Industrial Decision Support System (IDSS) in Weed Control and Management Strategies: Expert Advice Using Descriptive Schemata and Explanatory Capabilities

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Abstract— This paper details the implementation of an industrial decision support system (IDSS) application to provide expert advice on weed control and management strategies. Due to the qualitative and subjective nature of the strategies, output based intensively on conventional and numerical data poses a level of complexity that can hinder stakeholders from interpreting the data and applying the results effectively to the problem area. To overcome this, the IDSS application employs descriptive schemata and self-generated explanations.

I. INTRODUCTION

Parthenium weed (*Parthenium hysterophorus* L.) infestation has demonstrated the ability to cause significant environmental, health and financial problems if not managed properly in areas occupied by agricultural industries. Its rapid spread has covered 170,000km² (10%) of Queensland, Australia [1]. Economically, the uncontrolled spread of parthenium weed¹ has the potential to cause losses of A\$109-129 million annually [2]. One of the primary steps taken to curb this infestation is by providing expert advice on the best control and management strategies to stakeholders concerned. This paper will investigate the design of an industrial intelligent decision support system (IDSS) application that uses descriptive schemata and explanatory capabilities (discourse semantics) to provide expert advice in the area of parthenium weed control and management strategies.

II. IDSS FRAMEWORK

In this specific application, the IDSS knowledgebase can be composed of data types originating from sources as diverse as geographical information system (GIS), human experts, anecdotal references, graphics, multimedia, and databases [3-5]. With such diversity and variant, the IDSS poses an atypical challenge in the design and development of the framework. The challenge is to incorporate innovative intelligent software methodology to complement existing technology to fulfill the necessary requirements. [6]. The

framework is referred to in Fig. 1 which comprises the following subsystem components which has been detailed in [7]:

- **Editor Layer.** Var-function editor and If-Then rule editor components.
- **Data Layer.** Knowledgebase component.
- **System Layer.** Fuzzifier, inference engine and meta-consequent function components.
- **Input Layer.** Input user interface component.
- **Output Layer.** Singular and/or multiple output and explanation components.
- **Discourse Layer.** Discourse semantics and explanation components.
- **Real-World Layer.** Data originating from knowledge external to data layer.

The IDSS within this framework is essentially a hybrid meta-fuzzy expert system incorporating meta-fuzzy logic, explanatory capabilities and industrial process models, process procedures and regulatory constraints. The knowledgebase is composed of human experts' knowledge of existing practices, as well as regulatory procedures and established dynamic models describing the application process. The integration of such component can result in the following features:

- **Layered component architecture.** Each component of the expert advisory system is designed as individual modules to facilitate ownership, security, accountability, maintainability, upgradeability, adaptability and flexibility.
- **Fuzzy meta-consequent post adjustment.** Adaptation of fuzzy consequent to requirements of local trend and exception handling.
- **Explanatory capabilities (Discourse semantics).** Provision for explaining and justifying the outputs provided by the IDSS application.
- **Descriptive schematics.** Enables extensive numerical data of an output to be presented descriptively using schematics.

¹ * 'Parthenium weed' is always referred to by its complete name in both literature and actual practice.

Fig. 1. Industrial decision support systems (IDSS) framework with subsystem components to provide explanatory capabilities and descriptive schematics.

Layered component architecture and *fuzzy meta-consequent post adjustment* have been previously disclosed in [8-11]. This paper will detail the *explanatory capabilities* (*discourse semantics*) and *descriptive schematics* of the IDSS.

III. FOUNDATIONS FOR DESCRIPTIVE SCHEMATA AND EXPLANATORY CAPABILITIES

The majority of current DSS applications in agriculture provide recommendations and advice to end users in quantitative format [12]. Its usefulness is limited as end users must undertake conscious effort to 'interpret' these results. Previous research has indicated that computerized solutions provided by expert systems accompanied by an explanation or justification can make these recommendations more acceptable to end users [13-16]. In addition, descriptive recommendations of expert systems using qualitative symbols or schemata to describe its outcome can facilitate comprehension as compared to numerical-only data. It has been shown that end users require data to be charted or graphically presented to facilitate better understanding [17].

Due to the hybrid nature of the knowledgebase data types, an explanation may not necessarily be implemented in a primarily textual context. Hence, to handle all data types, the discourse semantic module in the IDSS application is implemented as: A. Discourse using textual semantics, and B. Discourse using descriptive schemata and multimedia.

A. Discourse Using Textual Semantics

The conventional explanatory function often involves format in purely textual context in a conversation-interaction

manner (i.e. printed English text). The theoretical base for explanation function in conventional expert systems and its construction is explained by [13]. In the specific objectives of the proposed IDSS application, it is practical to extend textual explanations in conjunction with other forms of expression as part of its functionality.

B. Discourse Using Descriptive Schemata and Multimedia

In addition to textual semantics, the IDSS application should also be required to explain its inferential process using non-textual presentation. The challenge arises from the fact that in some application (e.g. spatial expert advisory systems) knowledgebase is composed of data types ranging from GIS datasets, graphics, video clips, pictorial and audio clips. Therefore, a provision is made to include multimedia and descriptive data types using symbolics or schemata into its explanatory capabilities.

IV. METHOD AND IMPLEMENTATION

A. REST3 Method

In order for the IDSS application to gain explanatory capabilities, the REST3 (Rule Explanation for Expert Systems Using Service Tags, Tables and Tracing) technique has been designed and developed specifically for this task. Fundamentally, the mechanics of REST3 employ the use of service tags to keep a linear rule trace of all relevant If-Then rules that have instantiated as a result of an ongoing inferential process. All rules in the knowledgebase have a tag appended to each completed If-Then statement. These tags do not influence nor play any part in the inference process of the system. Its primary purpose is only to provide a pointer to the tables used in REST3. These tables will hold all relevant discourse material that will subsequently be consolidated to provide the explanation and justification for the final recommendation.

A simplified example of the linear rule tracing process is as follows. In Fig. 2, if three rules fires as a result of an inference process (e.g. rule 134, 226, and 076), the service tags of these rules will be written to the *Active Table*. However, noting that rule 226 has a service tag property of 000 (i.e. not all rules have an associated discourse or explanation), indicating that it has no discourse function, it is thus omitted from the table. In each tuple of the Active Table, we further note that rule 134 has a DOF 0.35 and a discourse threshold of 0.50. The threshold allows end users and knowledge engineers to specify to what degree an If-Then rule fulfils the membership criteria of a fuzzy membership before it qualifies as part of the discourse process. This prevents information overload from having to explain every rule that has fired.

Fig. 2. *REST3* (Rule Explanation for Expert Systems Using Service Tags, Tables and Tracing) method to facilitate explanatory capability in the IDSS framework.

In this example, rule 134 ($\text{DOF } 0.35 < 0.50$) is not considered integral to the final discourse, hence the linear trace for this particular rule terminates at this point. However, rule 076 ($\text{DOF } 0.63 > 0.50$) would initiate a further pointer to the *Discourse Table*. This table holds the discourse to every rule that has a service tag other than 000. All discourse semantics are in full-textual sentences. In some cases, a discourse may contain further details in the form of media files. This is indicated by its *Media Tag*. In the instance of rule 076, it has an *Exception Service Tag*. In most cases, explanation for a final recommendation is needed to justify an output that has been superseded by an external input (i.e. meta-consequent). In the presence of such an occurrence (i.e. rule 076 BUT 045), this would initiate a

pointer to the *Exception Table*. Similar to the *Discourse Table*, this table holds the discourse to every exception as a result of a simple-consequent or a multi-consequent application. This rule exception 045 has a further property of a *Media Tag* that indicates it has an associate video (in the *Media Table*) file that can further support the explanation. At the end of the linear trace process, all tables with active tuples are consolidated in the *Discourse Proforma*. This proforma provide a standardized and formal structure to allow output formatting by different output or linguistic processor (i.e. GUI or NLP processors).

B. Descriptive Schemata

Fig. 3. Descriptive schemata as a result of a defuzzifying process involving If-Then-Case-Of meta-consequent post adjustment functions introduced in [10]. Note at each inferential phase, the REST3 are generated at A, B, C and D.

Descriptive schemata are generated as a series of symbols. These symbols will inherently provide qualitative data to represent numerical data that has been defuzzified as a result of a previous inferential process as in Fig. 3. In this example, the original input values are $x_1, x_2, \dots, x_n$ into the fuzzy RHS consequent membership values. The appropriate rules will fire, therefore generating the final composite consequent, $y_1, y_2, \dots, y_n$, for each of the fuzzy degree-of-fulfillment (DOF). At this junction, instead of a final defuzzified value, the value is mapped against the appropriate schematics. Also note that every instantiation of rules within the system will generate a REST3 tag file at points A, B, C and D. This implementation uses the fuzzy meta-consequent post adjustment functions described previously in [7, 8, 10].

There are three types of schematics applied to the IDSS application in control and management of weeds. These are type *S*, *T* and *A*. Each respectively represents *control strategy*, *confidence threshold* and *directed action*. These schematics have been adapted and extended from [18]. The symbols and its purpose will be explained in later sections. In this way, complex advice such as, "Contain the known infestation to within the boundaries of matured plants allowing it to spread within its own habitat, but do not allow it to spread across the boundary", can be conveniently expressed. Conversely, a similar output using conventional numerically based data would have been complex and cumbersome.

C. Implementation

The functional construct of the explanatory capability and descriptive schemata are as in Fig. 4. From the previous point A, B, C and D, these tags are fed into the REST3 subsystem to generate the explanation (discourse) for the preceding inferential process shown in Fig. 3. As a result of

this, each symbolic output will be associated and accompanied by an explanation or justification.

V. TEST RESULTS

The functionality of the IDSS application was tested by applying its inferential process to a 50 x 50 meter site that has been identified as having patches of parthenium weed infestation (Fig. 5). The critical sectors (i.e. areas of known infestation) are delineated with a border. In Fig. 5, four sectors numbered 1 to 4 have been identified. For each of this sector, the IDSS application will provide appropriate advice on how to control and manage the known infestation. The expert advice is provided in the three types of descriptive schemata and explanation in the following sections.

A. Type S: Control Strategy

Each control strategy schematics has an inside and outside region designated by a boundary (i.e. circle). The lighter shade of green in any of the two regions indicates the original weed density. After implementation of the suggested control strategy, any increase in density of the population is indicated by a darker shade of green. Complete eradication or reduction to a very low or minimal density is indicated by the absence of any shading. The final output of the control strategy type is shown in Fig. 6. Here, the expert advice for the appropriate control strategy for sector 1, 2 and 3 are type *eradication* and for sector 4, type *containment*, has been inferred. For further variant of

Fig. 4. The subsystem structure detailing the discourse semantics component that provides explanatory capability in supporting descriptive schemata. Note the tags of A, B, C and D resulting from Fig. 3.

schematics for weed and management control strategies, refer to [18].

Fig. 5. Zone G, known site of parthenium weed infestation. Isolated patches of critical zones are delineated with a border.

B. Type T: Confidence Threshold

In addition, each control strategy schemata is complemented by an impact meter to indicate the *confidence threshold*. This meter provides the confidence level required by stakeholders to ensure that the expert advice provided by the IDSS application is sound or unsound against the control strategy's predicted effectiveness if it were to have actually taken place. Darker shade readings indicate that the effectiveness of the control strategy is *guaranteed*. The lighter shade indicates a *probable* level of effectiveness.

The schematic for confidence threshold is only meaningful when associated with the relevant control strategies inferred previously for each of the critical sectors in Fig. 6. The threshold for critical sector 1 can be guaranteed to be up to 75% effective. As for sector 2, the threshold is a high 90-100% effectiveness. Referring to Fig. 5, critical sector 2 is a smaller area and due to its smaller area of coverage, a control strategy will have optimal and better impact as correctly

Fig. 6. Control strategies (1, 2, 3: Eradication; 4: Containment) provided by the IDSS application, with corresponding confidence threshold for each of the relevant critical sectors.

inferred by the IDSS application. Critical sector 3 shows a relatively more concentrated weed density and mature plants. This accounts for a lower potential impact of 50-75% effectiveness.

For critical sector 4, the control strategy is *containment* in weed density. Protected fauna is found in this sector (not shown in the figure). Therefore, a general knock-down herbicide cannot be applied which can result in the accidental eradication (due to overspray and spillovers) of the protected fauna and other tolerated species in the same sector. Instead, the suggested action is manual weeding (see next section on directed actions). This would ensure that weeds are selectively removed. However, due to the economic viability and practicality of such an action, its potential impact is guaranteed at only 50% effectiveness. And at the same time, since the control strategy is for containment as opposed to eradication, that is, it is easier to allow the plant to grow within the habitat than to remove it, it may have a probable 100% effectiveness as a result of the control strategy.

C. Type A: Directed Actions

Recommended actions uses a different set of symbolic schematics to indicate *how* an action is to be taken based on the control strategy. As the recommended actions to be taken (e.g. boom spraying or crop dusting) can involve large scale application, this cannot be carried out arbitrarily even if the impact meter indicates a very high level of effectiveness. Weeds have a tendency to disperse in all directions, and often more so in one or two directions than any of the others. Note that a control strategy and actions taken to implement the strategy are factors that are mutually exclusive. An optimal control strategy does not necessarily guarantee a high level of success if a less appropriate action has been taken to implement it. Therefore, the application of each action needs to be indicated directionally to maximize the effectiveness of the control strategy and its combined actions. To simplify the representation of the recommended actions and to maintain the symbols at a practical and useable level, approximation of the total numbers of existing propagules along each compass direction or particular arcs around the infested location is taken into account, while ignoring distances. For example, in Fig. 7, the schematics for sector 2 indicate that the actions should be primarily concentrated on the eastern and western directions with particular focus on the southern zone of the infested area to maximize the effectiveness of the action taken.

The IDSS application employs directed action schematics in conjunction with textual instructions and explanations (with appropriate media, if available) to indicate what actions to take (Fig. 7). For critical sectors 1, 2 and 3, identical actions have been provided. The IDSS has the benefit of referencing detailed databases which can be reproduced in verbatim. In this example, a list is simply reproduced as part of its *explanatory capabilities*. As for critical sector 4, the directed actions are to be applied to the entire sector with explicit instructions *not* to take any actions (i.e. herbicide application).

VI. DISCUSSION

The results above demonstrate that the IDSS is capable of providing expert advice on strategies to control and manage weeds. Its results are enhanced and made more

Fig. 7. Direct actions for each critical sector. Note the first three instructions (1, 2, 3) are database listing while 4 is an explanation.

comprehensible by employing descriptive schemata and self generated explanations. In the event that a stakeholder were to adhere to the expert advice given by the IDSS application, in the absence of human experts' advice, the resulting outcome of the decisions would be totally acceptable in actual practice.

VII. FURTHER WORK

Work in progress is currently being carried out to introduce these techniques to different type of industries (e.g. energy, digital entertainment), incorporating different types of schemas specific to the problem.

VIII. SUMMARY

This paper has presented an industrial decision support system (IDSS) framework to show that in applications requiring descriptive in lieu of numerically based output, it can successfully employ descriptive schemata and explanatory capabilities. These features can help facilitate comprehension and better interpretation, and the subsequent application, of the expert advice as perceived by the stakeholders.

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