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A Generic Design Environment for the Rural Industry Knowledge Acquisition

Shah Jahan Miah[a1], Don Kerr[b], John Gammack[a] , Tom Cowan[c]

[a] Griffith Business School, Department of Management, Griffith University, Logan Campus, Queensland, Australia

[b] Faculty of Business, University of the Sunshine Coast
Maroochydore DC, Queensland, Australia

[c] Mutdapilly Research Station, Department of Primary Industries and Fisheries, Queensland, Australia

Abstract

This paper describes a new knowledge acquisition method using a generic design environment where context-sensitive knowledge is used to build specific DSS for rural business. Although standard knowledge acquisition methods have been applied in rural business applications, uptake remains low and familiar weaknesses such as obsolescence and brittleness apply. We describe a decision support system (DSS) building environment where contextual factors relevant to the end-users are directly taken into consideration. This “end user enabled design environment” (EUEDE) engages both domain experts in creating an expert knowledge-base and business operators/end users (such as farmers) in using this knowledge for building their specific DSS. We document the knowledge organisation for the problem domain, namely a dairy industry application. This development involved a case study research approach used to explore dairy operational knowledge. In this system end users can tailor their decision-making requirements using their own judgement to build specific DSSs. In a specific end user’s farming context, each specific DSS provides expert suggestions to assist farmers in improving their farming practice. The paper also shows the environment’s generic capability.

Keywords: knowledge acquisition; design environment; rural application; DSS process

1 Introduction

The knowledge acquisition process generally involves problem formulation from the extracted knowledge in the problem domain. Gunn et al. (1999) discusses existing knowledge acquisition techniques based on manual learning, machine learning and logic programming. However, these methods suffer from difficulties such as poor understanding of the key issues of knowledge, users’ ability to incorporate issues outside their area of expertise and the need to engage highly computational techniques for the purpose (Gunn et al. 1999; Pietersma *et al*. 2003; Walker and Johnson, 1996).

[1] Corresponding author Tel.: +61 0421325617; Fax: + 61 07 33821408.
Email address: s.miah@griffith.edu.au (Shah J. Miah)

Meantime rural industry uptake of agricultural DSS is low, (e.g. Cox, 1996; Kerr, 2004; McCown, 2002), and end user development of DSS is problematic (Wagner, 2000). The problems identified present a clear motivation for the development of a straightforward knowledge acquisition method for rural businesses. Farmers' knowledge of local conditions and expert knowledge of science and best practice are both required for effective decision making, particularly in a context of an industry undergoing rapid changes. Combination of knowledge from the both parties is important. Therefore, in this paper, we describe an expert-driven knowledge acquisition method for modelling domain knowledge relevant to building farm-specific DSS for rural business operators.

We called the new solution software environment an "end user enabled design environment" (EUEDE). EUEDE represents a specific type of design environment where end users (the people who will be the primary user of the system) involvement is central. Another reason is that our aim is to focus on the end user's thought processes, relevant technology and their own judgement in order to give them active participation in their own application development. This design environment enables the farmer (end-user), to build a specific DSS that assists decision making by reporting on the potential production that can be achieved using relevant improvement strategies. In addition, the design itself will be able to deal with a range of rapidly changing factors in rural business operations (for example as shown in Kerr and Winklhofer, 2005).

Previous studies reported that low adoption rates are one of the problems associated with current DSS usage in rural business domains (Cox, 1996; Kerr, 2004; McCown, 2002). These studies identify three main reasons that influence the adoption rate of agricultural DSS, namely:

1) The developed DSS does not adapt to the rapidly changing situation in farming businesses
2) Many of the DSS modules are developed by researchers with the intention of discovering data relationships rather than solving real world and practical problems
3) Researcher or solution developer often uses their theoretical knowledge for problem solving rather than using farmers' practical knowledge for problem solving.

In addition, Fountas et al. (2006) suggests that farmers base their problem solving on their unique experience and familiarity with their own farm and that because of this, farmers are more likely to utilize information in ways not fully understood by researchers or advisors. The factors suggested above indicate that there is a need for site-specific, updatable, and re-configurable systems to accommodate changes within the context of each farm. The EUEDE design environment discussed in this paper offers a different knowledge acquisition process whereby a domain expert can provide up-to-date and generic problem-relevant knowledge into the knowledge base. Subsequently, this knowledge base is used for building a specific DSS for the rural business operator.

The EUEDE aims to allow the business operators to re-use and share their knowledge in a specific business context. Previously, a problem ontology model using a knowledge acquisition architecture was developed in medical informatics (Achour *et al*. 2001) which implemented the idea of re-use and sharing concepts. Achour's *et al.* (2001) work was about designing a knowledge acquisition tool in which medical experts are enabled to create and maintain a knowledge base. Their solution model for knowledge acquisition has not revealed its generic capability for general users although it has practical implications in the medical industry. We also adopted the idea of creating and reusing knowledge components in designing for generic feasibility of knowledge acquisition in EUEDE. Our approach goes further though, in facilitating the flexibility to build a specific DSS for decision requirements at the end user level.

In comparison to expert systems and other conventional DSS, our approach aims to present a new ontologically-informed architecture, that will deal with problems such as systems rigidity, end user subjectivity in the context of use, obsolescence, limitations of a single expert source, maintenance problems due to requirement for a knowledge engineering intermediary and differences in problem solving emphases between end users and designers. IDIOMS (Gammack et al. 1992) is a design environment for building intelligent DSS that proposed a solution for the above issues. The IDIOMS approach prioritised a constraint-based knowledge representation for extracting expert decision making rules from databases rather than acquiring rules qualitatively from human experts. In the knowledge acquisition process of EUEDE, an ontological set of expert parameters and rules for decision making is identified by domain experts, which is then used to generate the target-relevant DSS according to the end users decision making requirements.

Unlike the other knowledge acquisition methods in the rural domain such as POSEIDON (Gunn et al. 1999) and decision-tree induction (Pietersma et al. 2003), EUEDE enables a straightforward knowledge acquisition process for the domain experts. In this approach, domain experts identify required knowledge components for a scoped problem domain. They specify the decision making parameters, variable factors, instances and their relationships (examples from the dairy case are given in tables 2 and 4). Afterwards, they formulise relationships by defining ratios for each potential level of production in each production class and add expert suggestions for improvement within each class. These ratios come from known industry statistics and science, are stored in the knowledge repository and are later used in displaying guidance in the developed specific DSS. Without extensive re-engineering, experts can update this knowledge with current or emerging information, such as new policies, market requirements or properties from new diet or climate science. This provides a further advance in that the terms understood within the industry are designed into the ontology rather than interpreted by an intermediary and relate directly to its source research and other documentation.

The rest of the paper is organised in the following manner. The next section (section 2) describes a case of a single system development in the dairy industry, this is used as an example and proof of concept to key stakeholders. Section 3, methods and data extraction, describes the methods adopted and data collection procedures for the EUEDE. Section 4 describes the data collected from expert focus group sessions then section 5 describes how these knowledge components are converted into a generic model. Section 6 explains the knowledge acquisition and decision model in the developed design environment. Finally, the discussion and summary section (section 7) presents a brief summary and justification of the ontology development for outlining the knowledge acquisition system within the target problem domain.

2 A Dairy Industry Case: the Milk protein problem

In this section we describe a representative rural industry application: the protein level of cows' milk. Several recent research studies have reported on the effect of climate change on rural business domains, for instance on Australian milk protein production (Kendall et al., 2006). Heat stress can reduce milk protein (DRDC, 2003), but apart from climate-relevant factors, biological factors (such as a cow's health, stage of lactation, body condition and genetics) also influence milk protein production (Givens and Shingfield, 2003; Schingoethe, 1996). Whilst the three main factors affecting milk protein content are nutritional, physiological and genetic factors (Givens and Shingfield, 2003), these vary from farm to farm, region to region. Different regional herbage and diets results in low concentrations of milk protein especially in Queensland and Western Australia (Walker et al. 2004), and several other factors, including herd management practices (White, 2001) can affect milk protein levels. Such findings force farmers to consider a range of relevant factors in their operational decision making.

Industry factors relating to pricing and markets also impact on decision making. The Australian dairy industry's deregulation in 2000 resulted in a drastic change (Parker et al., 2000), such that milk factories provided seasonal price incentives based on the constituents of milk, in particular, milk protein. Decision making factors, not only for this case, but, we contend, for other rural businesses are thus shaped both by internal and externally business-oriented factors. There is a general need to assess the production potential impact of these different factors on rural business, but also, a specific need to optimise decisions at the farm level.

3. Methods and Data extraction

Following an overview presentation of the proposed design the dairy industry stakeholders suggested that ***milk protein enhancement*** was a suitable test domain. A case-study approach was then used to acquire an in-depth understanding from documentation and from dairy experts of the decision-making factors related to milk protein production.

For initial knowledge acquisition several two-hours to three-hour focus group (Focus group method - Morgan, 2002) sessions were held, comprising dairy domain experts with different areas of expertise, including dairy extension professionals, nutritionists, physiologists, dairy practitioners and dairy researchers. Their enthusiastic exchange of ideas helped establish a clear and shared understanding of the issues. The experts agreed on six main factors associated with milk protein enhancement, namely *dry matter intake in feed; feed value; water management; herd management; heat stress management* and *breed management*. From these factors, subsequent focus group meetings identified a list of decision-making parameters and their specific impacts, providing the basis for the EUEDE's problem ontology.

For knowledge verification, we used a convergent interviewing technique (Dick, 2002) in which experts were asked individually about aspects of the elicited knowledge, until agreement was reached. The final knowledge base was verified with other industry experts and against documentation. A process flow diagram is given below (in Figure 1) to illustrate our approach to knowledge extraction using qualitative techniques. As part of existing literature analysis, a set of internal and external documentation was reviewed based on different dairy factors that affect milk protein.

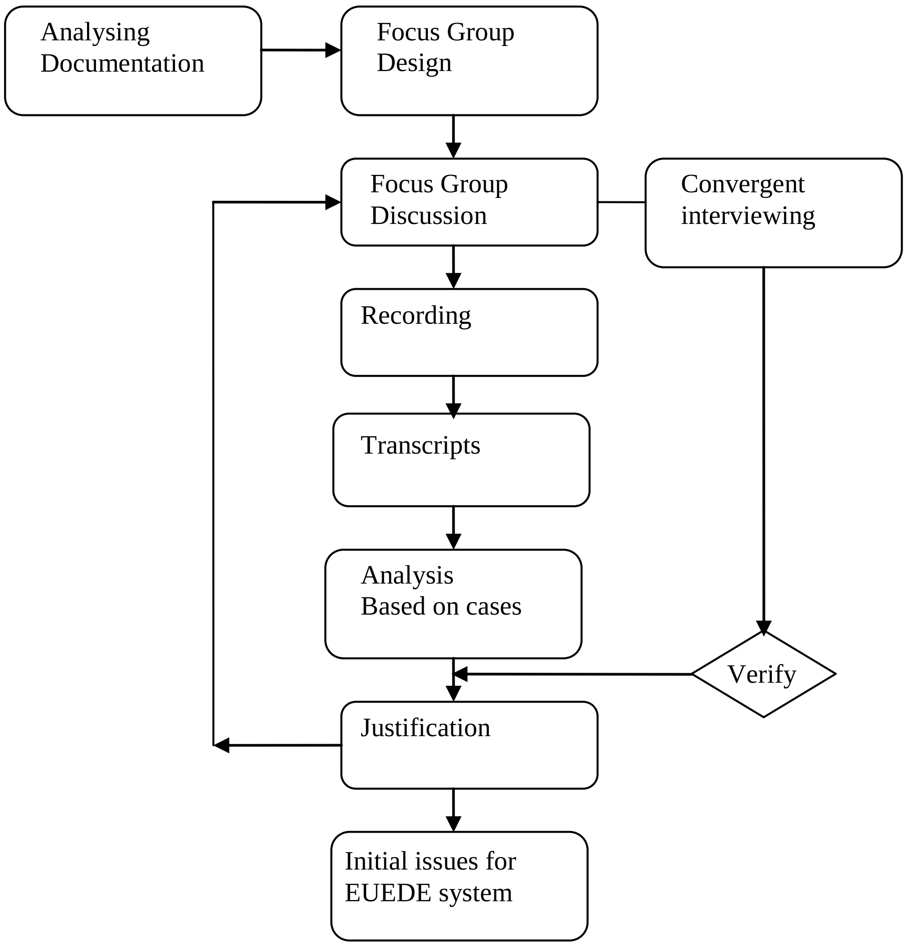

Figure 1: The process flowchart for knowledge acquisition using qualitative data collection techniques

4. Data findings

In this section, we will show how the six identified factors apply specifically for milk protein enhancement, but we contend that these are also applicable to rural livestock production potentials generally, including dairy, beef cattle, sheep, goat, pig, and chicken farming industries.

We describe the relationships between the inputs and the critical factors of milk protein enhancement in dairy operations which were identified from the extracted knowledge and supplemented by reference to an industry reference manual (DPI, 2006).

4.1 Influence of different factors

The effect of the six factors is shown in table 1. For each factor, participants suggested how its optimisation could potentially lift milk protein levels in daily production by a specific percentage range.

Experts agreed that the amount of dry matter (DM) intake in daily feed is important to improving milk protein production. The specific amount is relative to body weight, but also depends on other factors such as the cow's stage of lactation, production potential, and amount of feed on offer and feeding types and methods. Individual experts suggested nutritional targets, with which others agreed: in this instance, experts agreed a target limit of DM intake as 3.5% of a cow's body weight.

Variations in a cow's diet also impacts milk protein levels. Useful estimates of feed quality include NDF (neutral detergent fibre), crude protein (CP), starch and sugar levels of feed items. Related factors such as feed processing, growing seasons and feeding methods also play important roles in feed quality. Rules of thumb were captured for these factors e.g. specifying sugar and starch levels as a percentage of the total ration.

Table 1: Six factors with the potential ranges for improvement

Influencing Factors	Parameters with required amount	Potential gain for milk protein production
Dry matter intake	DM = 3.5% of body weight (in kg)	0.1% to 0.2%
Feed values	NDF = 30% of total diet CP = 15% of total diet Starch = 25% of total diet Sugar = 6% of total diet	0.1% to 0.3%
Water management	Daily water = 80 litre/cow	0.05% to 0.2%
Herd management	Feed frequency = 6 times/day	0.1% to 0.7%
Heat stress management	Temperature-Humidity Index (THI) >78 Shade area = 5 sqr metres/cow	0.1% to 0.4%
Breed management	Major breed = Jersey	0.1% to 0.5%

Water management is one of the most dominant factors associated with changes in protein levels in milk. A cow requires approximately 80 litres of water per day during summer (DPI, 2006).

In herd management, the stage of lactation also impacts milk protein levels. There are considered to be a total of 300 milking days for the production of cow's milk, and rules relating to cow's body condition score, calving pattern and health apply.

Minimising heat stress, particularly in summer, is a significant management factor. Heat stress impacts are estimated as a Temperature-Humidity Index – THI (a mathematical correlation between local temperature and humidity). Milk composition may be affected above 78 so various shade and cooling strategies were suggested.

Finally, genetics also makes a difference: certain breeds produce a relatively higher protein percentage. A herd dominated by Jersey cattle for example can produce a milk protein percentage gain of up to 0.5%.

5 Generic knowledge modelling

Rather than use the knowledge base to develop a specific expert system, we parameterised the extracted knowledge using a specific ontology-based development methodology. We partially utilised an approach for ontology development called METHONTOLOGY (Fernandez et al., 1997), which advocates the use of a structured informal representation to support the ontology development (Bally et al., 2004). The scope of ontology development allows development of generic and reusable decision-making components that can enable the domain experts to outline their decision-making scenarios within a specific farming condition. The components of the ontology are summarised in table 2

Table 2: Terms used in the problem ontology development

Ontology terms	Definitions
Parameters	Attributes that have input values and help determine the factor values
Relationships	Type of impacts of the parameters on the factors. For example, “is-a” means the required level of the parameters will be one defined value. “depends on” means the required level of the parameters will be a co-relational value
Ratios	Mathematical figure that defines a rule to set the desired level of the parameters value
Inputs	Current values of the parameters which will be entered by the users
Required level	The desired level of the parameters value which is a estimated value from the rules
Scope	The difference between the required level and the current level.

The methodology of the problem ontology development involves five phases: knowledge acquisition; conceptualisation, evaluation, specification, and implementation. The decision-making parameters are identified and documented for the different protein dominant classes/factors in the knowledge acquisition phase. In the conceptualisation phase, the relationships associated with the decision-making parameters are defined. The evaluation phase involves domain experts to refine the reusability options and for verification against user requirements. In the specification, a complete knowledge base is developed for the problem ontology. The developed ontology is then programmed in the implementation phase. Our ontology’s details are specifically scoped to the milk protein domain, (given by the policy context set for the project), and we specify these next. The major parameters however, are held to be generic across intensive livestock industries, and the architecture and approach more generally lend themselves to application in industries beyond these.

In our domain model, parameters in any dairy farm are classified into three common instances: *animal instances* including parameters relevant to the cow's physiological and breed conditions; *management instances* including parameters relevant to local farming conditions; and *climate instances* including parameters relevant to external impacts such as heat stress. These parameters are outlined in Table 3.

Table 3: Parameter details for the EUEDE system

Different instances	Parameters	Definitions of the parameters
Animal Instances	Average live weight	Cows' average live weight, normally measured in kg
	Days in milk	Cows' average milking days considered to be 300 days.
	Major breed	Cows' breed, for example, Jersey, Friesian.
	Average milk protein	Protein level in milk yield as a percentage.
	Milk per day/cow	Total milk produced by a cow per day measured in litres.
	ABV	Australian Breed Values : a practice for improving values from cows.
	Water availability per day	Allocation of adequate amount of fresh water daily
Management Instances	Frequency of feeding	Approximate measure of how often cows are fed daily.
	Feeding access to pasture	Cows' access to pasture where they move freely to feed
Climate Instances	Temperature-humidity (THI) index	Mathematical correlation between local temperature and humidity for specific farming region
	Distance between the shade and feeding area	Distances cows usually walk for feeding. This helps in determining energy for body maintenance.
	Approximate shade length	total shade length to protect cows from the elements
	Sprinklers	A device that supplies cool water to maintain cows' normal body temperature and protect from extreme heat.

To model the domain knowledge, our focus was to use acquired knowledge components that enable generic reasoning in outlining facts for DSS building. In this way, the model can be re-used in other domains of rural businesses for building this type of system without any intermediary requirement. Thus without involvement of an external knowledge engineer, a domain expert can be involved in interpreting and understanding the domain knowledge before any actual development occurs, the following model, Figure 2, shows how the dairy operational knowledge was modelled for the EUEDE system development.

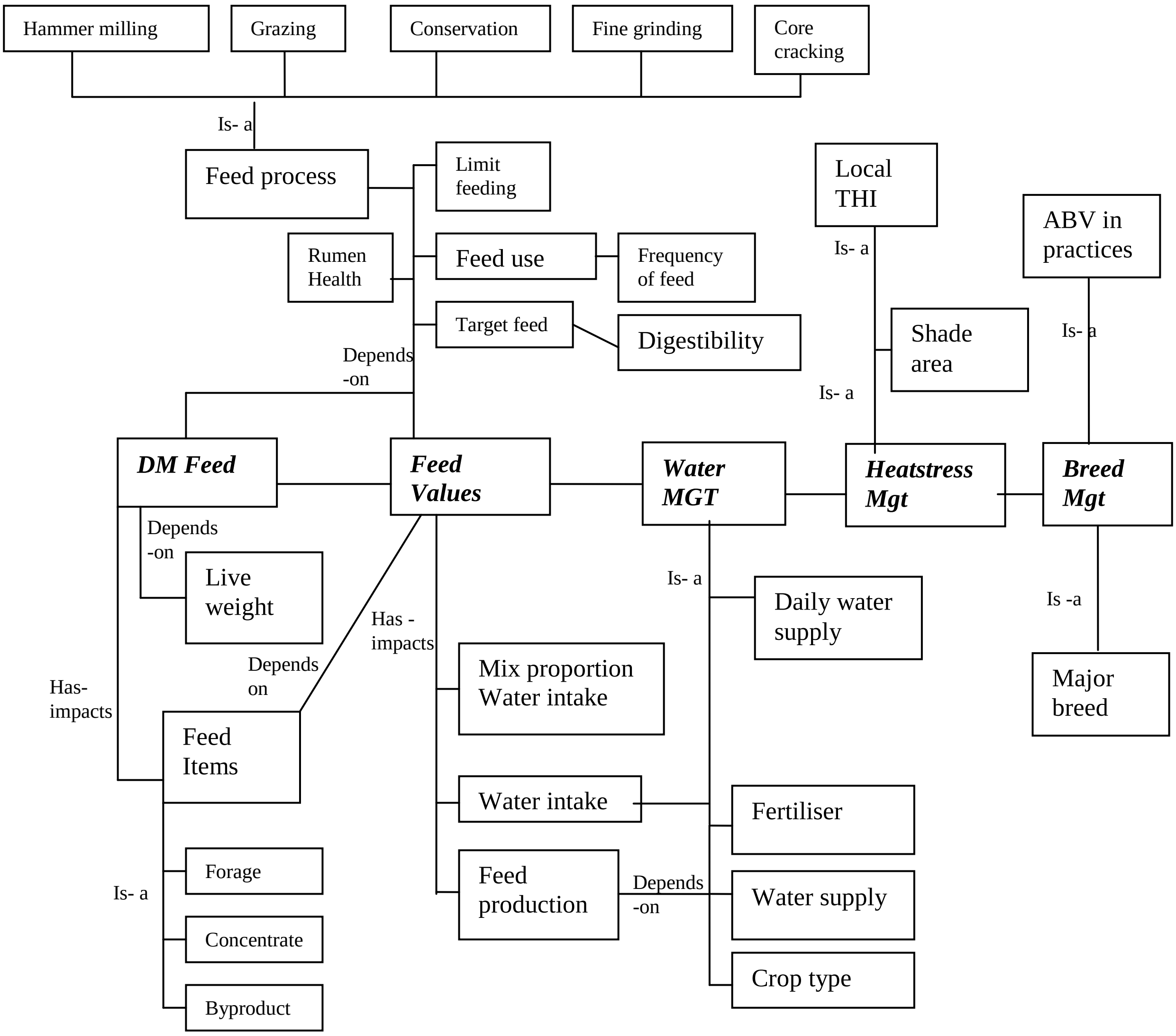

Figure 2: Generic knowledge model in the EUEDE

Figure 3 shows the knowledge base repository where the domain expert can acquire generic knowledge components from any intensive livestock business domain. The expert can select relevant parameters from the model or potentially add new ones as (for example) new science or different feedstuffs become available, and a DSS can then be dynamically generated using the range of parameters relevant to the task in question. In this figure, the acquired knowledge shows a complete knowledge base from the milk protein enhancement domain in the dairy as an example. An end user would select the parameters applicable to their own decision making and add farm relevant information, such as number of cows and diet details. Figure 4 shows a report generated from this information, indicating specific deficiencies for a particular farm, and related further advice and expert information can follow (Figure 5).

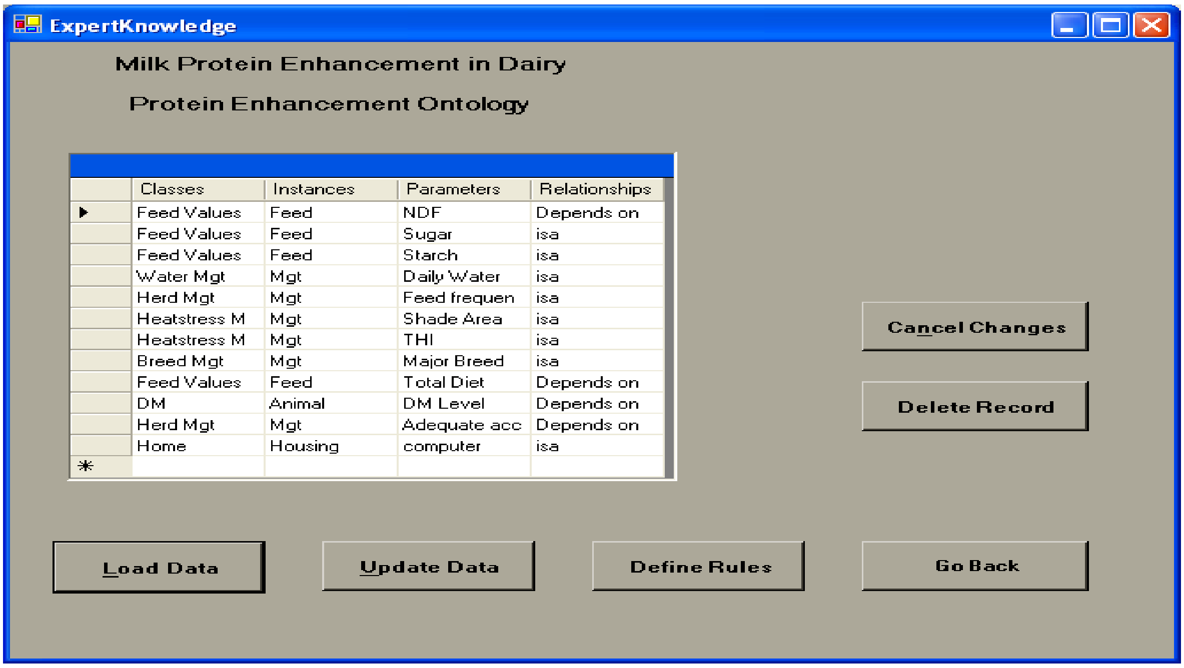

Figure 3: Knowledge repository in the EUEDE.

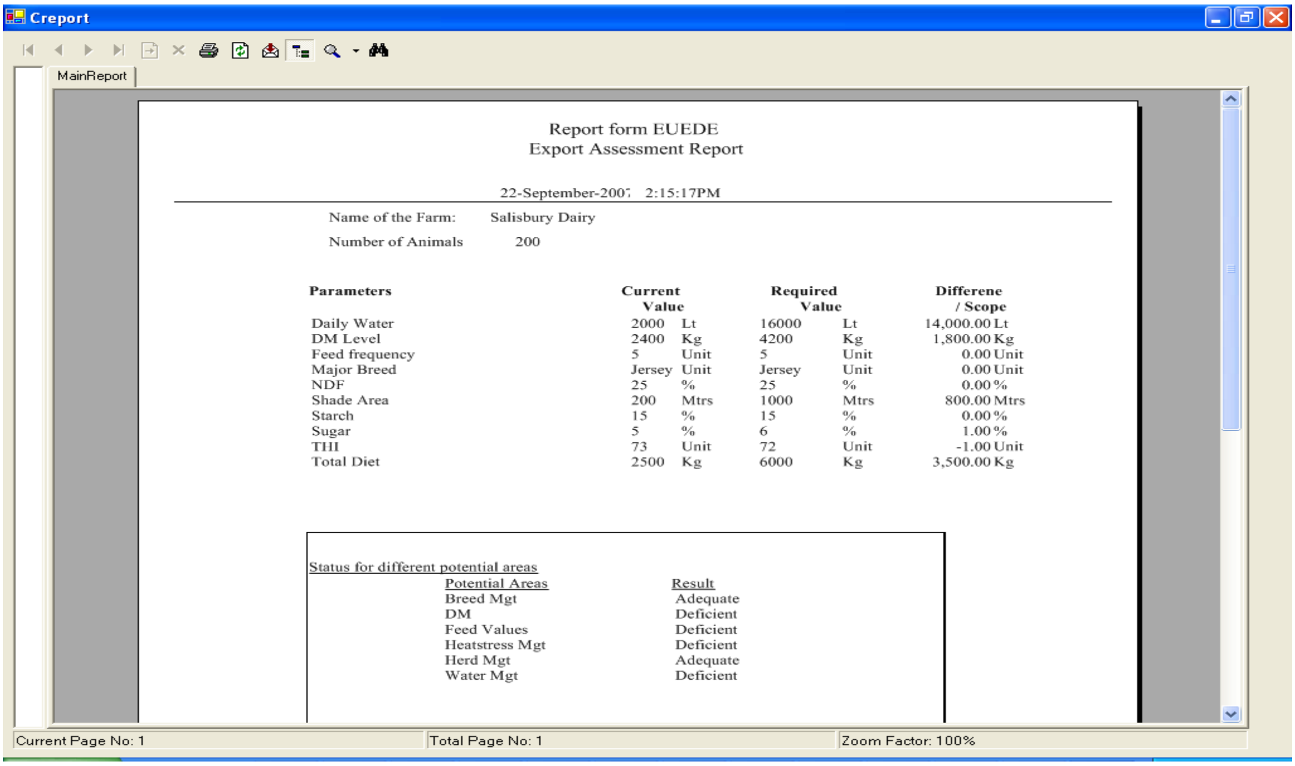

Figure 4: Overall assessment report produced from the dynamically built DSS in EUEDE

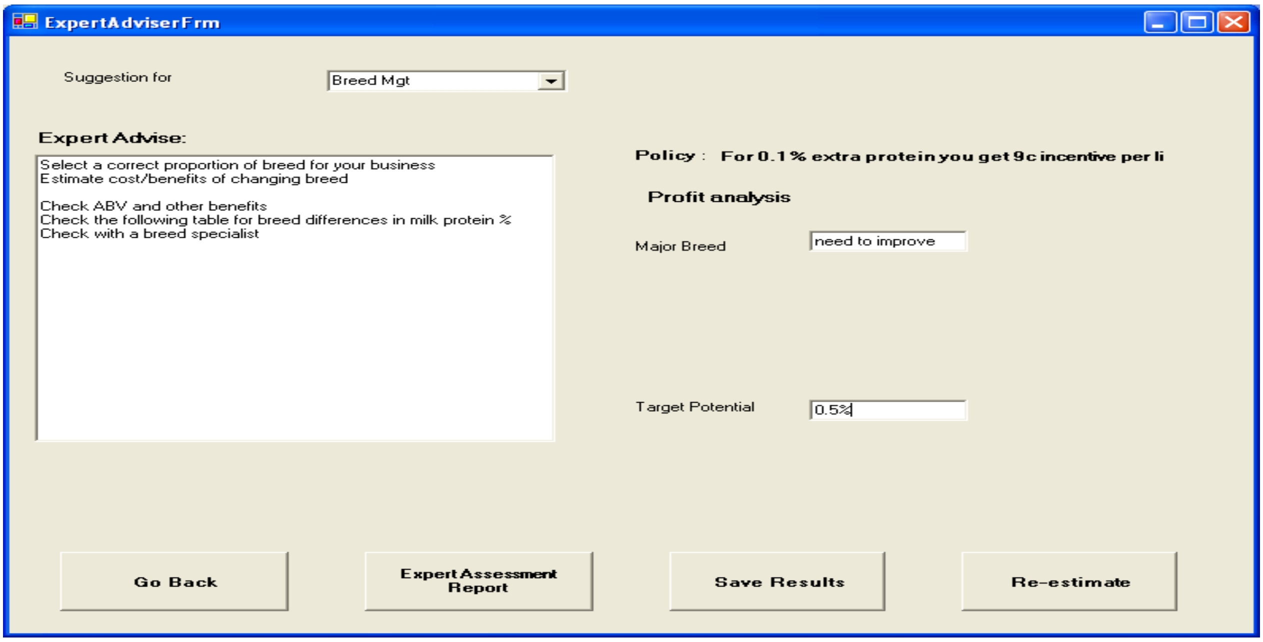

Figure 5: Specific outcomes from the developed DSS in EUEDE.

5.1 Rules creation

The main function here is the development of rules based on heuristic knowledge. The process involves simplifying domain knowledge into knowledge components using parameters that apply in to defining a farming situation. For example, dry matter intake (DM) is a factor that determines milk protein level. We use a bottom-up design method, as the decision-making rules need to be resolved first. The following is an example of one type of rules generation:

For the relationship: <u>is-a</u>

Required level = Estimated values input by domain experts

Where the required values are given by the experts

For the relationship: <u>depends- on</u>

*Required level = ratio * parameter*

Where required level = factors (changeable by domain experts) that determines output variable level

Ratio is any variable (changeable by domain experts) that determines relations (e.g 4% of body weight)

and Parameter is the decision making attribute variable (also changeable by domain experts)

In this way, specific farming knowledge is converted into a knowledge base for building decision support tools since it establishes meaningful relationships between factors and parameters within the ontology. This relationship defines the required level of the potential influencing factors that have impacts on rural business production. By differentiating between the required or optimal status (as outlined by experts) and the current status (as entered by farmers), a developed DSS can identify the scope for specific improvements, supplemented by expert suggestions and information. This uses the knowledge components at a reconfigurable and generic level, allowing them to be reused and shared in producing other specific DSS.

The decision outcomes are processed in terms of conventional IF-THEN rules, for example:

Condition 1

If current DM feed level >= required DM feed level,

Then

No scope for DM improvement

Condition 2

If required DM feed level > current DM feed level,

Then

Scope for improvement with potential protein enhancement of max 0.2%

In such conditions the system will calculate the deficient DM amount and make a specific recommendation

Table 4: Activity roles in the EUEDE system

Domain expert activities	**Farmers/business operators activities**
• establish a meaningful knowledge base in the adopted problem domain defined by domain experts as such extension professionals • identify specific parameters influencing a decision • specify relationships between the parameters and output variable levels • set up mathematical relationships for estimating required level in production to compare with current status	• tailor decision-making requirements to a farmer's specific farming situation defined by end-users such as farmers • allow farmer's own choice of parameters to selection • give farmers more specific expert outcomes on their current farming status

6. Knowledge acquisition and decision model

The aim of the knowledge acquisition approach was to simplify rural business domain knowledge into different building-blocks and store it into a central knowledge repository so that it could be used for DSS development. Figure 6 shows the knowledge acquisition process and associated decision support building. Domain experts extract the knowledge components such as business production goals and the factors relevant to achieving those. Subsequently, domain experts formulate the rules by defining the relationships and ratios among parameters. They also record the expert suggestions for each factor for use in reports displayed for the developed DSS.

To define the decision-making process, Figure 6 illustrates the generic decision process model from 'knowledge components into decisions in our proposed system. In the context of Precision Agriculture, Fountas et al. (2006) describe a general data-flow diagram to characterise farmers' decision-making process in information-intensive practices which was validated for several decision-making operations by both university farm managers and commercial farmers. Fountas et al.'s (2006) data-flow model was based on Skidmore's (1997) methodology for structured systems analysis and design for designing IS, while our data-flow model for decision making process was based on a practical decision making approach outlined in the industry best practice handbook (DPI, 2006) for milk protein management, which was used for farmers' decision making. In this approach, both knowledge and data inform decision as illustrated in the figure 6.

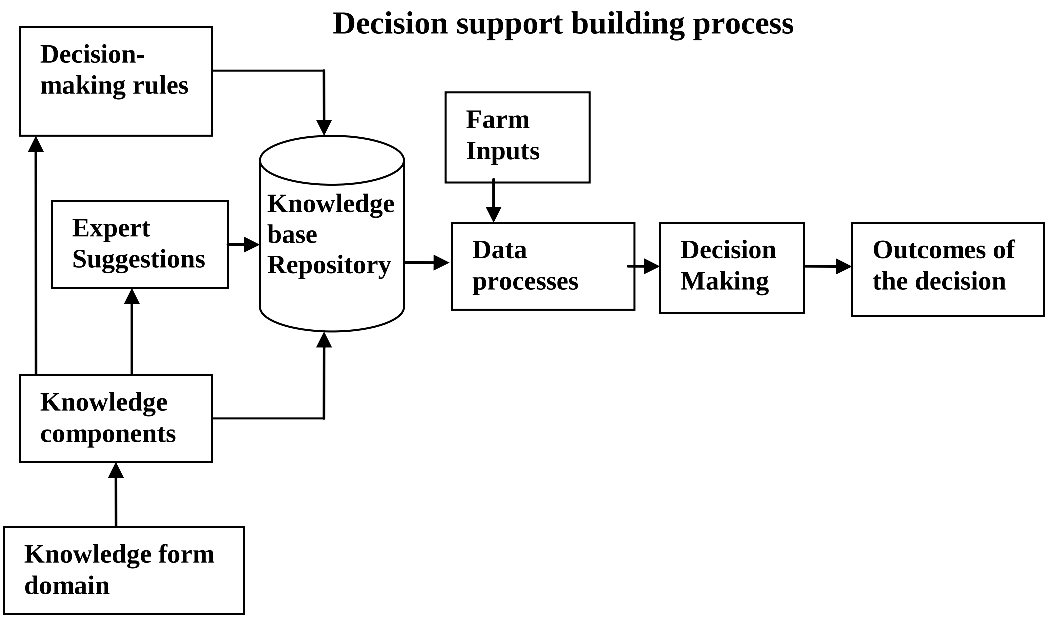

Figure 6: Knowledge acquisition and decision process model of EUEDE

7. Discussion and summary

The objective of this paper was to discuss an upgradeable knowledge model of the design environment which offers a straightforward method of rural business knowledge acquisition for building specific DSS. The paper reported the application of the rural business knowledge in the development of a new design environment called EUEDE where the business operators get assistance from domain experts in building their specific DSS. For instance, the goal was to explore dairy operational knowledge from a dairy expert's perspective since the EUEDE solution environment has been outlined from this knowledge. However, operational knowledge from any other rural industries can be used in this design environment by upgrading the reusable knowledge model. This facilitates a generic knowledge acquisition that is workable in any rural businesses. For outlining generic knowledge model, we examined some critical aspects that have impacts on the rural business potentials. For example, critical aspects that caused decreasing or increasing milk protein level in production from the practitioner's point of view, although many other aspects that could have great impact on protein concentrate in milk production were overlooked.

The proposed knowledge acquisition process in the EUEDE contributes to decision support tool development in rural industries by reducing technological constraints that appear as rigid options to end-users. This is caused by a great range of changing decision requirements and the need to use various rules of thumb in the rural sector that often might not be suited to traditional DSS design methodologies. The upgradeable provisions for the business operators can reduce the contrast between individual farming practice and the relevant technological actions. Earlier researches, such as in bioinformatics (Baker et al., 1999; Lambrix and Edberg, 2003), in World Wide Web design (Crampes and Ranwez, 2000; Liddle et al., 2003; Sunagawa et al., 2003) and medical informatics (Achour et al., 2001; Gennari et al., 2002; Musen, 1998) justified ontology development as an established and workable concept in effective knowledge modelling. Unlike other domains, we used the ontology development approach as a progressive way to model knowledge from the dairy operational domain, which was utilised for developing and delivering specific and target-relevant DSS because of its generic capability. Our developed ontology framework enables us to differentiate knowledge components from the problem domain and conceptualise them in a generic model, so that the relationship between the knowledge components could form the rules for decision making. These rules can be changed at any time depending on the domain expert's judgment (decision-making rules in terms of heuristic based estimation). This also reduces the complexity in mapping of functions to the system components in the developed DSS. In addition, as Hyland-Wood et al. (2006) suggested, ontology-based development could enhance capability of software maintenance.

Our proposed system could be easily maintainable because users hold options for mapping the knowledge components of system functions of the developed DSS.

The decision making aspect of the rural businesses such as beef cattle, or sheep industry are very similar with the dairy, because the potentials of the production also depends on the similar types of factors relevant with animal management or climate. For instance, the decision making rules associated with water supply in the dairy business could be applied to the beef cattle industry by changing the required amount of water for beef cattle. Therefore, to adjust the EUEDE within the other domain, we can change the name of the parameters, potential factors and the rules for decision making. For example, there are six main potential factors in dairy for the milk protein enhancement however; there are four main potentials for the beef cattle in enhancing the quality of meat (for example, breed management, heat stress management, feed management, and feed values). So, it is predicted that this EUEDE architecture could be utilised for building the DSS applications in beef cattle industry.

Acknowledgement

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References

Achour, S.L., Dojat, M., Rieux, C., Bierling, P., Lepage, E., 2001. A UMLS based knowledge acquisition tool for rule based clinical decision support system development, Journal of the American Medical Informatics Association, vol. 8, pp. 351-360.

Baker, P.G., Goble, C.A., Bechhofer, S., Paton, N.W., Stevens, R., Brass, A. 1999. An ontology for bioinformatics applications, Bioinformatics, vol. 15, pp.510-520.

Bally, J., Boneh, T., Nicholson, A. E., Korb, K. B., 2004. Developing an ontology for the Meteorological Forecasting Process, Decision Support in an Uncertain and Complex World: The IFIP TC8/WG8.3 International Conference, (Available at URL: http://vishnu.sims.monash.edu.au:16080/dss2004/proceedings/pdf/08_Bally_Boneh_Nicholson_Korb.pdf)

Cox, P.G., 1996. Some issues in the design of Agricultural Decision Support Systems, Agricultural Systems, vol. 52, pp.355-381.

Crampes, M., Ranwez, S., 2000. Ontology-supported and ontology-driven conceptual navigation on the World Wide Web, Proceedings of the eleventh ACM on Hypertext and Hypermedia, San Antonio, Texas, USA.

Dairy Research and Development Corporation-DRDC, 2003. Protein Plus: Improving dairy milk protein levels, CSIRO website, (Available at URL: http://www.csiro.au/index.asp?type=faq&id=Milk%20protein%20content&stylesheet=divisionFaq)

Dick, B., 2002. Convergent interviewing. Session 8 of Areol - action research and evaluation on line, (Available at URL: http://www.scu.edu.au/schools/gcm/ar/areol/areol-session08.html)

DPI, 2006. Protein Plus Check Book: A Guide to Increasing Milk Protein % and Profit, Department of Primary Industries and Fisheries, Queensland Government, Australia.

Fernandez, M., Gomez-Perez, A. & Juristo, N. 1997. METHONTOLOGY: From Ontological Art Towards Ontological Engineering, Presented to AAAI97, Workshop on Ontological Engineering, Stanford University, pp. 33-40.

Fountas, S., Wulfsohn, D., Blackmore, B.S., Jacobsen, H.L., Pedersen, S.M., 2006. A model of decision-making and information flows for information-intensive agriculture, Agricultural Systems, vol 87(2), 1 February 2006, pp. 192-210.

Gammack, J.G., Fogarty, T.C., Battle, S.A., Ireson, N.S. & Cui, J. 1992. Human Centered Decision Support: The IDIOMS System, Journal of AI & Society, vol. 6, pp. 345 – 366.

Gennari, J.H, Musen, M.M, Fergerson, R.W., Grosso, W.E., Crubezy, M, Eriksson, H., Noy, N.F., Tu, S.W., 2002. The evaluation of Protégé: An Environment for Knowledge Based systems development, available at URL: http://smi-web.stanford.edu/pubs/abstracts_by_author/Noy,N.papers.html,

Givens, D.I., Shingfield, K.J., 2003. Improving the nutritional quality of milk, In Dairy Processing, Improving Quality, pp.515-531, (G. Smit, editor) (Available at URL: http://www.chipsbooks.com/dairypro.htm)

Gunn, A., Sutcliffe, G., Walker, D., 1999. Knowledge acquisition for natural resources management, Computer and Electronics in Agriculture, vol. 23, pp. 71-82

Hyland-Wood, D., Carrington, D., Kaplan, S., 2006. Enhancing software maintenance by using semantic web techniques, International Semantic Web Conferences (ISWC) 2006, (available at URL: http://www.itee.uq.edu.au/~dwood/papers/SoftwareMaintenanceViaSemWeb.pdf)

Kendall, P.E., Nielsen, P.P, Webster, J.R., Verkerk, G.A., Littlejohn, R.P., Matthews, L.R., 2006. The effects of providing shade to lactating dairy cows in a temperate climate, Livestock Science. vol. 103, pp.148–157.

Kerr, D., 2004. Factors influencing the development and adoption of Knowledge Based Decision Support Systems for small, owner-operated rural businesses, Artificial Intelligence Review, vol. 22, pp.127-147.

Kerr, D., Winklhofer, H., 2005. The effect of rapid rural industry changes on the development of a decision support system for dairy farmers in Australia, Computers and Electronics in Agriculture, vol. 50, pp.61-69.

Lambrix, P., Edberg, A., 2003. Evaluation of ontology merging tools in bioinformatics, Proceedings of Pacific Symposium on Bioinformatics, vol. 8, pp.589-600.

Liddle, Stephen W., Hewett, Kimball A., Embley, David W., 2003. An Integrated Ontology Development Environment for Data Extraction, 2nd International Conference on Information Systems Technology and its Applications, National Technical University, Kharkiv, Ukraine, June 19-21.

McCown, R.L., 2002. Changing systems for supporting farmer's decisions: problems, paradigms, and prospects, Agricultural Systems, vol.74, pp.179 -220.

Morgan, D. L., 2002. Focus Groups as Qualitative Research, second edition, Sage Publications Inc, California.

Musen, M.A., 1998. Modern architectures for intelligent systems: Reusable ontology and problem solving methods, Proceedings of AMIA symposium, 46-52, (available at http://smi-web.stanford.edu/pubs/SMI_Reports/SMI-98-0734.pdf)

Parker, A., Woodford, K., Woods, E., 2000. Deregulation and restructuring in the Queensland dairy industry, occasional paper, 7 (2), school of natural and rural systems, the University of Queensland, Brisbane, Australia. vol. 7 (2), pp.1-28.

Pietersma, D., Lacroix, R., Lefebvre, D. Wade, K.M., 2003. Induction and evaluation of decision trees for lactation curve analysis, Computers and Electronics in Agriculture, vol. 38, pp. 19-32

Schingoethe, D., 1996. Dietary influence on protein level in milk and milk yield in dairy cows, Animal Feed Science Technology, vol. 60, pp.181-190.

Skidmore, S., 1997. Introducing Systems Analysis, MacMillan Press Ltd, Oxford, UK.

Sunagawa, E., Kozaki, K., Kitamura, Y., Mizoguchi, R., 2003. An environment for distributed ontology development based on dependency management. Proceedings of the 2nd International Semantic Web Conference (ISWC2003), pp. 453-468.

Wagner, C. 2002. End Users as Expert System Developers?: Journal of End User Computing, vol. 12, (3), pp.3-9.

Walker, D.H., Johnson, A.K.L. 1996. Delivering flexible decision support for environmental management: a case study in integrated catchment management, Australian Journal of Environmental Management, Vol. 3 (3), pp, 174-188

Walker, G.P., Dunshea, F.R., Doyle, P.T., 2004. Effects of nutrition and management on the production and composition of milk fat and protein: a review, Australian Journal of Agricultural Research, vol. 55, pp.1009-1028.

Walker, G.P., Stockdale, C.R., Wales, W.J., Doyle, P.T., Dellow, D.W., 2001. The effect of level of grain supplementation on milk production responses of dairy cows in mid-late lactation when grazing irrigated pastures high in paspalum, Australian Journal of Experimental Agriculture, vol. 41, pp.1-11.

White, C.L., 2001. Factors affecting milk protein concentration in Australian dairy cows, Australian Journal of Dairy Technology, vol. 56, pp.153.