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

Eleven simulation models were developed to plan and design several dairy farm facilities. A decision tree was developed for each simulation model, then the simulation models were integrated into the relevant decision trees. C# programming language was used to develop an expert system via simulation models and decision trees. The objective is to develop an expert system to plan and design dairy farm facilities for dairy farms in hot climates.

Keywords

Expert systems, simulation models, precision livestock farming

Abstract

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Planning and designing dairy farm facilities is a sophisticated work where a multitude of procedures should be carried out which requires time and efforts; moreover, making mistakes is also possible [1]. It is necessary to develop computer tools that have the ability to pre-process the data so as to produce value-added information, in order to accelerate analyses and improve decision-making. This paper aims at developing 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.

Methodology

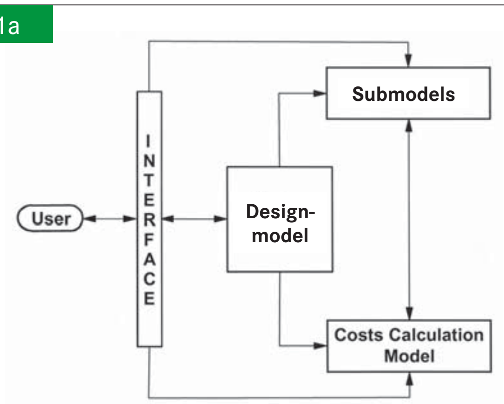
Eleven simulation models were developed to plan and design several dairy farm facilities. Subsequently, an electronic spark map (decision tree) was integrated into the relevant spark maps. Afterwards, C# language (C Sharp), which is an object-oriented programming language [2], was used to develop an 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 (**figure 1a + 1b**), 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 6 dairy farms were used to carry out the expert system validation and evaluation.

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 [3; 4]. 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.

Results

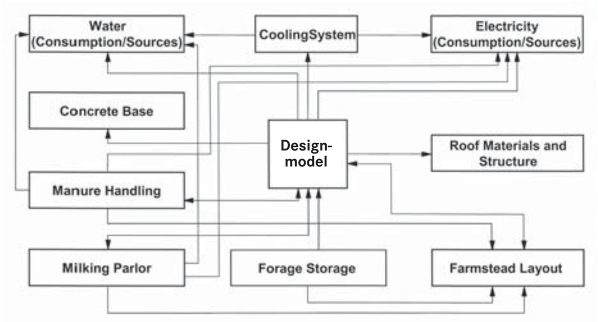
The expert system is developed in order to be used either as separated units, which means each model and each sub-model can be used as a stand-alone unit. This may be the case of an existing farm having several facilities but it is required to plan and design a new facility which is not existing on farm. Moreover a complete unit, i.e. a new farm can be planned and designed using all models and sub-models by means of follow wizard.

Fig. 1a



Structure of the expert system with designmodel, submodels, and cost calculation model

Fig. 1b



Structure and relations of the submodels within the designmodel

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. Data of 6 dairy farms were used to perform the validation and evaluation of Design Model. The statistical analysis of the actual and calculated values (**table 1**) elucidated that COV for the output data were between 4.1 % (σ = 0.03) and 3.3%. The calculated accuracy of the Design Model is 98.9 %.

The expert system is able to make three different housing designs (corral systems), which are: One Corral System, One Side of Corrals, and Two Sides of Corrals. A short description of examples of these three designs, calculated by the expert system, is given in **table 2**. Selecting roof material (reed mats, straw mats, burnt-clay bricks, polished aluminium, or insulated aluminium) depends on climatic conditions. In addition, the roof types suitable for different corral systems are: Horizontal Roof and Mono-Slope Roof which are suitable for "One Corral", Compound (2 parts) Roof and Mono-Slope Roof which are appropriate for "One Side of Corrals", and Compound (3 parts) Roof and Open Ridge Roof which are best suited for "Two Sides of Corrals".

The „One Corral System" is designed to house a small herd (< 20 cows) but this design can be adjusted to house more cows (up to ~40 cows). According to the specification of this design, the shade structure covers one third of the total area, i.e. shading is 33 % (all shading areas in the examples are calculated for an east-west orientation of the feeding line). This system is able to house more cows in one corral than the other systems but it might provide lower shading which is negatively evaluated under hot climate conditions. Due to this the expert system has specified lower cowshed height for this system in order to avoid sun intrusion into the corral as much as possible.

Table 1

Validation data of the designmodel

	Parameter *Parameter*	**Buchtenlänge [m]** *Corral length [m]*	**Buchtenbreite [m]** *Corral width [m]*	**Anzahl Buchten in einem Gebäude** *Number of corrals in one house*	**Anteil Fressplatzfläche an der Bucht** *Ratio of feeding area to corral area*
Farm 1	realer Wert *actual value*	26.15	11.52	20	0.1
	errechneter Wert *calculated value*	26.32	11.4	20	0.1
Farm 2	realer Wert *actual value*	22.37	9.1	20	0.09
	errechneter Wert *calculated value*	22.22	9	20	0.09
Farm 3	realer Wert *actual value*	21.85	20.22	1	0.06
	errechneter Wert *calculated value*	22	20	1	0.06
Farm 4	realer Wert *actual value*	23.38	17.18	1	0.09
	errechneter Wert *calculated value*	23.53	17	1	0.09
Farm 5	realer Wert *actual value*	35.52	14.33	1	0.06
	errechneter Wert *calculated value*	35.29	14.17	1	0.06
Farm 6	realer Wert *actual value*	27.96	9.7	6	0.07
	errechneter Wert *calculated value*	28.13	9.6	6	0.07

This ultimately results in more span or distance between two posts carrying its steel structure, because when lower cowshed height is specified, the force of air that thrusts the cowshed will be minimized. The consequence of this is a decrease of the required building resistance which results in possible and acceptable increase of the span between the posts. This reduces costs and eases the movement of cows without facing many barriers.

"One Side of Corrals" is suitable for medium herds (up to ~120 cows). Although the cowshed is relatively long, most of the sun intrusion will be across the width which results in 75 % shading. The concrete base designed for one-sided corrals will often be relatively long. When we have a long concrete base we should divide this into smaller concrete bases put as pieces near to each other and leaving 2.5 cm as free space. That will give chance to the concrete base to elongate when temperature is high, thus preventing the concrete base from breaking down because of the elongation. In other words, the long concrete base will be built as pieces separated by gaps of 2.5 cm.

The design "Two Sides of Corrals" is best suited for large herds (> 200 cows) where the cowshed would be too long if it were „one-sided". The sun intrusion will be considerably across the width as the width in this design is big (about one half of the length) because there are two sides. However, there will be no sun intrusion across the feeding area, resulting in high shading of 90 %; in other words, this design can provide much more shade with higher cowshed which provides better microclimate for dairy cows. Although both sides of corrals use the same feeding alley, this design requires more steel for cowshed structure and more concrete volume. The main reason for this is that the concrete base for double-sided corrals requires more thickness than for one-sided corrals. In a double-sided design, the cows will stand in two parallel feeding areas which will exert loads on the feeding line. Therefore, the thickness of the different parts of the concrete base must be greater in order to provide balancing, to support the loads concentrated in a shorter area of the concrete base, and to avoid bending of the feeding line. In the one-sided design, the feeding line is longer and the loads will be distributed on a larger area. Moreover, there is just one side of corrals that will need no balance with non-existing parallel corrals. Overall impact will result in reducing the thickness of the concrete base designed for one-sided corrals.

Table 2

Comparison among three different corral designs

Modell/ Submodell *Model/ submodel*	**Variable** *Variable*	**Ein-Buchten-System** *One corral*	**Einreihiges Buchten-System** *One line of corrals*	**Zweireihiges Buchten-System** *Two lines of corrals*
Designmodell *Designmodel*	Anzahl Kühe je Corral *number of cows in one corral*	20	12	12
	Beschattung [%] *shading [%]*	33	75	90
	First-Höhe [m] *cowshed height [m]*	4.5	6.5	8.2
Betonfundamente Submodell *Concrete base submodel*	Betonfundamente Länge pro Bucht [m] *concrete base length per corral [m]*	27.5	9.6	11.5
	Betonfundamente Volumen pro Bucht [m³] *volume of concrete base per corral [m³]*	24.9	16	28.3
Dachkonstruktion und -material Submodell *Roof material and structure submodel*	Dachtyp roof type	Flachdach oder Pultdach *horizontal roof or mono-slope roof*	versetzte Pultdächer *mono-slope roof or compound roof (2 parts)*	versetzte Pultdächer oder Satteldach mit offenem First *compound roof or open ridge roof (3 parts)*
	Stahl pro Bucht [t] *steel (tons per corral)*	1.1	1.3	1.6
	Spannweite [m] *post span [m]*	8.5	4.8	5.8

Table 3a

Comparison between two designs, each house with 40 cows

Modell/ Submodell *Model/ submodel*	**Variable** *Variable*	**Ein-Buchten-System** *One corral*	**Einreihiges Buchten-System** *One line of corrals*
Designmodell *Designmodel*	Anzahl Corrals je Gebäude *number of corrals in one house*	1	4
	Anzahl Kühe je Corral *number of cows per corral*	40	10
	Abschattung [%] *shading [%]*	35	70
	Firsthöhe [m] *cowshed height [m]*	4.5	6
Betonfundamente Submodell *Concrete base submodel*	Betonfundamente Länge pro Bucht [m] *concrete base length per corral [m]*	27.5	9
	Betonfundamente Volumen pro Bucht [m³] *volume of concrete base per corral [m³]*	24.9	15
	Betonfundamente Volumen pro Gebäude [m³] *volume of concrete base per house [m3]*	24.9	60
Dachkonstruktion und -material Submodell *Roof material and structure submodel*	Dachtyp *roof type*	Flachdach *horizontal*	Pultdach *mono-slope*
	Stahl pro Bucht [t] *steel (tons per corral)*	1	1.25
	Stahl pro Gebäude [t] *steel (tons per house)*	1	5
	Spannweite [m] *post span [m]*	8.5	4.5

Table 3b

Comparison between two designs, each house with 150 cows

Modell/ Submodell ***Model/ submodel***	**Variable** ***Variable***	**Einreihiges Buchten-System** ***One line of corrals***	**Zweireihiges Buchten-System** ***Two lines of corrals***
Designmodell *Designmodel*	Anzahl Buchten je Gebäude *number of corrals in one house*	10	10
	Anzahl Buchten je Seite *number of corrals per side*	10	5
	Anzahl Kühe je Corral *number of cows per corral*	15	15
	Abschattung [%] *shading [%]*	76	89
	Firsthöhe [m] *cowshed height [m]*	6.5	7.5
Beton-fundamente Submodell *Concrete base submodel*	Betonfundamente Länge pro Bucht [m] *concrete base length per corral [m]*	14.5	14.5
	Betonfundamente Volumen pro Bucht [m^3] *volume of concrete base per corral [m^3]*	24	35.5
	Betonfundamente Volumen pro Gebäude [m^3] *volume of concrete base per house [m^3]*	241	356
Dach-konstruktion und -material Submodell *Roof material and structure submodel*	Dachtyp *roof type*	Pultdach *mono-slope*	Satteldach. offener First *open ridge*
	Stahl pro Bucht [t] *steel (tons per corral)*	1.25	1.55
	Stahl pro Gebäude [t] *steel (tons per house)*	12.5	15.5
	Spannweite [m] *post span [m]*	7.25	7.25

When it is intended to design a farm where the farm size is between small and medium (**table 3a**) or between medium and big (**table 3b**), the design is ought to be prone to the smaller design, if there are no reasons against this , e.g. dimensions of the total area of the farm. According to **table 3a**, where One Corral has been compared to One Side of Corrals under a pre-condition that both house the same number of 40 cows, the required building materials (steel and concrete) are minimized when the design of One Corral is implemented in comparison to the One Side of Corrals.

Similarly, when One side of Corrals has been compared to Two sides of Corrals under a precondition that the farm houses 150 cows (**table 3b**), the required construction materials are minimized when One Side of Corrals is implemented. Hence, the bigger designs ought to be implemented with significantly higher number of cows. In this case, the amount of the entailed building materials will be minimized when the farm houses a big number of cows.

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. Afterwards, it plans the farmstead layout, and it 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.

Literature

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