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Optimization of livestock feed blend by use of goal programming

Zoran Babić [a],*, Tunjo Perić [b]

[a] Faculty of Economics, 21000 Split, Matice hrvatske 31, Croatia
[b] Bakeries Sunce d.o.o., 10431 Sveta Nedelja, Croatia

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ABSTRACT

This paper presents a model for determining an optimal blend of ingredients for livestock feed by application of goal programming. Besides the standard problem of livestock feed where the requirements for basic nutrients have to be met at minimized costs and which is solved mainly by linear programming, the authors also introduce the goals of meal quality where different requirements of decision makers are modeled by goal programming.

1. Introduction

Cattle feed blend is a mixture of ingredients used for animal feeding. An adequate quality of feed blend ensures the growth of livestock to meet the increasing needs for food in a continually increasing population. The increasing size, income, and living standard of the population leads to an ever higher demand for food products of animal origin, which can be provided by increasing the quantity and quality of livestock feed. The increase of quantity cannot be achieved only by larger acreage and imports, as the arable land is limited and so are the funds available for livestock feed import and animal food products import. Consequently, rational production of high quality livestock feed is an important task of any economy. Such livestock feed has to meet the nutritional requirements of livestock in order to maximize weight gain, while production of such feed has to be economical, which can be achieved only by an optimal blending of ingredients.

Optimization of ingredients blend in terms of nutritional requirements and in terms of economic criteria can be carried out by application of mathematical optimization methods. These mathematical methods can quickly and efficiently determine an optimal combination of ingredients to meet the nutritional requirements of livestock leading to a rational use of available resources and cost reduction.

Since 1951, when Waugh defined the feeding problem in mathematical form, linear programming (LP) has formed the basis of livestock ration formulations (Waugh, 1951). However, linear programming has many limitations in formulating rations in practice. Rehman and Romero (1984) found them mostly in singularity of objective function and the rigidity of the constraint set. Lara (1993) also criticizes practical applications of LP due to the restrictions placed on the decision maker's preferences through a singular objective function.

From that time many other mathematical programming methods have been used in the problem of livestock ration formulations. Rehman and Romero (1987) were first to use goal programming because they found that goal programming does not impose such rigid conditions and also allows consideration of several decision criteria. Lara and Romero (1994) used interactive multi-criteria programming (STEM method) with the intention to relax over-rigid specifications of nutrient requirements of livestock rations. Houghton and Portougal (1997) used multi-stage process for the reengineering of the production planning process in the food industry. Their production planning model is a variant of the discrete lot-sizing and scheduling problem. Glen and Tipper (2001) used linear and integer programming in agricultural planning in developing countries. Tozer and Stokes (2001) used multi-objective programming approach to reduce nutrient excretion from dairy cows through incorporation of nutrient excretion functions into a ration formulation framework. Similarly Bailleul et al. (2001) used multi-objective optimization method and modified the traditional least-cost formulation algorithm to reduce nitrogen excretion in pig diets. Anets and Audsley (2002) presented a multiple objective linear programming model developed to consider a wide range of farming situations, which allows optimization of profit and environmental outcomes. Itoh et al. (2003) formulated the model of crop planning under uncertainty in agricultural management using linear programming and fuzzy constraints. Castrodeza et al. (2005) gave a multi-criteria fractional model for feed formulation with economic, nutritional and environmental criteria. Together with the search for the lowest possible cost, they introduced some other aspects such as maximizing diet efficiency and minimizing any excess that may lead to unacceptable damage to the environment. Ghosh et al. (2005) again

* Corresponding author. Tel.: +385 21 430 643; fax: +385 21 430 701.
E-mail addresses: babic@efst.hr (Z. Babić), tunjo.peric1@zg.t-com.hr (T. Perić).

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used goal programming technique for nutrient management by determining the optimum fertilizer combination for rice production in West Bengal. Pomar et al. (2007) developed multi-objective optimization model based on the traditional least-cost formulation program to reduce both feed cost and total phosphorus content in pig feeds. Pla (2007) presented a very interesting review article, which is a survey of different mathematical methodologies used in sow herd management. Trienekens and Zuurbier (2008) gave some quality and safety standards in the food industry, while Han et al. (2009) gave some relationships and quality management in the Chinese pork supply chain. Finally, Niemi et al. (2010) used stochastic dynamic programming to determine the value of precision feeding technologies for grow-finish swine.

Besides the standard problem of feed where the requirements for basic nutrients have to be met at minimized costs and which is solved mainly by linear programming, the authors also introduce the goals of meal quality where different requirements of decision makers are modeled by goal programming. Consequently, the main goals of this paper are:

(a) To point to the fact that optimization of feed ingredients blend is a multi-criteria problem.
(b) To develop a multi-criteria programming model for ingredients blend optimization, including the criteria of meal quality.
(c) To apply the model of goal programming in the solution of the described problem.

The rest of the paper is organized as follows:

In Section 2 the general multi-criteria model for determination of feed ingredients blend are formulated. In Section 3 input data are given for the particular problem of determining the feed blend for pig fattening. Section 4 formulates the multi-criteria and goal programming model for solving the posted problem, and in Section 5 four scenarios due to decision making preferences are presented. In Section 6 the analyses of obtained results are considered while Section 7 presents the conclusions.

2. Multi-criteria programming model for determination of feed blend ingredients

Formulating the model for determination of feed blend ingredients we have to consider:

- blend preparation costs,
- the needs of the animals for which the blend is prepared, and
- blend quality.

Consequently, it would be ideal if the blend preparation costs were minimal, the needs of the animal completely satisfied, and the quality of feed maximal. Therefore it can be said that the preparation of an optimal feed will require the following criteria:

1. Cost expressed in monetary units.
2. Nutrients (in percentage) needed for the maximal weight gain.
3. Nutrients (in percentage) affecting the quality of the blend, and thus also the weight gain of the animal for which the feed is prepared.

The aim of the second criterion is to obtain a blend containing components that will maximize weight gain in animals. In our example the weight gain has to be achieved by maximizing nutrients, i.e. by favouring those kinds of feed that contain high digestibility ingredients. Higher digestibility ensures higher weight gain with a smaller blend quantity, which eventually reduces feed costs.

Table 1
Sorts of feed (PS-2).

		Price—c_{i1} (Min)	Nutrients—c_{i2} (Max)	Water—c_{i3} (Min)
H1	Barley	1.75	70	11.0
H2	Maize	1.75	80	12.0
H3	Lucerne	1.65	32	6.9
H4	Powdered milk	6	86	8.4
H5	Fish meal	9	69	9.0
H6	Soya	2.7	92	10.0
H7	Soya hulls	3.5	79	11.0
H8	Dried whey	9	78	6.0
H9	Rape pellets	1.8	66	8.0
H10	Wheat	1.8	79	12.0
H11	Rye	1.8	75	11.4
H12	Millet	3.5	65	10.0
H13	Sunflower pellets	1.8	68	7.0

The aim of the third criterion is to maximize the blend quality in terms of its shelf life, which is achieved by reducing the content of water. Reduced water content allows the same weight gain with a smaller blend quantity, which eventually also reduces feed costs.

All the three criteria are correlated and inherently conflicted. Namely, most expensive kinds of feed are those that contain ingredients contributing most to weight gain, as well as those containing a small quantity of water. However, feeds containing the best nutrients need not also be those that contain a small quantity of water. That can be seen from the input data for the three criteria in Table 1.

All of these criteria are of economic importance because each one of them contributes to some extent to the business performance expressed in profits. Cost reduction affects business performance directly, whereas feed blend quality affects it through better weight gain in animals and better quality of the final product (meat). Better quality ensures better prices and directly contributes to the better business performance. It has to be noted, however, that there is no guarantee that the company will achieve the best business result at minimal feed cost. Also, maximizing quality of feed blend will not necessarily lead to an optimal performance. Consequently, the company will achieve optimal performance by producing feed blends that are adequate in terms of both cost and quality. The optimal acceptable levels of criteria functions have to be determined by analyzing the relation between the criteria functions levels and the total performance, which cannot be done without participation of the decision maker.

Obviously, the problem of determining an optimal blend for feed is a multi-criteria programming problem (see Anets and Audsley, 2002). If we want to solve it by MCDM, we have to start from the following:

- Criteria for determining an optimal blend are given.
- The blend has to satisfy the needs for nutrients of the given kind and category of animal.
- A certain number of feed sorts are available that can be used as blend components.

Let us introduce the following marks:

f_j	functions of optimization criteria ($j=1, \ldots, p$),
m	number of different needs for nutrients in a particular kind and category of animal,
b_k	need for a nutrient of k kind in the blend unit ($k=1, \ldots, m$),
n	number of available sorts of feed
c_{ij}	i coefficient of j criterion function ($i=1, \ldots, n$; $j=1, \ldots, p$)
x_i	quantity (share) of a particular feed in the blend ($i=1, \ldots, n$)

a_{ik} quantity of the k nutrient per unit of the i feed ($i=1, \ldots, n$; $k=1, \ldots, m$)

The multi-criteria problem of determining an optimal blend for feed has p criteria functions, and the optimal blend is formulated from n sorts of feed. Each kind of feed contains a certain quantity of nutrients affecting its quality. In this example m nutrients are considered and for each one of them there are minimal or maximal requirements for the quantity (b_k) needed in an optimal ration of feed blend.

Let us now formulate a multi-criteria linear programming model (MCLP) to determine the optimal feed blend:

$$\text{Min (Max)}\left[\sum_{i=1}^{n} c_{i1}x_i, \cdots, \sum_{i=1}^{n} c_{ip}x_i\right] \quad (1)$$

$$\text{s.t.} \quad \sum_{i=1}^{n} a_{ik}x_i \geq (\leq)\, b_k (k=1,\cdots,m) \quad (2)$$

$$\sum_{i=1}^{n} x_i = 1 \quad (3)$$

$$x_i \geq 0, \quad (i=1,\cdots,n) \quad (4)$$

Naturally, besides the constraint of minimal needs for particular nutrients (b_k) there can also be other constraints, such as for example the maximal quantity of a particular nutrient. It is also frequently required that a particular sort of feed is not included in quantities too large or too small. All the requirements will depend on the kind of animal and suggestions of nutritionists.

The relation (3) is set when the blend recipe is composed, with the possibility to make the left side of this constraint less than 1, for the ingredients of additives to the blend no matter what the blend ingredients are.

We will now establish the MCLP model for determining the optimal feed blend, and then we will reformulate the model into a corresponding goal programming model following the nutritionists' suggestions. The difference from some other similar papers is in taking two new criteria, which reflect the quality of the feed blend, the criterion which takes into account the maximum digestibility of feed blend, and the criterion requesting that optimal blend contains minimum share of water. We also show the way how the decision maker can make his/her decisions interactively changing the priorities of posted goals or learning about the optimal decision through the formulation of the model.

3. Input data for determination of feed blend for pig fattening (PS-2)

Our case processes the given data required to work out the optimal feed plan (feed blend) for pig fattening PS-2. The mark PS-2 represents the blend recipe for pigs of 20–50 kg, while PS-1 stands for the recipe for pigs up to 20 kg, and PS-3 for pigs of 50–100 kg, etc. The meal has to contain minimal and maximal shares of daily nutrients. Determination of maximal and minimal share of nutrients in the blend is based on scientific research. The given data are shown in Tables 1–3.

The sort of feeds used to prepare the feed blend for this kind of livestock (pigs of 20–50 kg), their price per unit, and the percentage of nutrients and water per ingredient unit are shown in the Table 1. The total cost has to be minimized, the share of nutrients in the blend has to be maximized, and the share of water in the optimal meal has to be minimized.

The nutrients needed in the feed used for growing pigs and the required quantities (as suggested by nutritionists) are shown in Table 2. Some of the ingredients are required in minimal and some in maximal quantities.

Table 2
Needs for nutrients.

Nutrients		Constraint type	Min or Max requirement—b_k
E1	Raw protein	≥	14.0
E2	Pulp	≤	7.0
E3	Calcium—Ca	≤	0.80
E4	Phosphorus—P	≥	0.50
E5	Ash	≤	7.0
E6	Metionin	≥	0.50
E7	Lizin	≥	0.74
E8	Triptofan	≥	0.11
E9	Treonin	≥	0.45
E10	Izoleucin	≥	0.52
E11	Histidin	≥	0.23
E12	Valin	≥	0.46
E13	Leucin	≥	0.77
E14	Arginin	≥	0.55
E15	Fenkalanin	≥	0.54

Table 3 is a nutrition matrix and its elements a_{ik} are the contents of a particular nutrient in the feed unit.

4. Solving the problem for determination of the feed blend

4.1. Multi-criteria model

Based on the data given in the above tables and in compliance with the requirements of the decision makers the multi-criteria linear programming model is formulated, which minimizes the function of blend costs and the function of the water share in the blend while maximizing the function of the total nutrients in the blend.

4.1.1. Model 1

The multi-criteria programming model is easily established on the basis of the data from Tables 1–3. The coefficients of the three goal functions are given in the Table 1, while the constraints are included by following the data from Tables 2 and 3.

$$\text{Min} \sum_{i=1}^{13} c_{i1}x_i \quad \text{(cost)} \quad (5)$$

$$\text{Max} \sum_{i=1}^{13} c_{i2}x_i \quad \text{(nutrients)} \quad (6)$$

$$\text{Min} \sum_{i=1}^{13} c_{i3}x_i \quad \text{(water)} \quad (7)$$

$$\sum_{i=1}^{13} a_{ik}x_i \geq (\leq)\, b_k \quad (k=1,\cdots,15) \quad (8)$$

$$\sum_{i=1}^{13} x_i = 0.97 \quad (9)$$

$$0 \leq x_i \leq 0.15, \quad (i=1,\cdots,13) \quad (10)$$

The multi-criteria model thus includes three goal functions, 13 decision variables, and 16 constraints. Constraint (9) is the relation (3) from the starting model with the right side of constraint of 0.97. Namely, the diet plan always includes 3% of various vitamin additives disregarding the ingredients included in the optimal

Table 3
Nutrition matrix (a_{ik}).

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
E1	11.5	8.9	17.0	33	61	38	42	12	36	13.5	12.6	11.0	42
E2	5.0	2.9	24.0	0.0	1.0	5.0	6.5	0.0	13.2	3.0	2.8	10.5	13.0
E3	0.08	0.01	1.3	1.25	7.0	0.25	0.2	0.87	0.6	0.05	0.08	0.1	0.4
E4	0.42	0.25	0.23	1.0	3.5	0.59	0.6	0.79	0.93	0.41	0.3	0.35	1.0
E5	2.5	1.5	9.6	8.0	24	4.6	6.0	9.7	7.2	2.0	1.45	4.0	7.7
E6	0.18	0.17	0.28	0.98	1.65	0.54	0.6	0.2	0.67	0.25	0.16	0.2	1.5
E7	0.53	0.22	0.73	2.6	4.3	2.4	2.7	1.1	2.12	0.4	0.4	0.4	1.7
E8	0.17	0.09	0.45	0.45	0.7	0.52	0.65	0.2	0.46	0.18	0.14	0.18	0.5
E9	0.36	0.34	0.75	1.75	2.6	1.69	1.7	0.8	1.6	0.35	0.36	0.28	1.5
E10	0.42	0.37	0.84	2.1	3.1	2.18	2.8	0.9	1.41	0.69	0.53	0.53	2.1
E11	0.23	0.19	0.35	0.86	1.93	1.01	1.1	0.2	0.95	0.17	0.27	0.18	1.0
E12	0.62	0.42	1.04	2.38	3.25	2.02	2.2	0.7	1.81	0.69	0.62	0.62	2.3
E13	0.8	1.0	1.3	3.3	4.5	2.8	3.8	1.2	2.6	1.0	0.7	0.9	2.6
E14	0.5	0.52	0.75	1.1	4.2	2.8	3.2	0.4	2.04	0.6	0.5	0.8	3.5
E15	0.62	0.44	0.91	1.58	2.8	2.1	2.1	0.4	1.41	0.78	0.62	0.62	2.2

Table 4
Marginal solutions.

	Costs (min) X_1^*	Nutrients (max) X_2^*	Water (min) X_3^*
Barley	0.15	0	0
Maize	0.15	0.15	0
Lucerne	0.026	0	0.082
Powdered milk	0	0.15	0.15
Fish meal	0	0.0522	0.0192
Soya	0.1215	0.15	0.15
Soya hulls	0	0.15	0
Dried whey	0	0.15	0.15
Rape pellets	0.15	0	0.15
Wheat	0.15	0.15	0
Rye	0.0725	0.0178	0.1188
Millet	0	0	0
Sunflower pellets	0.15	0	0.15

Table 5
Payoff table.

	X_1^*	X_2^*	X_3^*
Costs—f_1	**1.83645**	4.21434	3.71694
Nutrients—f_2	71.8975	**79.0368**	71.3588
Water—f_3	9.7209	9.58272	**8.00292**

meal. The model also includes additional constraints on the quantity of particular sorts of feed. Namely, to make the diet plan as heterogeneous as possible the model limits the share of any ingredient to maximally 15%. Thus if x_i is the share of i feed in the optimal blend the constraints $x_i \leq 0.15$ $(i=1,\ldots,13)$ are introduced. Consequently, the last two relations from the Model 1 in our example have the above form.

The problem is first solved separately in terms of each goal function, i.e. the so called marginal solutions are determined. The optimal solutions in terms of each goal function are shown in Table 4. Table 5 is the payoff table, i.e. it shows the values of all the three goal functions for the obtained marginal solutions.

The diagonal of the payoff table shows the optimal values of the single functions (ideal point). It is obvious that each of the proposed solutions is good only in terms of its" goal function". Thus for example the solution (blend) X_2^* involves 2.3 times higher cost, and the solution X_3^* twice higher cost than the optimally possible solution X_1^*. In order to obtain the so called best compromise solution the problem has to be solved by one of the multi-criteria programming methods.

4.2. Goal programming model

In agreement with the decision maker (farm owner) it was decided to try to solve the problem by reformulating it into a corresponding goal programming model. The decision maker set the goal values for all the three goal functions, which were in accordance with the obtained marginal solutions. The goals were:

1. To determine the diet plan whose cost will be 1.85 monetary units ($\overline{f_1} = 1.85$).
2. To determine the diet plan in which the share of nutrients in the feed blend will be 77 ($\overline{f_2} = 77$).
3. To determine the diet plan in which the share of water in the feed blend will be 8.3 ($\overline{f_3} = 8.3$).

This establishes the goal programming model in which the three goal functions are reformulated into constraints (equations). Naturally, it is difficult to achieve all the three goals, therefore deviation variables are introduced, and the model goal function becomes the sum of deviation variables, which has to be minimized. All the three goal functions are reformulated into constraints with both deviation variables, i.e. for each goal it is possible to obtain a solution whose value is higher or lower than the required goal value. The model becomes the goal programming problem.

4.2.1. Model 2

$$\text{Min} \left[\sum_{j=1}^{3} (d_j^- + d_j^+) \right] \tag{11}$$

$$\text{s.t.} \quad \sum_{i=1}^{13} c_{i1} x_i + d_1^- - d_1^+ = \overline{f_1} = 1.85 \tag{12}$$

$$\sum_{i=1}^{13} c_{i2} x_i + d_2^- - d_2^+ = \overline{f_2} = 77 \tag{13}$$

$$\sum_{i=1}^{13} c_{i3} x_i + d_3^- - d_3^+ = \overline{f_3} = 8.3 \tag{14}$$

$$\sum_{i=1}^{13} a_{ik} x_i \geq (\leq)\, b_k \quad (k=1,\ldots,15) \tag{15}$$

$$\sum_{i=1}^{13} x_i = 0.97 \quad (16)$$

$$0 \le x_i \le 0.15, \quad (i = 1, \ldots, 13). \quad (17)$$

5. Scenarios for determination of feed blend ingredients

In agreement with the decision maker the problem is solved in three variants (scenarios) in which all the set goals do not have equal weights. The consequence is that the objective function of the goal programming model assumes three different forms depending on the priority rank. In these scenarios the goals are ranked as follows:

Scenario A. First priority: minimization of exceeding costs (d_1^+)
Second priority: minimization of nutrients shortfall (d_2^-).
Third priority: minimization of water excess (d_3^+).In this case the model goal function assumes the following form:

$$\text{Min}\,[P_1 d_1^+ + P_2 d_2^- + P_3 d_3^+] \quad (18)$$

where $P_i\,(i=1,2,3)$ are very high positive numbers for which $P_1 \gg P_2 \gg P_3$.
In this way the goal programming model first fulfils the first priority (i.e. tries to make the variable d_1^+ equal to zero), then the second priority (if other constraints allow it), and finally the third priority.

Scenario B. First priority: minimization of nutrients shortfall (d_2^-).
Second priority: minimization of exceeding costs (d_1^+).
Third priority: minimization of water excess (d_3^+).
Now the goal function is:

$$\text{Min}\,[P_1 d_2^- + P_2 d_1^+ + P_3 d_3^+]. \quad (19)$$

Scenario C. First priority: minimization of water excess (d_3^+)
Second priority: minimization of exceeding costs (d_1^+).
Third priority: minimization of nutrients shortfall (d_2^-). In this case the function is:

$$\text{Min}\,[P_1 d_3^+ + P_2 d_1^+ + P_3 d_2^-] \quad (20)$$

6. The analyses of the obtained results

Table 6 shows the obtained results for all the three scenarios.

In the first scenario the costs are exactly at the required limit (1.85), there is a shortfall for the second goal of $d_2^- = 77 - 73.29 = 3.71$ units, and the third goal (water quantity) is exceeded by $d_3^+ = 9.8339 – 8.3 = 1.5339$ units. Similar considerations are possible in the second and the third scenario. However, in all the three solutions the quantity of raw protein is significantly exceeding (22.9–25.76 units) the minimal requirements (14 units). The decision maker required the solution in which protein quantity would not be so large. Due to this, deviation variables d_4^- and d_4^+ are introduced into the constraint for raw protein, and deviation variable d_4^+ is introduced into the goal function to minimize the exceeding of that goal. Also, the requirement for raw protein is reformulated as an equation in which $\overline{b_1} = 14$ with possible positive or negative deviations. Consequently, the fourth scenario has the following priorities:

Scenario D. First priority: minimization of exceeding costs (d_1^+) and of exceeding quantity of raw protein (d_4^+).
Second priority: minimization of nutrients shortfall (d_2^-).
Third priority: minimization of water excess (d_3^+).

Table 6
Scenarios.

	Scenario A	Scenario B	Scenario C	Scenario D
Barley	0.127	0.0402	0.0724	0.15
Maize	0.15	0.15	0	0.15
Lucerne	0	0	0.0641	0
Powdered milk	0	0.0672	0.0835	0.099
Fish meal	0	0	0	0.02
Soya	0.1309	0.15	0.15	0
Soya hulls	0	0.15	0	0.02
Dried whey	0	0	0.15	0
Rape pellets	0.15	0	0.15	0
Wheat	0.15	0.15	0	0.15
Rye	0.112	0.15	0.15	0.081
Millet	0	0	0	0.15
Sunflower pellets	0.15	0.1126	0.15	0.15
Costs	1.85	2.4087	3.2987	2.5799
Nutrients	73.2909	77	71.1513	71.8493
Water	9.8339	10.2549	8.3	9.9549

As within the first priority there are deviational variables measured in different units we have to use some normalization technique to overcome incommensurability. We will use percentage normalization, i.e. we will transform the goal function so as to divide deviation variables set in the same priority level by their target values. Here the decision maker wants to make minimization of exceeding costs more important than minimization of protein excess. Weight coefficients (within the same goal) are therefore introduced into the goal function so that costs are three times more important. In this way the model becomes a combination of weighted and lexicographic goal programming (see Tamiz et al. 1998). Finally the objective function of the goal programming model for the scenario D has the following form:

$$\text{Min}\,\left[P_1\left(3d_1 + /\overline{f_1} + d_4^+/\overline{b_1}\right) + P_2 d_2^- + P_3 d_3^+\right] \quad (21)$$

The obtained optimal solution does not completely satisfy the decision maker, because this diet plan has not used two important ingredients x_5 (fish meal) and x_7 (soya hulls). Two additional constraints are therefore introduced allowing these two ingredients to be represented by at least 2% ($x_5 \ge 0.02$, $x_7 \ge 0.02$). The obtained result is finally completely satisfactory for the decision maker and it is shown in the last column of the Table 6. In this scenario the quantity of protein is by 5.3831 higher than in the minimal requirements i.e. it amounts to 19.5381 (Table 7).

Any additional requirements made by the decision maker can be easily added to the model, but he has to be warned that it is not possible to meet all the requirements because the model involves a number of hard constraints that are given in the Table 2, such as the need for minimal or maximal nutrient quantities.

The choice of the final solution naturally depends on the decision maker. In our case we have shown four different scenarios representing the four different kinds of requirements that the decision maker may make. All the possibilities are naturally not considered, because the model allows introduction of additional constraints at any time resulting with new compromise solutions. Some requirements could (due to other constraints) lead to a situation where there is no solution, but it would only mean that the additional constraints are "too hard" and that it is necessary to intervene in the model by moderating some of the requirements.

Table 7
Deviation analysis for scenario D.

Nutrients		Constraint type	Min or Max requirements—b_k	Shortfall	Excess
E1	Raw protein	=	14.0	0	5.3831
E2	Pulp	≤	7.0	1.4633	0
E3	Calcium—Ca	≤	0.80	0.4297	0
E4	Phosphorus—P	≥	0.50	0	0.0698
E5	Ash	≤	7.0	2.8534	0
E6	Metionin	≥	0.50	0	0
E7	Lizin	≥	0.74	0	0.1774
E8	Triptofan	≥	0.11	0	0.1409
E9	Treonin	≥	0.45	0	0.2629
E10	Izoleucin	≥	0.52	0	0.4654
E11	Histidin	≥	0.23	0	0.2031
E12	Valin	≥	0.46	0	0.6324
E13	Leucin	≥	0.77	0	0.7245
E14	Arginin	≥	0.55	0	0.6354
E15	Fenkalanin	≥	0.54	0	0.4637
Goal functions					
f_1	Costs	=	1.85	0	0.7299
f_2	Nutrients	=	77	5.1507	0
f_3	Water	=	8.3	0	1.6549

In the end, let us analyze the deviation from the set goals and given constraints for the scenario D. The analysis is shown in Table 7. These data can be the basis for the decision maker to intervene into the model again and possibly loosen or tighten some of the constraints and change the priority rank or target values.

7. Conclusion

The goal programming model proves to be a useful procedure in determining the optimal livestock feed blend. In a relatively simple way the decision maker is allowed to introduce into the model a number of additional requirements that are easily reformulated into mathematical form relatively easily leading to new output results. The paper shows how a standard multi-criteria problem is transformed into a goal programming model in the form of weighted and lexicographic goal programming, leaving open the issue of adequate weighing of single elements in the goal function and deviation variables.

The developed model can be successfully used in solving similar problems in practice that are dependent on several criteria, e.g. feed blend for another kind of livestock of a diet plan for a larger group of people (hospitals, canteens, etc.)

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