An expert system for planning and designing dairy farms in hot climates

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Abstract: Eleven simulation models were developed to plan and design several dairy farm facilities. Subsequently, an electronic spark map (decision tree) was developed for each simulation model, and then the simulation models were integrated into the relevant spark maps. Afterwards, C# language (C Sharp), which is an object-oriented programming language, was used to develop an expert system via the simulation models and the electronic spark maps. The developed expert system is able to plan and design several dairy farm facilities, e.g. housing system (corrals system), shade structure and roof material, concrete base, cooling system, milking parlour, forage storage, and manure handling system. Subsequently, it plans the farmstead layout, and it leads to implement the technologies, equipments, and machines required for performing several farm operations. Furthermore, it studies water and electricity requirements of the planned dairy farm and the available sources on site. Moreover, it calculates the capital investment and the fixed, variable, and total costs. Data of six dairy farms were used to carry out the expert system validation and evaluation. The differences between the actual and calculated values were determined and the standard deviations were calculated. The coefficients of variation range between 3% and 7%. The accuracy of the developed expert system is 94.5%.

Keywords: expert systems, simulation models, spark maps, precision livestock farming, dairy cows

1 Introduction

Planning and designing dairy farm facilities is a sophisticated work where a multitude of procedures should be carried out which require time and efforts; moreover, making mistakes is also possible. Lacroix et al. (1998) stated that in order to accelerate analyses and improve decision-making, it is necessary to develop computer tools that have the ability to pre-process the data so as to produce value-added information.

A dairy farm consists of several facilities, such as housing system, milking parlour, manure tank(s), forage storage, and several machines for different facilities. Hence developing a simulation model, which is a

quantitative system, for each facility is required; and then integrating the developed simulation models into an expert system, which is a rule-based system, will combine the advantages of both systems in a hybrid system.

The coupling of symbolic (qualitative) and numerical (quantitative) reasoning has received a great deal of attention from those working in artificial intelligence and other disciplines. There are two primary reasons for the interests in coupling. First, there is a need to assist those using complex numerical algorithms and programs. The second reason for the recent interests in coupled systems is the need to deal with problems involving ambiguous, contradictory, and imprecise data. For these cases, a problem solving environment that is more robust than traditional environments is needed (Engel, Beasley and Barrett, 1990).

Expert system development has been accelerated with

the increasing availability of special programming languages and expert-system shells. These tools are able to speed the time-consuming development of expert systems. Existing expert-system programs range from the very complex to those which are very task-specific and narrowly defined. Extremely complex systems represent those being developed by artificial-intelligence theorists who are attempting to emulate the thought process of the human brain. The tasks performed by expert systems are numerous; the functional categories for expert-system applications are interpretation, prediction, diagnosis, monitoring, debugging, repair, instruction, control, design, and planning (Doluschitz, 1990).

The common form of an expert system is a computer program, with a set of rules or equations that analyses information or data supplied by the user, about a specific problem, and recommends one or more courses of user action. The expert system may also provide mathematical analysis of the problem (Giarratano and Riley, 2005).

This paper aims to develop an expert system to plan and design dairy farm facilities, to compute the required amounts of construction materials, to implement technologies and to calculate the costs.

2 Materials and methods

The expert system was prototyped to contain two main models and nine sub-models, which are a total of eleven simulation models for planning and designing dairy farm facilities. The two main models are: (1) Design Model in form of electronic spark map which designs the housing system (corrals system), and (2) Costs Calculation Model which calculates the capital investment and the fixed, variable and total costs of the dairy farm constructions, technologies, land, and cows. Figure 1 shows the architecture of the expert system and the reciprocal interactions between the main models and the sub-models on one side, and the user-interface on the other side.

The sub-models, simulation models integrated into electronic spark maps, are in input/output exchange relation to each other and to the Design Model which is
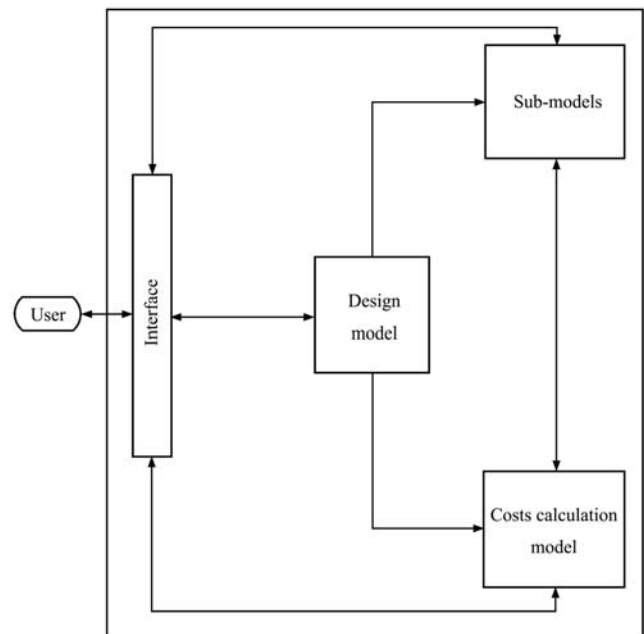

Figure 1   Architecture of the expert system

the mentor of the sub-models. The sub-models are: (1) Concrete Base Sub-Model which is responsible for designing the concrete base of the feeding line and feeding bunks; (2) Roof Materials and Structure Sub-Model which specifies the appropriate roof material according to the climate conditions, and then it configures the suitable roof type; (3) Manure Handling/ Constructions Sub-Model designs the required manure tanks and the handling system; (4) Milking Parlour Constructions Sub-Model is able to plan and design the milking centre inclusive milking parlour, collecting yard, and parlour rooms; (5) Forage Storage Constructions Sub-Model determines the specifications of the horizontal silo and the storage shed; (6) Farmstead Layout Sub-Model which plans the dairy farm and distributes its different facilities over a two-dimensional layout; (7) Cooling System Sub-Model configures the cooling system, which is highly required in hot climates, and specifies its components; (8) Water Sub-Model determines the water requirements/consumption of the dairy farm versus the available sources as governmental supply and/or drilling a well; (9) Electricity Sub-Model determines the energy requirements/consumption of the dairy farm versus the available sources as governmental supply and/or using generators. Furthermore, some sub-models perform two or three operations, and such sub-models are divided into several parts accordingly.

The sub-models which are responsible of concrete constructions for determined facilities, compute automatically the required amounts of building materials (iron rods, cement, sand, and gravels). Some sub-models require data from other sub-models; Figure 2 shows the interactions between the different sub-models taking into consideration their dependence on the Design Model.
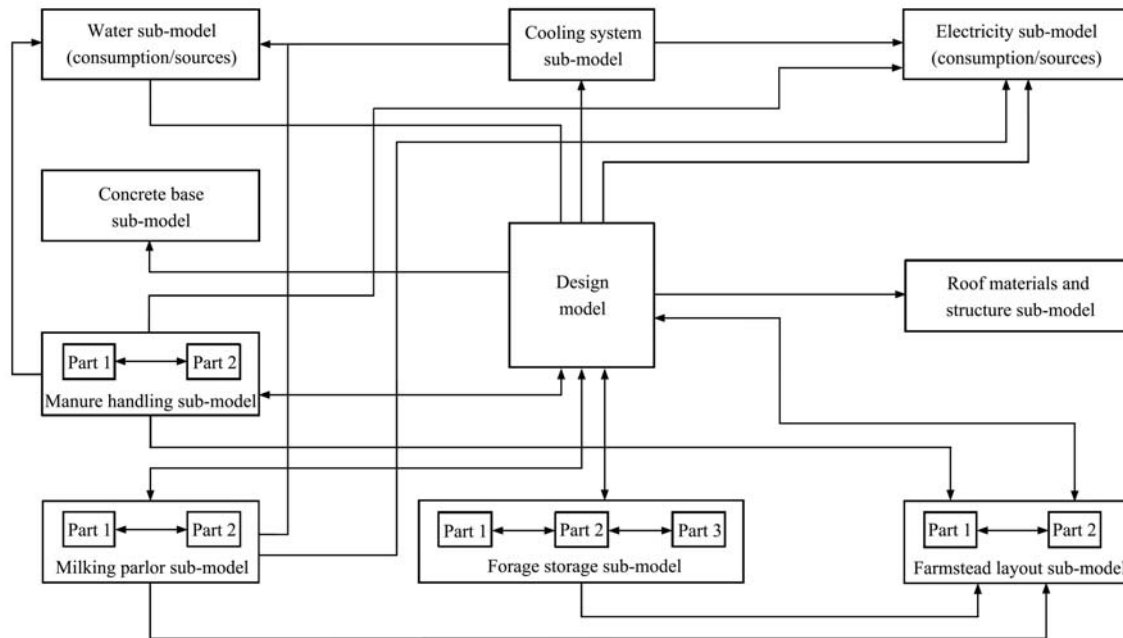
Figure 2   Architecture of the expert system sub-models

The simulation models were developed using the plans, designs, parameters, variables, and constant values of the dairy farm facilities and their concrete structures available in the references, mainly in Lindley and Whitaker (1996) and in Bartali (1999). Further knowledge was acquired by making contacts with the experts of the Cattle Information System of Egypt (CISE) in order to mimic the expertise thought.

The simulation models were formed as If-Then rules, where applicable, in order to be convenient to be later encoded in the expert system. Subsequently, MS-Excel was used to develop an electronic spark map (decision tree) for each simulation model, i.e. for each dairy farm facility, and then the simulation models were integrated into the relevant electronic spark maps. The equations (algorithms), inequation (constraints), and the If-Then rules, of a simulation model, are written in the input cells of the relevant spark map with descriptive characteristics at each branch code and a decision at each terminal node. The spark maps were configured to form the heuristics of the expert system, i.e. they are the coupling method and the transition phase between the simulation models and

the expert system. Afterwards, C# language (C#, 2005), which is an object-oriented programming language, was used to develop the expert system via the simulation models and the spark maps to form the back diagram code of the expert system, and then to develop the user interface.

Validation and evaluation of the expert system were carried out using data of six Egyptian dairy farms and their facilities, as examples of dairy farms in hot climates. The data were acquired from the CISE. The differences between the actual values acquired from the CISE and the calculated values by the expert system were determined. Afterwards, the standard deviation (σ) and the coefficient of variation (COV) were calculated for each output value. The percentage of the calculated value to the actual value was calculated for each output data and then the average, which is the system's accuracy, was computed.

2.1 Algorithms and assumptions

The Roof Materials and Structure Sub-Model (RSM) is presented here as an example to show how the expert system was developed, where it consists of several sub-models.

The model assists the designer in making decisions to select the roof material (reed or straw mats, polished or isolated aluminum, or burnt-clay bricks) and the roof type (horizontal, mono-slope, open-ridge, or compound) suitable for the selected corral distribution (two sides of corrals, one side of corrals, or one corral); afterwards, the roof and structure dimensions will be specified. Moreover, it calculates the capital investment and the fixed, variable, and total costs of the shade structure and the roof material.   The mathematical model requires some input data, such as shade dimensions, roof slope, cowshed height, corrals distribution, span between two posts, some other engineering parameters, and actual local market prices.   According to the inserted input data, the designer will be advised to implement one of the available roof types.   Subsequently, the expert system will make the calculations for all of the available roof types which guide the designer to compare the output data of the different roof types, and then to make the right decision.   The system will provide the designer with several output data such as: roof dimensions, structure dimensions, number of posts, and some special dimensions for each of the roof types.

2.1.1   General factors and concepts

Lindley and Whitaker (1996) stated that yards or corral systems are best suited to dry, hot climate zones. Ikeguchi and Okushima (2001) investigated the relationship between roof type, roof slope angle, and wind direction and air movement inside and outside the house.

The designer should gather some information about the climate conditions of the location where the dairy farm will be established, such as precipitation (mm/year), wind speed (m/s), wind direction, mean maximum temperature (℃), relative humidity (%), and sunshine (%).   Subsequently, a decision should be made to select one of the available roof materials according to the following conditions:

1) If wind speed <1.8 m/s and precipitation <80 mm/year, then reed mats, or straw mats are best suited.

2)   If   wind   speed   >1.8   m/s   and precipitation   >80 mm/year, then polished aluminum (reflection 90 - 70%), isolated aluminum,

burnt-clay bricks, concrete (expensive), or wood (available?) are best suited.

Subsequently, the designer should input some required information about the selected roof material, such as: weight per m^2, price per m^2, and lifetime. Automatically, the system displays several output data, such as roof weight (which is useful for selecting the steel sections) and the fixed, variable, and total costs. Furthermore, the spark map is empowered by a range of values for each required input data in order to help the designer in deciding and selecting the required values.

Some general factors affect directly the decision making.   The following mathematical model summarizes those factors.   The shade width (W_{SH} , m) can be calculated as follows, where A_{SH} (m^2) is the shade area, and L_{SH} (m) is the shade length:

$$W_{SH} = \frac{A_{SH}}{L_{SH}} \qquad (1)$$

The roof slope angle (α,^{o}) can be calculated according to the following equation, where m (%) is the roof slope:

$$\tan \alpha = \frac{m}{100} \qquad (2)$$

Additionally,

$$L_{SH} = L_H = L_R = L_S \qquad (3)$$

where, L_R (m) is the roof length, L_S is structure length, and L_H (m) is the dairy house length. With the following conditions:

if $H_C \geq 5$, then $30 \leq W_{SH} \leq 50$ (4)

$$19 \leq m \leq 45 \qquad (5)$$

where, H_C (m) is the cowshed height.

2.1.2   Corrals distribution and roof types

- If Two Sides of Corrals under One Cowshed, then:
  Horizontal Roof, Open Ridge Roof (recommended), or Compound Roof (3 Parts)

- If One Side of Corrals under One Cowshed, then:
  Horizontal Roof, Mono-Slope Roof, Compound Roof (2 Parts)

- If One Corral under One Cowshed, then:
  Horizontal Roof

2.1.3   Roof and structure specifications

Some important mathematical models should be considered, in general, for all next steps in RSM, such as

the models which specify the value of Span or distance between two Posts in the direction of structure length (S_P, m), margins (M, m), and R which is a Constant depending on roof type.

- There are two cases to specify the value of S_P:

o   Case 1:   if $W_C \geq 8$, then $S_P = \dfrac{W_C}{2}$ (6)

and always $W_C \leq 15$, then $S_P \leq 7.5$ (7)

o   Case 2:   if $W_C \leq 7.5$, then $S_P = W_C$ (8)

and always $W_C \geq 4$, then $S_P \geq 4$ (9)

in General: $4 \leq W_C \leq 15$, then $4 \leq S_P \leq 7.5$ (10)

Thus, the posts are parts of the limits or borders between the corrals, and may just one post be in the middle of each corral.

- The Value of M:

$$0 \leq M \leq 2$$ (11)

- The value of R:

Horizontal roof: $R = 2$ (12)

Mono-slope roof: $R = 2$ (13)

Open ridge roof: $R = 4$ (14)

Compound (2 parts) roof: $R = 3$ (15)

Compound (3 parts) roof: $R = 4$ (16)

Horizontal roof

Figure 3a shows the horizontal roof, where its specifications can be calculated according to the following model.   The roof width is W_R (m), and W_{SH} is (m) shade width:

$$W_R = W_{SH}$$ (17)

The roof area (A_R, m^2) can be calculated as follows, where L_R (m) represents roof length:

$$A_R = W_R \times L_R$$ (18)

$$A_R = A_{SH}$$ (19)

The structure width (W_S, m) can then calculated as follows:

$$W_S = W_R - (2 \times M)$$ (20)

The Number of posts in one row (N_P), and the total number of posts for one cowshed (N_{Pt}) can be calculated as follows:

$$N_P = \dfrac{L_S}{S_P} + 1$$ (21)
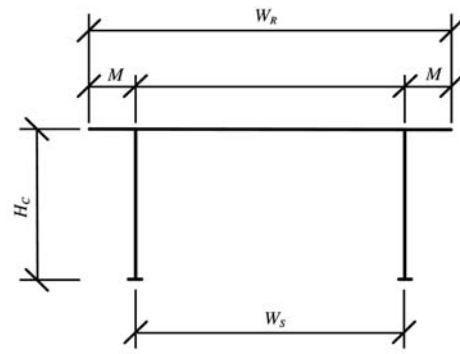
$$N_{Pt} = N_P \times R$$ (22)

Figure 3a   Horizontal roof.

Mono-slope roof

Figure 3b shows the mono-slope roof, where its specifications can be determined as follows:

$$W_R = \dfrac{W_{SH}}{\cos \alpha}$$ (23)

$$A_R = W_R \times L_R$$ (24)

$$W_S = [W_R - (2 \times M)] \times \cos \alpha$$ (25)

$$N_P = \dfrac{L_S}{S_P} + 1$$ (26)

$$N_{Pt} = N_P \times R$$ (27)

$$H_{CS} = H_C - \{[W_R - (2 \times M)] \times \sin \alpha\}$$ (28)

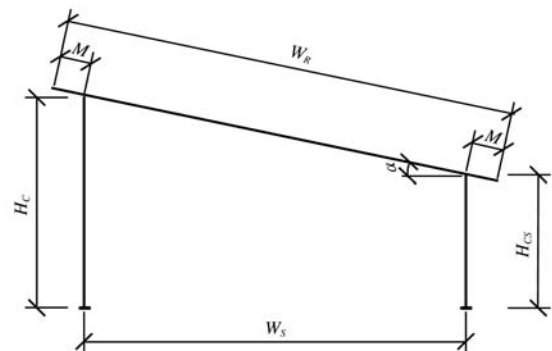where, H_{CS} (m) is the height of the cowshed side.

Figure 3b   Mono-slope roof

Open ridge roof

This roof type (Figure 3c) is made of two Mono-Slope roofs.   The windward roof width (W_{WR}, m) can be calculated as follows, where W_{LR} (m) is leeward roof width:

$$W_{WR} = \dfrac{W_{SH}}{2 \times \cos \alpha}$$ (29)

$$W_{LR} = W_{WR}$$ (30)

$$A_R = (W_{WR} \times L_R) + (W_{LR} \times L_R) \qquad (31)$$

On the other hand, the opened ridge width (W_{OR}, m) can be calculated as follows, where W_{LB} (m) is the width of feeding line and feeding bunks:

$$W_{OR} = W_{LB} - (2 \times M \times \cos \alpha) \qquad (32)$$

The windward structure width (W_{WS}, m) is calculated as follows, where W_{LS} (m) is the leeward structure width:

$$W_{WS} = [W_{WR} - (2 \times M)] \times \cos \alpha \qquad (33)$$

$$W_{LS} = [W_{LR} - (2 \times M)] \times \cos \alpha \qquad (34)$$

$$W_S = W_{LB} + W_{WS} + W_{LS} \qquad (35)$$

$$N_P = \frac{L_S}{S_P} + 1 \qquad (36)$$

$$N_{Pt} = N_P \times R \qquad (37)$$

$$H_{CS} = H_C - \{[W_{WR} - (2 \times M)] \times \sin \alpha\} \qquad (38)$$

With the following condition, where the designer might re-input other value of margins to adjust W_{OR} value between 0.5 and 2 m:

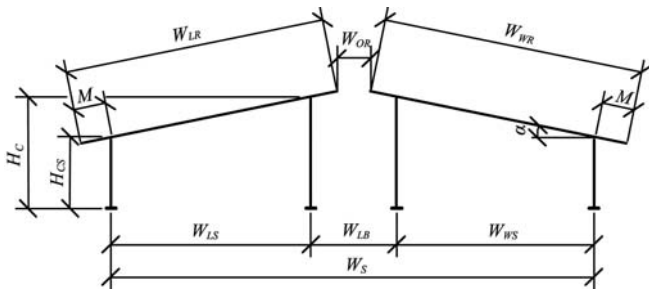$$0.5 \leq W_{OR} \leq 2 \qquad (39)$$

Figure 3c   Open ridge roof

Compound (two parts) roof

This roof type is made of one Main Horizontal Roof and one Mono-Slope Roof (Figure 3d).   The main roof width (W_{MR}, m) can be calculated as follows:

$$W_{MR} = \frac{W_{SH}}{2} + M \qquad (40)$$

$$W_{LR} = \frac{W_{SH}}{2 \times \cos \alpha} \qquad (41)$$

$$A_R = (W_{MR} \times L_R) + (W_{LR} \times L_R) \qquad (42)$$

Th   e main structure width (W_{MS}, m) can be calculated as follows:

$$W_{MS} = W_{MR} - (2 \times M) \qquad (43)$$

$$W_{LS} = (W_{LR} - M) \times \cos \alpha \qquad (44)$$

$$W_S = W_{MS} + W_{LS} \qquad (45)$$

$$N_P = \frac{L_S}{S_P} + 1 \qquad (46)$$

$$N_{Pt} = N_P \times R \qquad (47)$$

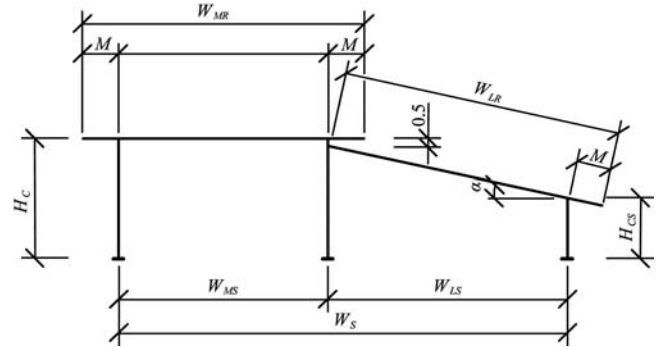$$H_{CS} = (H_C - 0.5) - [(W_{LR} - M) \times \sin \alpha] \qquad (48)$$

Figure 3d   Compounds (two parts)

Compound (three parts) roof

This roof type is made of one Main Horizontal Roof and two Mono-Slope Roofs (Figure 3e), hence:

$$W_{MR} = W_{CB} + (2 \times M) \qquad (49)$$

where, W_{CB} (m) is the concrete base width.

$$W_{WR} = \frac{W_{SH} - [W_{MR} - (2 \times M)]}{2 \times \cos \alpha} \qquad (50)$$

$$W_{LR} = W_{WB} \qquad (51)$$

$$A_R = (W_{WR} \times L_R) + (W_{MR} \times L_R) + (W_{LR} \times L_R) \qquad (52)$$

$$W_{WS} = (W_{WR} - M) \times \cos \alpha \qquad (53)$$

$$W_{LS} = (W_{LR} - M) \times \cos \alpha \qquad (54)$$

$$W_S = W_{WS} + W_{CB} + W_{LS} \qquad (55)$$

$$N_P = \frac{L_S}{S_P} + 1 \qquad (56)$$

$$N_{Pt} = N_P \times R \qquad (57)$$

$$H_{CS} = (H_C - 0.5) - [(W_{WR} - M) \times \sin \alpha] \qquad (58)$$
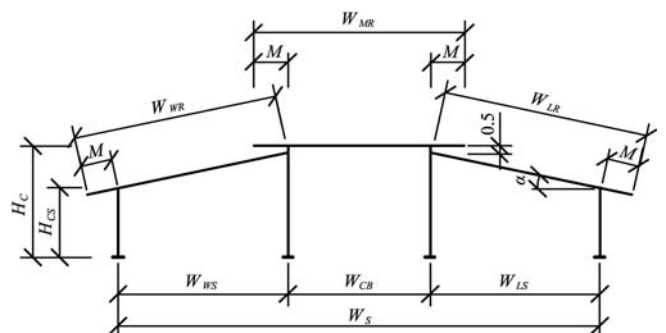
$$W_{CB} = W_{MS} \qquad (59)$$

Figure 3e   Compounds (3 parts)

2.1.4   Roof materials

Several materials are used as roof covering materials:

- **Reed mats**

The total number, mass, and price of required reed mats can be computed as follows, where N_{RM} is the number of reed mats, A_{RM} (m^2) is the surface area of one reed mat:

$$N_{RM} = \frac{A_R}{A_{RM}} \qquad (60)$$

The total mass of reed mats (M_{tRM}, kg) can be calculated as follows, where M_{RM} (kg/Mat) is the mass of one reed mat:

$$M_{tRM} = N_{RM} \times M_{RM} \qquad (61)$$

The Total Price of Reed Mats (P_{tRM}, Currency) can be calculated using the following equation, where P_{RM} (Currency/Mat) is the pice of one reed mat:

$$P_{tRM} = N_{RM} \times P_{RM} \qquad (62)$$

- **Straw mats**

The total number, mass, and price of required straw mats can be estimated as follows; where N_{SM} is the number of straw mats; A_{SM} (m^2) is the surface area of one straw mat; M_{tSM} (kg) is the total mass of straw mats; M_{SM} (kg/Mat) is the mass of one straw mat; P_{SM} (Currency/Mat) price of one straw mat; and P_{tSM} (Currency) is the total price of straw mats:

$$N_{SM} = \frac{A_R}{A_{SM}} \qquad (63)$$

$$M_{tSM} = N_{SM} \times M_{SM} \qquad (64)$$

$$P_{tSM} = N_{SM} \times P_{SM} \qquad (65)$$

- **Polished aluminum**

The total mass and price of required polished aluminum can be calculated as follows, where M_{tPA} (kg) is the total mass of polished aluminum; M_{PA} (kg/m^2) is the mass of one square meter of polished aluminum; P_{PA} (Currency/m^2) is the price of one square meter of polished aluminum; and P_{tPA} (Currency) is the total price of polished aluminum:

$$M_{tPA} = A_R \times M_{PA} \qquad (66)$$

$$P_{tPA} = A_R \times P_{PA} \qquad (67)$$

- **Isolated aluminum**

The total mass and price of required isolated aluminum can be computed as follows, where M_{tIA} (kg) is the total mass of isolated aluminum; M_{IA} (kg/m^2) is the mass of one square meter of isolated aluminum; P_{IA} (Currency/m^2) is the price of one square meter of isolated aluminum; and P_{tIA} (Currency) is the total price of isolated aluminum:

$$M_{tIA} = A_R \times M_{IA} \qquad (68)$$

$$P_{tIA} = A_R \times P_{IA} \qquad (69)$$

- **Burnt-clay bricks**

The total mass and price of required burnt-clay bricks can be estimated as follows, where M_{tBC} (kg) is the total mass of burnt-clay bricks; M_{BC} (kg/m^2) is the mass of one square meter of burnt-clay bricks; P_{BC} (Currency/m^2) is the price of one square meter of burnt-clay bricks; and P_{tBC} (Currency) is the total price of burnt-clay bricks:

$$M_{tBC} = A_R \times M_{BC} \qquad (70)$$

$$P_{tBC} = A_R \times P_{BC} \qquad (71)$$

2.1.5   Costs calculation

The capital investment and the fixed, variable and total costs of the shed can be calculated as follows, where C_{FS} (Currency/Year) is the fixed costs of the shed; C_{IS} (Currency) is the capital investment of the shed; C_{TS} (Currency/Year) is the total costs of the shed; C_{VS} (Currency/Year) is the variable costs of the shed; P_{RCM} (Currency) is the price of roof covering material which is any of the aforementioned roof materials; P_{tSC} (Currency) is the total price of the steel construction; and t_S (Year) is the lifetime of the shed:

$$C_{IS} = P_{RCM} + P_{tSC} \qquad (72)$$

$$C_{FS} = \frac{C_{IS}}{t_S} \qquad (73)$$

$$C_{TS} = C_{FS} + C_{VS} \qquad (74)$$

$$t_S = 20 \qquad (75)$$

The value of P_{RCM} will be equal to the total price of the chosen roof material. A civil engineer should be consulted to make the final design and the concrete piers of the posts, hence P_{tSC} could be calculated.

3   Results

The expert system is developed in order to be used either as separated units, which means each model and

each sub-model can be used as a stand-alone unit which is the case of an existing farm having several facilities but it is required to plan and design a new facility which is not existing on farm, or as a complete unit, i.e. a new farm will be planned and designed using all models and sub-models by means of follow wizard.   When using follow wizard, a multitude of the output data of one model/sub-model will be used as input data in other models/sub-models.   Furthermore, several input data inserted into one model/sub-model will be transmitted automatically as input data for other models/sub-models.

3.1   User interface

Figure 4 shows the main window of the expert system, where the menus are also shown.   The user interface of roof material and structure sub-model is shown in Figure 5 as an example of the user interface of the other sub-models.   The output data are shown in Figure 6.

The Roof Materials and Structure Sub-Model requires 20 input data, actually they are 29 input data, but 12 of them are dedicated for the different roof materials thereof one will be selected/checked.   On the other hand, 11 input data are already shown in their input boxes thereof

some data are automatically transmitted from Design Model and Concrete Base Sub-Model by means of follow wizard and the others are shown as recommendations although   the   designer   may   substitute   them. Subsequently, the sub-model displays 36 output data thereof 12 output data are equal to zero because they belong to different roof materials and roof types thereof one   roof   material   and   one   roof   type   will   be selected/checked.

Some engineering parameters should be specified by the designer, such as roof, slope, roof type, and span between two posts.   Moreover, the specifications of the selected roof material should be inserted to the input data window (Figure 5), e.g. surface area of one reed/straw mat, price per mat or per square meter, mass per mat or per square meter, and the expected variable costs of the selected roof material.   The selected/checked roof type will decide which design will be followed by the system (Figures 3a through 3e), and then the relevant algorithm. The different specifications of the configured shed are shown in the output data window (Figure 6).   The most

Figure 4   Main window of the expert system

Figure 5　Input data window of roof material and structure sub-model of the expert system

Figure 6　Output data window of roof material structure sub-model of the expert system

effective specifications are those concerning roof dimensions, which are dependent on the selected roof type i.e. roof design, and consequently the structure dimensions, and the costs. Data of six dairy farms were used to carry out the validation and evaluation of Roof Material and Structure Sub-Model. Several calculated and actual output data have been found to be identical (Appendix B).

3.2 Expert system validation and evaluation

Validation and evaluation of expert systems are often confused. Validation determines if the problem was solved correctly, whereas evaluation measures the system's accuracy (Batchelor et al., 1992). Data of several dairy farms were used to carry out the validation and evaluation of the expert system and its different simulation models and electronic spark maps.

Data of six dairy farms were used to perform the validation of the Design Model and the Concrete Base Sub-Model. The statistical analysis of the actual and calculated values (Table 1) elucidated that COV were 2.90% (σ = 0.01), 5.54% (σ = 0.03), 4.12% (σ = 0.01),

7.31 % (σ = 0.13), and 3.59% (σ = 0.03) for amounts of concrete, gravels, cement, sand, and iron rods, respectively.

Data of five milking parlours were used to accomplish the validation of the Milking Parlour Constructions Sub-Model. The statistical analysis of the actual and calculated values (Table 2) illustrated that COV were 4.24% (σ = 0.01), 5.70% (σ = 0.01), 5.75% (σ = 0.003), 6.05 % (σ = 0.04), and 5.19% (σ = 0.05) for amounts of concrete, gravels, cement, sand, and iron rods,

respectively.

Data of three manure storage tanks were used to achieve the validation of the Manure Handling/Constructions Sub-Model. The statistical analysis of the actual and calculated values (Table 3) showed that COV were 2.51% (σ = 0.04), 4.30% (σ = 0.05), 4.24% (σ = 0.01), 5.80% (σ = 0.15), and 5.56% (σ = 0.20) for amounts of concrete, gravels, cement, sand, and iron rods, respectively.

Table 1   Data of design model and concrete base sub-model

Farm	Parameter	L_C	W_C	N_{HC}	W_{CB}	V_{CB}	V_G	M_C	V_S	M_I
1	Actual Value	26.15	11.52	20	9.80	282.50	225.98	91415	114.50	9.64
	Calculated Value	26.32	11.40	20	9.80	278.16	222.53	90402	111.26	9.52
2	Actual Value	22.50	9.00	20	9.60	194.06	155.19	62785	78.50	7.38
	Calculated Value	22.22	9.00	20	9.60	193.05	154.44	62741	77.22	7.32
3	Actual Value	21.50	20.50	1	4.70	23.52	18.82	7609	9.52	1.06
	Calculated Value	22.00	20.00	1	4.70	23.40	18.72	7605	9.36	1.05
4	Actual Value	23.50	17.00	1	4.20	24.87	19.91	8049	10.07	1.00
	Calculated Value	23.53	17.00	1	4.20	24.75	19.80	8043	9.90	0.99
5	Actual Value	35.50	14.20	1	3.65	27.16	21.74	8789	11.03	1.22
	Calculated Value	35.29	14.17	1	3.65	27.03	21.62	8783	10.81	1.21
6	Actual Value	28.10	9.60	6	6.90	95.97	76.79	31060	38.90	3.41
	Calculated Value	28.13	9.60	6	6.90	95.50	76.40	31037	38.20	3.38

Note: * For nomenclature, see Appendix A.

Table 2   Data of milking parlour constructions sub-model

Parlour	Parameter	L_{PM}	W_{PM}	L_{MC}	W_{MC}	A_{CY}	V_{CCP}	V_G	M_C	V_S	M_I
1	Actual Value	24.50	7.50	41.30	8	60	94.50	75.66	30680	38.00	4.02
	Calculated Value	24.23	7.60	40.80	7.6	60	94.35	75.48	30664	37.74	3.98
2	Actual Value	27.00	10	38.50	10	56	108.9	87.20	35350	43.80	4.64
	Calculated Value	26.75	10	38.45	10	56	108.7	86.97	35333	43.48	4.59
3	Actual Value	41.50	11.5	58.70	11.5	120	181.3	145.2	58860	72.90	7.71
	Calculated Value	41.19	11.5	58.58	11.5	120	181.03	144.8	58833	72.41	7.64
4	Actual Value	17.00	9	25.00	9	20	55.06	44.10	17875	22.15	2.61
	Calculated Value	16.94	9	24.72	9	20	54.97	43.97	17866	21.98	2.58
5	Actual Value	21.25	9	31.50	9	34	61.32	49.10	19905	24.68	3.49
	Calculated Value	21.20	9	31.26	9	33.6	61.22	48.97	19896	24.48	3.45

Note: * For nomenclature, see Appendix A.

Table 3   Data of manure handling/constructions sub-model

Parameter	Tank 1		Tank 2		Tank 3	
	Actual Value	Calculated Value	Actual Value	Calculated Value	Actual Value	Calculated Value
V_{CT}	28.50	28.04	25.80	26.22	5.25	5.17
V_G	22.70	22.43	20.75	20.98	4.18	4.13
M_C	9120.10	9113.28	8516.50	8522.45	1680.80	1679.63
V_S	11.50	11.22	10.21	10.49	2.12	2.07
M_I	1.79	1.72	2.78	2.87	0.16	0.16

Note: * For nomenclature, see Appendix A.

Data of four cooling systems were used to complete the validation of the Cooling System Sub-Model. The statistical analysis of the actual and calculated values (Table 4) demonstrated that COV were between 2.25% (σ = 0.23) and 4.13% (σ = 0.13).

Data of four horizontal silos were used to act upon the

validation of the Forage Storage Constructions Sub-Model. The statistical analysis of the actual and calculated data (Table 5) elucidated that COV were 3.4% (σ = 0.03), 5.5% (σ = 0.04), 5.2% (σ = 0.01), 7.3% (σ = 0.07), and 4.3% (σ = 0.04) for amounts of concrete, gravels, cement, sand, and iron rods, respectively.

Table 4   Data of cooling system sub-model

System	Parameter	N_{tCF}	Q_{CP}	P_{rCP}	L_{tCP}	d_{CP}	N_M
1	Actual Value	37	1	230	224	18	37
	Calculated Value	37	0.9	223	224	18	37
2	Actual Value	36	1	230	180	18	36
	Calculated Value	36	0.9	222	180	18	36
3	Actual Value	4	-	-	-	-	-
	Calculated Value	4	-	-	-	-	-
4	Actual Value	10	0.27	200	57.6	11	10
	Calculated Value	10	0.24	194	57.6	11	10

Note: * For nomenclature, see Appendix A.

Table 5   Data of forage storage constructions sub-model

Silo	Parameter	V_{CHS}	V_G	M_C	V_S	M_I
1	Actual Value	600.3	479.2	193.2	240	24.17
	Calculated Value	594.2	475.4	193.1	237.7	23.92
2	Actual Value	732	585	235.8	292.5	29.49
	Calculated Value	725.2	580.1	235.7	290.1	29.21
3	Actual Value	972.5	776	313.1	389	33.35
	Calculated Value	962.9	770.3	312.9	385.2	33.04
4	Actual Value	100.9	80.6	32.5	40.4	3.82
	Calculated Value	99.9	79.9	32.5	39.9	3.78

Note: * For nomenclature, see Appendix A.

Data of 4 dairy farmstead layouts were used to carry out the validation of the Farmstead Layout Sub-Model. The statistical analysis of the actual and calculated values (Table 6) clarified that COV were between 5.31% (σ = 0.011) and 7.63% (σ = 0.008).

Table 6   Data of farmstead layout sub-model

Farm	Parameter	X_F	Y_F	A_{tFA}	P_F
1	Actual Value	200.40	178.00	3.56	757.00
	Calculated Value	200.20	177.60	3.55	755.60
2	Actual Value	198.23	252.00	4.99	900.46
	Calculated Value	198.00	251.50	4.97	899.00
3	Actual Value	119.64	91.20	10.91	421.68
	Calculated Value	119.50	91.00	10.87	421.00
4	Actual Value	113.82	117.35	1.34	462.34
	Calculated Value	113.70	117.10	1.33	461.60

Note: * For nomenclature, see Appendix A.

Data of 5 dairy farms were used to make the validation of the Electricity and Water Sub-Models. The statistical analyses of the actual and calculated values showed that COV were 4.2% (σ = 0.10) and 5.9% (σ = 0.14) for electricity and water consumption, respectively (for nomenclature, see Appendix A).

The calculated accuracy of the expert system for planning and designing dairy farms in hot climates is 94.5%.

4   Discussion

Simulation models, which quantitatively mimic the behaviour of a particular system, are not capable of

directly explaining and justifying their output and hence are not well suited as stand-alone decision support systems for the farmer. Conversely, expert systems are knowledge-based systems that use the factual knowledge, procedural rules, assumptions, and heuristics to perform a specific task. Nevertheless, they tend to lack quantitative precision since they are not designed to efficiently carry out numeric simulations. The combination of simulation models and expert systems are known as hybrid systems. The advantages of hybrid systems: simulations can provide the quantitative information for expert systems; expert systems provide missing parameters for simulation models; expert systems can provide the best selection of inputs to a simulation model; expert systems can select the appropriate simulation model to be used; and expert systems can interpret the simulation's output (Greer et al., 1994). This concept has been exploited to develop an expert system for planning and designing dairy farms, where a simulation model had been developed for each dairy farm facility and then the resulting simulation models had been integrated into an expert system. Furthermore, a spark map had been developed for each simulation model and the resulting spark maps are considered as heuristics of the expert system. The spark maps are considered as a transition phase between the simulation models (normative approach) and the expert system (positivistic approach). This is also in agreement with Batchelor et al. (1992) that employing the normative approach often requires restructuring the problem solving process by substituting for the expert's established ideal in a way that results in relatively the same prescriptive conclusions as the expert. Simulation systems provide a means of substituting mathematical models which incorporate established research principles and the knowledge of many experts for the established ideal of the expert. Furthermore, the positivistic approach is usually employed when a problem solving process is systematic and objective; and when the solution process can be represented as a decision tree. The spark map represents the coupling of symbolic (qualitative) and numerical (quantitative) reasoning, where coupling concept is contingent to that developed by Engel, Beasley and

Barrett (1990) using blackboards, but instead using blackboards the developed expert system for planning and designing dairy farms in hot climates uses electronic spark maps. Hence, this expert system is a deep coupled system, since it explicitly represents the process' function, inputs and outputs, and usage constraints and limitations. Furthermore, the expert system had been configured using two programming concepts. The first is the spark mapping of individual sub-models and integrating each simulation model into the relevant spark map, i.e. using the structured systems analysis and design method which addresses technological aspects of system development by breaking down system development into smaller parts (sub-models), each part consists of a sequence of stages, each stage consists of a number of steps, and each step consists of a number of tasks. The second programming concept is the use of C# programming language which is the object-oriented technique to buffer the expert system from the details to individual processes.

Knowledge acquisition has been identified as the 'bottleneck' in the expert system development process. Structured induction offers a method for acquiring and formalizing knowledge. Induction is the opposite of deduction, a more familiar process whereby general knowledge is applied to a specific problem to predict an outcome. Induction takes specific examples, and develops general knowledge which is consistent with those examples. From such a set of examples, rules representing underlying knowledge can be derived, and structured into a decision tree, later known as spark map. The decision tree can then be developed into a functional knowledge base for an expert system. Structured induction takes a sample set of scenarios and applies a mathematical algorithm to them. The output is a spark map, optimized according to a predetermined criterion, with descriptive characteristics at each branch node and a decision at each terminal node. A spark map expresses the knowledge contained in the example set in an ordered and efficient structure. Since many decision trees are possible for a given set of examples, optimization must be employed to get the most efficient tree possible; this was achieved using actual values acquired from several dairy farms and comparing them with the values calculated by

the expert system.   Knowledge acquisition and formalization using structured induction in which an induction algorithm was used to derive rules.   This perception is contingent to that stated by Broner, King and Nevo (1990).   Sensitive parameters, dependent variables, and constant values of a developed algorithm were structured to be used as input/output data of the relevant spark map and later to configure its interface.

The developed expert system for planning and designing dairy farms in hot climates is a computer program with a set of inequation (constraints), If-Then rules and equations (algorithm) that analyses data supplied by the user/designer, and recommends one or more courses of user action.   The expert system provides mathematical analysis of the planning and designing procedures, which agrees with Giarratano and Riley (2005).

Thorough system validation and verification had been performed in order to reveal and uproot system errors and to verify system accuracy.   This procedure is contingent to that stated by Thomson and Schmoldt (2001).

A potential drawback exists when providing access to sophisticated software.   Such technology may increase considerably the power of users to make or influence decisions that were formerly beyond the limits of their knowledge and experience.   Very powerful software packages allow users to perform all manners of inappropriate statistical tests on data without full knowledge of what they are doing.   While current statistical software manuals contain a great deal of information regarding model specification and assumptions, they cannot replace a well-founded understanding of basic statistics by the experimenter (Thomson and Schmoldt, 2001).   Therefore, this expert system is addressed to dairy farm designers as end users with high academic training.

5   Conclusions

The developed expert system is able to plan and design several dairy farm facilities; specify their different dimensions; and compute the required amounts of construction materials (iron rods, cement, sand, and gravels).   Afterwards, it plans the farmstead layout; and determines the water and electricity requirements versus the available sources on site.   Furthermore, it calculates the capital investment and the fixed, variable, and total costs.

The methodology developed in this paper represents a new approach for developing expert systems by using the simulation models for practical implementation. Furthermore, integrating a simulation model into a specially customized electronic spark map to form the heuristic and the back diagram code of an expert simulation system represents a new approach.

Further refinements are under consideration in order to improve the expert system, based on the suggestions noted in the preliminary evaluation that will be made by the end users in the first year of system deployment, which leads to issuing the second version of the expert system.

Further research can be carried out, using similar methodology, to develop an expert system which is able to plan and design dairy farms in cold climates.

Acknowledgements

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Appendices

Appendix A   Nomenclature

Parameter	Unit	Description
A_{CY}	m^2	Area of collecting Yard of Milking Parlour
A_{tFA}	ha	Farm Total Area
d_{CP}	mm	Diameter of Cooling System Pipe Line
E_{FY}	kWh	Farm Total Electricity Consumption per Year
L_C	m	Corral Length
L_{MC}	m	Length of Milking Centre
L_{PM}	m	Length of Milking Parlour
L_{tCP}	m	Total Length of Cooling System Pipe Lines
M_C	kg	Cement Mass
M_I	Ton	Iron Mass
N_{HC}		Number of Corrals in One House
N_M		Number of Microsprinklers
N_{tCF}		Total Number of Cooling Fans
P_F	m	Farm Perimeter
P_{rCP}	kPa	Pressure of Cooling System Pump
Q_{CP}	m^3/h	Discharge of Cooling System Pump
V_{CB}	m^3	Total Volume of Concrete Base
V_{CCP}	m^3	Required Concrete Volume for Constructions of Milking Centre
V_{CHS}	m^3	Required Concrete Volume for Horizontal Silo
V_{CT}	m^3	Concrete Volume of Manure Tank
V_G	m^3	Gravels Volume
V_S	m^3	Sand Volume
W_C	m	Corral Width
W_{CB}	m	Concrete Base Width
W_{FY}	m^3/Year	Farm Total Water Consumption per Year
W_{MC}	m	Width of Milking Centre
W_{PM}	m	Width of Milking Parlour
X_F	m	Farm Dimension in the X-Axis
Y_F	m	Farm Dimension in the Y-Axis

Appendix B Actual data acquired for making the validation of roof material and structure sub-model

Symbol	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
A_{SH}	5875.84	3639.77	197.85	184.07	377.68	1442.50
L_{SH}	114.00	90.00	14.00	17.00	14.50	57.60
m	8.00	10.00	0.00	12.00	0.00	10.00
H_C	8.20	7.50	5.00	4.50	5.00	7.80
Corrals Distribution	2 Sides of Corrals	2 Sides of Corrals	One Corral (Pie)	One Corral	One Corral	One Side of Corrals
Roof Type	Compound 3 Parts	Open Ridge Roof	Horizontal Roof	Mono-Slope	Horizontal Roof	Compound 2 Parts
M	2.00	1.50	0.00	0.00	1.00	1.00
Sp	5.80	4.50	7.00	8.50	7.10	4.80
R	4.00	4.00	2.00	2.00	2.00	3.00
W_{CB}	9.80	9.60	4.70	4.20	3.65	6.90
W_{LB}	4.00	5.00	4.50	4.00	3.50	4.50
Roof Material	Reed Mats	Straw Mats	Straw Mats	Straw Mats	Reed Mats	Reed Mats
A_{RM}	9.00	-	-	-	4.00	9.00
A_{SM}	-	4.00	4.00	4.00	-	-
P_{RM}	12.00	-	-	-	3.50	10.00
P_{SM}	-	5.00	4.00	3.50	-	-
M_{RM}	3.00	-	-	-	1.00	3.00
M_{SM}	-	1.50	1.20	1.20	-	-
P_{RCM}	8500.00	9500.00	200.00	171.00	332.50	1667.00
P_{tSC}	93000.00	71500.00	3250.00	3000.00	6250.00	23750.00
t_S	20.00	20.00	20.00	20.00	20.00	20.00
C_{VS}	1000.00	1000.00	100.00	100.00	50.00	180.00
α	5.00	5.70	0.00	7.00	0.00	5.70
W_R	-	-	14.00	11.00	26.00	-
L_R	114.00	90.00	14.00	17.00	14.50	57.60
A_R	-	-	-	-	-	1500.00
W_S	47.67	39.34	14.17	10.86	24.11	23.10
L_S	114.00	90.00	14.00	17.00	14.50	57.60
N_P	21.00	21.00	3.00	3.00	3.00	13.00
N_{Pt}	84.00	84.00	6.00	6.00	6.00	39.00
H_C	8.20	7.50	5.00	4.50	5.00	7.80
H_{CS}	6.20	5.80	-	3.00	-	6.20
W_{WR}	21.00	20.10	-	-	-	-
W_{LR}	21.00	20.00	-	-	-	12.50
W_{OR}	-	2.00	-	-	-	-
W_{WS}	19.00	17.00	-	-	-	-
W_{LS}	19.00	17.00	-	-	-	11.50
W_{MS}	-	-	-	-	-	11.50
W_{MR}	14.00	-	-	-	-	13.50
N_{RM}	704.00	-	-	-	95.00	167.00
N_{SM}	-	910.00	50.00	50.00	-	-
P_{tRM}	8500.00	-	-	-	332.50	1667.00
P_{tSM}	-	4700.00	200.00	171.00	-	-
C_{IS}	101500.00	76200.00	3450.00	3171.00	6582.50	25420.00