AN APPROACH FOR MULTI-CRITERIA DECISION MAKING METHOD SELECTION AND DEVELOPMENT

Yongchang Li, Neil Weston, Dimitri Mavris
Aerospace System Design Laboratory (ASDL)
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0150

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Abstract

The existence of various decision making methods implies that in order to obtain the desired solution for a given decision making problem the suitable method should be utilized since the use of inappropriate method may create a misleading solution., However, the selection of the most appropriate decision making method is an area that has not been given adequate consideration.

The research presented in this paper proposes a Multi-criteria Interactive Decision-making Advisor and Synthesis (MIDAS) process that facilitates the selection of the most appropriate Multi-Criteria Decision Making (MCDM) method for a problem. This process provides more insight to the Decision Maker (DM) with regard to fulfilling different preferences, such as developing an advanced decision making method. An aircraft concept selection problem was performed as a proof of implementation.

1 Introduction

In modern aerospace system design, progressively more and more emphasis has been given to conceptual and preliminary design stages in order to increase the probability of success of a design at the completion of the design process [1] [2]. To achieve the success in these phases, one is expected to make wise decisions which will have a considerable impact on the final design solution. Thus, decision making, which is at the core of the design process, needs to be carefully formulated and carried out.

Almost every engineering design problem inherently has multiple criteria which need to be satisfied. Since aerospace systems are complex systems with interacting disciplines and technologies, the Decision Makers (DMs) dealing with such design problems are involved in balancing the multiple, potentially conflicting attributes/criteria, transforming a large amount of customer supplied guidelines into a solidly defined set of requirement definitions. As a result, all the criteria have to be simultaneously taken into account, and compromise becomes an essential part of the decision making process.

To handle this type of Multiple Criteria Decision Making (MCDM) problem in the early design stage, various methods have been developed. Currently, over 70 decision making methods have been proposed with the intention of facilitating the decision making process. In addition, with the complexity of the decision problem and the demand for more capable methods increasing, new methods keep emerging. Paradoxically, these numerously existing methods have not eased the decision making problem expected, but complicated the problem because one has to determine which method is most appropriate before he/she can proceed, while considering the fact that the use of inappropriate method may create misleading solutions to the decision making problem. However, deciding on the appropriate decision making method may be viewed as a difficult problem for the DMs, since this selection itself is a complicated MCDM problem and this is an area which has not been given adequate consideration.

2 Motivation

Over the past decades, many efforts have been made to facilitate the selection of the most appropriate decision making method for a given problem. Various approaches have been developed and can be classified into three main types, including the tree diagram[3][4], criteria approach [5][6][7][8], and expert or intelligent systems [9][10][11]. The tree diagram has been the traditional approach proposed by the researchers since the importance of the method selection was first recognized. This approach embodies a taxonomy of MCDM methods in the form of a tree diagram that consists of nodes and branches connected by choice rules. Users can use these tree diagrams to reach one or more methods for a given problem by going through the corresponding branches of the diagram. Some criteria for evaluating MCDM methods were proposed as an alternative solution for this method selection problem. By utilizing this approach the most appropriate MCDM method is identified by evaluating the methods with respect to a set of criteria for the given problem. In the 1990's, researchers developed different expert and intelligent systems to aid the DMs in choosing the appropriate MCDM method. Those systems work by asking the user a series of questions and then eliminating options until the most appropriate method based on the user's answers is determined.

Although the approaches described previously present some capabilities for finding a suitable decision making method for a given problem, they also have some disadvantages in handling these types of problems. Some of them require that the user has certain knowledge about different available methods (e.g. criteria approach), and some of them are just too simplistic to suggest the most suitable method (e.g. tree diagram). In addition, none of the approaches have a comprehensive sample of existing MCDM methods. This lack of methods in the selection pool means the method selected using these approaches may not be the most appropriate method for the problem under consideration. The most appropriate method may exist, but is excluded from the selection process. Furthermore, the existing approaches are not able to produce the final solution to the given decision making problem. They either cannot find the most appropriate method for the given problem, or just find the name of the selected method, but they can not help the decision maker reach the final solution if the decision maker has no knowledge about the selected method. This situation is shown in Figure 1. Therefore, a new approach with more capabilities needs to be developed to facilitate the MCDM method selection.

3 Multi-Criteria Interactive Decision Making Advisor and Synthesis Process (MIDAS)

An intelligent, knowledge-based advisor system referred to as Multi-Criteria Interactive Decision-Making Advisor and Synthesis process (MIDAS) is proposed in this study to fulfill the needed capabilities. Figure 2 illustrates the MIDAS process. It can be seen that the MIDAS process includes a MCDM library storing widely used decision making methods, and a knowledge base providing the information required for the method selection

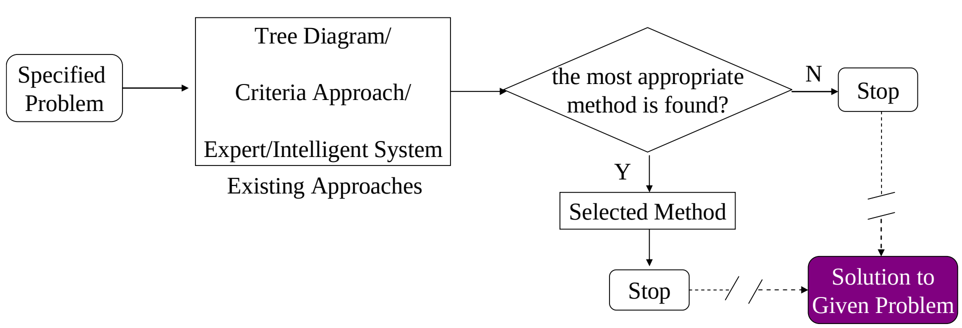

Figure 1: Limitations of Existing Method Selection Approaches

process. The information and data in these two repositories will be used to form a line of reasoning to complete the method selection.

MIDAS is designed to alleviate the DMs' burden of identifying the most appropriate decision making method and support them in obtaining a high quality decision through the decision making process. It is capable of finding the most appropriate method for the decision making problem and then using the selected method to produce a final result. In addition, it can provide guidance to generate new method if no method in method pool is appropriate for the given problem. With this approach, MIDAS fills in the gaps existing in the current method selection approaches as shown in Figure 1.

3.1 Decision Making Method Selection

Basically, a decision making problem has certain characteristics, such as those associated with uncertainty, feasibility and hierarchy. A decision making technique may not be suitable for solving a given problem if it does not have capabilities to deal with some key characteristics of that problem. For example, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) does not take into account uncertainty that often exists in some problems, Analytical Hierarchy Process (AHP) is not able to deal with the dynamic behavior of the problems, and Joint Probability Decision Making (JPDM) technique cannot accurately represent the DM's preference information [12]. If a decision maker has no knowledge about these methods, it is difficult to pick the most appropriate method.

On the other hand, different decision making techniques have their own requirements, assumptions and limitations. That is, different techniques require different input data, preference information and decision rules. Hence, if a problem with certain properties is solved using a decision making technique which is designed for this type of problem, or whose characteristics best meet the characteristics of this type of problem, a better solution can be obtained. This is the concept that the MIDAS uses to select the most suitable decision making technique.

To select the most appropriate decision making technique, the MIDAS process starts to evaluate the problem by interacting with the DM by a series of questions, which are related to different aspects of a decision making problem. To facilitate the selection of a decision making method, the advisor can provide options for the answers to the corresponding questions.

After the questions are answered, the advisor will analyze this information and rank the methods in order of appropriateness using

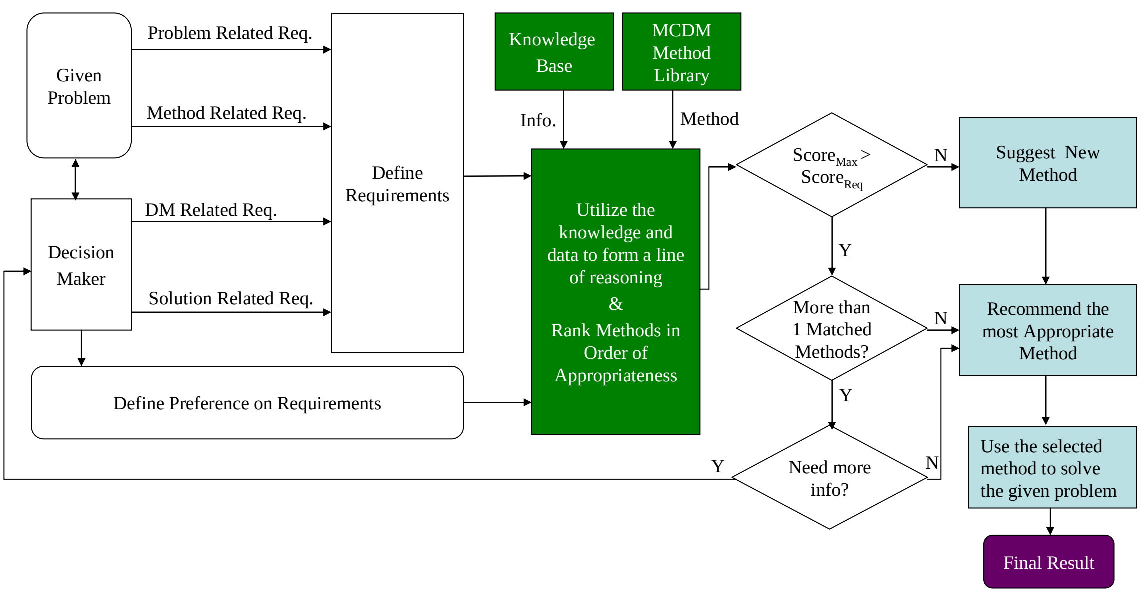

Figure 2: MIDAS Process

the index given by Equation (1). Finally the methods with appropriateness indexes greater than the threshold will be recommended as appropriate methods to solve the problem under consideration. In Equation (1), AI represents the appropriate index that a method possesses when it is evaluated with respect to the given problem.

$$AI_i = \frac{1}{n}\sum_{i=1}^{n} w_i I_i \quad (1)$$

where n is the number of criteria used to examine the characteristics of decision making methods or the given problem. Each such characteristic corresponds to one examination criterion which has two or more values. $W = \{w_1, w_2, \cdots, w_n\}$ is the weighting vector on the examination criteria. $I_i = \{b_i, b_{2,} \cdots, b_n\}$, and b_i is defined as:

$$b_i = \begin{cases} 1 \text{ if } c_{ji} = a_i \\ 0 \text{ if } c_{ji} \neq a_i \end{cases} \quad \mathrm{i} = 1, 2, \cdots, \mathrm{n}; \ \mathrm{j} = 1, 2, \cdots, \mathrm{m}$$

where a_i is the value of the *i*-th characteristic of the decision problem, and c_{ji} is the value of *i*-th characteristic of the *j*-th method in the method library.

3.2 Decision Validation

A DM is usually familiar with one or two decision making methods, and thus tends to use these methods to deal with any decision problems. It can be seen that a decision method good at handling one type of problem is maybe incapable of handling other types of problems. Therefore, only using decision making methods that the decision maker is familiar with often produces inappropriate decisions for some problems. This indicates that the decision validation should be performed before the decisions are implemented. The MIDAS is able to validate the decisions made using a specific method.

The validation process is similar to the method selection process except that the decision solution is known in advance. In order to validate the decisions, one must verify that the method used to make the decision is appropriate. At this point, the selection of the most appropriate method discussed in section 3.1 becomes one part of the decision validation process. After the method selection is conducted, if the method suggested by the MIDAS approach is the same as the one the DM used to make the decision, it implies that the decisions made are valid. Otherwise, if a different method is recommended, it indicates the decisions made are not appropriate and need to be refined using the recommended method.

3.3 Decision Making Using a Specific Method

After a decision making method is selected as the most appropriate method to deal with the problem under consideration, the DM will employ this method to formulate the problem and produce the desired decision solution. However, there exists a variety of methods and it is improbable that the DM will be familiar with all of them. Thus, the DM may require guidance in the use of the method to obtain the final solution, even without a complete understanding of the algorithm used in the method.

The MIDAS is capable of providing guidance for the DM when a specific method in the MCDM library is selected. For each method in the MCDM library, the advisor supplies an explicit step by step problem solving procedure for the DM to follow. This procedure can be completed through the corresponding user interface. To use an unfamiliar method, the DM is only required to input some basic information associated with the problem, such as the number of the alternatives, the number of the attributes, and the preference information. Then the decision maker can follow the explicit guidance provided by the advisor to reach the final solution.

3.4 New Method Development

In some cases, the decision advisor may not be able to find an appropriate method for the given problem from the MCDM library. This may occur when the problem is more complicated than the types of the problems typically considered by MIDAS, or simply because of the limited number of methods included in the MCDM library.

Table 1: New Method Generation

	1	2	3	4	5	6
Feasibility Check?	Yes	No				
Optimization/ Selection	Selection Only	Optimization Only	Optimization + Selection			
Uncertainty Analysis?	Yes	No				
Risk Analysis?	Yes	No				
Input Matrix Available	Decision Matrix	Comparison Matrix	None			
Complexity	Hierarchical	Single	Hierarchical + Single			
Preference	Relative Weight	Utility Function	Relative Weight + Utility Function	Class Function	None	
Weight	Given	Assigned	Calculated	None		
Info. Required	Interested of Area	Utility Function	Goals	Probabilities + Utility Function	None	
Decision Rules	Maximize Clossness to Ideal Solution	Maximize the Utility Function	Maximize POS	Ordinal Ranking	Minimize the Variation to the Set of Goals	Minimize the Aggregate Function
Visulization	Yes	No				
Dynamic/Static	Danamic	Static				
Subjective/Obj. Varable	Subjective Only	Objective Only	Subjective + Objective			
Complete/Incomp.	Complete	Incomplete				

The MIDAS is capable of handling this issue. When the advisor can not find an appropriate method for the problem under consideration, it will analyze the answers and information that the DM has provided about the problem. Based on the analysis, the advisor will discern what capabilities are required for a method to be fulfilled to deal with the problem through the morphological matrix shown in Table 1. Then it will give the DM some advice for solving the current problem. The advice can suggest that the DM find an existing decision making method with some certain capabilities or characteristics which is not included in the MCDM library. If there is not such existing technique, or the expected technique can not be found by the DM, the advisor will suggest that the DM create a new method capable of handling the current problem and the advice provided by the advisor will provide hints for developing the new technique. These hints may be to combine two or more existing techniques in the library to generate a hybrid method, or to create a new method with required capabilities.

4 MIDAS System

As illustrated in Figure 2, the operation of MIDAS is supported by two databases, a knowledge base and a method base, and a reasoning module that utilizes the information in the databases to accomplish the method selection task. To fulfill the MIDAS capabilities, the MIDAS process is implemented using a knowledge-based advisor system that consists of a user interface, an inference engine, an MCDM library, and a knowledge base, as depicted in Figure 3

The user interface of the MIDAS system allows the user to interact with the system in order to accomplish a certain task, as shown in Figure 4. The user is able to communicate with the system by inputting the required information and commands using the user interface. The advisor can respond to the user's query by outputting some data and graphs through the interface to complete the interaction.

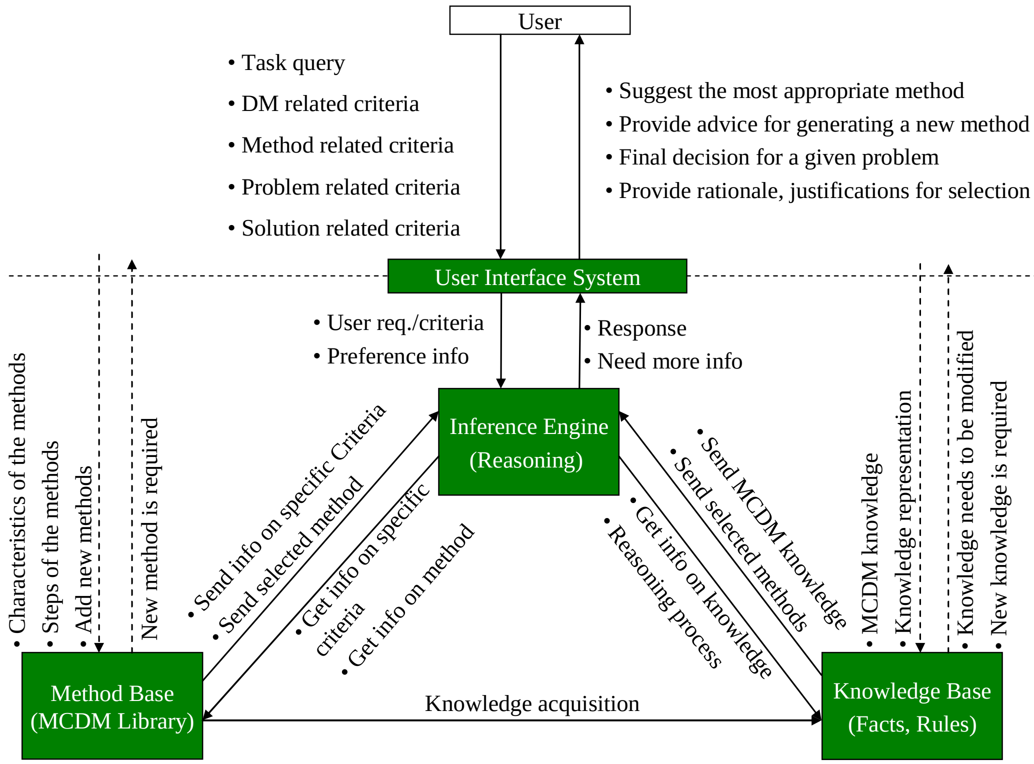

Figure 3: Architectural Framework of MIDAS System

The inference engine of the MIDAS system is the control mechanism that applies the information present in the knowledge base and method base to the task-specific data to arrive at a conclusion through reasoning. In the reasoning process, the inference engine organizes and controls the steps taken to solve the problem, manipulates the knowledge contained in the knowledge and method bases and handles the execution of the system.

The knowledge base is the core of the advisor system. In the knowledge base the facts and rules are stored in some format, which include both factual and heuristic knowledge and support the judgment and reasoning of the inference engine. Knowledge is acquired from expert and other documented sources. The necessary knowledge associated with selecting the most appropriate MCDM method, validating the decision made and generating a new decision making method is formulated in the knowledge base and stored as a set of rules.

The method base, also referred to as the MCDM library, stores the information associated with a number of widely used MCDM methods. In this study, each method is represented by two sets of data: one indicates the characteristics of the method; the other provides the problem solving procedure of the method. The characteristics of the MCDM methods are divided into four categories: DM related, method related, problem related and solution related characteristics, and each category is independent of the others.

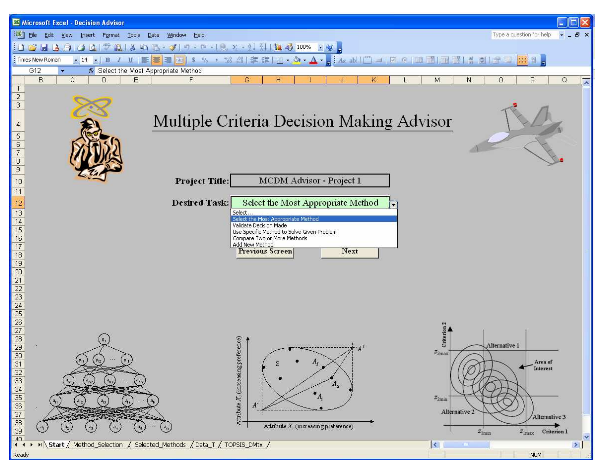

Figure 4: MIDAS User Interface

To complete certain task, the user sends a query to the system through the user interface, and, based on the specified task, the system will request the necessary information from the user. After the user provides the information (inputs) to the system, the inference engine will analyze the inputs and utilize the information and knowledge stored in the knowledge and method bases to form a line of reasoning. Then conclusions will be drawn for the original task query and the outputs will be presented to the user through the user interface. During the process, additional information may be required from the user so that iterations may occur in order to produce an explicit and convergent conclusion.

5 Implementation

In order to demonstrate capabilities of the MIDAS system, a Personal Air Vehicle (PAV) concept selection problem is performed as a proof of implementation.

5.1 PAV Concept Selection Problem

The Personal Air Vehicle was envisioned as a potential replacement for automobile transportation which could provide a solution for the increasingly congested highways. For this personal transportation purpose, PAVs will provide a routine doorstep-to-destination personal travel, which is a system solution involving air and ground transportation.

Three advanced PAV concepts were derived from the corresponding baselines: one helicopter configuration, (Robinson R44), one gyroplane configuration, (Groen Hawk4), and one tiltrotor configuration, (Bell 609). In developing the advanced PAV concepts, probabilistic design methodology was applied to account for uncertainty or variability existing in the design process. The objective of the concept selection is to select the most viable concept that can best perform the PAV mission. Viability of a design concept is measured by the probability of satisfying certain desired levels of three criteria: Doorstep to Destination (D-D) time, Direct Operating Cost (DOC) and noise. One can see that all the criteria are desired to be as small as possible, therefore zero as a lower bound was assigned to all the criteria. The maximum acceptable values that must be satisfied are defined as: 4 hrs for D-D time, and 130 $/hr and 79dB for DOC and noise respectively.

5.2 Decision Making Method Selection and Decision Validation

In order to obtain a desired solution, an appropriate decision making method should be identified first and then aid the DM to reach the final solution. The MIDAS system is used to fulfill these tasks.

Since the development of the PAV advanced concept occurs in the early design stage, each concept carries a family of alternatives instead of a point design to avoid a rapid design freedom drop off and cost lock-in [1][2]. The relationship between input variables and metrics of interest is captured by a metamodel represented by Response Surface Equations (RSEs). Thus, the metrics of interest will be derived by utilizing the RSEs and distributed over the design space. That is, the quantification of each metric is represented by a distribution rather than a single value which exhibits the uncertain nature of the problem. This uncertainty feature is a key characteristic that needs to be taken into account when one selects the decision making methods for the PAV advanced concept selection problem.

To select the most appropriate method for the PAV concept selection problem, the user sends the query to the advisor system to request the method selection task and inputs the information about the problem. For the PAV concept selection problem, the information is related to the key characteristics discussed previously and other problem related, DM related, method related and solution characteristics.

The advisor then analyzes the inputs using the information in the knowledge base and sequentially calculates the appropriateness score for each method in the method base. The final result of the method selection is illustrated in Figure 5. It can be seen that the Joint Probability Decision Making Technique (JPDM) is evaluated as the best method to deal with the PAV concept selection problem.

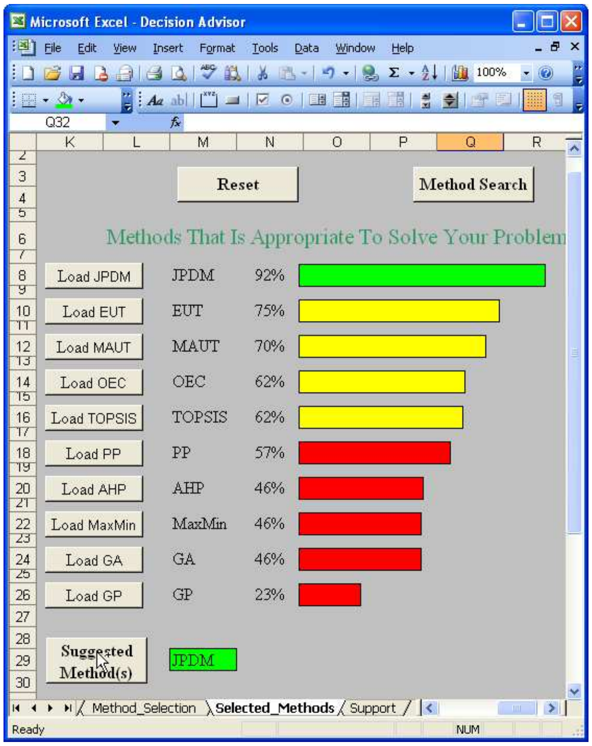

Figure 5: Method Selection Results for PAV Concept Selection Problem

The decision validation process is similar to the method selection process, except that the decision has been already made using another method. To validate the decision made, the method selection process should be executed first. If the selected method is the same as the method used, the decision should be valid, otherwise the decision needs to be reevaluated using the selected method suggested by the MIDAS.

5.3 Decision Making Using JPDM

Once the JPDM method was chosen, the DM needs to employ it to obtain the final solution for the concept selection problem, that is, to decide which concept is the most viable configuration to perform the PAV mission.

The MIDAS can help the DMs to use methods that they are not familiar with. When a method is selected as the most appropriate method to solve the current problem, the advisor can invoke the method, which has a rigorous step by step problem solving procedure stored in MCDM library.

In this example, the JPDM technique was selected as the most appropriate method. To use the JPDM technique, one can simply click the "Load JPDM" button shown in Figure 5, and the JPDM technique will be loaded. The advisor supplies explicit instructions that can be followed by the DMs. The only actions expected from the DMs are inputting some necessary data such as the number of the alternatives, the number of criteria. The rest of the assessments can be completed by clicking the corresponding buttons following the guidance. The data required by JPDM can be obtained by some sampling technique such as a Monte Carlo Simulation using the available RSEs. Uncertainty is propagated to the system level by defining appropriate probability distributions for uncertain mission requirements, vehicle attributes and infused technologies. The area of interest is defined by the upper limits and lower limits of the criteria which were given in Section 5.1.

Based on the data input, the advisor can automatically produce the joint probability distribution of the criteria using the JPDM technique. In addition the advisor can calculate the joint Probability of Success (POS) for each concept and univariate probability of success for each criterion. The respective probabilities of success are listed in Table 2. From this table, one can see that the advanced helicopter has the highest probability of success which indicates it is the best concept to perform the PAV mission.

Table 2: Concept Selection Result

Alternatives	Joint POS	P(*D-D*<4 hr)	P(*DOC* <130 $/hr)	P(*Noise* < 79 db)
Adv_Helicopter	0.2708	0.5572	0.4736	0.9759
Adv_Gyroplane	0.2004	0.481	0.2855	0.955
Adv_Tiltrotor	0	1	0	1

5.4 New Method Generation

The JPDM technique appears to be an effective multi-criteria decision making method that can measure the goodness of alternatives based upon their probability of success. The advantages of the JPDM do not elimilate its own underlying limitations. In the JPDM, the POS is obtained by integrating the joint probability density function over the area of criterion values that are of interest to the customer for the Joint Probability Mode (JPM) model, or by counting the number of the occurrences of the alternative solutions within the area of interest for the Empirical Distribution Function (EDF) model. Obviously, the calculation of POS does not take the absolute location of the Joint Probability Distribution Function (JPDF) into account, which leads the JPDM to become awkward for concept selection when the calculated POS' of the alternatives are very similar but their JPDF locations are very different. It is clear that the POS calculation can not fully capture the performance of the alternatives and therefore produces biased estimation for the alternatives' goodness. Thus, the JPDM technique needs to be improved in order to be able to make high quality design decisions.

The improvement can be completed by revising an existing method or developing a brand new method resulting in a hybrid method or a new method capable of fulfilling the capabilities that are required to make better decisions. The MIDAS is able to help the DM to generate the methods with improved performance in the process of selecting the most appropriate method for the problem under consideration.

Assume that a decision maker wants to find a desirable method to solve the PAV concept selection problem. The DM is concerned about his or her preference and wishes that the preference information can be represented by a more sophisticated model rather than the relative weight. It is also assumed that the DM understands other characteristics of the problem as discussed in Section 5.2.

After the characteristics of the PAV concept selection problem are entered to the advisor system, the advisor finds there is no appropriate method which is capable of dealing with this problem. However, the advisor is able to provide hints that may be used to create a hybrid or new method. Three hints are provided by the advisor, and they are: combining the JPDM with Expected Utility Theory (EUT), physical programming, and loss function.

Since utility has the capability of representing a decision maker's preference information by measuring the "goodness" of the decision making criteria, the first hint provided by the advisor is selected for the new method generation. As the JPDM technique still has highest appropriateness score, the new method will be developed based on this technique. The utility function used by EUT technique can improve the calculation of the POS of JPDM technique, thus it is used in the JPDM to represent the preference information.

A hybrid decision making method was developed from the JPDM technique using the utility function to represent DM's preference. Table 3 shows the joint utility for the alternatives and utility for each of the criterion. Since the tiltrotor concept is infeasible, it is eliminated before processing the selection problem.

Table 3: Joint Utility and Univariate Utility of Each Concept and Criterion

Alternatives	JU	U(D-D)	U(*DOC*)	U(*Noise*)
Adv_Helicopter	0.5519	0.2095	0.2154	0.1270
Adv_Gyroplane	0.3653	0.1446	0.1170	0.1037

Comparing the results shown in Table 2 and Table 3, one can get the same goodness ranking for the PAV concept selection problem with respect to the given criteria. Though the results obtained from the original JPDM technique and the hybrid method are the same, the accuracy offered by these two methods is different. The hybrid method makes the two concepts more distinguishable: the 15% difference in goodness increases to 20% after the proposed method was applied. Study shows that the advanced helicopter and the advanced gyroplane have similar distributions and deviations from their respective targets. Even in this case, the hybrid method still gives a more explicit result than JPDM in indicating which alternative is the best solution. When dealing with the cases in which alternatives have very different distributions, the hybrid approach will be much more competent than the original JPDM technique

6 Concluding Remarks

A decision making method selection approach, referred to as MIDAS process, was developed in this study to help the decision maker to select the most appropriate method for a given problem. The MIDAS process provides an interactive way to let the user select the method and then directs him or her in the use of the selected method to reach the final design decision. It can also produce the hints for new method development if no method is suggested for the given problem. In general, MIDAS provides an interactive way to effectively fulfill the method selection task.

The PAV advanced technology concept selection problem was solved, as an example, utilizing the MIDAS process. The most appropriate decision making method was first selected among a set of methods, and then the problem was solved using the selected method. With the intention of making better decisions, the decision maker required the preference information to be represented by a more sophisticated model. The decision making advisor provided several hints that were used to develop a new method that had the capabilities to deal with the problem. A hybrid method was developed based on the JPDM technique using utility theory. The result shows that the improvement was achieved with the use of the proposed method.

It is worth noting that the knowledge base and method base can be expanded so that new knowledge and methods can be infused into the advisor system, which will greatly increase the capability of the MIDAS system.

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