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Development of a Decision System to Aid Project Managers in Determining Information Technology Project Status

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***Abstract*—In the project management environment, it is critical to know how the project is performing from the viewpoint of scope, schedule, cost, and other constraints. One source reports that 70% of IT-related projects do not meet their objective [1]. This paper builds on prior efforts to develop a collaborative agent decision system that aids in recommending the status of a project using color indicators (Red, Yellow, Green) that are based on the progress and standing of the project-related constraints. Progressions in the research, such as knowledge acquisition activities conducted with subject matter experts (SME) to acquire project management domain knowledge, and efforts to incorporate fuzzy logic into the decision system, are discussed.**

***Keywords*—project management, R-CAST, knowledge acquisition, decision support system**

I. Introduction

Despite the advancements that form today's technology and modern processes and practices, negotiation of the many steps involved with successfully managing a large project is extremely difficult. Information technology projects seem to be particularly hard to manage; it has been reported that 70% of all IT-related projects do not meet their objectives [1]. Maintaining visibility of the status for large, complex projects is of major importance [2].

A Project Manager assumes the lead role in managing a project. Managing a project includes identifying requirements; defining clear and attainable objectives; balancing the competing demands for quality, scope, time, and cost; and adapting the specifications, plans, and approach to the distinct concerns and expectations of the various stakeholders. Projects are sometimes divided into lifecycles that help with scheduling, managing and controlling them. [3, 4]

There are many variables that factor into the decision for project status. These include the input from the team experts; information regarding the project's constraints of scope, schedule, cost and performance; and other environmental contexts. Accounting for all of these variables increases the complexity of the decision facing the project manager. According to [5], the human mind cannot perform a successful decision analysis in situations that are characterized by a large number of decision variables. It has also been discovered that if a decision maker is given more than four facts then the quality and speed of his decisions are reduced [6]. The project manager can employ decision support system technology to assist in the decision-making process.

In this research, we have employed the Recognition-primed Decision-making enabled Collaborative Agents for Simulating Teamwork (R-CAST) architecture to serve as the foundation of a decision system to aid in the status decision of an information technology project. As presented in [7], experiments have shown that the R-CAST architecture has the capability to reason over knowledge related to the project management domain and suggest a status of the project by denoting a Red, Yellow, or Green color indicator that is based on the state of the project management environment variables.

The remainder of the paper is outlined as follows: introduction to R-CAST; discussion of efforts made to populate R-CAST with project management knowledge; conclusion; and future work section.

II. R-CAST: The Framework of the Decision System

The evolution of research in the field of decision support systems (DSS) has allowed the emergence of such systems to assist specific types of decision makers faced with specific kinds of problems. Research that is characteristic of DSS often focuses on how information technology can improve the efficiency with which a user makes a decision and can improve the effectiveness of that decision. [8, 9] R-CAST is an example of a decision system that can aid specific types of decision-makers. Through its application as a decision aid in the military domain toward battlefield simulations, R-CAST has shown to yield benefits associated with: 1) integrating team intelligence, 2) the ability to provide a flexible solution to develop decision aids for supporting human decision making under time pressure, and 3) the ability to act as a virtual teammate to human members in rigorous information and knowledge exhaustive domains [10, 11].

R-CAST, developed at The Pennsylvania State University, is a "team-oriented cognitive agent architecture built on top of the concept of shared mental models (SMM) in team cognition,

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the theory of proactive information delivery, and Klein's Recognition-Primed naturalistic decision model" [11]. According to [12] R-CAST was developed "to study (a) high-level cognitive behaviors such as adaptive decision-making and planning, and (b) team behaviors such as collaboration and information sharing."

In the R-CAST architecture, a knowledge base (KB) component exists that allows the declaration of variables and rules that are relative to the context of the environment. There is also an experience knowledge base component (EKB) that stores experiences, or cases, that aid in problem solving within the domain. Detailed information about the R-CAST components can be found in [12].

In this work, we are concerned with using the R-CAST architecture to develop a collaborative agent system that will recommend the status of a project. More specifically, we intend to design, develop and demonstrate a system using the R-CAST architecture that can make a relevant and accurate recommendation of project status (Red, Yellow, or Green) after reasoning over a knowledge and experience knowledge base that is related to the context of a situation in a project management environment.

III. Discussion: Populating R-CAST with Project Management Knowledge

In this section, we present current efforts to remove the military knowledge from the R-CAST KB and EKB with the goal of populating them with project management domain knowledge. Next, the first knowledge acquisition (KA) iteration to acquire this knowledge is discussed. A second KA iteration, which focuses on incorporating fuzzy logic into the research, is discussed later.

A. First KA Iteration: Preliminary Subject Matter Expert (SME) Interviews

In our endeavor to attain project management knowledge, interviews were conducted with 10 professionals serving as SMEs in the project management domain. For this research, a professional was considered an SME if he is Project Management Professional (PMP) certified. Our premise is that a professional can be considered proficient in project management concepts and methods if they have earned this certification. More information about the PMP certification can be found on the Project Management Institute website [13].

To facilitate the interviews, 3 information technology project management oriented cases were created along with an accompanying project schedule and Gantt chart that was produced using the Microsoft (MS) Project tool. Specifically, the 3 cases were developed to represent each of the possible project status decisions: Red, the project is at risk for not being completed on-time or on schedule; Yellow, where the project is at risk but it is possible to bring it back on schedule; and Green, where the project is on schedule and there are no immediate high impact risks that can degrade the project's performance.

The purpose of using cases for the interviews was to observe the reasoning process of the SME as they referenced prior experiences to arrive at a Red, Yellow, or Green project status decision for the case. The idea is that the observations will be used to develop a case that takes into account some of the project's information (status of project team resources, actual budget spent, and the like) that the SMEs identified as being pivotal for a project manager to know when deciding on the status of a project. The observations will also be used to develop a case that is tailored to fit into the configuration of the R-CAST architecture. A more detailed description of the intent and structure of the cases used during the first KA iteration can be found in [7].

1) Preliminary Interview Results: As shown in Fig. 1, for each of the scenarios, the status decision reached by the SMEs was not a unanimous choice. In the cases of Scenario #2 (where the expected outcome is Red) and Scenario #3 (where the expected outcome is Green), 70% of the SMEs concluded that the project status was 'Red' and 'Green', respectively. (Note: The 'Other' category in Fig. 1 for Scenario #3 reflects that one SME did not provide a status classification.) Interestingly, in the case of Scenario #1, where the expected outcome is Yellow, only 40% of the SMEs concluded that the project was 'Yellow' and 50% of the SMEs concluded that the project was 'Red'.

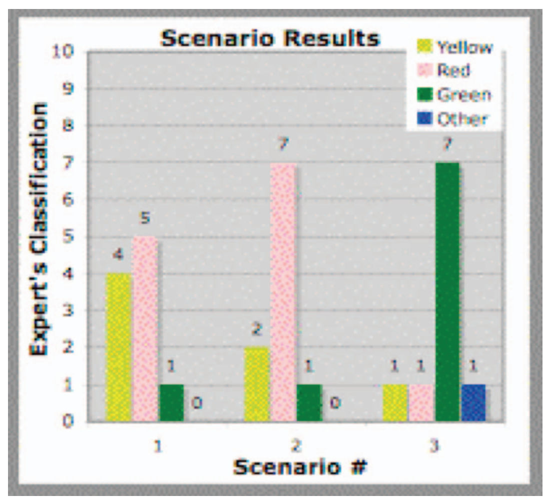


Figure 1. Results of preliminary interviews (first KA iteration).

From the results, we can infer that the SMEs were fairly consistent in diagnosing the project status when the expected outcome was Red or Green. However, in the case of a Yellow project status, there was more inconsistency present. When visualizing the range of Green-Yellow-Red, there is less doubt in the instances where the project can be categorized near the ends of the range (i.e., Green or Red). On the other hand, there is more ambiguity in determining the status when the outcome falls on the borderline of two status indicators. The goal of this research is to use R-CAST to handle the uncertainty and ambiguity that a project manager can experience when determining the status of the project.

In an effort to manage this uncertainty, it was decided to incorporate fuzzy logic into the research to determine the range of the Red, Yellow, and Green status indicators by inferring how the state of a combination of environment variables (i.e., scope, schedule, cost) will influence the project status. The description and result of the fuzzy logic interview scenarios are presented in the next section.

B. Fuzzy Logic Interviews

The second iteration of knowledge acquisition with the SMEs is concerned with incorporating fuzzy logic concepts into the research to assist with managing the uncertainty in determining the status of a Yellow project. Fuzzy logic joins language and human intelligence together by using mathematics to construct models that approximate related elements whose relationship can be characterized as uncertain or vague [14]. Fuzzy set theory provides a formal system for representing and reasoning with uncertain information. Lotfi Zadeh formally defined fuzzy set theory in 1965 [15]. He extended traditional set theory by changing the two-valued indicator function to a multivalued membership function. The membership function assigns a "grade of membership," ranging from 0 to 1 inclusive, to each object in the fuzzy set. Zadeh formally defined fuzzy sets, their properties, and various algebraic operations on fuzzy sets. In a later paper [16] he introduced the concept of linguistic variables, which have values that are linguistic in nature (i.e., height = {tall, medium, short}).

The primary use of fuzzy sets in this research is related to the concept of dividing a domain into a group of overlapping classifications. Each of the classifications is a fuzzy set; together they represent a decomposition of the domain. An element in the domain has some grade of membership, from 0 to 1 inclusive, in each fuzzy set within its domain. The grade of membership is determined by a function called a membership function; the shape of the fuzzy sets used in the domain decomposition basically determines the membership function.

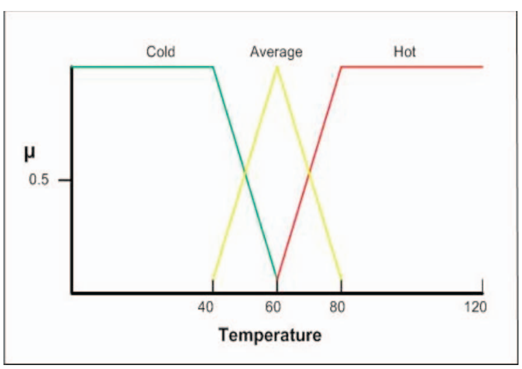


Figure 2. Example domain decompositions.

In Fig. 2, the membership value is shown on the y-axis and the values contained within the domain "Temperature" are shown on the x-axis. The domain "Temperature" over the range 0 to 120 is decomposed into three fuzzy sets: Cold, Average, and Hot. A "Temperature" value of 30 would have membership = 1 in fuzzy set Cold and membership = 0 in both the Average and Hot fuzzy sets. A "Temperature" value of 50 would have membership = 0.5 in both the Cold and Average fuzzy sets and membership = 0 in the Hot fuzzy set.

The use of fuzzy set concepts in the knowledge acquisition process was aimed at modeling, for the experts, that the categories of Green, Yellow, and Red could be interpreted as fuzzy sets over the cost/scope/schedule domains. This decomposition actually represents two key ideas. First, the change from one category to another is gradual. That is, there is a point where cost/scope/schedule is definitely in one of the categories (say, Green for instance) but as the value of the associated attribute pushes the status toward an adjacent category (in this example, Yellow) the membership in the original (Green) category gradually decreases (versus changing from 1 to 0 as a step function).

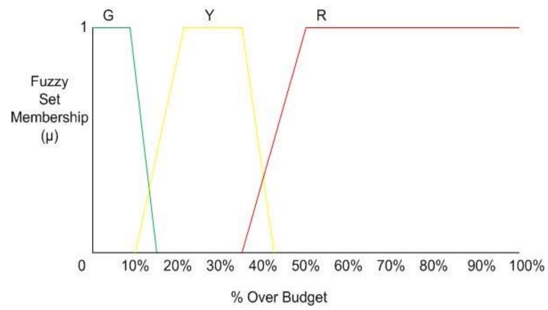
The second concept is related to trying to define the ranges in which an attribute could be classified into the three categories. Part of the uncertainty associated with judging whether a project is Yellow or not might be related to the difficulty in deciding where an attribute "suddenly" changes from Green to Yellow (and vice versa), or Yellow to Red (and vice versa). By modeling the domains of cost/scope/schedule as decompositions of overlapping fuzzy sets, it might be easier for the experts to provide, and agree upon, the ranges of the fuzzy sets (as opposed to the ranges of the crisp sets where there is no concept of gradual change).

Similar to the first iteration of interviews described in the previous section, one case with an expected outcome of Yellow was created for use in observing the SME's reasoning process. Also, various fuzzy exercises with the intent of identifying ranges for a Red, Yellow, and Green project with respect to the scope, schedule, and cost were developed. The remainder of this section will focus on the intent and results of the fuzzy exercises.

1) Fuzzy Logic Exercises: The fuzzy exercises were developed with the intent to use this information to model the condition of the scope, schedule, and cost constraints by identifying crisp [14] values that will be used to approximate fuzzy ranges. The idea is that modeling the condition of the constraints will provide an idea as to where the constraint can be classified within the Red, Yellow, and Green ranges at any point during a project. From the acquired SME knowledge, we will be able to infer fuzzy rules for the decision system [17].

Fig. 3 depicts a fuzzy set decomposition of the "over budget" domain. The intent of this decomposition was to provide a starting point for the SMEs to reason about how to classify (that is, set the endpoints of the fuzzy sets to signify) a project as Green, Red, or Yellow when considering how much the project is over budget. The basic assumption is that a project is Green and Red if it is 0% and 100% over budget, respectively. In Fig. 3, a project is considered Green if it is a member of the range of being 0% – 18% over budget; Yellow if it is in the 10% – 42% range; and Red if it is 35% - 100% range. The goal of the exercise questions in this example is to find out if the SME agrees with the assumed Red, Yellow, and Green ranges that the researchers defined or if modifications to the ranges are necessary. In questions (a), (c), and (e), the

SME is asked, respectively, to identify the range of a Green, Yellow, and Red project with respect to the cost being over budget. Questions (b), (d), and (f) request the SME to identify the subset of the indicated range where the membership into the set is 1. The information collected from the questions will be used for translation in the EKB of the R-CAST decision system to aid in determining the status of an information technology project.



The figure above depicts a fuzzy set decomposition of the "over budget" domain.

The assumption used for the questions below is that the project has a fixed budget.

a) In general (at any point during the project), with respect to the percentage (%) over budget, what % range characterizes a GREEN project?

b) In this range, where is the project exclusively GREEN?

c) In general (at any point during the project), with respect to the percentage (%) over budget, what % range characterizes a YELLOW project?

d) In this range, where is the project exclusively YELLOW?

e) In general (at any point during the project), with respect to the percentage (%) over budget, what % range characterizes a RED project?

f) In this range, where is the project exclusively RED?

Figure 3. Knowledge acquisiton exercise to elicit Over Budget fuzzy range values.

The above example fuzzy exercise was only one of the four exercises that were conducted during the second iteration of knowledge acquisition activities to acquire fuzzy range data. While size constraints preclude an in-depth discussion of all four exercises, it should be noted that they all produced similar results. As such, the results from the above Over Budget exercise will be discussed in detail as a representative sample.

2) Initial Fuzzy Logic Interview Results (% Over Budget Fuzzy Exercise): The initial interviews using fuzzy logic concepts were conducted using two SMEs. The results indicated a significant difference in the assumptions made by the researchers and the range values provided by the SMEs. In addition to differing with the researchers, there was disparity between the 2 SMEs as well.

Table 1 presents the data collected from the SMEs that will be used to model a fuzzy set that represents the Red, Yellow, and Green range values for a project over budget. The '*Question*' column represents the letter of the question presented in the example in the previous section.

TABLE I. INTERVIEW RESULTS: FUZZY LOGIC RANGE VALUES (2 SMES)

Question	*SME #1*	*SME #2*	*Avg. Range*
A	0 – 10%	0 – 5%	0 – 7.5%
B	0 – 5%	0 – 4%	0 – 4.5%
C	5 – 30%	5 – 15%	5% - 22.5%
D	15 – 25%	13 – 15%	14 – 20%
E	25 – 100%	15 – 100%	20% - 100%
F	30 – 100%	15 – 100%	22.5 – 100%

As indicated in Table 1, for question (a), SME #1 believed that a project could be considered Green until it is 10% over budget. Alternatively, the data collected from SME #2 were stricter, where a project could be considered Green only until it was 5% over budget. In question (b), the SMEs had a 1% variance in where they viewed the membership into the Green set as 1.

When focusing on the range of a Yellow status indicator question (c), it is clear that the SMEs agreed as to where the Yellow range should begin (5% over budget). On the other hand, there was a 15% difference between the 2 SMEs as to where the range should end. In question (d), SME #1 felt that a project could be considered Yellow if it is between 15 – 25% over budget. Again, the data collected from SME #2 was more rigid, only allowing for a 2% window (13 – 15%) as to when a project can have a membership of 1 in the Yellow range.

For question (e), where the range of a Red status indicator for a project that is over budget is considered, SME #1 believed that the range is between 25 – 100% over budget. SME #2 thought that the cost constraint should be Red if it lands in the 15% - 100% over budget range. In question (f), SME #1 felt that a membership of 1 in the Red range should span 30 – 100%. Interestingly, SME #2 thought that the entire Red range, which was provided by the SME in question (e), should be considered as having a membership of 1 into the fuzzy set. The reason that SME #2 provided was that there would not be enough money available after the project goes 15% over budget if it is a fixed budget as the exercise indicates.

As a result of the observable difference in the acquired range values, plans have been made by the researchers to interview more SMEs. The data attained from the interviews will be analyzed to determine if the disparity in the range values will decrease or increase in degree. Also, it is possible that the amount of experience of the SMEs may contribute to the disparity of the ranges. The relevance of this information will also be analyzed as more data is collected. As indicated in [7], the amount of experience of the SME will only be taken into consideration as a deciding factor in what information to use in an effort to arrive at a resolution to conflicting thoughts when developing rules for the decision system.

As a change in approach to the fuzzy exercise, different fuzzy ranges may be realized by removing the % ranges values from the x-axis of the figure that is used in the exercise (Fig. 3) to acquire fuzzy range values. It is possible that by having the % values already on the scale, the SME may feel restricted and influenced to not deviate too far from what is indicated in the example. Removing the % ranges may encourage results that are more innovative. Thus, modifying the approach in the fuzzy exercises is under consideration for future knowledge acquisition interviews to attain fuzzy logic range values.

Similarly, a change in the method employed by the researchers to elicit fuzzy range values from the SME, may influence communication of different range values. A possible change to the interview approach could include taking time to educate the SME about fuzzy logic. Specifically, using examples of fuzzy sets that represent other domains to educate the SMEs may enhance their understanding of fuzzy logic and provide more clarity to the purpose of the interview when needed. However, this change in interview approach may be difficult to institute due to time constraints of the interviews. Further, the learning curve, a factor that will influence the amount of time needed for the interviews, of each of the SMEs in relation to comprehending fuzzy logic is unknown.

Fig. 4 models the results of the exercise into a fuzzy decomposition that depicts the average range of the SME's opinions using the 'Avg Range' column in Table 1. As indicated in Table 1, the Green range in Fig. 4 is between 0 – 7.5%. Within the Green range, the membership value of 1 into the Green fuzzy set falls into the 0 – 4.5% range. The Yellow range is considered if the cost constraint of a project reaches 5% - 22.5% over budget. It is important to point out the overlap that exists between the Green and Yellow ranges of 2.5% (5 – 7.5% on the x-axis). The Red range falls into the span of 20% - 100% over budget. Again, there is a 2.5% overlap between the Yellow and Red fuzzy range values (20% - 22.5%.

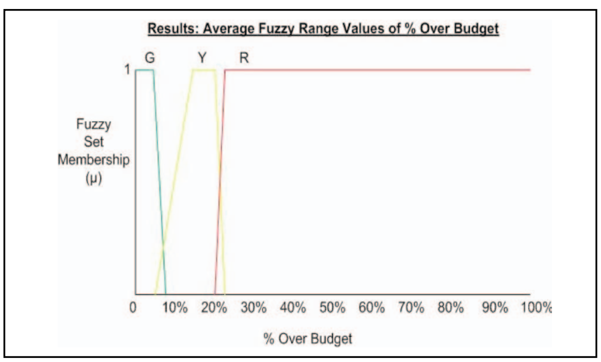


Figure 4. Fuzzy set depicting results of % Over Budget exercise.

While using the average of the range opinions may not be the optimal solution, we believe that it is a reasonable approach to use in the interim so that the construction of a "proof of concept" decision system can proceed. After additional SMEs are interviewed, other techniques will be investigated to aggregate the different range value opinions if necessary. One possible scheme is to use least squares regression analysis. This method can be used to find a representation that provides the best-fit and minimal error with respect to the data [18]. Other techniques will also be considered.

IV. Conclusion

In this paper, we presented efforts made to populate the R-CAST system, which was previously populated with military knowledge, with project management domain knowledge to aid in the project status decision of information technology projects. The results of two knowledge acquisition (KA) iterations were also presented.

As indicated in the results of the first KA iteration and subsequently performed during the second KA iteration, the research progressed in the direction of incorporating fuzzy logic into the research to handle the uncertainty that a project manager can experience when determining the status of a project. The second KA iteration focused on learning fuzzy range values of Red, Yellow, and Green project statuses with respect to the condition of the project constraints. In this paper, an exercise that was used in the second KA iteration to acquire fuzzy range values for a project that is over budget was presented. The results of the second KA iteration show that there are some differences between the data collected from the SME that will be used to model the range values in a fuzzy set.

V. Future Work

In an attempt to collect more fuzzy range value data, additional interviews with SMEs will be conducted. The accumulated data will be analyzed to determine if the present disparity in the range values will increase or decrease in degree.

Future work of this research will also focus on translating the acquired SME knowledge and fuzzy range value data into fuzzy rules for the decision system.

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