.7	22.5	12.3	0.4	15.9
Barley	-	-	10.0	10.0	10.0
Wheat	10.0	10.0	10.0	10.0	10.0
Soybean meal	15.5	14.4	14.3	12.0	12.7
Cottonseed meal	-	-	-	-	0.5
Wheat bran	25.0	25.0	25.0	25.0	25.0
Wheat bran, special sup.	-	11.4	11.0	12.0	5.0
Rice bran	10.4				
Alfalfa meal	-	-	-	6.0	6.0
Citrus pulp	6.0	6.0	6.0	6.0	6.0
Cottonseed hulls	4.2	1.5	2.2	-	-
Wheat straw					
Molasses	3.0	3.0	3.0	3.0	3.0
Limestone	1.3	1.3	1.3	1.2	1.1
Dicalcium phosphate	-	-	-	-	-
Premix, Salt, Binder	4.9	4.9	4.9	4.8	4.8
Cost (I.L.)	237.42	238.22	239.91	242.69	243.89
Crude protein, %	16.0	16.0	16.0	16.0	16.0
Digestible protein, %	13.3	13.4	13.3	13.3	13.2
Crude fiber, %	7.8	7.3	7.9	8.3	7.8
Calcium, %	0.80	0.80	0.80	0.80	0.80
Phosphorus, %	0.65	0.65	0.65	0.65	0.60
Feed units/100 kg	89.0	89.0	89.0	89.0	89.0
Met. Energy Mcal/100 kg	237.2	240.9	240.2	238.8	242.5

Reviewing the different steps in the restrictions, it can be seen that constraints on feed ingredients can increase the cost of the final formula.

Technical restrictions can be evaluated in this manner to judge the need for different or additional equipment.

Nutritional constraints regarding use of certain ingredients should be properly revised if these have a serious effect on the cost of the final formula as in the present case.

Availability restrictions in a situation of this type can not be changed, but it is important to find the formula where a certain ingredient is more effective. This point will be further developed.

The present study deals essentially with the ingredient problem, taking into consideration the fact that nutritional requirements are unchangeable. This is not always the case in practice, and consideration should be given to the cost for each unit of a nutrient. In the present problem, where Crude protein and Energy were always limiting factors, the computer gives information on the economic effect of relieving any such constraint.

One can see that if Metabolizable Energy would have been used as the Energy criteria, a different solution would have been obtained.

Feedstuffs can be compared according to their nutrient content. Morrison (48) modified a system developed by Petersen, and gave to all ingredients a "value of corn" and a "value of soybean meal". In other words, the protein and energy content of every ingredient can be calculated in relation to the market price of soybean meal, as the most typical protein ingredient, and of corn, as an energy ingredient. Preston (63) slightly modified this system, added Calcium and Phosphorus as additional factors that can affect the dollar-value of an ingredient, and applied a computer program to calculate the relative value of any ingredient as a function of the market prices of soybean meal, corn, dicalcium phosphate and limestone. One value can be calculated for ruminants, based on Digestible Energy and Crude protein, and one for poultry and swine based on Metabolizable Energy, and a "balanced crude protein" which considers the most limiting amino acids.

The formulas of Table VI show that under constant conditions of price the interrelationships between ingredients can change their relative value. This can be complemented with additional information on cost given by the computer. Taking corn and sorghum as examples (priced at 253.20 and 233.20 respectively): formula 4 calls only for corn, and the opportunity price for sorghum is 233.08, very close to the actual cost. In formula 5, sorghum was used, and corn would have been considered only at a price of 250.55. This change was produced by the exclusion of wheat straw from the formula. Corn was used again in formula 9, but was excluded in formula 10, by the restriction dealing with wheat bran. Its opportunity price was 251.30 in this case.

This illustrates the point that the real value of one ingredient is a function of the formula used, and of the relationship between the other ingredients in that same formula.

The composition of least-cost formulas for the other three types of diets, with all the restrictions, are reported in Table VII.

Underlined values in the table indicate some type of restriction.

The cost of the fixed products was different in this set of formulas for the dairy rations on one side and for the cattle and heifer rations on the other.

TABLE VII. LEAST-COST FORMULAS

FOR DAIRY 14, CATTLE AND HEIFERS UNDER STANDARD RESTRICTIONS

	Dairy 14	Cattle	Heifers
Corn	-	5.9	38.1
Sorghum	21.9	15.0	1.1
Barley	10.0	10.0	11.0
Wheat	10.0	15.0	
Soybean meal	8.3	-	14.2
Cottonseed meal	-	3.6	-
Wheat bran	25.0	17.0	17.0
Wheat bran, special supply	5.0	3.0	3.0
Rice bran		7.0	
Alfalfa meal	5.0	5.0	6.0
Citrus pulp	6.0	5.0	
Cottonseed hulls	-	4.4	-
Molasses	2.8	3.0	3.0
Limestone	1.1	1.0	0.9
Dicalcium phosphate	0.1	0.3	0.9
Premix, Salt, Binder	4.8	4.8	4.8
Cost	236.10	221.00	255.11

TABLE VII. CONTINUATION

	Dairy 14	Cattle	Heifers
Crude protein, %	14.1	12.0	15.5
Digestible protein, %	11.5	9.1	13.3
Crude fiber, %	7.4	8.2	6.2
Calcium, %	0.80	0.75	0.75
Phosphorus, %	0.60	0.60	0.65
Feed units/100 kg	88.0	85.0	94.0
ME Mcal/100 kg	244.6	240.0	
$NE_{maint.}$ Mcal/100 kg	163.6	162.1	168.7
NE_{growth} Mcal/100 kg	107.4	104.2	110.1

To draw conclusions about the relative dollar-value of the ingredients in the four different ruminant formulas, and thus discuss the best allocation of the limiting ingredients, the information given on this subject by the computer was summarized in Table VIII. All grains and oil meals are included in this chart, but minerals and fixed ingredients were omitted.

For the ingredients not included in the formula, the "lower cost" value indicates the cost at which it would have been considered in the solution. For included ingredients, the figures shown under "upper" or "lower cost" are the prices of each ingredient that would result in the amount used to the indicated upper or lower activity. For ingredients limited at the maximum level, the "upper cost" value indicates the cost at which it would still have been considered. For ingredients forced at a minimum level, the "lower cost" figure indicates the actual dollar-value in that particular formula. This information is valid provided everything else in the formula remains constant.

Negative values for an activity, which are meaningless, will be indicated by a minus sign. Infinity values of cost which can be negative or positive according to the restriction will be noted as several dots. M indicates a high input cost, to obtain the proper information. The four different formulas will be abbreviated in this case as: 16, 14, CA, and HE.

Limited ingredients for the four formulas were evaluated on a tentative basis.

Several of the limited ingredients were priced under their comparative value and thus their use was very convenient. A simple comparison shows higher dollar-values for these ingredients (wheat, wheat bran, rice bran, citrus pulp) in the cattle formula, but no conclusions can be taken with a single set of data.

TABLE VIII. COST INFORMATION - GENERAL FORMULAS

Ingredient	Formula	Input Cost	Activity	Lower Activ.	Upper Activ.	Upper Cost	Lower Cost
Corn	16	253.20	-	-	2.3	...	251.30
	14	id.	-	-	0.6	...	253.18
	CA	id.	5.9	-	18.2	265.16	246.79
	HE	id.	38.1	30.0	39.0	253.64	252.23
Sorghum	16	233.20	15.9	13.4	16.4	235.03	226.43
	14	id.	21.9	21.0	26.6	233.22	225.83
	CA	id.	15.0	-	19.1	238.48	...
	HE	id.	1.1	-	12.4	234.03	232.88
Barley	16	258.20	10.0	6.2	14.0	...	244.06
	14	id.	10.0	-	11.9	...	244.19
	CA	id.	10.0	-	16.8	...	247.89
	HE	id.	11.0	5.2	12.7	...	244.62
Wheat	16	233.20	10.0	6.7	12.8	256.60	...
	14	id.	10.0	-	11.4	254.15	...
	CA	id.	15.0	-	22.0	259.26	...
	HE	M	-	-	2.0	...	257.26
Soybean meal	16	390.20	12.7	12.3	13.2	392.44	378.29
	14	id.	8.3	5.4	8.3	408.56	389.40
	CA	id.	-	-	3.5	...	380.74
	HE	id.	14.2	13.8	14.2	395.23	363.98

TABLE VIII. CONTINUATION

Ingredient	For-mula	Input Cost	Acti-vity	Lower Activ.	Upper Activ.	Upper Cost	Lower Cost
Cottonseed meal	16	340.20	0.5	-	0.9	351.90	337.97
	14	id.	-	-	3.4	...	324.61
	CA	id.	3.7	-	9.0	349.38	252.29
	HE	id.	-	-	0.4	...	335.65
Wheat bran	16	192.80	25.0	14.6	25.7	247.57	...
	14	id.	25.0	24.6	27.4	244.86	...
	CA	id.	17.0	-	22.9	255.26	...
	HE	id.	17.0	13.9	17.4	244.82	...
Wheat bran s.s.	16	217.80	5.0	-	5.7	247.57	...
	14	id.	5.0	4.6	7.4	244.86	...
	CA	id.	3.0	-	8.9	255.26	...
	HE	id.	3.0	-	3.4	244.82	...
Rice bran	16	M	-	-	0.4	...	264.50
	14	M	-	-	2.3	...	261.88
	CA	217.80	7.0	-	12.0	268.85	...
	HE	M	-	-	0.9	...	264.03
Alfalfa meal	16	273.00	6.0	5.5	6.3	...	215.92
	14	id.	5.0	4.8	7.4	...	207.56
	CA	id.	5.0	-	13.8	...	223.08
	HE	id.	6.0	4.8	6.2	...	205.31

TABLE VIII. CONTINUATION

Ingredient	For- mula	Input Cost	Acti- vity	Lower Activ.	Upper Activ.	Upper Cost	Lower Cost
Citrus pulp	16	200.00	6.0	3.0	18.6	212.02	...
	14	id.	6.0	2.1	7.2	208.99	...
	CA	id.	5.0	2.9	11.8	216.54	...
	HE	M	-	-	1.8	...	212.75
Cottonseed hulls	16	132.80	-	-	0.2	...	107.79
	14	id.	-	-	1.4	...	100.71
	CA	id.	4.4	3.9	5.9	238.75	109.57
	HE	id.	-	-	0.1	...	98.07
Wheat straw	16	M	-	-	0.2	...	89.79
	14	M	-	-	1.2	...	82.52
	CA	M	-	-	3.8	...	117.29
	HE	M	-	-	0.1	...	78.36
Molasses	16	157.50	3.0	2.4	3.4	163.91	...
	14	id.	2.8	-	8.6	174.19	157.44
	CA	id.	3.0	-	3.8	179.33	...
	HE	id.	3.0	-	3.2	158.72	...

Other useful information can be obtained from a table like this: some of the used ingredients are extremely overpriced (barley, alfalfa meal). Cottonseed meal shows a relative value inferior to its actual price. Wheat straw does not show great potential value as a crude fiber supplier unless there are no cottonseed hulls available for the Cattle formula.

The analyzed formulas were, as mentioned, calculated using a general type of restrictions. It can be seen however that the presence or absence of one ingredient can change the make-up of the formula and the relative value of the ingredients. The next step was to study actual formulation under different conditions of ingredient availability.

II. Analysis of Ruminant Formulas for Two Specific Months:

September 1968 and May 1969 were selected as sample months.

September 1968. Changes in formulation took place during this month. Under actual operation, a change in the regular supply of one ingredient can make a formula change necessary. Changes in the wheat bran supply was the most common single cause of formula modifications. Other changes within a month can originate from a desire to introduce or withdraw some ingredients in a gradual manner. During this particular month, the Dairy 16 formula suffered three changes, the Dairy 14 and Cattle compositions were modified twice, and the Heifer formula remained constant.

The comparison between hand calculated formulas and computer least-cost formulas was not considered. Hand calculations do not always follow strictly the established requirements for every single property. They also use more flexible information on the actual analysis of some major ingredients, making any comparison based on standard figures meaningless. Instead of this, the amounts of limiting ingredients used for each type of formulation were used as a criteria, and least-cost formulas were computed using these figures, which involve subjective decisions on allocation of ingredients.

The different formulas for the same ration during one month are of importance from the operational standpoint and for information on storage and manufacturing needs. For information on allocation of ingredients, a weighted average of the individual formulas during the month supplies the required information. These average formulas are shown in Table IX. Underlined values indicate some type of restriction.

The use of cottonseed meal was forced in the Dairy 16 and Dairy 14 rations for comparative purposes. Formulation without this lower level constraint resulted in less use of this product than reported.

During September 1968 the production of ruminant feeds included: 1,160 ton of Dairy 16 concentrate, 330 ton of Dairy 14, 910 ton of Cattle feed and 270 ton for Heifers (Appendix I). The total amount of limiting ingredients for this month is given in Appendix II. The distribution of these quantities between the four formulas is reported in Appendix III.

The real critical ingredients requiring allocation under the conditions of prices prevailing at that time were: wheat, wheat bran (regular and special supply), rice bran and citrus pulp. Cottonseed meal and cottonseed hulls are limited, but least-cost formulation considered these ingredients under the upper level of availability, so they do not represent a problem. Barley and alfalfa meal entered the formula only when forced, so the availability factor was not involved in optimal distribution.

Cost information data includes only the 5 critical ingredients. A high price M was assigned to the ingredients when they were not included in a certain formulation (Table X).

TABLE IX. AVERAGE FORMULAS DURING SEPTEMBER 1968

	Dairy 16	Dairy 14	Cattle	Heifers
Corn	8.1	8.9	10.9	33.6
Sorghum	16.8	23.0	15.0	-
Barley	12.5	10.8	13.4	20.0
Wheat			5.0	
Soybean meal	11.7	7.8	-	14.4
Cottonseed meal	4.2	1.4	5.3	-
Wheat bran	23.0	26.1	14.4	18.5
Wheat bran s.s.	4.1	4.6	2.5	0.8
Rice bran			7.1	
Alfalfa meal	4.2	5.1	6.2	5.9
Citrus pulp	6.3	6.0	8.2	
Cottonseed hulls	-	-	3.0	-
Molasses	3.0	-	3.0	-
Limestone	1.0	1.2	0.6	1.0
Dicalcium phosphate	0.1	0.1	0.4	0.8
Premix, Salt, Binder	5.0	5.0	5.0	5.0
Cost	242.55	233.93	227.02	257.86

TABLE IX. CONTINUATION

	Dairy 16	Dairy 14	Cattle	Heifers
Crude protein, %	16.0	14.0	12.0	15.5
Digestible protein, %	13.3	11.5	9.2	13.3
Crude fiber, %	7.6	7.6	8.3	6.5
Calcium, %	0.75	0.80	0.75	0.75
Phosphorus, %	0.60	0.60	0.60	0.65
Feed units/100 kg	89.0	88.0	85.0	94.0
ME Mcal/100 kg	242.9	243.2	240.6	
$NE_{maint.}$ Mcal/100 kg		162.4	161.0	168.2
NE_{growth} Mcal/100 kg		106.6	104.0	110.0

TABLE X. COST INFORMATION - SEPTEMBER 1968

Ingredient	Formula	Input Cost	Activity	Lower Activ.	Upper Activ.	Upper Cost	Lower Cost
Wheat	16	M*	-	-	18.6	...	257.26
	14	M	-	-	14.8	...	254.16
	CA	233.20	5.0	-	18.0	259.26	...
	HE	M	-	-	3.4	...	250.62
Wheat bran	16	192.80	23.0	17.4	25.0	244.82	...
	14	id.	26.1	19.9	27.9	244.82	...
	CA	id.	14.4	-	23.8	255.26	...
	HE	id.	18.5	16.0	19.3	217.80	...
Wheat bran, s.s.	16	217.80	4.1	-	6.1	244.82	...
	14	id.	4.6	-	6.4	244.82	...
	CA	id.	2.5	-	12.0	255.26	...
	HE	id.	0.8	-	19.3	244.09	192.80
Rice bran	16	M	-	-	1.7	...	264.03
	14	M	-	-	1.5	...	261.88
	CA	217.80	7.1	-	15.1	268.85	...
	HE	M	-	-	1.7	...	250.71
Citrus pulp	16	200.00	6.3	1.7	18.3	212.75	...
	14	id.	6.0	6.0	20.7	209.00	...
	CA	id.	8.2	5.0	15.8	216.54	...
	HE	M	-	-	3.1	...	205.53

*Notations and abbreviations of Table VIII have been used.

This analysis would indicate that some of the decisions adopted were reasonable (wheat and rice bran allocation to the Cattle formula). Others should be revised (distribution of wheat bran). A volume factor should be added to any reasoning of this sort; a better solution for a high volume formula will have the most significant economic effect. Under regular conditions of individual formulation this type of analysis can give some hints for improved results.

III. Simultaneous Formulation:

At this stage simultaneous formulation was attempted using a simple model first and then with all the restrictions for practical operation.

The restrictions included the exact amounts of the limiting ingredients to be used, with minimum imposed levels of barley and alfalfa meal. The compositions of the four formulas are presented in Table XI.

In this solution, all the wheat bran identified as special supply was used in addition to the regular supply. From the standpoint of formulation this becomes one ingredient, with a composite cost based on the proportion and individual costs of both sources. For comparative purposes these two ingredients were noted individually.

The output must be controlled from the nutritional point of view. The result indicates a need to determine if rice bran can be an ingredient in dairy formulas. At the included levels in this formulation it should have no deleterious effects. The make-up of the Heifer formula, with no wheat bran and more than 7% of rice bran and citrus pulp, should also be tested from a palatability and texture standpoint. Nevertheless, there is no valid reason to exclude this solution. A minimum of wheat bran or any other desirable restriction could be easily added to the program.

TABLE XI. MULTIPLE FORMULATION - SEPTEMBER 1968

	Dairy 16	Dairy 14	Cattle	Heifers
Corn	-	-	9.8	8.0
Sorghum	31.6	39.8	<u>15.0</u>	37.6
Barley	<u>10.0</u>	<u>10.0</u>	<u>10.0</u>	<u>10.0</u>
Wheat	-	-	5.0	-
Soybean meal	11.6	8.4	1.4	17.4
Cottonseed meal	5.4	1.7	0.7	-
Wheat bran	16.2	20.7	30.4	-
Wheat bran, s.s.	2.9	3.6	5.4	-
Rice bran	3.9	-	-	7.3
Alfalfa meal	<u>4.0</u>	<u>5.0</u>	<u>6.0</u>	<u>6.0</u>
Citrus pulp	5.5	4.5	7.5	7.3
Cottonseed hulls	-	-	-	-
Molasses	2.7	-	<u>3.0</u>	-
Limestone	1.0	1.0	0.8	-
Dicalcium phosphate	0.2	0.3	-	1.4
Fixed ingredients	5.0	5.0	5.0	5.0
Cost	244.37	236.91	219.44	262.17
Crude protein, %	16.0	14.0	12.0	15.5
Digestible protein, %	13.2	11.5	9.4	13.2
Fiber, %	7.0	7.0	8.0	6.0
Calcium, %	0.76	0.73	0.70	0.75
Phosphorus, %	0.60	0.60	0.60	0.65
Feed units/100 kg	89.0	88.0	85.0	94.0

Underlined values in the table indicate some type of restriction

The solution obtained was optimal under the described requirements and was the only one considering the total amounts of every ingredient used. The partition of ingredients between formulas might be changed however if the matrix was written in a different order. To test this a different run of the same program was made where the order of the formulas was: Dairy 16, Cattle, Dairy 14, Heifers (decreasing order of volume). This changed the proportion of citrus pulp, molasses, etc. in two of the formulas but resulted in the same total cost. A change in order changed also the number of iterations needed to reach the optimal solution and thus the computational time. A way was not found to predict the most efficient solution from the standpoint of the computer.

The matrix for this multiple formulation problem included 72 rows and 80 columns; the optimal solution was reached after 113 iterations and the computing time was about 2 min. In the alternative solution described, the number of iterations was 146, and the time in this case 2.8 min.

A regular individual formula for the computed ruminant feeds had a matrix size of 12 rows and 17 columns (including the potential ingredients). A solution was reached normally after 10 - 15 iterations, with a computing time varying between 0.25 - 0.40 min.

The section of the L.P. program which gives information on levels and costs of nutrients and ingredients was excluded for the multiple formulations, since the nature of the equations and their right hand side values makes this information of little practical value.

A comparative chart of utilization of ingredients is summarized in Table XII. It includes the limiting and non-limiting materials used according to hand formulation, individual formulation and multiple formulation. Tons have been used as the unit in this case, and the different methods of calculation are notated H, I, and M respectively.

TABLE XII. INGREDIENTS DISTRIBUTION - SEPTEMBER 1968

Ingredient	Form.	Dairy 16	Dairy 14	Cattle	Heifers	Total
Corn	H	-	-	95	38	133
	I	94	29	99	91	313
	M	-	-	88	22	110
Sorghum	H	268	93	135	38	534
	I	195	76	136	-	407
	M	366	131	136	102	735
Barley	H	144	36	122	54	356
	I	144	36	122	54	356
	M	116	33	91	27	267
Wheat	H	-	-	46	-	46
	I	-	-	46	-	46
	M	-	-	46	-	46
Soybean meal	H	132	30	-	40	202
	I	135	26	-	39	200
	M	134	28	13	47	222
Cottonseed meal	H	49	5	26	-	80
	I	49	5	48	-	102
	M	62	6	6	-	74
Wheat bran	H	315	101	153	59	628
	I	315	101	154	52	622
	M	222	80	326	-	628

TABLE XII. CONTINUATION

Ingredient	Form.	Dairy 16	Dairy 14	Cattle	Heifers	Total
Rice bran	H	-	-	65	-	65
	I	-	-	65	-	65
	M	45	-	-	20	65
Alfalfa meal	H	48	17	56	16	137
	I	49	17	56	16	138
	M	46	16	55	16	134
Citrus pulp	H	73	20	74	-	167
	I	73	20	74	-	167
	M	64	15	68	20	167
Cottonseed hulls	H	27	1	59	-	87
	I	-	-	27	-	27
	M	-	-	-	-	-
Molasses	H	35	10	27	8	80
	I	35	-	27	-	62
	M	32	-	27	-	59

A chart of this type shows the differences that occur due to the method used in calculation. Unrestricted ingredients can be used at rather different levels, changing their dollar-value according to the combination of ingredients. The partition of limiting ingredients might be modified in order to obtain optimization. Some of the feedstuffs considered as limited are used under the level of availability.

The effect on cost of the simultaneous versus individual formulations is illustrated in Table XIII.

Not all the differences obtained should be credited to the multiple formulation *per se*. Some improvement stems from better utilization of ingredients which were considered limiting but that in fact were not (cottonseed meal).

TABLE XIII. COMPARATIVE ECONOMIC EFFECT OF METHOD OF FORMULATION SEPTEMBER 1968

Type	Amount	Individual		Multiple	
		Cost/ton	Total	Cost/ton	Total
Dairy 16	1,160	242.55	281,358.00	244.37	283,469.20
Dairy 14	330	233.93	77,196.90	236.91	78,180.30
Cattle	910	227.02	206,588.20	219.44	199,690.40
Heifers	270	257.86	69,622.20	262.17	70,785.90
Total	2,670		634,765.30		632,125.80

Difference: I.L. 2,639.50 ($ 754.14)

The difference in favor of the multiple formulation represents a saving of I.L. 0.99 ($0.28) per ton for the particular month studied.

It can be seen that in multiple formulation single formulas are not least-cost, but the whole solution is lower in cost.

To check the validity of the method and its potential saving effect, a different month was analyzed.

May 1969. The same criteria using a weighted average of the individual formulas during the month was used in this case. Two formulation changes took place in the Dairy 16 and Dairy 14 rations, one in the Cattle ration and no changes in the Heifer formula during the month.

The production figures for the four types of feeds were: 1,250 ton of Dairy 16, 610 ton of Dairy 14, 1,000 ton of Cattle and 400 ton of Heifers, giving a total production of 3,260 ton of ruminant feeds (Appendix I).

The actual use of the limited ingredients is given in Appendix III.

The average weighted individual formulas are shown in Table XIV.

Underlined values indicate some type of restriction.

The nutrient content of the formulas is similar to those previously described and a discussion of this is omitted.

The solution by multiple formulation is presented in Table XV. The imposed levels of barley and alfalfa meal were maintained according to the particular situation of the month. This was slightly different than the general table of restrictions.

TABLE XIV. AVERAGE INDIVIDUAL FORMULAS - MAY 1969

	Dairy 16	Dairy 14	Cattle	Heifers
Corn	16.5	8.1	10.4	43.8
Sorghum	1.9	19.6	15.0	-
Barley	9.5	9.5	7.2	11.0
Wheat	10.0	10.0	15.0	
Soybean meal	8.0	4.2	-	11.2
Cottonseed meal	6.9	5.8	4.9	4.1
Wheat bran	24.7	23.9	16.4	16.2
Wheat bran s.s.	4.4	4.2	2.9	0.5
Rice bran			5.1	
Alfalfa meal	4.1	4.1	4.0	6.4
Citrus pulp	4.7	4.2	6.1	
Cottonseed hulls	-	-	4.6	-
Molasses	3.0	-	2.3	-
Limestone	1.3	1.4	0.7	0.9
Dicalcium phosphate	-	-	0.4	0.9
Fixed ingredients	5.0	5.0	5.0	5.0
Cost	239.49	233.17	223.10	258.41

TABLE XV. MULTIPLE FORMULATION - MAY 1969

	Dairy 16	Dairy 14	Cattle	Heifers
Corn	-	-	-	3.0
Sorghum	35.2	35.3	15.0	27.2
Barley	9.5	9.5	7.2	11.0
Wheat	-	3.3	24.8	16.8
Soybean meal	11.1	8.3	-	15.7
Cottonseed meal	4.6	1.1	1.5	-
Wheat bran	20.9	23.7	27.7	-
Wheat bran s.s.	3.7	4.2	4.9	-
Rice bran	2.1	-	-	6.2
Alfalfa meal	4.1	4.1	4.1	6.4
Citrus pulp	2.3	4.1	6.2	7.3
Cottonseed hulls	-	-	2.4	-
Molasses	-	-	0.2	-
Limestone	1.4	1.2	1.0	-
Dicalcium phosphate	0.1	0.2	-	1.4
Fixed ingredients	5.0	5.0	5.0	5.0
Cost	242.98	233.96	215.83	259.03

The underlined values represent minimum (barley, alfalfa meal) or maximum (sorghum) restrictions.

Most of the comments regarding the nutritional evaluation of the September 1968 solution apply to this set of formulas.

A discussion regarding the use of the ingredients follows.

Economic comparison. A table similar to the summary of costs of the September 1968 models (Table XIII) is presented in Table XVI for May 1969.

TABLE XVI. COMPARATIVE ECONOMIC EFFECT OF METHOD OF FORMULATION

MAY 1969

Type	Amount	Individual Cost/ton	Individual Total	Multiple Cost/ton	Multiple Total
Dairy 16	1,250	239.49	299,362.50	242.98	303,725.00
Dairy 14	610	233.17	142,233.70	233.96	142,715.60
Cattle	1,000	223.10	223,100.00	215.83	215,830.00
Heifers	400	258.41	103,364.00	259.03	103,612.00
Total	3,260		768,060.20		765,882.60
Difference: I.L.		2,177.60 ($ 622.17)			

On a per ton basis the difference in favor of the multiple solution was I.L. 0.67 ($0.19).

This particular solution with the multiple model was obtained after 111 iterations, using 1.76 min. of computer time.

IV. Ruminant-Poultry Formulations:

Two purposes applied to this part of the work: (a) feasibility of an increased matrix from the standpoint of computational time, and (b) interrelationship of ingredients used in two different types of feeds.

The distribution of certain ingredients for ruminants or poultry feeds is often quite obvious. Grains like corn and sorghum are used interchangeably in both kinds of feeds, but since these are not limiting ingredients there is no concern regarding optimal distribution. Less clear is the best

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use of wheat, which is limited, or wheat bran which may be used for pullets and heavy breeder rations.

The size of the matrix is important in order to get closer to a more general situation in a feed mill.

Three poultry formulas were added to the May 1969 rations. The volumes indicated correspond to actual production figures and the restrictions are those used for their formulation. The formulation shown does not correspond to this exact month. Formulas considered representative for these species were used to assume a distribution of ingredients. The formulas were re-calculated using L.P. and the least-cost solutions are shown in Table XVII.

TABLE XVII. POULTRY FEEDS, INDIVIDUAL FORMULATION

	Broiler Grower	Broiler Finisher	Heavy Breeder
Corn	43.6	28.4	5.0
Sorghum	22.9	42.7	57.4
Fish meal	3.0	1.0	3.0
Soybean meal	23.2	20.4	12.6
Wheat bran	-	-	10.9
Wheat bran, s.s.	-	-	-
Alfalfa meal	1.0	1.5	2.0
Molasses	-	-	-
Limestone	0.6	0.7	6.2
Dicalcium phosphate	1.2	1.4	0.9
Fixed ingredients	4.5	3.9	2.0
Methionine, g/ton	800	700	300
Cost	300.78	283.82	258.08

The production figures for the three poultry formulas were: Broiler-grower: 730 tons, Broiler-finisher: 600 tons and Heavy-breeder: 610 tons.

As ingredients for these formulas in the larger model, corn, sorghum and soybean meal were added at large free levels. No additional wheat was added to the amount used in the ruminant multiple solution problem but it was included as a potential ingredient for poultry formulas. So were cottonseed meal and rice bran. Fish meal was a limiting ingredient in poultry formulations and only minimum levels were specified to determine the best way to partition this ingredient. Wheat bran was included at a level of 14.6% of the heavy breeder formula, as in the sample formulation that was available. The individual least-cost formula used less than the allowed amount (10.9%). Alfalfa meal was forced into the formula at the required levels.

The simultaneous formulation of the seven formulas is reported in Table XVIII.

The matrix for the 7-formula model included 98 rows and 130 columns. An optimal solution was obtained after 265 iterations, with a computation time of 2.7 min.

The seven formulas analyzed represented 62.4% of the total production in the AMBAR Feed Mill for that particular month. The remaining 37.6% is composed of approximately 60 additional formulas.

The formulas obtained for the ruminant rations can be compared with those of the ruminant multiple solution for the same month (Table XV). Even if there were no great interrelationship of ingredients between ruminant and poultry feeds some differences can be observed. The flow of wheat bran resulted in a change in make-up and in cost of the ruminant formulas.

Simultaneous formulation caused a different distribution of the limiting ingredient (fish meal) in the poultry formulas.

TABLE XVIII. SIMULTANEOUS FORMULATION RUMINANT-POULTRY

MAY 1969

	Dai. 16	Dai. 14	Cattle	Heif.	Br.Gr.	Br.Fi.	H.Br.
Corn	-	-	-	3.4	27.8	28.4	5.0
Sorghum	32.4	35.7	15.0	26.5	40.1	42.7	56.4
Barley	9.5	9.5	7.2	11.0			
Wheat	3.2	0.2	22.9	16.5	-	-	-
Fish meal					4.6	1.0	1.0
Soybean meal	11.6	9.1	-	15.6	20.4	20.4	14.8
Cottonseed meal	3.4	-	1.7	-	-	-	1.6
Wheat bran	23.5	24.0	28.0	-	-	-	6.6
Wheat bran, s.s.	4.1	4.2	4.9	-	-	-	1.2
Rice bran	-	3.7	-	7.2	-	-	-
Alfalfa meal	4.1	4.1	4.1	6.4	1.0	1.5	2.0
Citrus pulp	1.7	3.1	7.6	7.0			
Cottonseed hulls	-	-	1.8	-			
Molasses	-	-	0.9	-	-	-	2.0
Limestone	1.5	1.4	0.9	0.1	0.6	0.7	6.1
Dicalcium phosphate	-	-	-	1.3	1.0	1.4	1.3
Fixed ingredients	5.0	5.0	5.0	5.0	4.5	3.9	2.0
Methionine, g/ton					800	700	500
Cost	241.49	232.88	215.74	258.50	298.16	283.75	257.89

The underlined values indicate some type of restriction.

A comparison of the utilization of critical ingredients according to the formulation system used is presented in Table XIX. I represents individual least-cost formulas using limitations dictated in hand formulation. M designates the multiple solution for ruminant formulas, and S is the notation for the simultaneous ruminant-poultry solution.

TABLE XIX. DISTRIBUTION OF CRITICAL INGREDIENTS

RUMINANT-POULTRY FORMULAS MAY 1969

Ingredient	Form.	Da.16	Da.14	Cat.	Heif.	Br.G.	Br.F.	H.Br.	Total
Wheat	I	125	61	150	-				336
	M	-	20	248	68				336
	S	40	1	229	66	-	-	-	336
Fish meal	I					22	6	18	46
	M								
	S					34	6	6	46
Wheat bran	I	364	171	193	67			66	861
	M	308	170	326	-				804
	S	345	172	329	-	-	-	47	893
Rice bran	I	-	-	51	-				51
	M	26	-	-	25				51
	S	-	22	-	29	-	-	-	51
Citrus pulp	I	58	26	61	-				145
	M	29	25	62	29				145
	S	22	19	76	28				145

The most economic distribution of certain limiting ingredients was generally speaking unpredictable, and some minor changes may be reflected in several differences in the formula. This relates also to the utilization of unrestricted ingredients, especially grains.

A chart with the economic effect of this type of formulation is illustrated in Table XX.

TABLE XX. COMPARATIVE ECONOMIC EFFECT OF METHOD OF FORMULATION RUMINANT-POULTRY FORMULAS MAY 1969

Type	Amount	Individual Cost/ton	Individual Total	Multiple Cost/ton	Multiple Total	Difference
Dairy 16	1,250	239.49	299,362.50	241.49	301,862.50	
Dairy 14	610	233.17	142,233.70	232.88	142,056.80	
Cattle	1,000	223.10	223,100.00	215.74	215,740.00	
Heifers	400	258.41	103,364.00	258.50	103,400.00	
Sub-total	3,260		768,060.20		763,059.30	5,000.90
Br. Grower	730	300.78	219,569.40	298.16	217,656.80	
Br. Fin.	600	283.82	170,292.00	283.75	170,250.00	
H. Breed.	610	258.08	157,428.80	257.89	157,312.90	
Sub-total	1,940		547,290.20		545,219.70	2,070.50
Total	5,200					7,071.40

The difference for ruminant formulas was I.L. 5,000.90 ($1,428.83) with a difference per ton of I.L. 1.53 ($0.44).

In the poultry formulas, there was a total saving of I.L. 2,070.50 ($ 591.57) with a unit value of I.L. 1.07 ($0.30). The total difference for the seven formulas amounted thus to I.L. 7,071.40 ($2,020.40) for a total of 5,200 tons.

The total figure would have decreased with different allocation of wheat bran for use in the heavy breeder formula, but the differences obtained for ruminant formulas in this larger model would be greater than those found in the four ruminant formula model. It is clear that the greater the size of the model, the higher the possibility of improving the economic effect of multiple formulation.

The figures presented here are only an example; they fit a certain situation which might or might not be characteristic. The principle involved however applies to any situation of this type since there is only one optimal solution to the problem of allocation of limiting factors.

CONCLUSIONS

1. The application of Linear Programming to feed formulation for AMBAR should include ruminant formulas. No specific economic comparisons with hand calculated formulas were made, but a chart of ingredient consumption (Table XII) shows the possibility of better utilization of ingredients. Time saving, accuracy in the formula and information on relative dollar-value of ingredients are additional factors in favor of L.P. formulation.

2. The effect of restrictions on cost has been discussed. A thorough revision of technical or nutritional restrictions should be made based on the effect on cost.

3. Effect on storage. Many changes in formulation stem from the fluctuations in availability of ingredients of erratic supply such as wheat bran. Since this ingredient has a great effect on the cost of the feed, economic studies should be conducted on the need of additional storage facilities to absorb maximum supply.

The same type of study is needed for seasonal products which represent a convenient purchase. The length of time during which these ingredients should be used depends on storage facilities and costs on one hand, and the desire of avoiding drastic changes in composition or cost on the other.

The effect of Linear Programming on total storage of ingredients under Israeli conditions refers only to the previous points, since inventory control policy imposes total tonnage of storage, and the distribution between ingredients becomes less important.

4. Individual least-cost formulas for a specific situation of restriction can give limited information on the best distribution of

ingredients between several formulas.

5. Multiple formulation appears to be a feasible and convenient technique in a large feed mill.

The main advantages of this system are:

(a). Least-cost solution as a whole. The economic effect of this optimization can vary according to conditions, but on a large scale of production even a slight per ton saving can represent a considerable total figure.

(b). The solution gives direct information on ingredient use for the programmed period. This data is useful for purchase purposes.

(c). One single program is needed for the entire formulation.

Drawbacks of this technique could be:

(a). The need of an accurate forecast of feed production.

(b). Additional information provided by the multiformula L.P. program is less meaningful.

(c). Possibilities of more drastic changes in one formula from one period to the next, unless properly controlled.

(d). Large number of formulas result in a large matrix size.

(e). The program needs to be solved with the aid of a large-size computer.

(f). Pricing policy of the final feeds should consider the fact that individual formulas are not least-cost.

(g). The nutrient content is not given in the solution and must be calculated from the formula.

6. In general the best way to handle a large number of formulas is by a combination of the two systems. Low volume formulas should be individually

calculated, applying the simultaneous formulation to the high volume feeds, where a cost reduction represents the greatest economic effect.

SUMMARY

Ruminant feed formulation was studied under the conditions prevailing in Israel. Data on production and formulation during a two year period was used to make an analysis of formulations using Linear Programming.

Of the different factors affecting cost of the final feed, availability of limiting ingredients was the most critical.

The problem of distribution of the limiting ingredients between the different ruminant formulas was studied. The relative value of an ingredient in a formula can be stated within certain limits for some type of ingredient combination. This type of information has some analytical value regarding allocation.

A better approach to the problem was to consider the whole production as one unit with restrictions, and to search an optimization of the distribution by Linear Programming.

A multiple model was designed including 4 formulas, each with 16 possible ingredients and 8 nutritional constraints. The solution, with a IBM 360-50 computer required less than 2 minutes of computing time.

An enlarged model of 7 formulas was also made with a proportional increase in computation time. The larger the number of formulas and ingredients, the greater the economic effect from the optimal solution.

The method of simultaneous formulation seems to offer practical possibilities of application for a feed mill under some type of common restrictions. Probably the combination of this technique with individual formulations for low volume feeds can be the most convenient. As with any other computing technique it requires the proper control of a nutritionist in the statement of the problem and in the revision of the results.

ACKNOWLEDGMENTS

I would like to express my great and sincere appreciation to Dr. Charles W. Deyoe, my major Professor, for his continuous help, guidance and assistance in all the phases of this work and graduate studies, and in the preparation of this manuscript.

I would like to extend this gratitude to Dr. Harry B. Pfost for his interest, suggestions, and great encouragement.

Special thanks are expressed to Dr. William J. Hoover, Head, Department of Grain Science and Industry for providing the means and conditions for carrying out this study.

Many thanks are given to Dr. James L. Morrill for his assistance and for being in the advisory committee and reviewing this manuscript.

I am very thankful to all members of the faculty and staff who were so helpful.

Special gratitude is expressed to my friends in AMBAR Ltd. (Israel) for their continuous technical, financial, and moral support. And to Elisheva my wife, and my three daughters for their help in making this experience possible.

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APPENDICES

APPENDIX I. MONTHLY RUMINANT AND TOTAL FEED PRODUCTION (TONS)

Year	Month	Dairy 16	Dairy 14	Cattle	Heifers	Tot. Rum.	Tot. Prod.
1968	1	1,870		750	370	2,990	8,640
	2	1,730		760	340	2,830	7,890
	3	1,680		800	360	2,840	8,060
	4	1,660		810	390	2,860	7,540
	5	1,360	150	770	390	2,670	7,380
	6	1,150	220	710	300	2,380	6,770
	7	1,190	260	910	270	2,630	7,770
	8	1,130	230	870	260	2,490	7,380
	9	1,160	330	910	270	2,670	7,800
	10	1,110	380	870	270	2,630	7,810
	11	990	370	880	270	2,510	7,240
	12	1,030	500	930	290	2,750	8,120
1969	1	1,080	440	880	330	2,730	8,270
	2	1,000	390	790	300	2,480	7,790
	3	1,310	400	880	320	2,910	8,590
	4	1,260	340	950	310	2,860	8,150
	5	1,250	610	1,000	400	3,260	8,340
	6	1,020	640	1,000	320	2,980	8,240
	7	1,020	700	1,080	310	3,110	8,880
	8	990	690	1,030	300	3,010	8,390
	9	970	700	1,090	300	3,060	8,750
	10	950	710	1,140	310	3,110	8,910
	11	990	620	1,130	240	2,980	8,680
	12	1,100	840	1,060	310	3,310	9,470

APPENDIX II. MONTHLY USE OF RESTRICTED INGREDIENTS

Year	Month	Wheat	Cotton S. Meal	Wheat Bran	Rice Bran	Alfalfa Meal	Citrus Pulp	Cotton S. Hulls	Molasses
1968	1	-	198	667	50	11	108	56	90
	2	-	163	652	54	31	113	68	86
	3	-	151	716	54	92	107	98	85
	4	-	152	718	55	94	107	98	86
	5	-	130	680	54	171	118	73	80
	6	-	128	611	55	170	116	69	73
	7	-	132	632	57	181	141	86	79
	8	44	108	604	61	162	141	62	75
	9	46	80	628	65	137	167	87	80
	10	24	94	625	64	125	116	82	79
	11	-	91	721	72	130	7	-	75
	12	33	133	725	48	118	98	64	82
1969	1	37	157	668	41	114	123	88	82
	2	40	149	612	24	51	116	79	74
	3	44	190	677	35	119	168	74	87
	4	213	171	656	39	124	170	77	86
	5	336	178	804	51	142	145	70	98
	6	314	153	758	62	146	49	60	89
	7	324	178	682	73	185	-	64	93
	8	164	173	713	72	166	-	48	90
	9	137	112	742	76	173	-	48	92
	10	140	175	745	46	164	-	68	93
	11	137	169	719	45	157	-	68	89
	12	137	190	742	57	176	-	96	99

APPENDIX III. DISTRIBUTION OF LIMITING INGREDIENTS

RUMINANT FORMULAS

	Dairy 16	Dairy 14	Cattle	Heifers	Total
September 1968					
Wheat	-	-	46	-	46
Cottonseed meal	49	5	26	-	80
Wheat bran	315	101	153	59	628
Rice bran	-	-	65	-	65
Alfalfa meal	48	17	56	16	137
Citrus pulp	73	20	74	-	167
Cottonseed hulls	27	1	59	-	87
Molasses	35	10	27	8	80
May 1969					
Wheat	125	61	150	-	336
Cottonseed meal	87	35	40	16	178
Wheat bran	363	172	193	76	804
Rice bran	-	-	51	-	51
Alfalfa meal	51	25	40	26	142
Citrus pulp	58	26	61	-	145
Cottonseed hulls	-	-	70	-	70
Molasses	38	18	30	12	98

A COMPUTER APPLICATION TO RUMINANT FEED FORMULATION UNDER ISRAELI CONDITIONS

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

The object of this study was to analyze different aspects of ruminant feed formulations under conditions existing in a feed manufacturing operation in Israel (AMBAR Ltd.). Actual data of production and formulation from a two year period were included. The nature of ingredient supplies in a country limited in soil, water, and amounts of different by-products used as feedstuffs imposes a number of constraints on the formulation of rations.

Availability restrictions, in addition to technical limitations on the use of some ingredients and level of use, or nutritional considerations which require the inclusion of some ingredients, can have an adverse effect on the cost of the final formula.

Linear Programming can be useful in evaluating the cost of the different restrictions, besides its convenience for accuracy in formulation, minimization of cost and time saving effect.

Technical restrictions can be overcome if it is economically justified. Nutritional restrictions should be subjected to revisions or review by biological trials. Limiting ingredients should be distributed to obtain the best utilization in the different types of feeds.

Individual formulations under different conditions of restrictions were analyzed. The L. P. program, in addition to the least-cost solution supplies information on the relative value of each ingredient under the specified conditions of formulation. By comparison of the dollar-values assigned to the ingredients according to the type of formula, some indications can be obtained on the most convenient way to use restricted ingredients. The value of this information is limited since it refers only to a specific situation and any change in composition can affect the validity of these relative cost levels.

A better approach to the problem is to consider the whole production as one unit, and to solve the different formulations simultaneously in order to ate the limiting ingredients in an optimal way.

The technique was applied to four ruminant formulas first, and in a .-formula model later, including three poultry rations. A higher per 'eduction in cost was obtained in the second model, since the combination .gredients offered more possibilities for optimization. Computing time ost were only slightly greater than the sum of individual formulations. The use of a multiple model requires a good forecast of the production an present some minor practical drawbacks, but offers clear economic ıtages.

In an operation like that analyzed, the most convenient method of action . combination of individual least-cost formulations for the numerous 'olume formulas and a multiple model for the limited number of large-ıe feeds which represent the highest economic potential.