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STANDARDISED MODELS FOR FARM PLANNING AND FARM DECISION MAKING IN GREECE

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Abstract: In this paper we present some models used in Greece for farm planning and farm decision making. All models were developed in the Department of Agricultural Economics of Thessaloniki University. Specifically, we present the operational research models used at farm or regional level in order to assist the farmers and the decision makers in improving their decisions. Among these are quadratic programming models, multiobjective programming models, data envelopment analysis models and three dimensional transportation models. First, we present a farm records and accounts computer system which provides the necessary economic and technical data for the application of the above models.

Keywords: Farm planning, model, data envelopment, transportation, computer farm records, accounts system

1. INTRODUCTION

One of the main characteristics of the last two decades is the wide application of mathematical models and especially of operational research models in farm management and farm decision making. Almost all operational research models have been applied with much success to several fields of agricultural economics to assist the farmers and farm decision makers in improving their decisions. Among these are the models of mathematical programming, like linear, parametric linear, integer, mixed integer, goal programming and quadratic programming and quite recently multiobjective programming and data envelopment analysis.

In this paper we present in brief some operational research models used in Greece for farm planning and farm decision making. Specifically, we present a linear

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programming model for the planning of a farm region in Greece. This model is expanded first to a linear parametric programming model and then to a mixed integer programming, to a quadratic programming and to a game programming model. We also present a multiobjective programming model for farm planning with multiple objectives and a data envelopment analysis model for the comparison and the maximisation of the relative efficiency of dairy farms in Greece. We proceed then with the presentation of a three dimensional transportation model, developed for the rational allocation of livestock and feeding stuff farm enterprises of a region in Greece.

All these models have given successful solutions to the real problems. The necessary data, used in application of these models are retrieved and processed by an Agricultural Records and Accounts Computer System (AGRAS), developed for this reason. It will be presented in brief, too.

2. THE AGRAS SYSTEM

The AGRAS system includes two data bases, one for cross sectional and one for time series data. The cross sectional data base is fed every year by the raw farm data from a sample of farms located in the area of Macedonia and Thrace in Greece. AGRAS processes all these data and automatically calculates the technical coefficients of models: quantities and value of seeds, pesticides, labour, etc. and the economic entries: production costs, profits, gross margin, net revenue, farm income, etc. for each individual farm of the sample, for the average farm of the sample, for the average farm of a group of farms of the same type and for the average farm enterprises, all for the year or period of time of concern (Figure 1). This allows the creation of a source of farm management data.

AGRAS was developed so that the input data and the results have the form of ready to print tables. Sixteen tables are used for each individual farm, eight tables are used for the average farm and four tables for the average farm and crop enterprises over a span of time. The last feature makes possible the representation of technical and economic data for the average farms and crop enterprises in time series. Thus the pattern of the main changes in the structure of farms are exhibited.

The sixteen tables for an individual farm present the available family labour, the farm plan, the inventory of the farm, the labour requirements of individual crops per month, the variable costs of individual crops, the labour used for general works of the farm and miscellaneous expenses and receipts.

The eight tables of an average farm present the availability of labour requirements and the rates of employment, the production plan, the composition of fixed assets, the labour requirements of crop enterprises, the requirements of crop enterprises in machinery, the fixed costs, the gross margin of the average farm and all farm management data of the crop enterprises.

The four tables of an average farm and crop enterprises over time present the production plan, the fixed assets, the fixed costs and the technical and economic data of crop enterprises for each year in a period of time. Each average farm record represents one year data. The time span includes the year for which average farms data have been computed.

The tables and particularly these ones concerning individual farms are compatible with the tables of the records and accounts system used by the Greek Ministry of Agriculture.

The carrying data over the tables and their printing is done automatically. A number of subroutines are used to control the inflow of data, and the processes of saving, printing, making charts, etc.

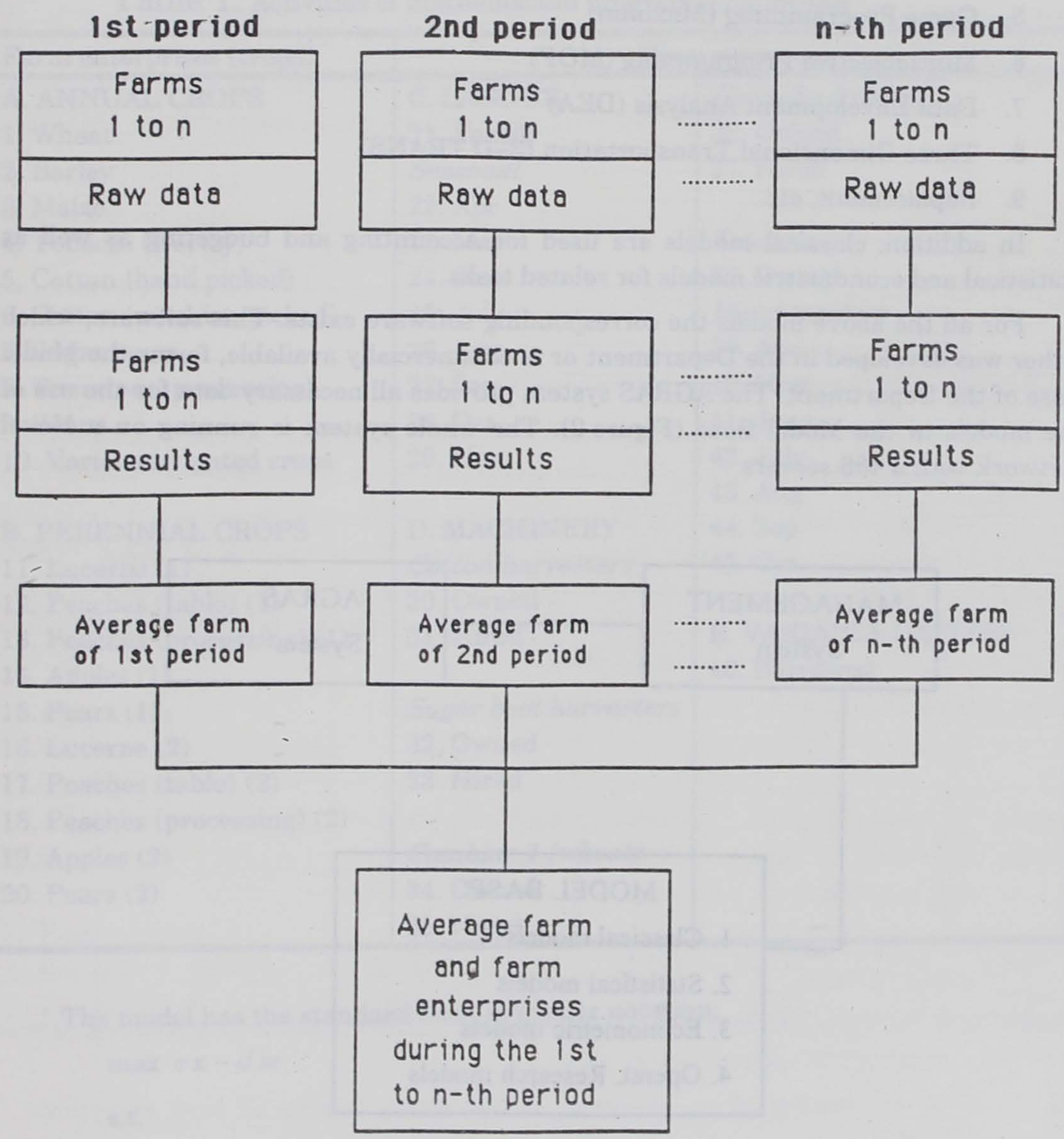

Figure 1: Flow chart of the AGRAS computer system

3. THE MODEL BASE

The mathematical models used in the Department of Agricultural Economics of Thessaloniki University for farm planning, farm management and farm decision making are usually of the following kinds:

1. Linear Programming (LP)
2. Parametric Linear Programming (PLP)
3. Mixed Integer Programming (MIP)
4. Quadratic Programming (QP)
5. Game Programming (Maximin)
6. Multiobjective Programming (MOP)
7. Data Envelopment Analysis (DEA)
8. Three Dimensional Transportation (3-D TRANS)
9. Replacement, etc.

In addition, classical models are used for accounting and budgeting as well as statistical and econometric models for related tasks.

For all the above models the corresponding software exists. This software, which either was developed in the Department or is commercially available, forms the Model Base of the Department. The AGRAS system provides all necessary data for the use of the models in the Model Base (Figure 2). The whole system is running on a Novel Network with a 486 servers.

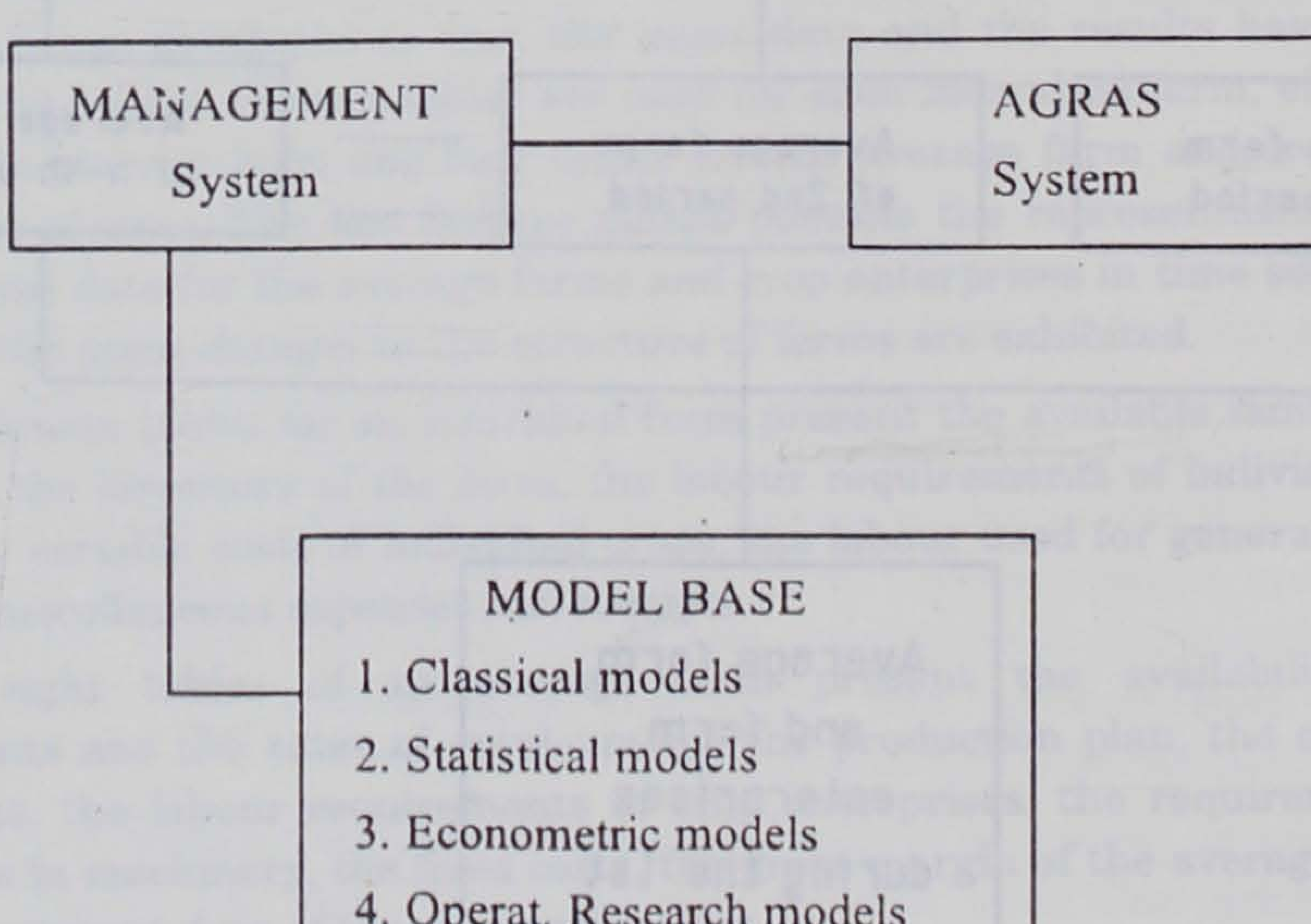

Figure 2. Model Base and AGRAS system

4. LP, PLP, MIP, QP AND MAXIMIN MODELS

Five models, namely LP, PLP, MIP, QP and Maximin programming model, were developed and applied to a farm region in Central Macedonia in Greece which covers an irrigated area of more than 16 thousand hectares.

LP model includes 75 constraints, referring to land, labour, capital and machinery, and 46 farm activities, divided into 29 farm enterprises (annual and perennial crops) and 26 farm resources, Table 1.

Table 1. Activities of mathematical programming models

Farm enterprises (crops)	Farm resources	
A. ANNUAL CROPS	C. LABOUR	*Combine 2 (corn)*
1. Wheat	21. Family	36. Owned
2. Barley	*Seasonal*	37. Hired
3. Maize	22. Apr	
4. Tobacco (Burley)	23. May	*Tractors*
5. Cotton (hand picked)	24. June	38. Owned
6. Cotton (machine picked)	25. July	*Hired tractors*
7. Sugar beets	26. Aug	39. Apr
8. Tomatoes (processing)	27. Sep	40. May
9. Beans	28. Oct	41. June
10. Various irrigated crops	29. Nov	42. July
		43. Aug
B. PERENNIAL CROPS	D. MACHINERY	44. Sep
11. Lucerne (1)	*Cotton harvesters*	45. Oct
12. Peaches (table) (1)	30. Owned	
13. Peaches (processing) (1)	31. Hired	E. VARIABLE CAPITAL
14. Apples (1)		46. Borrowed
15. Pears (1)	*Sugar beet harvesters*	
16. Lucerne (2)	32. Owned	
17. Peaches (table) (2)	33. Hired	
18. Peaches (processing) (2)		
19. Apples (2)	*Combine 1 (wheat)*	
20. Pears (2)	34. Owned	
	35. Hired	

The model has the standard form in matrix notation:

$$\max \; c x - d w$$

s.t.

$$A x + R w \begin{smallmatrix} > \\ = \\ < \end{smallmatrix} b$$

$$x, w \geq 0$$

where x is the vector describing 20 crops enterprises,

w is the vector describing 26 farm resources,

c is the vector describing gross margins of crop enterprises,

d is the vector describing variable costs of the resources,

b is the vector describing the available quantities of 75 resources,

A and R are matrices representing the technical and economic coefficients of crop enterprises and resources.

MIP model has the form of LP model with the exception that labour and machinery are restricted to integers. LP model makes up also the base for constructing PLP model.

QP model has the form:

$$\min \; V = x' S x$$

s.t.

$$A x + R w \gtreqless b$$

$$c x - d w = \lambda \quad 0 \leq \lambda \leq Emax$$

$$x, w \geq 0$$

where V is the variance of total gross margin,

S is the covariance matrix of gross margin,

$Emax$ is the maximum total gross margin which is achieved by LP model.

Using game theory, the model of maximin programming is developed. This model was selected for its pessimistic character between three models of game theory (maximin, Laplace and Savage regret) which were applied to the same set of data. Maximin model is based on LP model and uses as a criterion the maximin criterion (Wald's criterion). This model has the form:

$$\max \; u$$

s.t.

$$A x + R w \gtreqless b$$

$$x' C - w' D \geq z$$

$$x, w \geq 0$$

u free variable

where u is the expected final results of the game, which coincides with the total gross margin of the optimum farm plan,

C is the matrix of c_{ij}, where c_{ij} is the gross margin of crop enterprise i in year j,

D is the matrix of d_{kj}, where d_{kj} is the variable cost of resource k in year j,

z is the vector of variables, which are equal to the expected final results u of the game.

It is obvious that the maximin model has a different objective function than LP model and includes two sets of constraints, i.e. the normal constraints of LP and the maximin constraints. The first set refers to the averages of the time period of concern, whereas the second set is related to the whole time period. The maximin model includes 75 constraints of LP model plus maximin constraints and 45 variables.

The economic effects achieved by using the above models are given in Table 2. These suggest that if the objective function is the total gross margin, ignoring its variability, then it is good to choose one of the models of LP, PLP or MIP. PLP may achieve not only higher gross margin, but also higher profit and farm income, because it utilises better than the other models the remaining available farm resources. When some farm activities are presented in integers, MIP model is considered the most suitable one, although it achieves a smaller profit and farm income.

Table 2. Economic results of existing and suggested by mathematical programming models production plans

Economic results (USD)	Economic results achieved and expected in 1,000 USD					
	Exist.	LP	PLP	MIP	QP	MAX-IMIN
A. Gross margin (E)						
1. E	13741	14292	14301	14290	14132	13957
2. Standard dev. (s)	1730	1988	1962	1986	1837	1585
3. Variance coefficient	12,6	13,9	13,7	13,9	13,0	11,4
4. Limits of 95,45%	10281	10316	10377	10318	10458	10788
confidence interval	17202	18268	18224	18262	17807	17126
B. Fixed costs	11739	11739	11742	11739	11739	11739
C. Profits						
1. Average	2002	2553	2561	2551	2393	2218
2. Minimum	-1458	-1423	-1364	-1421	-1281	-951
D. Farm income						
1. Average	12182	12738	12744	12736	12639	12397
2. Minimum	8721	8763	8819	8765	8964	9228

Taking into account the risk and uncertainty included in yields, prices, the labour required and the capital needed, it is better to use the models of QP and maximin programming. They lead to the highest minimum economic results or they give the same economic results with the lowest variability, that is the highest minimum gross margin, profit and farm income.

5. MOP MODEL

MOP model was developed and applied to production planning of a farm in northern Greece consisting of both crop and livestock enterprises. The farm was found to consist of a number of hectares of irrigated land and include dairy cows.

MOP model was used with two basic goals: a) to maximise the total gross margin and b) to minimise the total variable costs.

The model has the following two objectives:

$$\max\ gx - d\,w$$

$$\min\ fx + d\,w$$

and the following set of constraints

$$Ax + Rw \gtreqless b$$

$$x, w \geq 0$$

where x is the vector of farm enterprises (crops and cows), Table 3,

w is the vector of farm resources,

g is the vector of gross margins of farm enterprises,

d is the vector of variable costs of resources,

f is the vector of variable costs of farm enterprises,

b is the vector of available quantities of farm resources,

A and R are the matrices of the technical and economic coefficients of farm enterprises and resources, respectively.

The solution is obtained by means of compromise programming (CP), which is one of the most suitable techniques to solve MOP models. Specifically, by introducing a1.and a2, the weights of two objective functions, MOP model is transformed to the following CP model:

$$\max\ a_1 \frac{gx - dw - m_1}{M_1 - m_1} + a_2 \frac{-fx - dw - m_2}{M_2 - m_2}$$

s.t.

$$Ax + Rw \gtreqless b$$

$$x, w \geq 0$$

where m_1 and M_1 are the optimal values of total gross margin (min and max, respectively) of the corresponding LP model with the first objective function,

m_2 and M_2 are the optimal values of total variable costs (min and max, respectively) of the corresponding LP model with the second objective function,

a_1 and a_2 are the weights of two objective functions, $0 \le a_1 \le 1$, $0 \le a_2 \le 1$, $a_1 + a_2 = 1$.

Table 3. Farm activities and constraints of the MOP model

VARIABLES	CONSTRAINTS	
A. Cash enterprises	A. Land (hectares)	D. Ration
1. Wheat (soft)	1. Total	20. Dry substance (max)
2. Barley 1	2. Wheat (soft)	21. Dry substance (min)
3. Maize 1	3. Barley 1	22. Peptic albumin
4. Cotton (machine picked)	4. Cereals	23. Energy (min)
5. Sugar beets	5. Maize 1	24. Cereals
6. Tobacco (burley)	6. Cotton	(min 50% concen.)
7. Tomatoes (for processing)	7. Sugar beets	25. Fats
8. Lucerne 1	8. Tobacco	(max 30% concen.)
9. Cows	9. Tomatoes	26. Beet dry pulp
	10. Lucerne 1 and 2	(max 25% concen.)
B. Feedstuffs self-prod.	11. Lucerne 3	27. Dry pulp / dry fodder
10. Lucerne 2		28. Straw / lucerne
11. Lucerne 3	B. Livestock (heads)	29. Cotton cake
12. Barley 2	12. Cows	(min 10% concen.)
13. Maize 2		30. Bran (max 30% concen.)
	C. Labour (hours)	31. Dry subst. by fodder
C. Feedstuffs bought	13. November-March	(min 50%)
14. Cotton cake	14. April	
15. Bran of wheat	15. May	E. Capital (drs)
16. Straw	16. June	32. Variable capital
17. Dry pulp of sugar beets	17. July	
18. Lucerne 4	18. August	
19. Barley 3	19. September-Octob.	
20. Maize 3		

The corresponding LP models which give the optimal values m_1, M_1, m_2 and M_2 to construct CP model, include 20 variables and 32 constraints (Table 3). Nine of 20 variables represent cash enterprises, 4 variables represent feedstuff enterprises, and the remaining 7 variables represent feedstuffs, supplied by the market. The 32 constraints refer to land, livestock, labour, variable capital and the cow ration.

From the above formulation of the CP model, it becomes clear that the value of its total objective function is strongly dependent on the weights a_i-s of two objective functions. As the values of weights a_i–s lie between 0 and 1, we run the model for all possible combinations of a_i–s and get a series of farm plans with their corresponding economic effects. Thus, first we get the mapping of their partial and combined goals and then we can choose those plans which promise to achieve the desired results and improve farm performance.

In Table 4 the existing plan and those proposed by the LP model for different goals are presented. Four goals and respectively four objective functions with the same set of constraints were achieved: the maximum and minimum total gross margin and the minimum and maximum total variable costs. As we can see, the values of both total gross margin and total variable costs of the existing plan lie between these minimum and maximum limits.

Table 4. Economic results of existing and optimum for various goals plans

Economic results in USD	Existing plan	Goal: Gross margin		Goal: Variable costs	
		max	min	max	min
1. Gross return	6068,0	6830,8	2465,2	6495,7	2289,9
2. Gross margin	4842,9	5555,4	1483,7	5218,0	1653,1
3. Variable costs	1225,1	1275,4	981,5	1277,7	636,8
4. Feeding costs	293,6	238,8	575,6	294,9	276,0
5. Fixed costs	4724,5	4724,5	4724,5	4724,5	4724,5
6. Total costs	5949,7	5999,9	5706,0	6002,2	5361,4
7. Profits	118,4	830,9	−3240,9	493,4	−3071,5

The economic effects achieved by the CP model for seven different weights are given in Table 5. The first production plan (Plan 1), coincides with the plan suggested by LP, when the goal is the maximisation of the total gross margin of the farm. The last one (Plan 7), is the same as that suggested by LP, when the goal is the minimisation of the total variable costs. The remaining plans, between these two, are the plans which combine two objectives, i.e. an increase in gross margin with a parallel reduction in variable costs. It is worth noticing that Plan 6 coincides with Plan 7, showing that variable costs cannot be further reduced.

Figure 3 shows the changes in gross margin and the level of variable costs. The costs decrease at a slow rate at the beginning of the process. The reduction rate becomes greater in the middle of the process, while at the end of this it flattens out. Exactly the same pattern is exhibited by the gross margins.

Table 5. Economic results of the production plans suggested by compromise programming

Economic results in USD	Plan 1 a1=1,0 a2=0,0	Plan 2 a1=0,8 a2=0,2	Plan 3 a1=0,6 a2=0,4	Plan 4 a1=0,5 a2=0,5	Plan 5 a1=0,4 a2=0,6	Plan 6 a1=0,2 a2=0,8	Plan 7 a1=0,0 a2=1,0
1. Gross return	6830,8	6743,1	6417,0	5743,3	2811,5	2289,9	2289,9
2. Gross margin	5555,4	5511,7	5259,8	4689,3	2134,8	1653,1	1653,1
3. Variable costs	1275,4	1231,3	1157,2	1054,1	676,7	636,8	636,8
4. Feeding costs	238,8	220,7	220,9	220,9	220,9	276,0	276,0
5. Fixed costs	4724,5	4724,5	4724,5	4724,5	4724,5	4724,5	4724,5
6. Total costs	5999,9	5955,9	5881,7	5778,6	5401,2	5361,4	5361,4
7. Profits	830,9	787,2	535,3	-35,3	-2589,7	-3071,5	-3071,5

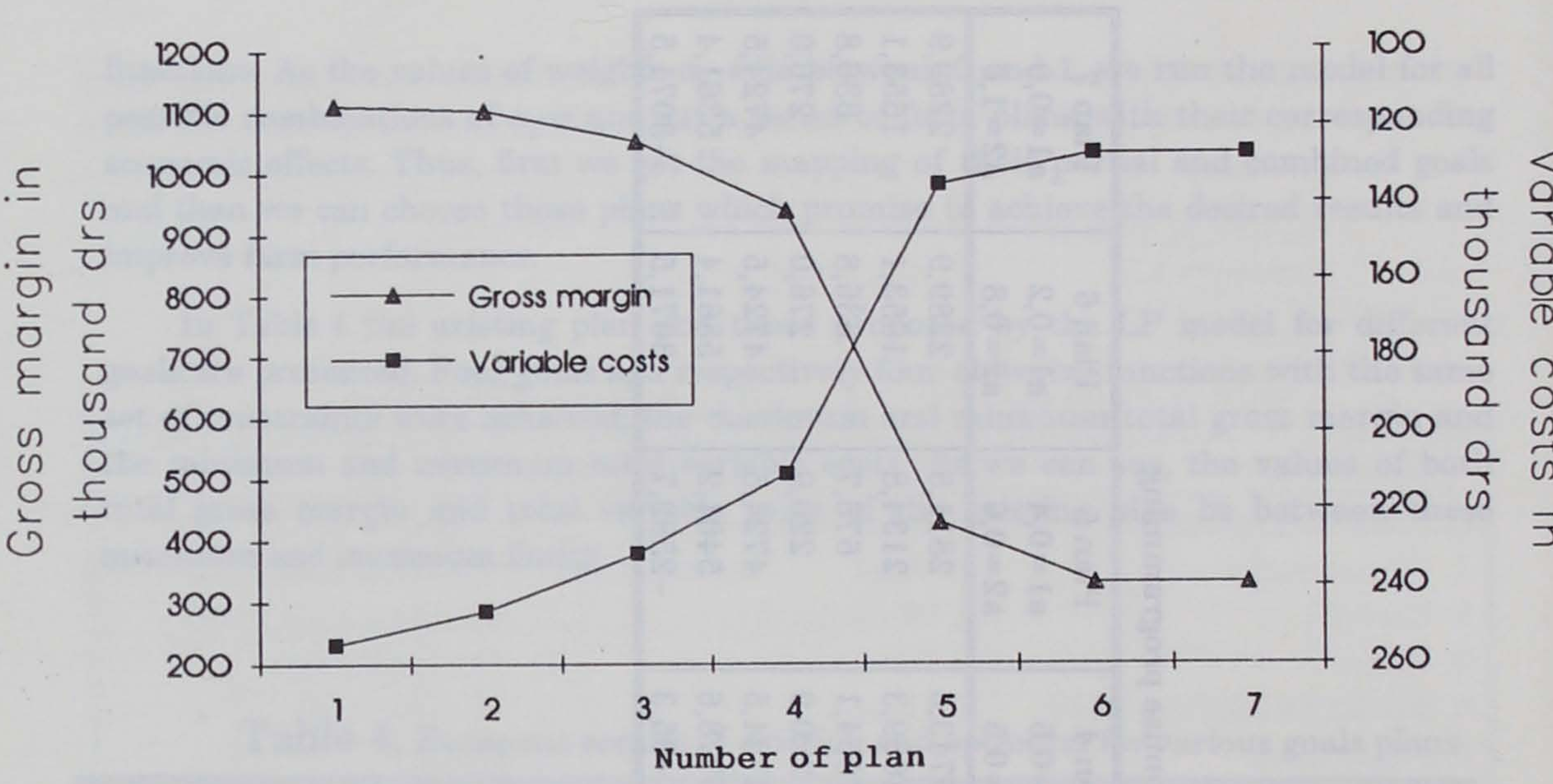

Figure 3. Gross margin and variable costs of the plans suggested by compromise programming

Since beyond the weights $a_1 = 0.5$ and $a_2 = 0.5$ the profits become negative, the reconciliation of two different goals can be realised for pairs (a_1, a_2) such that: $0.8 > a_1 > 0.6$, $0.2 < a_2 < 0.4$ and $a_1 + a_2 = 1$.

Both Plan 2 and Plan 3, which correspond to the above weights interval, give higher gross margins and profits, and lower feeding, variable and total costs than the existing plan. On the other hand these two plans compared with Plan 1, which is suggested by LP, give both lower gross margins and variable costs.

The comparison between the existing farm plan and Plans 1, 2, and 3 shows that MOP can give the optimum farm plan with respect to the gross margin as LP does. Further on, it gives a series of near-optimum farm plans. All these plans give greater gross margin than the existing plan, and achieve a lower gross margin but also lower variable costs than the optimum plan.

6. DEA MODEL

A DEA model was developed and used for the maximisation of the relative efficiency of dairy farms in Greece and the investigation of the factors that influence it.

A sample of 88 dairy farms, located in Central and Western Macedonia in Greece, were grouped into 9 classes to facilitate the application of DEA. The grouping was based on the number of cows bred in each farm. The first class includes farms with less than 10 cows while for each of the subsequent 8 classes the number increases by 10. The average farm was formed for each class and the required input - output coefficients for DEA model were calculated. The average farm of each class and their input and output coefficients are presented in Table 6.

Table 6. Inputs and outputs of dairy farms according to their size

Inputs–outputs of dairy farms	Classes of dairy farms according to the number of bred cows								
	<10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	>80
A. Number of class	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0
B. Inputs									
1.Number of cows	5,9	14,6	25,7	34,9	45,6	51,8	67,8	73,7	103,5
2.Non–irrigated land (strs)	54,8	92,6	77,0	54,5	68,3	0,0	0,0	212,5	230,0
3.Irrigated land (strs)	22,0	47,7	81,2	136,1	144,2	194,0	142,8	184,3	35,0
4.Labour (hours)	1740,4	3434,5	5076,0	6100,8	5984,2	6976,5	8459,3	10715,8	7686,0
5.Variable capital (th. drs)	435,1	981,8	1460,7	2099,6	2542,4	2582,1	1644,4	3177,5	2239,6
6.Feedstuff purchased(th.drs)	560,1	1892,6	3733,9	5338,0	5458,5	8189,9	9823,2	10059,4	13174,0
7. Build.–Land improv(th.drs)	1623,0	3374,3	5989,9	9477,0	8815,7	15807,5	11932,3	17736,2	31679,0
8. Machinery (th. drs)	1258,2	3284,0	5342,1	8188,8	10956,2	11976,5	8183,7	12802,3	15706,0
C. Outputs									
1.Annual milk prod.(kgrs)	21436,1	58264,1	114215,9	162635,7	190597,5	276555,5	331205,7	278974,7	442621,5
2.Calves sold (number)	3,3	6,4	9,4	11,0	17,7	6,5	21,7	20,0	22,5
3.Cows sold (number)	0,7	1,3	2,3	3,1	4,7	2,0	4,7	5,6	5,0
4.Value of cash crops (th. drs)	610,5	1131,8	1237,7	2183,0	2270,6	3020,9	321,3	2800,3	572,3
5.Subsidies (th. drs)	251,7	310,8	558,0	705,8	955,4	1307,1	1246,8	1198,5	1486,9

DEA model has the form:

$$\max \quad h_k = \sum_{r=1}^{s} u_r \, y_{rk} \,/\, \sum_{i=1}^{m} v_i \, x_{ik}$$

subject to $n+s+m$ constraints:

$$\sum_{r=1}^{s} u_r \, y_{rk} \,/\, \sum_{i=1}^{m} v_i \, x_{ik} \leq 1 \quad j = 1,2,3,\ldots,k,\ldots,n$$

$$u_r \geq \varepsilon \quad r = 1,2,\ldots,s$$

$$v_i \leq \varepsilon \quad i = 1,2,\ldots,m$$

where n is the number of the farms (average farms of classes) which are to be compared

m is the number of inputs

s is the number of outputs

x_{ij} is input i in farm j, $i=1,2,\ldots,m$

y_{rj} is output r of farm j, $r=1,2,\ldots,s$

u_r is the weight for output r

v_i is the weight for input i

h_k is the relative efficiency of the farm k

k is the farm under examination whose maximum relative efficiency is sought, $k=1,2,\ldots,n$.

ε is a small positive constant (usually equal to 10^{-6}).

The relative efficiency h_k of an average farm k is defined as the ratio of the sum of its outputs to the sum of its inputs weighted with appropriate weights.

The above DEA model used for the maximisation of the relative efficiency of average farm k, subject to the constraint that the relative efficiency of all the average farms taken separately, including its own, is less than or equal to one. From the solution of the model, the weights u_r and v_i, for which the relative efficiency h_k is maximised, are also found. The above DEA model is a non-linear programming model, more precisely a fractional programming model. Its solution is found through its dual model which is an LP model.

The inputs in DEA model are: a) the number of cows of the dairy farm, b) the acreage of non-irrigated and c) irrigated land cultivated by the farm which is used for the production of bulky feed, coarse grains or cash crops, d) labour hours needed, e) variable capital used by the crops, f) the cost of purchased feed, g) the annual expenses of buildings and land improvements and h) the annual expenses of machinery, Table 6.

The outputs considered are: a) the annual milk production, b) the production of meat from calves, c) the number of cows sold for meat, d) the value of the production of cash crops and e) the total amount of subsidies received by the farm. Subsidies were included among the outputs because they represent the direct effect of the policy (CAP) while the indirect effect is included in prices received.

Thus, DEA model consists of 9 average farms, 8 inputs and 5 outputs, i.e. the model in its initial non-linear fractional form contains 13 variables and 22 constraints. The corresponding dual linear model, which at the end was treated, contains 23 variables and 13 constraints.

The result achieved by DEA model are presented in Table 7. All the classes, except 3 and 8, can become fully efficient, that is, they can organise their inputs and outputs in such a way that the relation of their total outputs to total inputs, both properly weighted, is equal to one. This suggested that the present level of output can not be achieved by further reduction of inputs. In classes 3 and 8, where the relative efficiencies are found to be smaller than one, the present level of output can be achieved by lower level of inputs, since these classes are not fully efficient.

Table 7 contains the weighting factors of inputs and outputs for each of the classes. These factors show the degrees of importance of each input and output associated with the greatest level of efficiency that can be achieved by each class. A clear tendency towards the reduction of increase of the significance of inputs used and the produced outputs from class to class exists only in the annual milk production and partially in purchased feedstuffs. Indeed in Figure 4 the decreasing significance of annual milk production in the maximisation of the relative efficiency of average farms is clearly shown, as their size increases. This interprets the reality well since, as it is known, after a certain point all farms breed cows of approximately the same milk production capacity and give greater attention to the better organisation of inputs used.

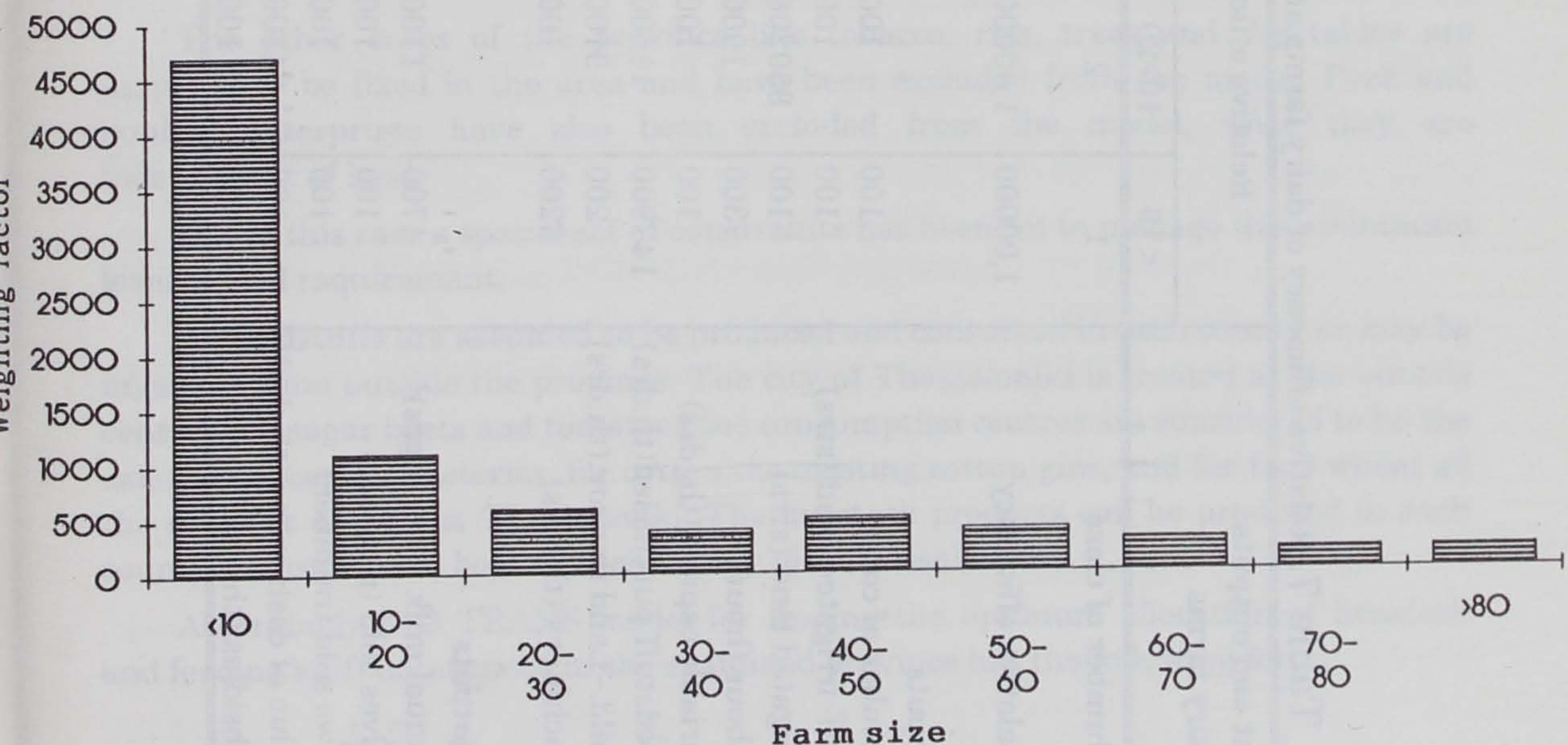

Figure 4. Weighting factors for milk production

Table 7. Relative efficiency of dairy farms and weighting factors of their inputs and outputs according to farm size

Input and outputs of dairy farms	Relative efficiency of dairy farms and weighting factors of their inputs and outputs according to farm size								
	<10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	>80
A. Number of class	1	2	3	4	5	6	7	8	9
B. Relative efficiency	1,00000	1,00000	0,98746	1,00000	1,00000	1,00000	1,00000	0,94369	1,00000
C. Inputs									
1.Number of cows	100	100	3701000	2204600	100	144300	100	100	100
2.Non-irrigated land (strs)	100	100	100	100	100	100	100	100	100
3.Irrigated land (strs)	100	850200	14000	100	100	100	100	51400	100
4.Labour (hours)	7300	1900	100	1300	1700	1200	8800	3900	6500
5.Variable capital (th. drs)	100	100	100	100	100	100	100	100	100
6.Feedstuff purchased(th.drs)	147900	11500	100	100	15700	9900	100	100	100
7.Build.-Land improv.(th.drs)	200	9100	400	1400	300	100	2000	100	1500
8.Machinery (th. drs)	3200	100	100	100	100	100	100	3600	100
D. Outputs									
1.Annual milk prod. (kgrs)	4700	1100	600	400	500	400	300	200	200
2.Calves sold (number)	100	100	792000	1491800	100	100	100	100	100
3.Cows sold (number)	100	100	1,1E+07	100	100	100	100	3826300	100
4.Value of cash crops (th.drs)	100	34100	100	5600	100	100	100	10900	100
5.Subsidies (th. drs)	100	100	100	100	100	100	100	100	100

Finally, regarding the classes 3 and 8, which are not fully efficient, we observe, that the inputs which are used can be reduced in total by 1.3% and 5.6%, respectively and the average farm of these classes can continue to produce the same outputs.

7. 3-D TRANS MODEL

A 3-D TRANS model was developed and applied for the rational allocation of livestock and feedstuffs crop enterprises in the province of East Macedonia and Thrace in Greece.

The province rears about 100,000 dairy cows, 140,000 fattening calves, 1,000,000 sheep and goats, 24,000 sows, etc. It has available about 490 thousand hectares of cultivated land and 600 thousand hectares permanent pastures of low grazing productivity for sheep and goats. The province imports more than 8% of wheat, 14% of barley and 30% of maize needed for feeding stuffs (Table 8). On the other hand it exports 2.9% of milk, 65.3% of beef meat and 4.8% of sheep and goat meat produced.

The province is divided into 6 counties, Serres, Drama, Kavala, Rodopi, Xanthi and Evros, which in the model represent simultaneously 6 consumption (marketing) and the 6 production (supply) centres.

3-D TRANS model includes three types of farm enterprises: livestock enterprises, feeding stuffs and crops. Specifically, the model includes 3 main livestock industries in the province which are: dairy cows, fattening calves and sheep-goats; 4 main feeding stuff crops: feed wheat, barley, maize and lucerne, and their competitors on similar land: sugar beets, tomatoes for processing, cotton and food wheat. It is noted that 3 livestock enterprises are included in the model in their corresponding product form, which is milk, beef meat, and sheep and goat meat.

The other crops of the province like tobacco, rice, trees and vegetables are assumed to be fixed in the area and have been excluded from the model. Pork and poultry enterprises have also been excluded from the model, since they are independent of land.

But in this case a special set of constraints has been set to manage their minimum level of feed requirement.

All feedstuffs are assumed to be produced and consumed in each county or may be imported from outside the province. The city of Thessaloniki is treated as the outside centre. For sugar beets and tomatoes the consumption centres are considered to be the existing processing factories, for cotton the existing cotton gins, and for food wheat all the counties as well as Thessaloniki. The livestock products can be produced in each county and consumed both in each county and Thessaloniki.

Accordingly 3-D TRANS model for finding the optimum allocation of livestock and feeding stuff enterprises in the examined province has the following form:

$$\min \sum_{i=1}^{r} \sum_{j=1}^{m} \left(\sum_{k=1}^{n} c_{ijk} \, x_{ijk} + \sum_{l=1}^{s} c'_{ijl} \, x'_{ijl} + \sum_{t=1}^{q} c''_{ijt} \, x''_{ijt} \right)$$

s.t.

$$\sum_{j=1}^{m} x_{ijk} \le a_{ik} \qquad i=1,2,\ldots,r \qquad k=1,2,\ldots,n$$

$$\sum_{j=1}^{m} x'_{ijl} \le a'_{il} \qquad i=1,2,\ldots,r \qquad l=1,2,\ldots,s$$

$$\sum_{i=1}^{r} x_{ijk} = b_{jk} \qquad j=1,2,\ldots,m \qquad k=1,2,\ldots,n$$

$$\sum_{i=1}^{r} x'_{ijl} \ge b'_{jl} \qquad j=1,2,\ldots,m \qquad l=1,2,\ldots,s$$

$$\sum_{i=1}^{r} x''_{ijt} = b''_{jt} \qquad j=1,2,\ldots,m \qquad t=1,2,\ldots,q$$

$$\sum_{j=1}^{m}\left(\sum_{k=1}^{n} \frac{x_{ijk}}{g_{ik}} + \sum_{l=1}^{s} \frac{x'_{ijl}}{g'_{il}} \right) = d_i \qquad i=1,2,\ldots,r$$

$$\sum_{j=1}^{m} \frac{x''_{ij3}}{g_{i3}} w_i \le d'_i \qquad i=1,2,\ldots,r$$

$$\sum_{i=1}^{r}\sum_{j=1}^{m}\sum_{t=1}^{q} \frac{x''_{ijt}}{g''_{it}} e_{tl} + \sum_{j=1}^{m} b'_{jl} = \sum_{i=1}^{r}\sum_{j=1}^{m} x'_{ijl} \qquad l=1,2,\ldots,s$$

$$x_{ijk}, x'_{ijl}, x''_{ijt} \ge 0$$

where x_{ijk} is the quantity (in tons) of crop k produced in region i and consumed at centre j,

x'_{ijl} is the quantity (in tons) of feedstuff l produced in region i and consumed at centre j,

x''_{ijt} is the quantity (in tons) of livestock product t produced in region i and consumed at centre j,

c_{ijk}, c'_{ijl}, c''_{ijt} are the unit production and transportation costs (drs/ton), respectively,

a_{ik} is the maximum quantity (in tons) of crop k which can be produced in region i,

a'_{il} is the maximum quantity (in tons) of feedstuff l which can be produced in region i,

b_{jk} is the required quantity (in tons) of crop k at consuming centre j,

b'_{jl} is the required quantity (in tons) of feedstuff l at consuming centre j for the needs of its poultry and pork enterprises,

b''_{jt} is the required quantity (in tons) of livestock product t at consuming centre j,

g_{ik} is the yield (ton/str.) of crop k in region i,

g'_{il} is the yield (ton/str.) of feedstuff l in region i,

g''_{it} is the yield (ton/head) of livestock t (corresponding product) in region i,

d_i is the total cultivated land area (strs) by irrigated or non-irrigated crops in production region i,

d'_i is the total available area (strs) under permanent pastures for sheep and goats in region i,

e_{tl} are the requirements (ton/head) of livestock t for feedstuff l,

w_i are the sheep and goats requirements (str/head) for grazing land in region i.

The number of variables and constraints of the above model, when it is stated as LP, as happened in this work, are 380 and 132, respectively. Twenty two of these constraints compose the set of common constraints; 12 of them are referred to the total irrigated and non-irrigated land of each production region, 6 are referred to the total available pasture land of each production region, and 4 to the livestock needs on feedstuffs in the whole province.

The optimum production plan in the province is given in Table 9 and Table 10. Specifically, the optimum allocation of livestock and feedstuffs production is presented in Table 10, while that of competitive crops to feedstuffs is presented in Table 9. In both cases the new production plan is compared with the existing one.

According to Table 9 the total production of sugar beets, tomatoes for processing and cotton remains unchanged at the optimal plan and is concentrated near to the processing factories. Food wheat production, which is in surplus in the province, decreases in favour of feedstuffs. According to Table 10, both feedstuffs and livestock production in the optimal plan are concentrated in fewer regions, especially milk, beef meat, barley and to less extent feed wheat. On the contrary, the distribution of the production of lucerne and sheep and goat meat showed little change, due to the high cost of transporting lucerne and dependence on grazing.

Referring to the self-sufficiency of the province in feedstuffs, we observe that this is increased for feed wheat, barley and maize, while that for lucerne remains at the existing level. This percentage increase in self-sufficiency can be achieved without any change both in total crop production of the province (except the small decrease in food wheat) and the sufficiency in livestock products.

Finally, the new optimum production plan achieves a total cost of supply 5.7% lower than the existing plan. In both plans, the total cost of supply includes the production and transportation costs of livestock products and feedstuffs, as well as the corresponding costs of the competitive with them crops included in the model.

Table 8. Feeding stuff consumption at consuming centres

Consu. centres	Feed wheat (tones)			Barley (tones)			Maize (tones)			Lucerne (tones)		
	Quant. prod. in region	Quant. impor. in region	Total quant.	Quant. prod. in region	Quant. impor. in region	Total quant.	Quant. prod. in region	Quant. impor. in region	Total quant.	Quant. prod. in region	Quant. impor. in region	Total quant.
Serres	30700	0	30700	61400	0	61400	49000	12500	61500	176000	0	176000
Drama	6000	4472	10472	17000	0	17000	17200	0	17200	42653	0	42653
Kavala	150	65	215	4500	2600	7100	7800	9385	17185	27000	0	27000
Xanthi	2000	0	2000	19758	3101	22859	16000	6000	22000	64288	0	64288
Rodopi	1300	0	1300	5800	6350	12150	23660	5840	29500	37000	1200	38200
Evros	9490	0	9490	26089	9624	35713	20377	23394	43771	155500	0	155500
Total (tones)	49640	4537	54177	134547	21675	156222	134037	57119	191156	502441	1200	503641
Total (%)	91,6	8,4	100,0	86,1	13,9	100,0	70,1	29,9	100,0	99,8	0,2	100,0

Table 9. Existing and optimum plans of competitive crops production in tones

Production region	Sugar beets		Tomatoes		Cotton		Food wheat	
	Existing	Optimum	Existing	Optimum	Existing	Optimum	Existing	Optimum
Serres	140706	159500	202623	215934	6520	0	170219	172311
Drama	50761	0	13982	0	762	0	64265	85249
Kavala	74244	135632	16623	0	0	0	30896	46358
Xanthi	34110	182368	18468	82824	25	0	37019	14108
Rodopi	130313	0	40463	0	3852	11210	104516	52685
Evros	269966	222600	6599	0	51	0	206662	201926
Total	700100	700100	298758	298758	11210	11210	613577	572637

Table 10. Existing and optimum plans of feeding stuff and livestock production

Production region, production and self sufficiency	Feeding stuff production (tones)							
	Feed wheat		Barley		Maize		Lucerne	
	Existing	Optimum	Existing	Optimum	Existing	Optimum	Existing	Optimum
Serres	30700	0	61400	54671	49000	122848	176000	135668
Drama	6000	3972	17000	4167	17200	0	42653	71430
Kavala	150	12651	4500	0	7800	7331	27000	87058
Xanthi	2000	0	19758	97384	16000	8591	64288	43113
Rodopi	1300	10611	5800	0	23660	13308	37000	47269
Evros	9490	26943	26089	0	20377	26746	155500	117903
Total production	49640	54177	134547	156222	134037	178824	502441	502441
Total requirements	54177	54177	2E+05	2E+05	2E+05	2E+05	5E+05	5E+05
Self sufficiency	91,6	100,0	86,1	100,0	70,1	93,5	99,8	99,8

Production region, production and self sufficiency	Livestock production (tones)					
	Milk		Beef meat		Sheep and goat meat	
	Existing	Optimum	Existing	Optimum	Existing	Optimum
Serres	67437	110425	9261	2551	2466	2489
Drama	21623	0	2988	0	1005	1009
Kavala	13666	0	1929	0	1258	1250
Xanthi	20647	0	4031	0	2850	2822
Rodopi	17844	55595	2692	0	1548	1526
Evros	24803	0	7998	26348	2220	2251
Total production	166020	166020	28899	28899	11347	11347
Total requirements	2E+05	2E+05	10028	10028	10800	108
Self sufficiency	103,0	103,0	288,2	288,2	105,1	105,1

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